ORP-68764
Revision 0

LAW Melter Offgas System Design Basis Flowsheets

24590-LAW-M4C-LOP-00001 Rev 6

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Office of River Protection

P.O. Box 450
Richland, Washington 99352

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Calculation Cover Sheet

RIVER PROTECTION PROJECT-WASTE TREATMENT PLANT			**JOB NO.:** **24590**
CALC NO. 24590-LAW-M4C-LOP-00001	**GROUP** Process Eng.		**FACILITY** LAW
SUBJECT LAW Melter Offgas System Design Basis Flowsheets			

CALCULATION STATUS ☐ PRELIMINARY ☐ COMMITTED ☒ CONFIRMED
☐ SUPERSEDED BY: ______________________ ☐ CANCELLED

SOFTWARE USED TO PERFORM CALCULATION

Check applicable boxes in this block to designate what General–Purpose Commercially-Available Software was used to perform calculation and enter the version in the field provided.

Note: ID older versions used in unrevised portion(s) of calc in "Notes/Comments:" below.

☒ Excel; version: Office 365 MSO, Version(16.0.12026.20100) ☒ Mathcad; version: 15 ☐ Mathematica; version:

Other Software Used to Perform Calculation ☒ None ☐ "Other Software" was not used in this revision. "Other Software" was used in previous revisions, refer to previous revisions for software details.

PROGRAM NAME	VERSION	UIF		COMPUTER PLATFORM		
	NO	NO	REV	MICROPROCESSOR	OPERATING SYSTEM	JO#

RECORD OF REVISIONS

NO.	REASON FOR REVISION	TOTAL NO. OF SHEETS	LAST SHEET NO.	ORIGINATOR	CHECKED	APPROVED/ ACCEPTED	DATE
6	Incorporated 24590-LAW-EIE-MS-18-0167 Rev. 0 and 24590-LAW-M4E-LOP-00012. I-129 now passes through the carbon bed with no mass change. Updated the caustic scrubber atomizing flow rate in the minimum and nominal cases. See Note 1.	262	46-3	N. Wilkins **Originator** By: Nancy Wilkins - newilkin Org Name: BNI Placed: Nov 18, 2019	B. Stiver **Checked** By: Brad Stiver - bastiver Org Name: HLW Process Engineering Placed: Nov 18, 2019	R. Hanson	12/18/19
5	Incorporated 24590-LAW-EIE-M-17-0034. HCl and HF now pass through the carbon bed with no mass change. DFs for iodine were added at the melter, the SBS, and the WESP.	260	260	N. Wilkins	N. Johnson	R. Hanson	1/18/18
0	Issued for use.	211	211	A.Coulam N. Wilkins	K. Eager D. Dodd Y. Nurdogan	J. Rouse	9/26/2007

Notes/Comments:

1. The following calculation sheets are affected by this revision: 5-6, 8 - 11, 38, 39, 46 - 47, 49 – 56, 58, 1-2, 1-5, 1-6, 1-9, 1-10, 1-13, 1-17, 1-19, 4-3, 4-4, 4-10, 4-28, 4-29, 4-30, 36-3 and 39-2. Revision bars are shown in the right margin.

Contents

1 Objective

The overall objective of this calculation is to develop design basis flowsheets for confirmation of equipment and piping design associated with the LAW melter offgas system (Systems LOP and LVP). Three flowsheet cases are developed. Minimum, maximum, and nominal offgas cases are developed assuming two melters in operation. The minimum, maximum, and nominal cases are expected during normal operation of the offgas system. An additional minimum case is developed assuming one melter is operating.

Each case provides offgas volumetric flowrate (SCFM and ACFM), mass flowrate, physical properties, primary gas compositions, and offgas contaminant compositions to be used for design purposes. In addition, the mass rates of nitrous and nitric acids from the carbon beds is calculated in Attachment 28.

To determine the offgas “actual” volumetric flowrate and the offgas humidity and density requires a simplified temperature and pressure balance included in the calculation. The temperature and pressure balances are primarily based on available published information, but in some instances (primarily for the pressure balance) are based on conservative assumptions. The defined temperatures and pressures are considered reasonably conservative for each offgas stream given the known process fluctuations that will occur during normal system operation and based on published information, basic engineering principles, and conservative assumptions. Therefore, the defined temperatures and pressures can be used as appropriate for design purposes. The scope of this calculation does not cover system operation during extreme upset conditions (i.e., off-normal events).

This calculation specifically defines design basis flowrates and physical properties for only one of the LAW LOP melter offgas trains. The other LOP offgas train is of identical design, is connected to the same style of melter, and has identical fixed air additions. The LAW vessel ventilation flowrates, hydrogen generation, and particulate loading are calculated in a sub-calculation included as Attachment 4. Refer to this attachment for the inputs, methodology, assumptions, calculations, and references related to determining the vessel ventilation flowsheets.

When using SCFM values from this calculation, users should be cognizant of standard conditions. In this calculation, standard conditions are defined as 20°C and 1 atm.

The row/column placement of the Attachment 1 spreadsheets is the same as previous revisions with respect to cell designations. Stream numbers appear in the same cells as previous revisions.

2 Inputs

2.1 Direct process inputs into this calculation are defined below in Table 1 as applied to the four cases (References in parentheses can be found in Section 9 or as noted):

Table 1 - Process Inputs for Flow Cases

Process Input		Minimum Case	Nominal Case	Maximum Case	Reference
1.	Atmospheric Pressure	Average is 29.22 in Hg (990 mbar)			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Section 4.12, Table 4-7)
2.	Melter Fixed Air Additions	19 SCFM(2,4)			24590-QL-HC4-W000-00094-05-00003 (Ref. 9.30, Table 4) 24590-101-TSA-W000-0010-409-882 (Ref. 9.8, pg 34)
3.	Melter Air Inleakage	149 SCFM(3,4)	N/A	N/A	24590-QL-HC4-W000-00094-05-00003 (Ref 9.30 , Table 4, pg 29)
4.	Caustic Scrubber Spray Air Flowrate per Nozzle	36 SCFM			24590-QL-POA-MKAS-00003-08-00003 (Ref. 9.45 , pg 33)
5.	Film Cooler Air Addition (including main and standby film coolers)	185 SCFM(4)			24590-QL-HC4-W000-00094-05-00003 (Ref. 9.30, Table 4)
6.	WESP Bulge Air Purge Flowrate	350 ACFM at 1 psig			24590-QL-POA-MKE0-00001-06-33 (Ref. 9.32 , Note 1)
7.	WESP Bulge Air Purge Temperature	5°F above WESP Inlet Temperature			24590-QL-POA-MKE0-00001-06-33, (Ref. 9.32, Note 1)
8.	Melter Glass Production	30 MT/day(1)			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 6-3)
9.	ADS Pump Feed Rate to Melter (Envelope A)	190 gph			24590-QL-HC4-W000-00011-03-00620, (Ref. 9.60, Section 7.1)
10.	Melter Plenum Temperature	NA	400°C	N/A	24590-101-TSA-W000-0009-87-00019 (Ref. 9.6, p T-3 [DM3300 melter tests])
11.	Compressed Air Temperature & Instrument Air Temperature	60°F			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Section 6.4)
12.	C5 area Temperature Range	59°F	N/A	113°F	24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 12-1)
13.	TCO Destruction Removal Efficiency (DRE) for VOCs & SVOCs	95%			24590-CD-POC-MBT0-00007-03-00001 (Ref. 9.63, pg 2 & 5)
14.	HEPA Filter Bank Particulate Removal Efficiency	99.95%			LAW Air Permit, Emission Unit ID 547, Item #32, pg. 8 of 11 (Ref. 9.61)
15.	SCR NOx Reduction Efficiency	98%			24590-CD-POC-MBT0-00007-03-00001 (Ref. 9.63, pg 2 & 5)
16.	Caustic Scrubber HCl, HF, and SO_2 Removal Efficiency	100%			24590-QL-POA-MKAS-00003-06-00001, (Ref. 9.9, pg 36)
17.	Caustic Scrubber NO_2 Removal Efficiency	5.8%		1.1%	24590-QL-POA-MKAS-00003-06-00001, (Ref. 9.9, pg 36)
18.	Caustic Scrubber CO_2 Removal Efficiency	1.83%		1.73%	24590-QL-POA-MKAS-00003-06-00001, (Ref. 9.9, pg 36)
19.	Catalyst Skid Electric Heater Discharge Temperature	750°F			24590-CD-POC-MBT0-00007-03-00009, (Ref. 9.57, pg 5) 24590-CD-POC-MBT0-00007-02-00001, (Ref. 9.11, Section 7.2, pg 16)
20.	Atomic weight of I-129	128.904988 g/mol			CRC (Ref. 10.2.6, pg. 11-72)
21.	Half Life of I-129	$1.7 \cdot 10^7$ g/mol			CRC (Ref. 10.2.6, pg. 11-72)
22.	Deleted				
23.	Deleted				
24.	Deleted				
25.	Operating Efficiency of Fan Exhausters	58%			24590-QL-POA-MACS-00007-04-00002 (Ref. 9.44)
26.	Caustic Scrubber Maximum Overall Pressure Drop	15.4 in. WG			24590-QL-POA-MKAS-00003-06-00001 (Ref. 9.9, Section 5.6, pg 13)

Process Input		Minimum Case	Nominal Case	Maximum Case	Reference
27.	Melter Plenum Vacuum	-5" WG			24590-101-TSA-W000-0010-409-359 (Ref. 9.46, pg 24)
28.	C2 Area Vacuum to Atmosphere	-0.1" WG			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Fig. 12-1)
29.	C3 to C2 Area Vacuum	-0.3" WG			24590-WTP-DB-ENG-01-001 (Ref. 9.39 Fig. 12-1)
30.	Melter Annulus to the melter gallery (C3 Area) Vacuum	-2" WG			24590-101-TSA-W000-0010-409-359 (Ref. 9.46, pg 24)
31.	Mercury Emission Limit	< 45 µg/ dry std. cubic meter			DWP (Ref. 10.2.22, Section III.10.H.1.b.v)
32.	Contractual Max I-129 Concentration in HLW Feed	$2.9*10^{-7}$ Ci / 100 g waste oxides			WTP Contract, Section C (Ref. 10.2.7, Table TS-8.3, pg C-129)
33.	Caustic Scrubber Demister Maximum Pressure Drop	14 in. WG			24590-QL-POA-MKAS-00003-06-00001 (Ref. 9.9, Section 5.6 & Attachment 9.2)
34.	Caustic Scrubber Packing Average Pressure Drop	0.42 in. WG			24590-QL-POA-MKAS-00003-06-00001 (Ref. 9.9, Section 5.6 & 5.10)
35.	C3 Area Minimum Relative Humidity	10% minimum			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 12-1)
36.	Contract Maximum of Hg in LAW Feed	1.4E-05 mol Hg/mol Na			WTP Contract, Section C (Ref. 10.2.7, Table TS-7.1, pg C-124)
37.	Ratio of specific heats of air	1.40			Lindeburg (Ref. 10.2.1, Table 23.7, pg 23-16)
38.	Deleted				
39.	Enthalpy of formation for Allyl Alcohol at 298.15K and 1 atm	-123.6 KJ/mol			Poling (Ref. 10.2.17, pg A.22)
40.	CO Enthalpy at 700 K	-98.518 KJ/mol			Barin (Ref. 10.2.2, pg 271)
41.	CO_2 Enthalpy at 700 K	-375.749 KJ/mol			Barin (Ref. 10.2.2, pg 272)
42.	Deleted				
43.	Steam Enthalpy at 700 K	-227.635 KJ/mol			Barin (Ref. 10.2.2, pg 650)
44.	Nitrogen Gas Enthalpy at 700 K	11.937 KJ/mol			Barin (Ref. 10.2.2, pg 935)
45.	Oxygen Gas Enthalpy at 700 K	12.499 KJ/mol			Barin (Ref. 10.2.2, pg 1093)
46.	Ammonia Gas Enthalpy at 700 K	-29.071 KJ/mol			Barin (Ref. 10.2.2, pg 942)
47.	Nitrogen Oxide Enthalpy at 700 K	102.599 KJ/mol			Barin (Ref. 10.2.2, pg 946)
48.	Nitrogen Dioxide Enthalpy at 700 K	50.456 KJ/mol			Barin (Ref. 10.2.2, pg 947)
49.	Latent Heat of Vaporization for Water @ 50°C	2382.9 KJ/kg			Felder, (Ref. 10.2.9, Table B.4, pg 628)
50.	Minimum Hanford Site Temperature	-23°F			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 4-7)
51.	Maximum Hanford Site Temperature	113°F			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 4-7)
52.	Minimum C3/C5 Temperature	59°F			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 12-1)
53.	Maximum C3 Temperature	95°F			24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 12-1)
54.	Iodine Ion DF at Melter	2.5			24590-WTP-ES-PE-19-001, Table 1 (Ref. 9.68 & 9.62)

(1) The LAW facility design capacity is 30 MT/day of glass based on 2 melters per the Basis of Design (Ref. 9.39). Therefore, the nominal and maximum glass production rates are defined as 30 MT/day.

(2) The overall melter fixed air additions is defined at 13.5 SCFM per vendor submittal 24590-QL-HC4-W000-00094-05-00003 (Ref. 9.30, Table 4) for all cases (injection air to the bubblers). Also included is 1 CFM @ 60 psig & 80°F (5 SCFM, converted from ACFM by using Equation 6b) for the purge from the ADS pumps, for a total of 18.5 SCFM, which is rounded up to 19 SCFM (24590-101-TSA-

W000-0010-409-882, Ref. 9.8, pg 34). PSA is used as the source of air for the transfer, per 24590-LAW-M6-LFP-00002002 (Ref. 9.35, representing one ADS pump). 80°F is the normal temperature for PSA, see 24590-LAW-MEC-PSA-00001 (Ref. 9.19, Section 8).

(3) The defined minimum melter air inleakage (149 scfm) includes the discharge chamber vent (29 scfm), and the total flow from the enclosure C5 ventilation supply to the melter plenum (120.1 scfm). This totals 149.1 SCFM. These values are from page 29 of 24590-QL-HC4-W000-00094-05-00003 (Ref. 9.30), the column labeled "Total Flow (SCFM)". Refer to Assumption 3 for the nominal and maximum melter air inleakage rates.

(4) Inputs 2,3 & 5 were not corrected to the standard conditions of 20°C and 1 atm. Standard conditions for these inputs were 14.73 psia and 15.56°C (Ref. 9.30, pg 56). The effect on the volumetric flowrates due to the difference between these standard conditions is less than 2 percent. These flowrates are small compared to the overall flowsheet and do not have a significant impact on the overall flowsheet results.

2.2 Molecular weights for components used in this calculation are listed in Table 2 below (CRC, Ref. 10.2.6):

Table 2 - Molecular Weight (g/mol)

Components	MW
Dry Air	29.0
Nitrogen (N_2)	28.01
Oxygen (O_2)	32.00
Argon (Ar)	39.95
Carbon Dioxide (CO_2)	44.01
Water (H_2O)	18.01
Nitrogen Oxide (NO)	30.01
Nitrous Oxide (N_2O)	44.01
Nitrogen Dioxide (NO_2)	46.01
Ammonia (NH_3)	17.03
Allyl Alcohol (1-Propen-3-ol, C_3H_6O) for VOC	58.1
Hydrogen (H_2)	2.02
Mercury (Hg)	200.59
Hydrogen Chloride (HCl)	36.46
Hydrogen Fluoride (HF)	20.01
Nitrous Acid (HNO_2)	47.01
Nitric Acid (HNO_3)	63.01
Sulfur Dioxide (SO_2)	64.06
Carbon Monoxide (CO)	28.01
Ammonium Nitrate (NH_4NO_3)	80.03
Particulates as Iron Oxide (FeO)	71.85

2.3 Refer to Section A4.2 in Attachment 4 for inputs related to the LAW Vessel Ventilation Design Basis Flowsheets.

2.4 Significant inputs were also obtained from process data recorded at the LAW DM-1200 pilot melter/offgas system at Vitreous State Laboratory. This data is included and identified in Attachments 5, 6, 9, 10, 11, 24, 28, 33, 34, 37 and 42.

2.5 Process stream numbers and offgas flowsheets are based on Process Flow Diagrams 24590-LAW-M5-V17T-00004, -00007, -00008, -00010, and -00011 (Ref. 9.13, 9.14, 9.15, 9.16, and 9.17).

2.6 Component dry air volume percentages for pure air additions to the offgas streams are defined based on the US standard atmosphere from CRC (Ref. 10.2.6, pg 14-20):

Table 3 - U.S. Standard Atmosphere Composition

Dry Air Components	Vol%
Nitrogen (N_2)	78.084
Oxygen (O_2)	20.9476
Argon (Ar)	0.934
Carbon Dioxide (CO_2)	0.0314

2.7 The coefficients for molar heat capacity equations for air and primary air components are as listed in Attachment 15, Columns B through E (Ref. 10.2.9, Table B.2 & Ref. 10.2.6, p. 6-133).

2.8 Pressure drop data for the LAW activated carbon units are as listed in Attachment 25, cell C-12 to C-15, per vendor submittal 24590-QL-POA-MWK0-00001-10-00015 (Ref. 9.33, pg 27, 30, 34 & 38).

2.9 The temperature condition, NH_3 concentration and % NH_4CO_3 recovered listed in Attachment 32 (cells highlighted in blue) are based on test data from 24590-QL-POA-MWK0-00001-13-00006 (Ref. 9.34, Table 7 & 8).

2.10 The batch volume of LFP-VSL-00002/4 is 3465 gallons and the cycle time for each LAW melter feed batch is 16 hours per calculation 24590-LAW-M4C-20-00002 (Ref. 9.47, Section 8).

2.11 The water vapor pressure data at different temperatures listed in Attachment 14 are obtained from CRC (Ref. 10.2.6, pg 6-5 & 6-6).

2.12 The catalyst skid preheater overall heat transfer coefficient is 2.74 Btu/hr-ft^2-°F and the catalyst skid preheater heat transfer area is 4056 ft^2 per Code 1 vendor submittal 24590-CD-POC-MBT0-00007-03-00008 (Ref. 9.24, pg 4).

2.13 The pressure drop across the control valve downstream of the WESP (LOP-FV-1140/2140) is 23.16 in. WG at 1216 ACFM (105°F and -0.8 psig) and 6.78 in. WG at 1997 ACFM (167°F and -3 psig) per datasheets 24590-LAW-JVD-LOP-11400/21400 (Ref. 9.36 & 9.58).

2.14 For the maximum case, the LAW process stream properties calculation (Ref. 9.65) was used as the data source for CO, VOC, HCl, HF, NO, NO_2, and SO_2 from stream LMP06. This calculation uses the Aspen Process Performance Simulation (APPS) model to calculate process properties for streams in WTP. Runs 26, 27, 28, 29 and 31 were specifically used to simulate the worst feed for CO & organics, HCl, HF, NOx and SO2, respectively.
The input data for constituent mass flows and total stream flowrates are obtained from RMVD-03242-03, Run 26, 27, 28, 29 & 31 (Ref. 9.65(a), Run xx*APPS Main USER INTERFACE v(3)(0)LAW_PIBOD_RUN_XX.xlsm*, worksheet “*APPS_VIT_Streams_1*”, Column GL) as follows:

Table 4 - Maximum Constituents Mass Flows from APPS

PIBOD Run No.	Description	Mass Flowrate (kg/hr)
Run 26		
Cell GL-31	LMP06 stream	1070
Cell GL-134	SVOC	0.588
Cell GL-135	VOC	0.214
	(Total VOC = SVOC +VOC used in Attachment 1 spreadsheets)	
Cell GL-179	CO	0.716
Run 27		
Cell GL-31	LMP06 stream	1040
Cell GL-183	HCl	0.0663
Run 28		
Cell GL-31	LMP06 stream	1390
Cell GL-185	HF	1.12
Run 29		
Cell GL-31	LMP06 stream	1150
Cell GL-193	NO	15.8
Cell GL-194	NO_2	10.5
Run 31		
Cell GL-31	LMP06 stream	771
Cell GL-198	SO_2	0.846

2.15 For the maximum case, the following decontamination factors (DFs) were applied to the SBS and the WESP. The DFs were applied to all cases for iodine (see Attachment 36). For conservatism, the minimum DF across the SBS is used to minimize constituent removal. The SBS DFs are from Ref. 9.66, Section 8.1, Min DF column (with the exception of I_2). The WESP DFs are from Ref. 9.65(b), 24590-RMVD-03242-01\ "*LOP-WESP-00001.DFs.xlsx*" spreadsheet, "LAW DFs" column, aqueous phase(with the exception of I_2). The I_2 DFs are from Table 1 of Ref. 9.68 (permission to use this report is included in Ref. 9.62).

Table 5 – DFs for Maximum Case

Constituent	Decontamination Factors (DF)	
	SBS	WESP
NO	1.3	1.44
HCl	1.9	3.53

Constituent	Decontamination Factors (DF)	
	SBS	WESP
HF	2.7	7.46
SO_2	43.1	1.00
I_2	3.6	4.8

2.16 Inputs specific to Attachment 45 are listed below. Attachment 45 is a separate attachment that is not used in the main body of this calculation; it is included to provide a possible correlation between the HF in the melter offgas and the amount of fluoride entering WTP in the feed.

(a) The total mass and the mass of HF at LVP04 are contained in Runs 1 – 23 of 24590-LAW-M4C-V11T-00001 Rev 0 (Ref. 9.65(b) & (c) \ Run xx \ "*APPS Main USER INTERFACE v(3)(0)LAW_PIBOD_RUN_XX.xlsm*" \"*APPS_VIT_Streams_1E*" worksheet, cells HI-31 & HI-185, respectively). The relative humidity of the stream is listed in cell HI-17.

(b) Not Used.

(c) The feed type and Leach Case of Runs 1 – 23 are listed in Ref. 9.65 (c), "*LAW PIBOD Run Setup.xlsx*", Column B, D & E. The mass of Na^+ and the mass of F^- in Runs 1 – 23 are listed in Ref. 9.65(c), "*LAW PIBOD Feed Compositions.xlsm*" (adjusted). The sheet correlates to the feed type, e.g. for Run 1, the feed type is Al-LL, in the "*Al-LL*" worksheet, Column I under "Adjusted Al-LL Feed Vector", Na^+ mass is 696854.6063 kg and F^- mass is 13699.41176 kg.

(d) The mass of F- (aq) in LCP01 and the LCP01 total mass flow for the 23 APPS runs are from 24590-RMVD-03242-02 & -03 ((Ref. 9.65(a) & (b), Run xx \"*APPS Main USER INTERFACE v(3)(0)LAW_PIBOD_RUN_XX.xlsm*" \ "*APPS_VIT_Streams_1*" worksheet, Cells FV-102 & FV-31, respectively).

3 Background

Offgas flowrates, humidity, densities, and composition are required to correctly size offgas equipment and piping so that individual unit functional and performance requirements are achieved and not exceeded. Therefore, design basis flowsheets representing minimal, nominal, and maximum operational conditions for the LAW melter offgas system were developed in this calculation. This was done using information from several sources including:

- WTP Basis of Design
- Research and Technology Reports
- Engineering Literature
- Vendor Submittals to the Project for Offgas Equipment
- Vendor Literature
- Engineering Codes
- Equipment Assembly Drawings
- Project Design Drawings

When required information was not available, conservative assumptions were made. These assumptions and their justifications are discussed in Section 6.0.

The intent of this revision is to incorporate the results from testing, which shows that the carbon bed cannot be credited with iodine removal. Iodine now passes through the carbon bed with no mass change.

4 Applicable Codes and Standards

ASME AG-1-1997 with the ASME AG-1a-2000 Addenda, *Code on Nuclear Air and Gas Treatment* as tailored in Appendix C of 24590-WTP-SRD-ESH-01-001-02. (Ref. 10.1.1)

5 Methodology

This calculation is performed primarily using MS Excel 2016 spreadsheets, but it also uses Mathcad 15 for some backup calculations. Referenced empirical data from appropriate testing or vendor calculations are used extensively in this calculation to establish results or as starting data for calculation of stream data. For example, the melter air addition rate is based on vendor calculation results, which in turn are based on appropriate test data. Other inputs to this calculation include temperatures from the Basis of Design, pressure drop and temperature changes across individual pieces of equipment based on design calculations or vendor data. See Section 2 and Section 6 for applicable inputs and assumptions for the calculation.

The general method to ensure the results of this calculation to be representative of the stated case, i.e. minimum, nominal, or maximum is by providing input values (sometimes identified as assumptions) appropriate to the case results. In some cases, a single value is appropriate for all cases. For the nominal case, inputs and assumptions appropriate to the goal of providing results representative of a nominal case are used. Likewise, for the minimum and maximum cases, the results are ensured to be those representative of a minimum or maximum case by the selection of appropriate inputs and assumptions. For example, a conservative production rate, minimum or maximum temperatures, and minimum or maximum injection or removal rates are selected. The development of a set of data that is representative of a minimum and maximum case does not require that all input values are at the corresponding extreme (e.g. maximum) because this would result in unreasonable results. Rather, specific inputs are selected for adjustment to the appropriate value (e.g. to the minimum, maximum, etc.). The adjusted inputs provide a sufficient number of conservative inputs to provide the desired overall results corresponding to the case (minimum or maximum).

The calculation is organized into four master spreadsheets representing different minimal, nominal, and maximum cases for one or two operating melters. Flowrates, temperature, pressure, concentrations of offgas components/contaminants and physical property information for each gaseous process stream in the LOP and LVP systems are defined for each of the four cases. Each cell within each spreadsheet has a reference column that identifies footnotes that link the cell contents to numerically listed notes, equation descriptions, assumptions, and/or direct reference discussions such as:

- "Nxx" represents Note xx listed on the "Notes" worksheet which provides definition of fundamental constants or linkage for cell data calculated in other attachments.
- "Exx" represents Equation xx listed on the "Equations" worksheet which provides description of cell equations or indicates when a fundamental equation is used.
- "Axx" refers to Assumption xx in Section 6 (Assumptions) of the calculation where assumptions are listed and justification that the constant is conservative and appropriate for use is provided.
- "Rxx" refers to "Reference xx" in the "References" worksheet where references for the values are provided.

The "Constants" worksheet contains a summary of fixed constants and case dependent constants used in the four master flowsheets. The master spreadsheets and spreadsheets that list the notes, equation, references and constants are included in Attachment 1. The "SUPPORT FILES" folder contains electronic copies of these spreadsheets.

The following is an overview of how the flowsheet is calculated around each unit in the offgas system. PFDs 24590-LAW-M5-V17T-00004, -00007, -00008, -00010, and -00011 (Ref. 9.13 - 9.17) cover the LOP & LVP systems.

An overall pressure balance is kept by setting the initial pressure to atmospheric and tracking the drop in pressure as the offgas travels through the system. Individual pressure drops are set for pipe lengths and treatment units. The flowsheet tracks the typical gas components and offgas contaminants such as N_2, O_2, CO_2, Ar, H_2O, NOx, NH_3, VOC, H_2, Hg, halides, SO_2, CO, I-129 and particulates. The potential formation of methyl iodide in the offgas from radiolytic and thermal reactions is low (Assumption 56) and therefore methyl iodide will not be included in the flowsheet.

(1) Melter

Gas contributions to the melter plenum are combined and sent to the film cooler. Gases that enter the melter plenum include steam from the melter feed, inleakage into the melter, and injection air through the bubblers. These streams are combined into stream LMP06, "Melter Offgas".

- The steam from the melter feed is set by calculating the mass rate of water to the melter in Attachment 5. This mass rate is then converted to SCFM in Attachment 2 and entered into cell E-8 of the main flowsheets.
- The standard volumetric flowrate of the air inleakage to the melter and the melter injection air are taken from vendor submittals (Inputs 2 & 3 in Section 2.1 and Assumption 3).

(2) Film Cooler

The gas then travels to the film cooler.

- Additional air flow added to the film cooler (cell C-12) is defined from a vendor submittal (185 scfm per Input 5, Section 2.1). The melter offgas stream (LMP06) and additional film cooler air (LMP11) are combined and become the "film cooler discharge" stream. The melter offgas stream (LMP06) temperature is defined in cell O-11 based on Input 10 and Assumption 29 (see Note R6 in "References" worksheet).
- The standard volumetric flowrate of the pressure control air injected into the system (LMP13) is taken from vendor submittal (Assumption 27). The film cooler discharge and the pressure control air are combined and become LMP14, "Controlled Offgas".

(3) Submerged Bed Scrubber (SBS) and Wet Electrostatic Precipitator (WESP)

The gas then travels through the SBS to remove large particulates and through the WESP to remove smaller particulates.

- The SBS discharge stream (LOP02) is assumed to be saturated with water vapor (Assumption 6) and the steam standard flowrate is adjusted (cell E-17) until the relative humidity (cell AC-17) is 100%.
- At the WESP, there is an air purge (LOP06) which is added to the stream; the WESP air purge flowrate is defined at 350 acfm at 1 psig per vendor submittal (Input 6). Dry air SCFM in the flowsheets (cell C-20) is adjusted until dry air ACFM in Cell Y-20 equals 350 ACFM.

- Both units (SBS and WESP) also have air inleakage, which is estimated (Assumption 21) and added to the offgas stream.
- The pressure drop across the control valve downstream of the WESP discharge is calculated in cell S-24 based on the equation developed in Attachment 41.

(4) Vessel Vent Offgas

Refer to Section A4.5 in Attachment 4 for methodology related to the LAW Vessel Ventilation Design Basis Flowsheets calculations. The following are determined in Attachment 4:

- Entrained particulate mass flowrates are determined in Attachment 4 and entered into cell EU-25 of the main flowsheets.
- Vessel vent air addition flowrates are estimated in Attachment 4 and entered into cell I-25 of the main flowsheets. This is added to the offgas flow through control valve stream and becomes LVP03, “Combined Offgas” (cell C-26).

(5) High Efficiency Particulate Filters (HEPA) and Preheaters

- The offgas is heated in the HEPA preheater before entering the HEPA filters to further remove particulates. The offgas temperature is heated to a 20ºC increase across the preheater to prevent condensation in the HEPA filters (Assumption 12); therefore, the temperature of the HEPA preheater discharge (LVP04) is increased by 20ºC in cell O-28.
- The ammonium nitrate that may form before the HEPA filters is calculated in Attachment 32. This mass flow is added to the mass flow of particulates in the “Combined Offgas” stream (LVP03) to obtain the mass flow of total particulate exiting the preheater in Cell EU-28.
- The particulate mass flow in the HEPA discharge (cell EU-30) is further reduced by the HEPA filter particulate removal efficiency of 99.95% (Input 14 in section 2.1).
- This unit also has air inleakage, which is estimated (Assumption 21) and added to the offgas stream.

(6) Activated Carbon Beds

The offgas then travels through the carbon beds where mercury is removed.

- The S-AC discharge temperature (cell O-33) includes the temperature change across the carbon beds defined in Assumption 61.
- The amount of mercury leaving the carbon beds is determined based on the environmental permit limit. This is calculated in Attachment 35 and the calculated mass flow of mercury in the Activated Carbon Bed discharge stream (LVP26) is entered into cell DK-33 of the main flowsheets.
- The LAW Melter I-129 emission is determined in Attachment 36 based on the contract maximum I-129 limit (Assumption 15) and the melter DF for I-129 (Input 54).
- This unit also has inleakage, which is estimated (Assumption 21) and added to the offgas stream.

(7) Catalytic Oxidizer/Reducer Skid (TCO/SCR)

The offgas has potentially high levels of NO_X because the melter decomposes the parent nitrate/nitrite compounds. Some of the resulting NO_X is decomposed to nitrogen and water in the melter, and some is removed by scrubbing in the SBS. VOCs are also present in the offgas stream. The remaining NO_X and VOCs will be removed by passing the offgas through a catalytic oxidizer/reducer skid.

The catalyst skid houses a set of four process components: heat exchanger, electric heater, Thermal Catalytic Oxidizer (TCO) catalyst bed, and Selective Catalytic Reducer (SCR) catalyst bed.

- Heat exchanger: The exchanger first raises the offgas temperature before it enters the catalyst beds by recovering heat from the hot offgas exiting the catalyst beds. The hot side of the heat exchanger heats the cold side offgas entering the SCO/SCR catalyst beds by transferring heat to the cold side and thus the hot side offgas get cooled prior to discharge from the catalyst skid. Temperatures from the heat exchanger cold side discharge (LVP10) and hot side discharge (LVP09) are calculated in Attachment 40 and those temperatures are entered into cells O-36 and O-45 of the main flowsheets.
- Electric Heater: The electric heater ensures that the offgas stream is at a minimum temperature of 750°F (Input 19) before entering the catalyst beds. This temperature is entered in cell Q-37 of the main flowsheets.
- TCO: The TCO unit oxidizes volatile and semi-volatile organic compounds. The offgas composition change and the temperature change from the heat of reaction are calculated in Attachment 20. The standard volumetric flowrate of steam in the TCO discharge (cell E-38 of the main spreadsheets) is determined by adding the steam standard flow formed from the reaction (Attachment 20) to the steam standard flow from the electric heater discharge. The mass flow of additional dry air, CO_2 produced, O_2 consumed and steam produced from the oxidation reactions are added to or subtracted from the corresponding upstream flowrates to obtain the mass flows in the TCO discharge (cells C-38, BI-38, BC-38 and BU-38 respectively of the main flowsheets). The temperature increase from the reactions in the TCO (per Attachment 20) is added to the TCO inlet temperature (calculated from Equation (17b) in Section 5.17) to determine the TCO discharge temperature (cell O-38 of the main flowsheets).
- SCR: The SCR requires ammonia for the chemical reaction to reduce NOx to nitrogen and water. The amount of ammonia required, the composition change of the offgas, and the temperature change from the heat of reaction are calculated in Attachment 8. The standard volumetric flow of ammonia dilution air (cell I-39) is set at 800 scfm (Assumption 60). The mass flow of ammonia required and calculated in Attachment 8 is entered into cell K-41 of the main spreadsheets. The standard flow of dilution air and the ammonia required are summed to obtain the diluted ammonia addition standard flow. The TCO offgas discharge (LVP12) flow and the ammonia (LVP13) flow are blended in cells C-43, D-43 & E-43 (LVP23 - SCR Input). The changes in gas composition and temperature from the chemical reaction are incorporated in row 44, "SCR Discharge". The mass flow of additional N_2 produced, O_2 consumed, net dry air, steam produced and residual ammonia from the reactions are added to or subtracted from the corresponding flowrates in "SCR Input" to obtain the mass flows in the SCR discharge (cells AW-44, BC-44, C-44, BU-44, and CS-44 respectively in Attachment 1 main spreadsheets). The temperature increase from the reactions in the SCR (per Attachment 8) is added to the temperature of the blended stream of gas and ammonia (calculated from Equation 17(b) in Section 5.17) to determine the SCR discharge temperature (cell O-44 of the main flowsheets).

The skid has an air inleakage rate which is estimated per Assumption 21, entered in cell C-46, and then added to the offgas stream dry air standard flowrate.

(8) Caustic Scrubber

The caustic scrubber removes acid gases from the offgas stream.

- The caustic scrubber discharge flowrate (cell C-48) is the total of the catalyst skid discharge flow, air inleakage flow and dry spray air determined in Attachment 39.

- The outlet temperature of the gas stream from the scrubber is calculated in Attachment 39 and entered in cell O-48 of the main flowsheets. The amount of acid gas (HCl, HF, SO_2, NO_2, CO_2) removed at the scrubber is determined based on the scrubber removal efficiency (Input 16, 17, 18) and this is incorporated in row 48. The mass flow of steam in the caustic scrubber discharge is calculated from the energy balance in Attachment 39 and entered in cell BU-48 of the main flowsheets.
- The scrubber has an air inleakage which is estimated per Assumption 21, entered in cell C-49, and then added to the main offgas stream dry air standard flowrate.

(9) Exhaust Fans

- The offgas stream is then pulled through exhaust fans before travelling through the stack. The temperature increase from compression as the gas is pulled through the exhausters is calculated in Attachment 7 and the exhauster discharge temperatures are entered into cell O-51 of the main flowsheets.
- The exhauster has an air inleakage which is estimated per Assumption 21, entered in cell C-52, and then added to the main offgas stream dry air standard flowrate.

(10) Stack

The offgas stream exits the stack at ambient temperature and pressure (Assumption 13 & Input 1, Section 2.1).

Fundamental Equations

Fundamental equations used in this calculation are defined in this section.

5.1 Offgas Mass and Volume Equations

Rearrange ideal gas law equation per Felder, Equation 5.2 (Ref. 10.2.9, Page 186) to solve for mass or volume:

$$P * V = n * R_G * T$$

Since $n = m/MW$

$$P * V = \frac{m}{MW} * R_G * T$$

Mass: $$m = \frac{P * V * MW}{R_G * T} \qquad (1a)$$

Volume: $$V = \frac{m * R_G * T}{P * MW} \qquad (1b)$$

Where:

n = Molar Flowrate (mol/hr)
m = Mass Flowrate (g/hr)
P = Absolute Pressure (Pa)
V = Volumetric Flowrate (m^3/hr)
MW = Molecular Weight (g/mol)
R_G = Gas Constant = 8.314 $m^3 \cdot Pa/(mol \cdot K)$
T = Absolute Temperature (K)

Equation (1a) is used to calculate the total mass flow from the total volumetric flow in Column K of Attachment 1 flowsheets (Equation Note E18 in "Equations" worksheet).
Equation (1b) is used in Attachment 2 to convert a mass flow to a volumetric flow.

5.2 Temperature Conversion

5.2.1 Convert from °C to °F

Temperature is converted from ºC to ºF as follows (Felder, Equation 3.5-4 (Ref. 10.2.9, Page 64)):

$$°F = °C * \frac{9°F}{5°C} + 32°F \qquad (2a)$$

Where:
°F = Temperature in Degree Fahrenheit
°C = Temperature in Degree Celsius

Equation (2a) is used to convert temperatures in column Q of Attachment 1 flowsheets (Equation Note E16 in "Equations" worksheet).

5.2.2 Convert from °F to °C

Rearrange Equation (2a) above:

$$°C = \left(°F - 32°F\right) * \frac{5°C}{9°F} \qquad (2b)$$

Equation (2b) is used to convert temperatures in column O of Attachment 1 flowsheets (Equation Note E17 in "Equations" worksheet).

5.3 Decontamination Factor

The decontamination factor is defined as follows:

$$DF = \frac{\text{Mass in}}{\text{Mass out}} \qquad (3a)$$

Where: DF = Decontamination Factor

Mass in = Mass flowrate at inlet (kg/hr)
Mass out = Mass flowrate at outlet (kg/hr)

The capture efficiency is defined as:

$$Capture\ Efficiency = \frac{mass\ in - mass\ out}{mass\ in} = \frac{mass\ in}{mass\ in} - \frac{mass\ out}{mass\ in} = 1 - \frac{1}{DF} = \frac{DF-1}{DF} \qquad (3b)$$

Equations (3a) and (3b) are used in Attachments 34 & 42. Equation (3a) is also used for the maximum case flowsheet in Attachment 1 to include a DF across the SBS and the WESP for NO, HCl, HF, and SO_2.

5.4 Mass Concentrations of Gas Species (mg/m^3)

The mass concentration of gas species (mg/m^3) is determined as follows:

$$Concentration = \frac{Mass}{Volume}$$

$$Concentration\ \left(\frac{mg}{m^3}\right) = \frac{Mass\ (kg/hr)}{Volume\ (ft^3/min)} * \frac{35.3145\ ft^3}{m^3} * \frac{10^6\ mg}{kg} * \frac{hr}{60\ min} \qquad (4)$$

5.5 Volume Concentrations of Gas Species (ppmv)

The volume concentration of gas species (ppmv) is determined as follows:

$$Concentration\ (ppmv) = \frac{Individual\ Gas\ Species\ Volume}{Total\ Volume} * 10^6\ ppmv$$

Substitute Equation 1(b) into the individual gas species volume in the equation above:

$$Conc_i\ (ppmv) = \frac{m_i * R_G * T_i}{P_i * MW_i * V_{tot}} * 10^6\ ppmv$$

Including units results in Equation (5) below:

$$Conc_i\ (ppmv) = m_i\left(\frac{kg}{hr}\right) * \frac{10^3 g}{kg} * \frac{hr}{60\ min} * \frac{8.314\ m^3 \cdot Pa}{mol \cdot K} * \frac{T_i(K)}{P_i\ (mbar)} * \frac{mbar}{100\ Pa} * \frac{1}{MW_i(g/mol)} * \frac{1}{V_{tot}\ (ft^3/min)} * \frac{35.3145\ ft^3}{m^3} * 10^6\ ppmv \qquad (5)$$

Where:

$Conc_i$ = Volume Concentration of gas species i (ppmv)
m_i = Mass Flowrate of gas species i (kg/hr)
P_i = Absolute Pressure of gas species i (mbar)

V_{tot} = Total Stream Volumetric Flowrate (ft^3/min)
MW_i = Molecular Weight of gas species i (g/mol)
R_G = Ideal Gas Constant = 8.314 $m^3 \cdot Pa/(mol \cdot K)$
T_i = Absolute Temperature of gas species i (K)

5.6 Ideal Gas Law Based Equation for converting SCFM to ACFM

The standard volumetric flowrate (SCFM) is converted to actual volumetric flowrate (ACFM) from the following equation [Felder Equation 5.2-5 (Ref. 10.2.6, page 188)]:

$$\frac{P_A * V_A}{P_S * V_S} = \frac{n_A * T_A}{n_S * T_S} \qquad (6)$$

Since $n_A = n_S$ (number of moles of gas does not change), simplifying Equation (6) above and solving for the actual volume V_A:

$$V_A = V_S * \frac{T_A}{T_S} * \frac{P_S}{P_A} \qquad (6a)$$

Where:

V_A = Actual Volumetric Flowrate (ACFM)
V_S = Standard Volumetric Flowrate (SCFM)
T_A = Actual Absolute Temperature (K)
T_S = Standard Absolute Temperature = 293.15 K
P_S = Standard Absolute Pressure = 1 atm = 1013.25 mbar
P_A = Actual Absolute Pressure (mbar)

Equation (6a) is used to calculate the actual volumetric flowrates (ACFM) in Column Y of Attachment 1 flowsheets (Equation Note E25 in "Equations" worksheet).

Similarly, rearranging Equation (6a) to convert ACFM to SCFM:

$$V_S = V_A * \frac{T_S}{T_A} * \frac{P_A}{P_S} \qquad (6b)$$

Equation (6b) is used in to convert actual flow (ACFM) to standard flow (SCFM) in Attachment 41.

5.7 Density Equation based on Ideal Gas Law

Density is defined as $\rho_G = \frac{m}{V}$, where m is mass and V is volume.

Substitute m in Equation (1a) into the density equation above:

$$\rho_G = \frac{m}{V} = \frac{P * MW}{R_G * T} * \frac{kg}{1000g} \qquad (7)$$

Where:

ρ_G = Gas Density (kg/m^3)
m = Mass Flowrate (kg/min)
V = Volumetric Flowrate (m^3/min)
MW = Molecular Weight (g/mol)
R_G = Ideal Gas Constant = 8.314 m^3*Pa/(mol*K)
P = Pressure (Pa). If P is in mbar, use the conversion factor 100 Pa /1 mbar.
T = Temperature (K)

Equation (7) is used to calculate density in Column AG of Attachment 1 flowsheets (Equation Note E27 in "Equations" worksheet).

5.8 Water Volumetric Flowrate Determination from Absolute Humidity

From the Ideal Gas Law equation for air and water at same pressure & temperature condition:

$$\frac{P * V_{H_2O}}{P * V_{Air}} = \frac{n_{H_2O} * R_G * T}{n_{Air} * R_G * T} = \frac{\frac{m_{H_2O}}{MW_{H_2O}} * R_G * T}{\frac{m_{Air}}{MW_{Air}} * R_G * T}$$

Simplify the equation:

$$\frac{V_{H_2O}}{V_{Air}} = \frac{m_{H_2O}}{m_{Air}} * \frac{MW_{Air}}{MW_{H_2O}}$$

Since H_A = mass of water vapor / mass of dry air = m_{H2O} / m_{Air} (Ref. 10.2.9, pg 244):

$$V_{H_2O} = V_{Air} * H_A * \frac{MW_{Air}}{MW_{H_2O}} \qquad (8)$$

Where:

n_{H2O} = Water Molar Flowrate (lbmol/hr)
n_{Air} = Air Molar Flowrate (lbmol/hr)
m_{H2O} = Water Mass Flowrate (lb/hr)
m_{Air} = Air Mass Flowrate (lb/hr)
R_G = Gas Constant = 0.7302 ft^3·atm/(lbmol·°R)
P = Pressure (atm)
T = Temperature (°R)
V_{H2O} = Water Volumetric Flowrate (ft^3/min)
V_{Air} = Dry Air Volumetric Flowrate (ft^3/min)
H_A = Absolute Humidity (lb water/lb dry air)
MW_{Air} = Dry Air Molecular Weight (lb/lbmol)
MW_{H2O} = Water Molecular Weight (lb/lbmol)

Equation (8) is used in column E of Attachment 1 as needed to calculate flow from absolute humidity (Equation Note E19).

5.9 Relative Humidity Equation

The relative humidity is calculated using the following equation:

$$H_R = \frac{p_{H_2O}}{p_{H_2O}^*(T)}$$ (Ref. 10.2.9, Equation 6.3-4, pg 243)

Since: $p_{H_2O} = y_{H2O} \cdot P$ (Ref. 10.2.9, Equation 6.3-1, pg 238)

$$\Rightarrow \quad H_R = \frac{y_{H_2O} \cdot P}{p_{H_2O}^*(T)}$$

The vapor pressure of water, $p_{H2O}^*(T)$, varies as a function of temperature. The water vapor pressure equations are determined in Attachment 14 as shown below:

$$p_{H_2O}^*(T) = 9.673 \cdot 10^{-6} * T^4 - 3.357 \cdot 10^{-4} * T^3 + 3.574 \cdot 10^{-2} * T^2 + 0.1843 * T + 6.445 \quad \text{(for T = 0 - 100°C)}$$

$$p_{H_2O}^*(T) = 2.181 \cdot 10^{-5} * T^4 - 7.807 \cdot 10^{-3} * T^3 + 2.002 * T^2 - 235.2 * T + 10220 \quad \text{(for T > 100°C)}$$

Therefore, the relative humidity equation can be written as follows:

$$H_R = \frac{y_{H_2O} * P}{9.673 \cdot 10^{-6} * T^4 - 3.357 \cdot 10^{-4} * T^3 + 3.574 \cdot 10^{-2} * T^2 + 0.1843 * T + 6.445} \quad \text{(9a)} \quad [\text{for } T \leq 100°C]$$

$$H_R = \frac{y_{H_2O} * P}{2.181 \cdot 10^{-5} * T^4 - 7.807 \cdot 10^{-3} * T^3 + 2.002 * T^2 - 235.2 * T + 10220} \quad \text{(9b)} \quad [\text{for } T > 100°C]$$

Where:

H_R = Relative humidity (%)
p_{H2O} = Partial pressure of water vapor (mbar)
y_{H2O} = Mole fraction of water vapor (which is equal to the volume fraction of water vapor per Ref. 10.2.9, p. 191)
P = Total system pressure (mbar)
$p_{H2O}^*(T)$ = Vapor pressure of water as a function of temperature (mbar)
T = Temperature (°C)

Equations 9a & 9b are used to calculate the relative humidity in Column AC of Attachment 1 flowsheets (Note N10 in the "Notes" worksheet).

5.10 General Heat Transfer Equation

The general heat transfer equation is shown below (Ref. 10.2.10, Equation 11-6, page 280):

$$Q = m * C_P * \Delta T \qquad (10)$$

Where:

Q = Energy transferred (kJ/hr)
m = Mass flowrate (kg/hr)
C_P = Heat capacity (kJ/kg·°C)
ΔT = Differential temperature (°C)

Equation 10 is used in heat balances for the TCO/SCR and Catalytic Skid Recuperative Heat Exchanger (Attachment 8, 20 & 40).

5.11 Absolute Humidity Equation

The absolute humidity equation is shown below (Felder, pg 244 (Ref. 10.2.9, Eq. 6.3-6)):

$$H_A = \frac{mass\ of\ water\ vapor}{mass\ of\ dry\ gas} = \frac{m_{H_2O}}{m_{Air}} = \frac{x_{H_2O}}{x_{Air}}$$

Since $x_{Air} = 1 - x_{H_2O}$

$$\Rightarrow \quad H_A = \frac{x_{H_2O}}{1 - x_{H_2O}} \qquad (11)$$

Where:

H_A = Absolute humidity (lb H_2O / lb Air)
m_{H2O} = Mass of water (lb/hr)
$m_{Air.}$ = Mass of air (lb/hr)
x_{H20} = Mass fraction of water vapor
x_{Air} = Mass fraction of air

Equation 11 is used to calculate the humidity ratio in Column AA of Attachment 1 flowsheets (Equation Note E31 in the "Equations" worksheet).

5.12 Molecular Weight

The molecular weight of offgas streams is determined as the weighted average of individual component molecular weights based on the volume % of offgas components (N_2, O_2, CO_2, Ar, H_2O) and volumetric concentrations (ppm) of other contaminants as shown below:

$$MW_{avg} = \sum(MW_i * y_i + MW_i * Conc_i/10^6) \qquad (12)$$

Where:

MW_{avg} = Molecular Weight of Offgas (g/mol)
MW_i = Molecular Weight of Gas Component i (g/mol)
y_i = Primary Gas Component Volume %
$Conc_i$ = Volumetric Concentration of Gas Contaminant i (ppmv)

Equation 12 is used in Column AE of Attachment 1 flowsheets (reference to Equation Note E56 in “Equations” worksheet).

5.13 Specific Activity Calculation for Iodine-129

The specific activity for I-129 is determined from the following equation:

$$AM_{I129} = \frac{\ln(2) * N}{HalfLife_{I129}} \quad \text{(Ref. 10.2.16, Section F, pg 29)}$$

Where: N = number of atoms per gram
AM_{I129} = specific activity of I-129 (disintegration/second/g or Bq/g)
$HalfLife_{I129}$ = half life of Iodine-129 (seconds)

Since: $N = N_{AG} / MW_{I129}$

Where: N_{AG} = Avogadro’s number ($6.02 * 10^{23}$ atoms/mol)
MW_{I129} = molecular weight of I-129 (g/mol)

$$AM_{I129} = \frac{\ln(2) * N_{AG}}{MW_{I129} * HalfLife_{I129}} \qquad (13)$$

Equation (13) is used in Attachment 36 to calculate the specific activity of I-129 which is then used to determine the maximum melter I-129 emission into the offgas.

5.14 Volume Fraction to Mass Fraction Conversion for Individual Gas Components

Volume fraction is converted to mass fraction as follows:

$$Mass\ fraction:\ x_i = \frac{m_i}{m_T} = \frac{n_i}{n_T} * \frac{MW_i}{MW_{avg}}$$

Since the volume fraction of a component in an ideal gas mixture equals the mole fraction of this component (Ref. 10.2.9, pg 191), the equation to convert the volume fraction to mass fraction can be shown as:

$$x_i = y_i * \frac{MW_i}{MW_{avg}} \qquad (14a)$$

Where:

x_i = Mass Fraction of Gas Component i
y_i = Volume Fraction of Gas Component i
m_i = Mass Flowrate of Gas Component i (g/hr)
m_T = Overall Mass Flowrate of the offgas stream (g/hr)
n_i = Molar Flowrate of Gas Component i (mol/hr)
m_T = Overall Molar Flowrate of the offgas stream (mol/hr)
MW_i = Molecular Weight of Gas Component i (g/mol)
MW_{avg} = Molecular Weight of Offgas (g/mol)

Equation (14a) is used to calculate the gas component mass fraction in Columns AY, BE, BK, BQ, and BW in Attachment 1 flowsheets (Equation Note E26 in “Equations” worksheet). The mass fraction is represented as wt% in Attachment 1 flowsheets.

Rearranging Equation (14a) to convert mass fraction to volume fraction:

$$y_i = x_i * \frac{MW_{avg}}{MW_i} \qquad (14b)$$

Equation (14b) is used to calculate the volume fraction in cells in Columns BA, BG, BM, and BS in Attachment 1 flowsheets (Equation Note E37 in “Equations” worksheet).

5.15 Outlet Temperature of Offgas Exhausters (Incorporating Fan Efficiency)

The ideal discharge temperature from isentropic expansion across the offgas exhausters (T_d) is calculated from Perry’s Equation 10-76 (Ref. 10.2.14, pg 10-45):

$$T_d = T_i \cdot \left(\frac{P_d}{P_i}\right)^{\frac{\gamma-1}{\gamma}} \qquad (15a)$$

Where:
T_d = ideal discharge temperature (K)
T_i = inlet temperature (K)
P_d = discharge pressure (atm)
P_i = inlet pressure (atm)
γ = ratio of specific heats = 1.4 for air (Ref. 10.2.1, Table 23.7, pg 23-16)

The final actual exhauster discharge temperature (T_f) is determined as shown below.

The compression efficiency is defined as (Ref. 10.2.4, Eq. 15.22, pg 357):

$$\eta = \frac{h_d - h_i}{h_f - h_i} = \frac{Cp \cdot (T_d - T_i)}{Cp \cdot (T_f - T_i)}$$

Where:
η = compression efficiency
h_d = ideal or isentropic discharge enthalpy (kJ/kg)
h_i = enthalpy at inlet temperature (kJ/kg)
h_f = enthalpy at actual discharge temperature (kJ/kg)
Cp = heat capacity (kJ/kg·°C)
T_d = ideal discharge temperature (°C)
T_i = inlet temperature (°C)
T_f = final actual discharge temperature (°C)

$$\Rightarrow \quad \eta = \frac{T_d - T_i}{T_f - T_i}$$

Solving for the actual exhauster discharge temperature T_f:

$$T_f = \frac{T_d - T_i}{\eta} + T_i \qquad (15b)$$

Exhauster operating efficiency, η, is 58% per Input 25 in Section 2.1.

Substituting T_d in Equation (15a) into Equation (15b):

$$T_f = \frac{T_i \cdot \left(\frac{P_d}{P_i}\right)^{\frac{\gamma-1}{\gamma}} - T_i}{\eta} + T_i \qquad (15c)$$

Equations (15a) and (15c) are used in Attachment 7 to calculate the final actual exhauster discharge temperature which is then entered into cell O-51 of Attachment 1 flowsheets.

5.16 Heat Capacity Calculation

Heat Capacity of Offgas Mixture

The offgas heat capacity is estimated from the individual component heat capacities and mass fractions per Felder, Eq. 8.3-17 (Ref. 10.2.9, pg 353):

$$Cp_m(T) = \sum x_i * Cp_i(T) \qquad (16a)$$

Where:
$Cp_m(T)$ = heat capacity of the offgas mixture (kJ/kg·°C)
x_i = mass fraction of gas component i

$Cp_i(T)$ = heat capacity of gas component i (kJ/kg·°C)

The heat capacity of each gas component varies with the temperature. The temperature dependent equations to estimate the heat capacity of primary gas components are shown in Attachment 15 (see Input 2.7).
Equation (16a) is used to calculate the offgas heat capacity in Column AK of Attachment 1 flowsheets (Equation Note E52 in "Equations" worksheet).

Heat Capacity of Ammonia

The heat capacity equation for ammonia is taken from Ref. 10.2.15, pg 657:

$$Cp = CPVAP\ A + (CPVAP\ B)*T + (CPVAP\ C)*T^2 + (CPVAP\ D)*T^3 \qquad (16b)$$

Where: Cp = heat capacity (J/mol·K)
T = temperature (K)

The coefficients for the ammonia heat capacity equation are from Ref. 10.2.15, pg 668:

CPVAP A = 2.731E+1
CPVAP B = 2.383E-2
CPVAP C = 1.707E-5
CPVAP D = -1.185E-8

The Cp result is then divided by ammonia's molecular weight (17.03 g/mol per Input 2.2) and reported as kJ/(kg*°C).

Equation (16b) is used to calculate the heat capacity in Cell AK-41 in Attachment 1 flowsheets (Equation Note E8 in "Equations" worksheet).

Heat Capacity of Allyl Alcohol (C_3H_6O)

The heat capacity equation for C_3H_6O used in Attachment 20 is taken from Ref. 10.2.17, pg A.36 & A.37:

$$Cp/R_G = a_0 + a_1\,T + a_2\,T^2 + a_3\,T^3 + a_4\,T^4 \qquad (16c)$$

Where: Cp = heat capacity (J/mol·K)
R_G = gas constant = 8.314 J/mol·K
T = temperature (K)

The coefficients for the allyl alcohol heat capacity equation are: (Ref. 10.2.17, pg A.37):

$a_0 = 0.248$ $a_1 = 34.938 \cdot 10^{-3}$ $a_2 = -1.685 \cdot 10^{-5}$
$a_3 = -0.192 \cdot 10^{-8}$ $a_4 = 0.324 \cdot 10^{-11}$

Equation (16c) is used in Attachment 20 to determine the allyl alcohol heat capacity.

5.17 Calculating the Temperature of a Blended Stream

In some instances in the flowsheet, two streams are blended (such as when the main offgas stream is blended with the film cooler air).

Per Equation (10), the energy balance is as follows:

$Q = m * Cp * (T_O - T_i)$

The system is assumed to be adiabatic and no mass is accumulated.

$Q = 0$

Mass in = Mass out

Heat capacity of a stream is dependent on temperature and the composition of the gas (see Equation (16a)). Enthalpy is usually calculated from a reference temperature which is assumed to be 0°C for simplification and does not appear in the equations below.

When two streams are blended, the mass of the combined stream is the sum of the two individual stream masses:

$$m = m_1 + m_2$$

$$m * Cp_O * T_O = (m_1 * Cp_{i1} * T_{i1}) + (m_2 * Cp_{i2} * T_{i2})$$

Solve for T_O:

$$T_O = \frac{(m_1 * Cp_{i1} * T_{i1}) + (m_2 * Cp_{i2} * T_{i2})}{m * Cp_O} \qquad (17a)$$

T_O and Cp_O are both unknowns. The Attachment 1 spreadsheet iterates until these values stabilize.

This method is used in Column O, rows 13, 15, 21, 26, 42 for blending non-reactive streams.

For reactive systems such as those around the SCR, the energy balance takes into account the heat of reaction as follows:

$$0 = Q_R + (m * Cp_O * T_O) - \{(m_1 * Cp_{i1} * T_{i1}) + (m_2 * Cp_{i2} * T_{i2})\}$$

Solve for T_O:

$$T_O = \frac{(m_1 * Cp_{i1} * T_{i1}) + (m_2 * Cp_{i2} * T_{i2})}{m * Cp_O} - \frac{Q_R}{mCp_O} \qquad (17b)$$

Where:

Q = heat transferred to or from surroundings (kJ/hr)

Q_R = heat of reaction (kJ/hr)
m = mass of total gas stream at outlet (kg/hr)
m_1 = mass of inlet stream 1 (kg/hr)
m_2 = mass of other inlet stream 2 (kg/hr)
T_i = inlet gas temperature (°C)
T_O = outlet gas temperature (°C)
T_{i1} = temperature of inlet stream 1 (°C)
T_{i2} = temperature of inlet stream 2 (°C)
Cp_O = outlet gas heat capacity (kJ/kg°C)
Cp_{i1} = heat capacity of inlet stream 1 (kJ/kg°C)
Cp_{i2} = heat capacity of inlet stream 2 (kJ/kg°C)

Again, T_O and Cp_O are unknowns. The temperature change (Q_R/mCp_O) for the SCR is calculated in Attachment 8, respectively. The Attachment 1 spreadsheet then iterates to find T_O using Equation (17b) and Cp_O. These variables are then used to recalculate the temperature changes in Attachment 8. This process repeats until the values stabilize. This affects cell O-44 of Attachment 1 flowsheets.

Equation (17b) is also used in cell O-38 to determine the temperature of the TCO discharge stream (LVP12); however, in this case there is only one incoming stream to the TCO.

5.18 Mass and Energy Balance around the Caustic Scrubber

Absolute Humidity Definition per Felder, Equation 6.3-6 (Ref. 10.2.9, pg 244), used in Attachment 44:

$$H = \frac{M_v \cdot p_v}{M_{dry} \cdot (P - p_v)} \qquad (18)$$

Where:
H = absolute humidity (kg water /kg air)
M_v = molecular weight of water vapor (g/mol)
M_{dry} = molecular weight of dry (vapor free) air (g/mol)
p_v = partial pressure of water (atm)
P = total system pressure (atm)

Enthalpy balance for the caustic scrubber:

$$c_s \cdot (T_{in} - T_s) + H \cdot \lambda_s = H_s \cdot \lambda_s$$

McCabe, Eq. 23-11 (Ref. 10.2.10, pg 663)

The humid heat, c_s, is defined as:

$$c_s = Cp_{air} + Cp_{H2O} \cdot H$$

McCabe, Eq. 23.-6 (Ref. 10.2.10, pg 661)

Where:
c_s = humid heat (kJ/kg·°C)
T_{in} = temperature of gas entering scrubber (°C)

T_s = saturation temperature of gas (°C)
H = absolute humidity at T_{in} (kg air /kg water)
H_s = saturation humidity at T_s (kg air /kg water)
λ_s = latent heat of vaporization at T_s (kJ/kg)
Cp_{air} = heat capacity of air (kJ/kg·°C)
Cp_{H2O} = heat capacity of water vapor (kJ/kg·°C)

Substituting c_s:

$$(Cp_{air} + Cp_{H2O} \cdot H) \cdot (T_{in} - T_s) + H \cdot \lambda_s = H_s \cdot \lambda_s$$

$$Cp_{air} \cdot (T_{in} - T_s) + (Cp_{H2O} \cdot H) \cdot (T_{in} - T_s) + H \cdot \lambda_s = H_s \cdot \lambda_s \qquad (19)$$

The mass of air entering the scrubber is equal to the amount of air leaving the scrubber. The amount of water in the offgas will change as the offgas get quenched by the liquid spray as it passes through and becomes saturated when it leaves the scrubber (Assumption 19).

The absolute humidity, H, is defined as (Ref. 10.2.9, pg 244):

$$H = \frac{m_{H2O\,in}}{m_{air}}$$

Where: m_{H2Oin} = mass of water in the offgas entering the scrubber (kg/hr)
m_{air} = mass of dry air (kg/hr), at gas inlet temperature T_{in}

Similarly, the saturation humidity at the scrubber outlet is defined as:

$$H_s = \frac{m_{H2Oout}}{m_{air}} \quad \leftrightarrow \quad m_{H2Oout} = m_{air} \cdot H_s$$

Where: m_{H2Oout} = mass of water in the saturated offgas leaving the scrubber (kg/hr) [Assumption 19]
m_{air} = mass of dry air (kg/hr), at gas saturation temperature T_s

Substituting H and H_s in Equation (19):

$$Cp_{air} \cdot (T_{in} - T_s) + Cp_{H2O} \cdot \frac{m_{H2Oin}}{m_{air}} \cdot (T_{in} - T_s) + \frac{m_{H2Oin}}{m_{air}} \cdot \lambda_s = \frac{m_{H2O\,out}}{m_{air}} \cdot \lambda_s$$

Multiplying by m_{air} on both sides:

$$m_{air} \cdot Cp_{air} \cdot (T_{in} - T_s) + m_{air} \cdot Cp_{H2O} \cdot \frac{m_{H2Oin}}{m_{air}} \cdot (T_{in} - T_s) + m_{air} \cdot \frac{m_{H2Oin}}{m_{air}} \cdot \lambda_s = m_{air} \cdot \frac{m_{H2O\,out}}{m_{air}} \cdot \lambda_s$$

$$m_{air} \cdot Cp_{air} \cdot (T_{in} - T_s) + Cp_{H2O} \cdot m_{H2O\,in} \cdot (T_{in} - T_s) + m_{H2O\,in} \cdot \lambda_s = m_{H2O\,out} \cdot \lambda_s$$

$$m_{H2O_{out}} = \frac{m_{air} \cdot Cp_{air} \cdot (T_{in} - T_s) + Cp_{H2O} \cdot m_{H2O_{in}} \cdot (T_{in} - T_s) + m_{H2O_{in}} \cdot \lambda_s}{\lambda_s} \qquad (20)$$

$$\Leftrightarrow \quad m_{H2O_{out}} - \frac{m_{air} \cdot Cp_{air} \cdot (T_{in} - T_s) + Cp_{H2O} \cdot m_{H2O_{in}} \cdot (T_{in} - T_s) + m_{H2O_{in}} \cdot \lambda_s}{\lambda_s} = 0$$

Equation (20) is used in Attachment 39 to determine the mass flow of water vapor in the offgas discharge from the scrubber.

5.19 Calculation of Mercury Concentration

The amount of mercury in the offgas is determined based on the contract maximum, 1.4E-5 mol Hg/mol Na (Input 36). All mercury that enters the melter is assumed to be carried into the melter offgas (Assumption 49).

The amount of mercury in the melter feed is determined based on the following cases (Assumption 57):

- Minimum case – 25% of the contract maximum (mol Hg/ mol Na) in a 6 M Na feed stream
- Nominal case – 50% of the contract maximum in an 8 M Na feed stream
- Maximum case – 100% of the contract maximum in a 10 Na feed stream

Sodium concentration in the melter feed is assumed to be 6 M for the minimum case, 8 M for the nominal case, and 10 M for the maximum case (Assumption 57).

The melter is fed at a nominal rate of 190 gph for Envelope A feed (most common LAW feed) (Input 9).

The molecular weight of Hg is 200.59 g/mol (Input 2.2).

The mercury fed into the melter in the maximum case is calculated based on the sodium concentration as follows:

$$Hg\ into\ the\ melter\ \left(\frac{kg}{hr}\right) = 1.4E-5\ \frac{mol\ Hg}{mol\ Na} * X\ \frac{mol\ Na}{L} * 190\ \frac{gal}{hr} * \frac{1000\ L}{264.17\ gal} * 200.59\ \frac{g\ Hg}{mol\ Hg} * \frac{kg}{1000\ g} \qquad (21)$$

Where X is the sodium concentration of the feed (mol Na/L).

Equation (21) is used in Cell DK-15 of Attachment 1 flowsheets to calculate the Hg mass flowrate in the offgas. Note that in the nominal and minimum cases, only 50% and 25% of the mercury contract maximum limit in LAW feed is used in Equation (21) to calculate the Hg mass flowrate in the offgas (see Assumption 57).

5.20 Energy Balance around the TCO and SCR

The Thermal Catalytic Oxidizer unit (LVP-SCO-00001) oxidizes volatile and semi-volatile organic compounds to water and carbon dioxide. The standard oxidization reactions in the catalyst skid TCO are shown below.

VOC Reaction (C_3H_6O - Allyl Alcohol): $2\ C_3H_6O + 8\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

CO reaction: $2\ CO + O_2 \rightarrow 2\ CO_2$

The NOx Selective Catalytic Reducer unit (LVP-SCR-00001) uses ammonia injection to reduce the NOx to nitrogen, oxygen and water through catalytic reactions with ammonia. Reactions of ammonia and NOx in the SCR include the following (Ref. 10.2.3, pg 39):

NO Reaction: $2\ NO + 4\ NH_3 + 2\ O_2 \rightarrow 3\ N_2 + 6\ H_2O$
$6\ NO + 4\ NH_3 \rightarrow 5\ N_2 + 6\ H_2O$

NO_2 Reaction: $6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$

The heat of reaction (ΔH_r) is the difference between the enthalpy of the products and the enthalpy of the reactants at a given temperature and pressure (Ref. 10.2.9, pg. 422).

$$\Delta H_r = \sum (v_i * \Delta H_i)_{products} - \sum (v_i * \Delta H_i)_{reactants} \qquad (22a)$$

In general terms, the enthalpy change for reactants and products is expressed as: (Ref. 10.2.9, Equation 9.1-3, pg. 423)

$$\Delta H = \frac{\Delta H_r(T)}{v} * n \qquad (22b)$$

Where $\Delta H_r(T)$ = heat of reaction at temperature T, kJ/mol
ΔH = enthalpy change for reactants or products at temperature T, kJ/mol
n = moles of reactant or product
v = stoichiometric coefficient

Equations (22a) & (22b) are used in Attachment 8 for the SCR and Attachment 20 for the TCO to determine the enthalpy change from the reactions in the TCO/SCR.

The energy balance around the TCO/SCR is expressed as:

$$0 = Q_R + m * Cp * (T_O - T_i) = Q_R + m * Cp * \Delta T \qquad (22c)$$

Therefore, the temperature change across the TCO & SCR is calculated by rearranging Equation (22c):

$$\Delta T = \frac{-Q_R}{m * Cp} \qquad (22d)$$

Where ΔT = temperature change across TCO/SCR, °C
Q_R = total enthalpy change from the reactions, kJ/hr
m = mass flowrate of inlet offgas to TCO/SCR, kg/hr
Cp = offgas heat capacity, kJ/kg· °C
T_i = temperature at inlet to TCO/SCR, °C

T_O = temperature at TCO/SCR outlet, ºC

Equation (22d) is used in Attachment 8 for the SCR and Attachment 20 for the TCO to determine the temperature change across the TCO/SCR which is then used to determine the temperature at TCO/SCR outlet in Attachment 1 flowsheets.

5.21 Energy Balance for the Catalytic Skid Heat Exchanger (LVP-HX-00001)

An energy balance for the heat exchanger is performed to determine the heat exchanger cold side and hot side outlet temperatures.

The overall heat transfer equation for the catalytic skid heat exchanger is per McCabe, Equation 11-14 (Ref. 10.2.10, pg. 282).

$$q_{Cat} = U_{Cat} * A_{Cat} * \Delta T_L \qquad (23a)$$

Where,

q_{Cat} = rate of heat transfer for the catalytic skid heat exchanger (W)
U_{Cat} = Overall heat transfer coefficient = 2.74 Btu/(hr·ft^2·F) (Input 2.12)
A_{Cat} = Overall heat transfer area = 4056 ft^2 (Input 2.12)
ΔT_L = logarithmic mean temperature difference (°C), which is defined as (Ref. 10.2.10, pg. 282) :

$$\Delta T_L = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2 / \Delta T_1)}$$

Since $\Delta T_2 = T_{CatHotIn} - T_{CatColdOut}$ and $\Delta T_1 = T_{CatHotOut} - T_{CatColdIn}$ for countercurrent flow (Ref. 10.2.10, pg. 277):

$$\Delta T_L = \frac{(T_{CatHotIn} - T_{CatColdOut}) - (T_{CatHotOut} - T_{CatColdIn})}{\ln\left(\frac{T_{CatHotIn} - T_{CatColdOut}}{T_{CatHotOut} - T_{CatColdIn}}\right)} \qquad (23b)$$

Where,

ΔT_L = log mean temperature difference for the catalytic skid heat exchanger (°C)
$T_{CatHotIn}$ = hot side fluid inlet temperature (°C)
$T_{CatHotOut}$ = hot side fluid outlet temperature (°C)
$T_{CatColdIn}$ = cold side fluid inlet temperature (°C)
$T_{CatColdOut}$ = cold side fluid outlet temperature (°C)

The overall energy balance for the catalytic skid heat exchanger is shown below (Ref. 10.2.10, Equation 11-6, pg 280).

$$q_C = q_H$$

$$\therefore\ m_{CatCold} * Cp_{CatCold} * (T_{CatColdOut} - T_{CatColdIn}) = m_{CatHot} * Cp_{CatHot} * (T_{CatHotIn} - T_{CatHotOut}) \qquad (23c)$$

Where,

q_C = heat gained by the cold side fluid (kJ/hr)
q_H = heat lost by the hot side fluid (kJ/hr)
$m_{CatCold}$ = cold side mass flow rate (kg/hr)
$Cp_{CatCold}$ = cold side fluid heat capacity (kJ/(kg·°C)
m_{CatHot} = hot side mass flow rate (kg/hr)
Cp_{CatHot} = hot side fluid heat capacity (kJ/(kg·°C)

Since the rate of heat transfer in Equation (23a) and (23c) is equal to each other:

$$m_{CatCold} * Cp_{CatCold} * (T_{CatColdOut} - T_{CatColdIn}) = U_{Cat} * A_{Cat} * \Delta T_L$$

$$m_{CatHot} * Cp_{CatHot} * (T_{CatHotIn} - T_{CatHotOut}) = U_{Cat} * A_{Cat} * \Delta T_L$$

Solving for $T_{CatColdOut}$ and $T_{CatHotOut}$:

$$T_{CatColdOut} = T_{CatColdIn} + \frac{U_{Cat} * A_{Cat} * \Delta T_L}{m_{CatCold} * Cp_{CatCold}} \qquad (23d)$$

$$T_{CatHotOut} = T_{CatHotIn} - \frac{U_{Cat} * A_{Cat} * \Delta T_L}{m_{CatHot} * Cp_{CatHot}} \qquad (23e)$$

An initial guess of the heat exchanger cold side and hot side outlet temperatures is made. Calculations are performed iteratively until the determined cold side and hot side outlet temperatures are the same as the initial outlet temperature guesses. See Attachment 40 for detailed explanations and calculations.

5.22 Chemical Concentrations for the Maximum Case

Different APPS runs from the LAW process stream properties calculation (Ref. 9.65(a)) were performed to simulate the worst feed for the applicable contaminants (NO, NO_2, VOC, HCl, HF, SO_2, CO) and applicable data from these runs will be used in this calculation. Run 25 for Hg was not used because the methodology used in this calculation was already more conservative than the APPS results by applying the Hg permit limit in the calculations (see Attachment 35). Run 30 for Iodine was not used for this calculation. For total iodine, it was more conservative to use the contract maximum iodine with a melter DF calculated in Attachment 36. APPS data (see Input 2.14) was then used to calculate the mass fraction for individual constituents in each APPS run. This mass fraction is then multiplied by the total stream mass flowrate in the LOP flowsheet (column K) to determine the mass of the individual constituent in the melter offgas. This was used in cells CA-11, CM-11, CY-11, DQ-11, DW-11, EI-11, and EO-11 of Attachment 1 flowsheets.

DFs for NO, HCl, HF, I-129, and SO_2 (Input 2.15) are applied to the SBS and the WESP to determine the mass flow and concentrations of these constituents as they pass through the SBS and WESP.

6 Assumptions

6.1 Assumptions Not Requiring Verification

1. The relative humidity (RH) for the melter cave air is assumed to be 30% for the minimum case, 40% for the nominal case, and 100% for the maximum flowrate case. For simplicity, this same range of relative humidity will also be used for dilution air or air inleakage into the offgas system.

   The melter cave air is from a C5 area. The humidity of the C5 areas is not defined per Ref. 9.39, Table 12-1. However, the humidity of the C3 areas is defined as a minimum of 10% (Input 35, Section 2.1). Since the C3 air is cascaded to the C5 areas for radioactive containment, it is reasonably assumed that the melter cave air has relative humidity greater than the minimum for C3 air. Therefore 30% RH is selected for minimum case flowsheet and 40% for nominal case. A 100% maximum RH is used for bounding conservatism. The same relative humidities are used for air inleakage because the inleakage air originates from C3 and C5 areas.

   This assumption is bounded by assuming 100% RH for the maximum case which is used for design and therefore does not require verification.

2. Plant service air and instrument air are assumed to be completely dry.

   Plant service air is supplied from BOF and has a dew point of -40F (Ref. 9.37, pg. 1).

   This assumption is reasonable and does not require verification.

3. The melter air inleakage rate is assumed to increase from the minimum (149 SCFM per Input 3, Section 2.1) by 150% for the nominal case and 200% for the maximum cases (224 and 298 SCFM respectively).

   Inleakage into the LAW melter is defined from a vendor submittal (Table 4, 24590-QL-HC4-W000-00094-05-00003, Ref. 9.30). However, these predictions are for a "new" melter and do not include any compensation for the thermal effects over time that have been known to increase melter inleakage to some degree. Doubling the melter inleakage for the maximum case is conservative and compensates for potential inleakage increase due to aged system. The melter air inleakage rate is relative small compared to the overall flow in the LOP system.

   This assumption is conservative and has a small effect on the overall flow within the offgas system; therefore it does not require verification.

4. Not Used.

5. Waste Oxides loading into the LAW glass is assumed to be 25%. It is also assumed that no iodine is lost in Pretreatment.

   In Attachment 5, waste oxide loading during testing is shown to be about 25% for Envelope A wastes. Waste loading at this rate maximizes the amount of waste being processed in WTP when generating 15 MT of glass per day per melter. This would maximize emission rates into the LAW offgas. This assumption is conservative for iodine emission determination in Attachment 36.

In addition, assuming that no iodine is lost in Pretreatment provides conservatism for iodine emissions.

Combined, these assumptions are conservative in maximizing the iodine emissions in the LAW offgas and therefore do not require verification.

6. The water content of the SBS discharge is assumed to have a relative humidity of 100%.

   The offgas discharge from the SBS is saturated with water vapor since the gas is bubbled through a submerged packed bed.

   This assumption is bounding and does not require verification.

7. The pressure drops across the hot side of the LAW catalytic skid heat exchanger (LVP-HX-00001) for the “minimum case, 1 melter” and the “minimum case, 2 melters” are assumed to be the same.

   The flow rate for the “1 melter” case is too low to fit the equation derived in Attachment 37. The flow rate for the “2 melters” case is higher and does fit the equation. The pressure drop for the 2 melter case is actually higher than the pressure drop for the one melter case; therefore this assumption is conservative.

   The minimum case with one melter is not used for equipment sizing. This assumption is conservative and does not need to be verified.

8. No steam is assumed to condense from the melter offgas once it is discharged from the SBS.

   The offgas will in reality cool, resulting in some condensation. Assuming no condensation results in slightly higher gas flowrates, which is bounding for this calculation.

   This assumption is bounding and does not require verification.

9. The nominal vessel ventilation offgas temperature is assumed to be 86°F which is the average of the minimal and maximum temperatures of the C5 area where the vented vessels are located (minimum 59°F and maximum 113°F per Ref. 9.39, Table 12-1).

   This assumption is only intended for the nominal case and using the average of the minimum and maximum temperatures is reasonable to represent the nominal case.

   This assumption is justified for the nominal case and therefore does not require verification.

10. The vessel ventilation maximum case offgas temperature is assumed to be 113°F based on the maximum temperature of the C5 area.

    The maximum C5 temperature is 113°F (45°C) as defined in the Basis of Design 24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 12-1). This is the maximum temperature of process cells where the vented vessels are located.

This is a bounding assumption since it will maximize overall offgas flowrates for these cases and thus does not require verification.

11. No heat loss is assumed to occur in any of the LOP piping.

    Offgas temperatures are expected to decrease from heat loss from un-insulated offgas piping and equipment. Assuming no heat loss will help maximize the overall offgas flowrate. All offgas piping in the secondary offgas system is insulated and therefore will have minimal heat loss.

    This assumption is bounding and therefore does not require verification.

12. An offgas temperature increase of 20°C across the HEPA preheater is assumed to be sufficient to prevent condensation.

    The function of the HEPA preheater is to sufficiently increase offgas temperature so that there is no potential for condensation on the HEPA filters that could lead to blinding. The 20°C temperature rise assumption is validated upon examination of the resulting offgas relative humidities in Cell AC-30 in the Attachment 1 spreadsheets. This examination shows that all post-HEPA relative humidities are below 40% and therefore there is no risk of condensation.

    This assumption was justified above and therefore does not require verification.

13. The ambient air temperature is assumed to be 25°C (77°F).

    This temperature is included for completeness (cell O-54 of the flowsheet) based on a nominal warmer season temperature and is not meant to represent the actual ambient temperature which will change with the season (Hanford site temperature range from -23°F to 113°F per Input 50 & 51 in Section 2.1). This nominal temperature is not used for any calculation in the spreadsheet.

    This does not require verification because it does not affect the calculation results.

14. The minimal vessel ventilation offgas temperature is assumed to be 59°F based on the minimum C5 temperature.

    The minimum C5 temperature is 59°F (15°C) as defined in the Basis of Design 24590-WTP-DB-ENG-01-001 (Ref. 9.39, Table 12-1). This is the minimum temperature of process cells where the vented vessels are located.

    This is a bounding assumption since it will minimize overall offgas flowrates as is intended for this case and therefore does not require verification.

15. The contractual maximum I-129 concentration in LAW feed is assumed to be the same as the maximum I-129 concentration in HLW feed, i.e. $2.9 \cdot 10^{-7}$ Ci / 100 g waste oxide (Input 32).

    The I-129 concentration limit for HLW feed is mandated by the WTP Contract (Input 32). There is no such limit for LAW. Since the radioactive material concentration in HLW feed is expected to be much higher in HLW than in LAW, the application of the maximum I-129 concentration in HLW to LAW is bounding and thus does not require verification.

16. No mass transfer is assumed to occur from the waste to the vessel ventilation offgas except for particulate entrainment, water vapor, and hydrogen gas generated from radiolysis.

    This is a simplifying assumption since any gaseous evolution from these solutions would be insignificant and already bounded by what is in the melter offgas streams.

    This assumption has minimal effect on the results of this calculation and therefore does not require verification.

17. Not Used.

18. Process air additions are assumed to have no offgas contaminants. Air inleakage into offgas systems is also assumed to have no offgas contaminants.

    Process air is from the Plant Service Air System that is in a non-contaminated area. The equipment locations where inleakage occurs are ventilated by the facility HVAC systems resulting in minimal air contamination.

    Therefore, this assumption does not require verification.

19. The offgas exiting the LVP caustic scrubber is assumed to be saturated (i.e., completely quenched).

    The offgas is sprayed with liquid water as it travels through the scrubber. The offgas will evaporate water as it passes through because of its high inlet temperature. It is conservative to assume that the gas is saturated as it leaves the scrubber because this maximizes the offgas mass flow traveling to the fans.

    This assumption does not require verification.

20. The HEPA preheater pressure drop is assumed to be 0.5 in. WG for the minimum case, 1 in. WG for the nominal case, and 5 in. WG for the maximum case.

    Estimates of pressure drops are from available technical data from the vendor, Chromalox (Ref. 10.2.21, pg I-21; see Attachment 43 for the vendor data). Pressure drop data for the actual preheater model purchased for the WTP is not available. However, graphs G-227ADH, G-112S3, G189-S1, and G-227-2 show that even under very high linear velocities, the pressure drop across the heaters are in most cases below -1 in.WG. The pressure drop for the maximum case is increased to 5 in. WG to provide contingency for design uncertainty. This is consistent with the maximum pressure drop assumed in Mechanical Systems calculation 24590-LAW-MEC-LVP-00004, Rev. 2, *Sizing of the LAW Offgas HEPA Electric Preheaters LVP-HTR-00001A and LVP-HTR-00003A* (Ref. 9.42, Assumption 6.1.2). Therefore, 0.5 in. WG will be used for the minimum case, 1 in. WG will be used for the nominal case, and 5 in. WG will be used for the maximum case to provide contingency.

    The pressure drop across the HEPA preheater is pretty small and would only have a negligible effect on the overall pressure drop; therefore, this assumption does not require verification.

21. To further define the overall offgas flowrates, cell/room air is assumed to leak into each major piece of offgas equipment through flanges and other connections up until the LVP extraction fans. The minimal inleakage is assumed at 5 SCFM as in a new (i.e., tight) system. However, the nominal and maximum inleakage is assumed at 10 SCFM as in an old system. The inleakage air is also assumed to have no impact on offgas temperature due to a low inleakage rate.

The assumed inleakage values were chosen to be conservative while not creating an unreasonable accumulated downstream flowrate. These values are comparable to those calculated for vessel inleakages in Attachment 4 (see Table 2 in Attachment 4, individual vessel inleakage rates range from 4 – 10 SCFM).

These leakage assumptions are used for flowsheet purposes only and are not intended as a prediction of actual leak rates. Since the inleakage rates used are conservative and relative small compared to the overall offgas flowrate, the inleakage rates have minimal effect on the overall offgas flowrate through the system; therefore this assumption does not require verification.

22. Relative humidities of the vessel ventilation offgas are assumed to be 50%, 75%, and 100% for the minimum, nominal, and maximum cases, respectively.

    Vessel ventilation offgas will have significant humidity since the individual flowrates to the vessel result in significant headspace residence and vessels are mechanically agitated resulting in entrained aerosols. The 100% relative humidity defined for the maximum case maximizes the water content in the vessel vent offgas and is bounding for design. The relative humidities of 50% (minimum case) and 75% (nominal case) are conservatively selected for the flowsheet calculation purpose.

    This assumption is conservative and therefore does not require verification.

23. The melter inleakage pressure is assumed to be equal to the melter enclosure pressure.

    This is a simplifying assumption and the impact of melter inleakage is small compared to the overall pressure of the system. The inleakage flowrate is defined in SCFM.

    This assumption does not significantly affect the calculation results and does not require verification.

24. The melter injected air pressure is assumed to be equal to the melter offgas pressure.

    This is a simplifying assumption and the impact of the injected air is small compared to the overall pressure of the system. The melter injected air flowrate is defined in SCFM.

    This assumption has no significant impact on the overall flowsheet results and does not require verification.

25. The film cooler addition air pressure is assumed to be equal to the film cooler discharge pressure.

    This is a simplifying assumption and the impact of the film cooler addition air pressure is small compared to the overall pressure of the system. The film cooler addition air flowrate is defined in SCFM.

    This assumption has no significant impact on the overall flowsheet results and does not require verification.

26. The pressure control air and controlled offgas air pressure is assumed to be equal to the film cooler discharge pressure.

    This is a simplifying assumption and the impact is small compared to the overall pressure of the system. The pressure control air flowrate is defined in SCFM.

    This assumption has no significant impact on the overall flowsheet results and does not require verification.

27. The nominal melter pressure control air flowrate is assumed to be 300 scfm (Ref. 9.46, page 90). The same control air flowrate (300 scfm) is also used for the maximum case. The pressure control air flow is assumed to be 200 scfm (67% of steady state) for the minimum case.

    Using the same value for both the nominal and maximum cases is appropriate because the pressure control air is attempting to maintain a set melter plenum pressure. If the melter offgas flow increases, the melter plenum vacuum decreases. The pressure control air flow would then decrease until the melter plenum vacuum returned to its setpoint. The maximum flowsheet case has a higher melter offgas flow than the nominal case. It is conservative to keep the pressure control air constant (not decrease it) for the maximum case because this maximizes the flow through the offgas system.

    This calculation does not simulate transient conditions and therefore this assumption does not require verification.

28. The vessel ventilation offgas pressure is assumed to be the same as the combined offgas pressure.

    This is a simplifying assumption and the impact is insignificant compared to the overall pressure of the system since the vessel ventilation offgas flowrate (SCFM) is relatively small in comparison with overall offgas flowrate.

    This assumption has minimal impact on the overall flowsheet results and therefore does not require verification.

29. The minimum and maximum plenum temperatures are assumed to be 300°C and 500°C, respectively.

    The operating temperatures that were used in melter tests are listed in 24590-101-TSA-W000-0009-87-00019 (Ref. 9.6, pg. T-3). The DM 3300 melter represented a 1/3 section of the LAW melter (3.3 m^2, see pg. 7 of Ref. 9.6) and was operated to maintain a target plenum temperature of 400°C ± 50°C. The DM100 and DM1200 melters were smaller (0.108 m^2 and 1.2 m^2, respectively; see pg. 7 of Ref. 9.6) and required small openings in the cold cap to prevent bridging of dried feed material across the melt surface (pg 15 of Ref. 9.6). As a result of these openings, the plenum temperatures were about 100 - 150°C higher, ranging from 450 - 650°C. Since the DM 3300 is larger and more representative of the WTP LAW melter, 400°C is used as the nominal plenum temperature, as shown in Input 10. 500°C is assumed as the maximum plenum temperature to provide some contingency above 400°C. Assuming a minimum plenum temperature of 300°C is reasonable because the low-low average plenum temperature alarm is set at 608°F (320°C), per 24590-LAW-JDX-LMP-00001 (Ref. 9.12, pg 131).

    The melter has a control for plenum temperatures; therefore, this assumption does not require verification.

30. For simplification, all of the VOC exiting the melters is assumed to travel through the SBS and WESP with no change in concentration.

    This provides a higher VOC concentration that the catalyst skid would need to treat.

    This is a bounding assumption and therefore does not require verification.

31. The HEPA filter bank pressure drop for the minimum, nominal, and maximum cases is assumed as 1.0 in. WG, 2 in. WG, and 10 in. WG respectively.

    Per 24590-WTP-SRDCN-ENG-17-00002, (Ref. 9.69, Table FK-4000-1 for safe change HEPA filters), new 2000 SCFM HEPA filters will have a maximum resistance (i.e., pressure drop) of 1.6 in. WG. However, they are structurally required to be able to withstand a 10 in. WG pressure drop for one hour per Ref.10.1.2, Table FK-5000-4. Given a constant offgas flowrate, the pressure drop across the HEPA filters is also expected to rise over time due to particulate loading. The pressure drop values assumed are 1.0 in. WG (new filters, minimal offgas flowrate), 2 in. WG (some particulate loading with nominal offgas flowrates), and 10 in. WG (extensive particulate loading and maximum offgas flowrate).

    The effect of one unit's pressure drop is small compared to the overall pressure drop of the system; therefore this assumption does not require verification.

32. Not Used
33. Not Used
34. Not Used
35. Not Used

36. For simplicity, pressure drops have been assumed across piping segments. For short segments, the pressure drops are assumed 2, 3, and 4 in. WG for the minimum, nominal, and maximum cases, respectively. For long segments, the pressure drops are assumed to be 4, 5, and 6 in. WG for the minimum, nominal, and maximum cases, respectively.

    Offgas piping after the SBS have been divided into "short" and "long" segments depending on the general location of equipment within the LAW facility. The "short" and "long" segments are defined per General Arrangement Drawings 24590-LAW-P1-P01T-00002, -00005 & -00006 (Ref. 9.26 -9.28). Long piping segments are defined in the following table.

Stream Number	Equipment		Location	
	Inlet	Discharge	Start	Finish
LOP08	WESP	LVP Heaters	3 ft Level; L-0123/0124 (Ref. 9.26)	48 ft Level; L-0304H (Ref. 9.27)
LVP08	LVP Exhausters	Stack	48 ft Level; L0304C/D/E (Ref. 9.27)	68 ft Level; Stack, NW Corner (Ref. 9.28)

    All other segments are considered short.

    According to page B-15 of Crane (Ref. 10.2.5), the maximum case (2 melters) airflow of 4230 SCFM (at the exhaust fans, cell I-51 of the Attachment 1 flowsheets), flowing through 100 ft of 10 in. pipe, will have a pressure drop of 0.9 in. WC (0.031 psi). In this calculation, most of the LVP piping is 18 inches in diameter (Ref. 9.49 - 9.54), which decreases the pressure drop significantly. LOP piping is 10 inch in diameter (Ref. 9.29 & 9.48). Pressure drop data is not available for 18 inch pipe, but using the same correlation for the same flow through a 8 in pipe results in a pressure drop of 2.7 in. WC (0.1 psi). Decreasing the pipe diameter by two inches more than doubles the pressure drop for the same flowrate. Increasing the pipe diameter to 18 inches should decrease the pressure drop significantly.

    The pressure drops assumed (2, 3, and 4 in. WG for the minimum, nominal, and maximum cases for short segments and 4, 5, and 6 in. WG for the minimum, nominal, and maximum cases for long segments) are reasonable. This can be illustrated by looking at the pipe between the SBS and the WESP. This pipe length is about 38 feet per isometrics 24590-LAW-P3-LOP-PW01224001 and -PW01224002 (Ref. 9.55 & 9.56) with a 10" diameter. In the maximum case for 2 melters, the flow through the SBS discharge pipe is 976 SCFM (Cell I-17 of the Attachment 1 flowsheets). On page B-15 of Crane, the lowest flow that correlates to a 10" pipe is 3000 SCFM. The pressure drop is 0.44 in. WG (0.016 psi) over 100 ft of pipe at 3000 SCFM. The actual pipe length is 38 feet, so the pressure drop is further reduced to 0.38 * 0.44 in WG. = 0.17 in. WG. The actual pressure drop would be even lower because the actual flow is less than 1/2 of that estimated here. These assumed pressure drops are considered conservative for the sole purpose of providing approximate pressure drops across LOP/LVP offgas system for flowsheet calculations (actual pressure drop through the offgas system can be found in Mechanical System line sizing calculations). These pressure drops are generous to account for pipe bends and entry/exit losses. Therefore, this assumption does not require verification.

37. Not Used
38. Not Used
39. Not Used
40. Not Used
41. Not Used
42. Not Used
43. Not Used
44. Not Used
45. Not Used
46. Not Used
47. Not Used

48. In Table 2 (Section 2), all VOCs are assumed to have the molecular weight of an allyl alcohol. Particulates are assumed to have the molecular weight of iron oxide.

    This is a simplifying assumption.

    This has an insignificant impact on the overall mass balance and therefore does not require verification.

49. All mercury in the LAW feed that enters the melter is assumed to volatilize into the melter offgas.

    This assumption is bounding for mercury content in the offgas and therefore does not require verification.

50. For simplification, the absolute pressure for the SCR ammonia addition (LVP13) and ammonia dilution air addition is assumed to be the same as the TCO discharge pressure since that is where they are added.

    The dilute air addition volumetric flowrate is defined in SCFM (Assumption 60) and the air pressure have no impact on the overall flowsheet results. The ammonia flowrates are determined based on the stoichiometric reactions in Attachment 8, and the ammonia pressure have minimal impact on the overall flowsheet balance.

    This assumption is justified and does not require verification.

51. The minimum, nominal and maximum pressure drops across the caustic scrubber are assumed at 5 in. WG, 10 in. WG, and 15 in. WG respectively.

The maximum overall pressure drop across the caustic scrubber is 15.4 in. WG per 24590-QL-POA-MKAS-00003-06-00001, pg 13, Ref. 9.9 (Input 26 in Section 2.1). Most of the pressure drop (14 in. WG) comes from the demister (Input 33). Given a constant offgas flowrate, the pressure drop across the demister could increase over time due to fouling. The pressure drop through the scrubber packing is insignificant (average 0.42 in. WG per Input 34). In this calculation, the minimum pressure drop is defined as 5 in. WG (new demister pad, minimal offgas flowrate). The nominal pressure drop is defined as 10 in. WG (some fouling, nominal offgas flowrate). The maximum pressure drop is defined as 15 in. WG (some fouling, maximum offgas flowrate).

The pressure drops assumed are based on Code 1 vendor submittal data and thus do not require verification.

52. Not Used.

53. The SBS minimum, nominal and maximum temperatures are assumed to be 40°C, 50°C and 55°C respectively.

The LAW SBS performs an identical function as the HLW SBS. That function is to quench melter offgas and regulate the offgas temperature for downstream offgas equipment. The SBS is required to operate in a condensing mode (i.e., below the inlet offgas dew point temperature) in order to prevent the concentration of accumulated solids and to allow adequate condensate purging of the system. This temperature control also effectively regulates the water split between the secondary liquid effluent system and the water that remains within the offgas as steam exits through the facility stack. As shown in Figures 4.12 and 4.14 of 24590-101-TSA-W000-0009-166-00001 (Ref. 9.5, pg F-56 & F-58), the VSL DM1200 SBS was successfully operated at approximately 50°C during the LAW MACT demonstration tests. This SBS is prototypical of the full-scale LAW SBS design. Therefore, this temperature of 50°C is considered the nominal SBS operating temperature. Based on the VSL testing data results (Ref. 9.5, Fig. 4.64, pg F-108 & Fig. 4.71, pg F-115), there is little fluctuation in SBS operating temperature. The maximum SBS operating temperature is defined as 55°C to account for temperature deviations. The SBS has a cooling jacket and is temperature controlled. By the end of the runs (LAW Test 1 & LAW Test 2A & 2B), the lowest SBS outlet temperature is still well above 40ºC; therefore, the minimum SBS operating temperature is defined at 40°C.

Since there was little fluctuation in operating temperature during tests of the SBS, the minimum, nominal and maximum LAW SBS temperatures assumed can be considered justified and do not require further verification.

54. Deleted.

55. The decontamination factor (DF) for mercury in the SBS is assumed to be 6.

This value is estimated from Westinghouse report WSRC-TR-95-0404 (Ref. 10.2.23) which describes treatment of mercury contaminated sludges using vitrification. The offgas system had an ejector-venturi scrubber which reduced the melter offgas temperature below the dew point, condensed most of the water vapor, and scrubbed the gas (Ref. 10.2.23, pg. 5). The offgas and condensate leaving the scrubber was collected in the offgas condensate tank (OGCT). The report lists the offgas mercury DFs for the OGCT as 8.28 and 3.32 (Ref. 10.2.23, Table 4, pg. 9). This averages to a DF of 5.8. A decontamination factor of 6 for Hg is used in this calculation.

This value is a conservative estimate. The SBS should have better liquid/gas contact than the venturi scrubber, increasing the ability to remove soluble mercury. This value is also consistent with the DF estimated in a previous WTP mercury assessment (Ref. 9.41, Section 7.4.3.3). This report is authorized for use in CCN 280470 (Ref. 9.40). Conservatism is used in this calculation when defining the maximum amount of mercury in the offgas based on the Hg contract maximum (Assumption 57). A bounding DF of 1 (no mercury removed in the SBS) is not reasonable and would lead to oversizing the carbon beds. Therefore, the assumed DF of 6 is deemed reasonable and does not require verification.

56. The presence of methyl iodide is neglected in this calculation due to the low probability that it is present in the offgas.

    Per a literature review documented in CCN 193249 (Ref. 9.43), both radiolytic and thermal reactions can result in the formation of methyl iodide. Calculations in the literature show that the conversion rate to methyl iodide due to the radiolytic reaction is approximately 1.4%. The conversion rate with the thermal reaction is 0.34%. Both conversion rates begin with a 10 mg/m^3 iodine concentration. This iodine concentration is much higher than what is present in the LAW offgas. According to Attachment 1, the highest concentration of iodine in the melter offgas is 0.596 mg/m^3 (minimum case, 2 melters, cell EE-11). This conversion is limited further in the presence of oxygen because a methyl radical will combine with oxygen much more readily than with iodine.

    In addition, the decomposition temperature of methyl iodide is 270°C (Ref. 10.2.11, Merck Index Monograph Number 6110, Methyl Iodide, Ref. 10.2.11). Since the melter plenum temperature is maintained from 300 – 500°C (see Assumption 29 in Section 6.1), the methyl iodide will decompose in the melter plenum. The solubility of methyl iodide is 1 part to 50 parts water (Ref. 10.2.11, Merck Index Monograph Number 6110, Methyl Iodide). Any methyl iodide that survives the temperatures in the melter plenum would dissolve in the submerged bed scrubber solution. Therefore, the probability that methyl iodide is present in the offgas is unlikely.

    This assumption is justified and does not require verification.

57. The amount of mercury in the melter feed is determined based on the Hg contract maximum and the following assumptions:
    - Minimum case – 25% of the contract maximum (mol Hg/ mol Na) in a 6 M Na feed stream
    - Nominal case – 50% of the contract maximum in an 8 M Na feed stream
    - Maximum case – 100% of the contract maximum in a 10 Na feed stream

    The contract maximum mercury concentration is related to the sodium concentration, 1.4E-05 mol Hg/mol Na (Input 36 in Section 2.1). The higher the sodium concentration, the higher the mercury concentration.

    To calculate the amount of mercury exiting the melter, the mol Hg/mol Na and the sodium molarity in the feed will both be varied. For mol Hg/mol Na, the maximum case uses 100% of the contract maximum. The minimum case uses 25% and the nominal case uses 50% of the contract maximum. The validity of this assumption can be seen in Attachment 3. These graphs show data from Ref. 9.64. The graphs were made from data in spreadsheet "TFCOUP6 Batch Evaluation" (in 24590-RMVD-03129), worksheet "Contract – LAW". In cell AQ-4, if "Hg+2" is selected (then hit F9), the resulting graph is Figure 1 in Attachment 3. This shows the ratio of mercury to sodium in each batch in feed vector TFCOUP6. Figure 2 is the same plot with the y-axis decreased to the mercury contract maximum.

    Figure 2 in Attachment 3 shows that the average ratio of mercury to sodium in the WTP feed is about 2.1E-06 mol Hg/mol Na. For the minimum flowsheet case, 25% of the contract maximum is used, which is equivalent to 1.4E-05 mol Hg/mol Na x 25% = 3.5E-06 mol Hg/mol Na. This is already higher than the average reported by TFCOUP6 (about 2.1E-06 mol Hg/mol Na) and is therefore conservative. Using 50% of the contract maximum for the nominal case (7.0E-06 mol Hg/mol Na) and 100% for the maximum case (1.4E-05 mol Hg/mol Na) are also conservative. The vast majority of feed batches will not contain this much mercury. Batches shown with mercury level above the contract maximum in Figure 1 will need to be blended with other feed so that the mercury remains below the contract limit before it is transferred to WTP. Note that although Ref. 9.64 is a committed calculation; however, the mercury data are confirmed data obtained directly from TFCOUP6.

The treated LAW concentrate that enters the LCP system is concentrated to 8 – 10 M Na in the TLP evaporator per 24590-QL-POA-MEVV-00001-08-01 (Ref. 9.59, pg. 11). This sodium range provides the basis for the nominal and maximum Na concentration values. If a feed has a tendency to precipitate salts, the feed will not be concentrated as much. To accommodate this, the minimum case is set as 6 M. If the feed is occasionally more dilute than the normal value, the offgas will have a lower mercury concentration but this would not affect the equipment design. The mercury concentration based on 10 M Na in feed is conservative for the maximum case.

The mercury content in the recycle from the SBS back to TLP in PT is neglected in this calculation. The Hg/Na ratio in the feed assumed for the maximum case is already six times larger than the overall weighted average (see Figure 2 in Attachment 3). The mercury concentration in the recycle that is reintroduced into the feed stream will vary depending on how much mercury was in the previous feeds. As lower concentration feeds are introduced, the amount of mercury in the recycle stream will decrease. As higher concentration feeds are introduced, the amount of mercury in the recycle stream will increase. The amount of mercury sent to the carbon beds will vary accordingly. The mercury concentration based on the contract maximum and a 10 M Na feed is conservative for the maximum case based on the overall weighted average of the mercury fed into the system.

58. For simplification, the ammonia dilution air is assumed to enter the offgas stream with no temperature increase from the fans.

    Since the system is under negative pressure, the dilution air fans will need minimal speed to overcome any pressure drop in the connecting piping to the offgas piping and temperature change across the fan is expected to be insignificant.

    This assumption has negligible effect on the overall balance and therefore does not require verification.

59. Leaching scenarios for the TFCOUP6 batches are assumed to agree with 24590-WTP-RPT-PE-07-001 (Ref. 9.67, pg 176-180). This report is authorized for use in CCN 280470 (Ref. 9.40). This report grouped the expected range of tank farm wastes that will be treated by the WTP Facility and recommended the most efficient way of processing each group in terms of performing caustic leaching on the solids and/or oxidative leaching of the solids to minimize the amount of HLW glass made. These scenarios are only used in Attachment 45, which proposes a correlation between the amount of HF in the feed and the amount present at the HEPA filters.

    Attachment 45 does not affect the Attachment 1 flowsheets and does not affect the results of this calculation. Therefore, this assumption does not require verification.

60. Ammonia dilution air is assumed to be 800 SCFM maximum. This is a requirement that will be placed on the vendor to allow flexibility for ammonia addition while keeping ammonia below flammable levels (Ref. 9.63,

pg. 5). Vendor calculation submittal 24590-CD-POC-MBT0-00007-02-00001 (Ref. 9.11, Section 9.2.4, pg 30) verifies that the actual maximum dilution air required for the SCR is 844.7 acfm (at 95°F and 14.34 psia) which is equivalent to 784 scfm using ideal gas law (less than the maximum dilution air of 800 scfm specified).

The assumed dilution air of 800 scfm is conservative and verified by the vendor calculation. Therefore, this assumption does not require verification.

61. For the three flowsheet cases, the temperature changes across the activated carbon unit are assumed to be -5°C, +5°C, and +20°C for the minimum, nominal, and maximum cases, respectively, to provide conservative results.

    Upon examination of Figures 4.12 & 4.14 of 24590-101-TSA-W000-0009-166-00001 (Ref. 9.5, Pages F-56 & F-58), it is observed that the differential between the activated carbon's inlet and outlet temperatures varies from approximately -5°C to +25°C. The largest temperature differentials are due to allyl alcohol spiking. In the first test, LAW Test 1, the outlet temperature continued to rise until allyl alcohol spiking stopped (see Figures 4.133a and 4.133b of Ref. 9.5, pg F-180/181). In the second test, LAW Test 2A, the temperature rose approximately 20°C and plateaued (see Figures 4.136a and 4.136b of Ref. 9.5, pg F-184/185).

    Because the temperatures in LAW Test 1 were continuing to rise, it is reasonable to assume that the carbon bed had not been fully conditioned to constituents in the offgas. In LAW Test 2A, the carbon bed was operated for a sufficient amount of time to be fully conditioned to offgas constituents. The cumulative run time for carbon bed conditioning at the conclusion of LAW Test 1 was ~32 hours (Ref. 9.5, Figure 4.133b, pg F-181) compared to ~182 hours at the conclusion of allyl alcohol spiking in LAW Test 2A (Ref. 9.5, Table 3.2, pg T-13). This additional time was sufficient for the carbon bed to acclimate to the offgas, as evident by the carbon bed outlet temperature plateauing during allyl alcohol spiking. The result from the second test, a 20°C rise, is representative of temperature rise limits that need be in place prior to LAW carbon bed operations.

    This assumption is justified based on testing data and therefore does not require verification.

62. The minimum temperature of the ammonia supply is assumed to be equal to the minimum Hanford Site temperature of -23°F (Input 50) and the maximum temperature is assumed to be equal to the maximum Hanford Site temperature of 113°F (Input 51).

    This assumption covers the expected ambient temperature range and does not require verification.

63. The nominal temperature of the ammonia supply is assumed to be 77°F based on the average temperature at the Hanford Site in July (76.6°F) per PNNL-15160 (Ref. 10.2.19, Table 3.1).

    This temperature is for the nominal case and is not used for design. This assumption does not require verification.

64. Standard temperature and pressure are assumed to be 20°C and 1 atm. This is this calculation’s definition of standard conditions and does not need to be verified.

65. The assumed fluoride/sodium molar ratio (kgmol of F^-/ kgmol of Na^+) for each TFCOUP6 batch used in Attachment 45 (“TFCOUP6 Batches” worksheet, Column B) is from 24590-WTP-M4C-V11T-00037 Rev B, 24590-RMVD-03212 (Ref. 9.64, (a), spreadsheet “TFCOUP6 Batch Evaluation.xlsx”, sheet “Contract-LAW”, Column J). Ref. 9.64 is a committed calculation; however, the fluoride/sodium molar ratio is confirmed data from TFCOUP6 (Ref. 9.18). In addition, Attachment 45 is not used in the body of this calculation; it is

included just to provide a possible correlation of HF in the melter offgas and the amount of fluoride entering WTP in the feed for planning information. Therefore, this assumption does not need to be verified.

66. The nominal temperature of the melter or offgas inleakage is assumed to be 80°F.

    This is approximately the overall mean temperature if the allowable C3 and C5 temperature ranges are combined, (59 - 95°F and 59 - 113°F, respectively; see Inputs 52 - 54).
    This temperature is for the nominal case and not intended for design. This assumption is reasonable for the nominal case and thus does not require verification.

67. Refer to Section A4.6 in Attachment 4 for assumptions related to the LAW Vessel Ventilation Design Basis Flowsheets.

6.2 Assumptions Requiring Verification

None

7 Calculations

As discussed in Section 5, calculations performed in this "calculation" are done in both Mathcad and Excel spreadsheets. These spreadsheets are included as hardcopy attachments. Electronic copies of the Mathcad and Excel spreadsheets are also included in the "SUPPORT FILES" folder.

The main calculation is performed in Attachment 1 that contains the master spreadsheets for the minimum, nominal, and maximum offgas flowrate cases. These spreadsheets define process information by stream number and stream name. Stream numbers are per PFDs 24590-LAW-M5-V17T-00004, -00007, -00008, -00010, and -00011 (Ref. 9.13 - 9.17). Notes are provided for each calculation cell or data input cell, which provides links to references, notes, equations, and/or assumptions. The "Notes", "References", and "Equation" note lists are included in Attachment 1. The list of assumptions is included in Section 6. Examples of a "note", reference, equation, or assumption note are N7, R10, E2, or A15, respectively. Refer to Attachment 1 for the minimum, nominal, and maximum case flowsheets.

As identified in the notes' list, several of the cell inputs are based on supporting calculations included as additional attachments. Many supporting calculations are developed in Excel spreadsheets and are included in the "SUPPORT FILES" folder. Other supporting calculations are performed in Mathcad. These Mathcad calculations and what is calculated within in them are identified in the following attachments:

Attachment 2	Melter Steam Generation Determination
Attachment 4	LAW Vessel Ventilation Design Basis Flowsheets
Attachment 7	Temperature Increase Across Offgas Exhausters
Attachment 8	SCR Temperature Increase, SCR Ammonia Addition Flowrate Determination, and Residual SCR Gas Discharge Mass Flowrate Calculation
Attachment 20	TCO Temperature Increase and Residual TCO Gas Discharge Mass Flowrate Calculation
Attachment 32	Ammonium Nitrate Formation
Attachment 35	Mercury Discharge from Activated Carbon Beds
Attachment 36	LAW Melter Iodine-129 Emission Determination

Attachment 39 Caustic Scrubber Outlet Temperature Determination
Attachment 40 Catalyst Skid Recuperative Heat Exchanger Discharge Temperature Determination

Discussion on how each supporting calculation is performed is included in each attachment, as appropriate. Refer to Section A4.7 in Attachment 4 for calculations related to the LAW Vessel Ventilation Design Basis Flowsheets.

Design basis flowsheet calculations in Attachment 1 for the offgas as it travels through the treatment units in the LOP and LVP systems are done based on the methodology and equations discussed in Section 5. The LAW glass production throughput is 30 MTG/day (Input 8, Section 2.1) for 2 melters in operation (nominal and maximum flowsheets).

8 Results and Conclusions

Offgas flowsheets were developed and are included in Attachment 1 for each gaseous process stream in the LAW melter offgas system (Systems LOP and LVP). Three flowsheet cases are based on two melters in operation (minimum, maximum, and nominal). An additional minimum case is shown assuming one melter is operating. Refer to Attachment 1 for the offgas flowsheet results.

For each stream, each case has the offgas volumetric flowrate (SCFM and ACFM), mass flowrate, physical properties, primary gas compositions, and offgas contaminant compositions to be used for design purposes.

Refer to Section A4.8 in Attachment 4 for the vessel ventilation flow results related to the LAW Vessel Ventilation Design Basis Flowsheets.

HNO_2 and HNO_3 concentrations and flowrates from the HEPA filters are listed below:

HNO_2	Concentration (ppmv)	Molar Flow (g-mol/h)	Mass Flow (kg/h)
min	8.8	1.23	0.0579
avg	29.4	5.22	0.245
max	56.2	11.1	0.522
HNO_3	Concentration (ppmv)	Molar Flow (g-mol/h)	Mass Flow (kg/h)
min	0.5	0.070	0.00441
avg	5.5	0.98	0.0617
max	42.4	8.37	0.527

HNO_2 and HNO_3 concentrations and flowrates from the carbon beds are as follows:

HNO_2	Concentration (ppm)	Molar Flow (g-mol/h)	Mass Flow (kg/h)
nom	25.3	4.51	0.212
max	32.1	6.36	0.299
HNO_3	Concentration (ppm)	Molar Flow (g-mol/h)	Mass Flow (kg/h)
nom	7.9	1.41	0.089
max	22.8	4.52	0.285

Hydrogen is generated from the LAW vessels at 0.023 SCFM (see Attachment 4, Section A4.8.3).

Margin

This is a process calculation to provide the design basis flowsheets for the LAW offgas LOP & LVP systems. No margin is added to the flowsheet results.

Conservatism

The following conservatism is applied to the calculation:

1. The melter air inleakage for the maximum case in Attachment 1 flowsheets is conservatively doubled (Assumption 3) to compensate for potential inleakage increase due to aged system.
2. The reduced solids capture efficiency for WESP in deluge operation is conservatively included in the calculation of the average solids DF in Attachment 34 to reduce the solids removed by the WESP and thus maximize the amount of solids in the offgas.
3. The amount of mercury in the offgas is determined based on the contract maximum, 1.4E-5 mol Hg/mol Na for conservatism. All mercury in the LAW feed that enters the melter is also assumed to volatilize into the melter offgas to maximize the mercury content in the offgas (Assumption 49).
4. A vessel vent relative humidity of 100% is defined for the maximum case (Assumption 22) to maximize the water content in the vessel vent offgas and is bounding for design.
5. A maximum relative humidity of 100% is defined for the melter cave air to maximize the water content in the air inleakage to offgas equipment for bounding conservatism (Assumption 1).
6. The SBS discharge is assumed to be saturated with water vapor and have a relative humidity of 100% as a bounding condition (Assumption 6).
7. Per assumption 5, the waste oxides loading into the LAW glass is assumed to be at a high 25%. It is also assumed that no iodine is lost in Pretreatment. Combined, these assumptions maximize iodine emissions in the LAW offgas.
8. The contractual maximum I-129 concentration in LAW feed is conservatively assumed to be the same as the contractual maximum I-129 concentration in HLW feed (expected to be higher for HLW feed; see Assumption 15) to maximize the I-129 release from the melter to the offgas in Attachment 39 calculation.
9. The pressure drops across the hot side of the LAW catalytic skid heat exchanger (LVP-HX-00001) for the “minimum case, 1 melter” and the “minimum case, 2 melters” are conservatively assumed to be the same (Assumption 7). The pressure drop for the 2 melter case is actually higher than the pressure drop for the one melter case, thus assuming the pressure drop for the 2 melter case as the pressure drop for the 1 melter case is conservative and provides a larger pressure drop for the minimum, 1 melter case.
10. Assuming no condensation from the melter offgas when it is discharged from the SBS results in slightly higher gas flowrates which is conservative for the calculation (Assumption 8).
11. No heat loss is assumed for any of the LOP piping; this will maximize the overall offgas flowrate and thus is conservative for the calculations (Assumption 11).
12. The offgas exiting the LVP caustic scrubber is conservatively assumed to be saturated in the energy balance calculations in Attachment 39 & 44 (Assumption 19).
13. All VOC exiting the melters is assumed to travel through the SBS and WESP with no change in concentration to maximize the VOC content in the offgas that the catalyst skid has to treat (Assumption 30).
14. For the maximum case flowsheet, the LAW process stream properties calculation (Ref. 9.65) was used as the data source for CO, VOC, HCl, HF, NO, NO_2, and SO_2 from stream LMP06. This calculation uses the Aspen Process Performance Simulation (APPS) model runs 26, 27, 28, 29 and 31 to simulate the worst feed for CO & organics, HCl, HF, NOx and SO_2, respectively.

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(c) 24590-RMVD-03242-01, *24590-LAW-M4C-V11T-00001, Rev 1, Support Files*

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A4.9.2 24590-QL-POC-MVA0-00001-12-08, Rev. B00, *Drawing - Fabrication Details*

A4.9.3 24590-CM-POA-MVA0-00002-03-04, Rev. B00, *Drawing - General Arrangement - Melter 1 Feed Vessel*

A4.9.4 24590-CM-POA-MVA0-00002-03-42, Rev. B00, *Drawing - General Arrangement - Melter 2 Feed Vessel*

A4.9.5 24590-CM-POA-MVA0-00002-03-11, Rev. F, *Drawing - General Arrangement - Melter 2 Feed Preparation Vessel*

A4.9.6 24590-CM-POA-MVA0-00002-03-22, Rev. F, *Drawing - General Arrangement - Melter 1 Feed Preparation Vessel*

A4.9.7 24590-CM-POA-MVA0-00002-03-53, Rev. D, *Drawing - General Arrangement - Concentrate Receipt Vessel*

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11 Attachments

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Attachment 3	Mercury Concentration in TFCOUP6 Feed Batches
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Attachment 27	Not Used
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Attachment 35	Mercury Discharge from Activated Carbon Beds
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Attachment 39	Caustic Scrubber Outlet Temperature Determination
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Attachment 41	Pressure Drop Across Damper Valve
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Attachment 1 Minimum, Nominal, and Maximum Offgas Flowsheets

By: Nancy Wilkins
Date: 11/15/2019

CALCULATION SHEET

Job No: 24590
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Subject: LAW Melter Offgas System Design Basis Flowsheets

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV
1	***LAW Melter Offgas System Design Basis Flowrates, Physical Properties, and Compositional Information (LOP Air Balance)***																				🟩		Case Dependent Constant																									
2	***Minimum Flowsheet - 1 Melter***				Number of Operating LAW Melters =>					1											🟦		Fixed Constant																									
3	Stream Number	Stream Name	Dry Air		Steam		Others		Total		Mass Flow				Temperature				Diff. Press		Absolute Pressure				Total		Hum. Ratio		Relative Hum.		Mol. Weight		Density				Heat Capacity				Not Used				Not Used			
4			SCFM$^{(N1)}$		SCFM$^{(N1)}$		SCFM$^{(N1)}$		SCFM$^{(N1)}$		kg/hr		lb/hr		°C		°F		in. WG		in. WC		mbar-a		ACFM		lb H_2O/lb Air		%		g/mol		kg/m^3		lb/ft^3		KJ/kg-C		Btu/lb-F									
5	Hanford Atmospheric Pressure (Pressure Balance)																				397	E21	990	R14																								
6	C2/C3 Area Vacuum																		-0.4	R18	397	E23	989	E22																								
7	Melter Enclosure Relative to C3 Gallery																		-2.0	R19	395	E23	984	E22																								
8		Steam from LAW Melter Feed			381	R39			381	E1	4.84E+02	E18	1.07E+03	E20	N/A		N/A				N/A				N/A						18.0	E56																
9	LMP01	Melter Air Inleakage	148	E7	1.0	E19	0.0	A18	149	R2/A3	3.04E+02	E18	6.70E+02	E20	15	E17	59	N11			395	A23	984	E22	151	E25	0.004	N11	30%	A1	28.9	E56	1.187	E27	0.0741	E28	1.005	E52	0.240	E54								
10	LMP02/03	Melter Injected Air	19	R1	0	A2	0.0	A18	19	E1	3.89E+01	E18	8.57E+01	E20	16	E17	60	R7			390	A24	972	E22	20	E25	0	A2	0%	A2	29.0	E56	1.172	E27	0.0732	E28	1.001	E52	0.239	E54								
11	LMP06	Melter Offgas	176	E13	382	E2	2.9	E57	561	E1	8.62E+02	E18	1.90E+03	E20	300	A29	572	E16	-5.0	R15	390	E23	972	E22	1,144	E25	1.288	E31	0.8%	N10	21.8	E56	0.444	E27	0.0277	E28	1.591	E52	0.380	E54								
12	LMP11	Film Cooler Air	185	R3	0	A2	0.0	A18	185	E1	3.78E+02	E18	8.34E+02	E20	16	E17	60	R7			390	A25	970	E22	190	E25	0	A2	0%	A2	29.0	E56	1.171	E27	0.0731	E28	1.001	E52	0.239	E54								
13		Film Cooler Discharge	361	E3	382	E3	2.9	E57	746	E1	1.24E+03	E18	2.74E+03	E20	240	E12	463	E16	-0.5	R16	390	E23	970	E22	1,362	E25	0.643	E31	1.5%	N10	23.6	E56	0.536	E27	0.0335	E28	1.405	E52	0.336	E54								
14	LMP13	Pressure Control Air	200	A27	0	A2	0.0	A18	200	E1	4.09E+02	E18	9.02E+02	E20	16	E17	60	R7			390	A26	970	E22	206	E25	0	A2	0%	A2	29.0	E56	1.171	E27	0.0731	E28	1.001	E52	0.239	E54								
15	LMP14	Controlled Offgas	561	E4	382	E4	2.9	E57	946	E1	1.65E+03	E18	3.64E+03	E20	198	E12	388	E16			390	A26	970	E22	1,586	E25	0.417	E31	2.6%	N10	24.7	E56	0.612	E27	0.0382	E28	1.301	E52	0.311	E54								
16	LMP14 Piping Pressure Drop																		-0.9	R16	389	E23	968	E22																								
17	LOP02	SBS Discharge	561	E5	50.5	A6	1.6	E57	613	E1	1.23E+03	E18	2.70E+03	E20	40	A53	104	E16	-26.4	N6	362	E23	902	E22	736	E25	0.055	E31	100.0%	N10	28.3	E56	0.981	E27	0.0612	E28	1.047	E52	0.250	E54								
18	FC/Jumper/SBS Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
19	LOP02 Piping Pressure Drop																		-2.0	A36	360	E23	897	E22																								
20	LOP06	WESP Bulge Air Purge	346	R5	0	A2	0.0	A18	346	E1	7.09E+02	E18	1.56E+03	E20	43	E17	109	R5			434	R5	1082	E22	350	E25	0	A2	0%	A2	29.0	E56	1.193	E27	0.0745	E28	1.005	E52	0.240	E54								
21	LOP08	WESP Discharge	913	E6	51	E6/A8	2.0	E57	965	E1	1.95E+03	E18	4.29E+03	E20	41	R10/E12	105	E16	-1.9	R20	358	E23	893	E22	1,173	E25	0.034	E31	60.4%	N10	28.5	E56	0.976	E27	0.0609	E28	1.032	E52	0.247	E54								
22		WESP Inleakage	5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
23	LOP08 Piping Pressure Drop																		-4.0	A36	354	E23	883	E22																								
24		Offgas Flow through Control Valve	918	E10	51	E10	2.0	E10	970.3	E1	1.96E+03	E18	4.31E+03	E20	41	E65	105	E16	-26.08	N24	328	E23	818	E22	1,288	E25	0.034	E31	55.1%	N10	28.5	E56	0.894	E27	0.0558	E28	1.032	E52	0.247	E54								
25	LVP01	Vessel Vent Offgas	39	E7	0.3	E19	0.02	E57	39	N3	7.95E+01	E18	1.75E+02	E20	15	E17	59	A14			328	A28	818	E22	48	E25	0.005	E63	50%	A22	28.9	E56	0.985	E27	0.0615	E28	1.006	E52	0.240	E54								
26	LVP03	Combined Offgas	956	E9	51	E9/A8	2.0	E57	1,009	E1	2.04E+03	E18	4.49E+03	E20	40	E12	104	E16			328	E55	818	E22	1,335	E25	0.033	E31	56.2%	N10	28.6	E56	0.897	E27	0.0560	E28	1.031	E52	0.246	E54								
27	LVP03 Piping Pressure Drop																		-2.0	A36	326	E23	813	E22																								
28	LVP04	HEPA Preheater Discharge	956	E10	51	E10/A8	2.0	E57	1,009	E1	2.04E+03	E18	4.49E+03	E20	60	A12	140	E16	-0.5	A20	326	E23	811	E22	1,431	E25	0.033	E31	20.8%	N10	28.6	E56	0.837	E27	0.0523	E28	1.034	E52	0.247	E54								
29	LVP04 Piping Pressure Drop																		-2.0	A36	324	E23	806	E22																								
30	LVP06	HEPA Discharge	956	E10	51	E10/A8	2.0	E57	1,009	E1	2.04E+03	E18	4.49E+03	E20	60	A11	140	E16	-1.0	A31	323	E23	804	E22	1,445	E25	0.033	E31	20.6%	N10	28.6	E56	0.829	E27	0.0518	E28	1.034	E52	0.247	E54								
31	HEPA Bank Inleakage		5	A21	0.03	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
32	LVP06 Piping Pressure Drop																		-2.0	A36	321	E23	799	E22																								
33	LVP26	S-AC Column Discharge	961	E10	51	E10/A8	2.0	E57	1,014	E1	2.05E+03	E18	4.51E+03	E20	55	A61	131	E16	-8.7	N16	312	E23	777	E22	1,479	E25	0.033	E31	25.1%	N10	28.6	E56	0.814	E27	0.0508	E28	1.033	E52	0.247	E54								
34	S-AC Column Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
35	LVP26 Piping Pressure Drop																		-2.0	A36	310	E23	772	E22																								
36	LVP10	Skid Preheater Discharge	966	E10	51	E10/A8	2.0	E57	1,019	E1	2.06E+03	E18	4.53E+03	E20	257	N23	494	E16	-0.2	R17	310	E23	772	E22	2,418	E25	0.033	E31	0.09%	N10	28.6	E56	0.500	E27	0.0312	E28	1.071	E52	0.256	E54								
37	LVP11	Skid Electric Heater Discharge	966	E10	51	E10/A8	2.0	E57	1,019	E1	2.06E+03	E18	4.53E+03	E20	399	E17	750	R11	-1.0	R17	309	E23	769	E22	3,078	E25	0.033	E31	0.01%	N10	28.6	E56	0.393	E27	0.0245	E28	1.102	E52	0.263	E54								
38	LVP12	TCO Discharge	966	E10/N22	51	E10/N22	2.0	E57	1,019	E1	2.06E+03	E18	4.53E+03	E20	399	N18	750	E16	-2.1	R17	307	E23	764	E22	3,099	E25	0.033	E31	0.01%	N10	28.6	E56	0.390	E27	0.0244	E28	1.102	E52	0.263	E54								
39		Ammonia Dilution Air	795	E7	5.1	E19	0.0	A18	800	A60	1.63E+03	E18	3.60E+03	E20	15	E17	59	N11			307	A50	764	E22	1,043	E25	0.004	N11	30%	A1	28.9	E56	0.922	E27	0.0575	E28	1.005	E52	0.240	E54								
40		Dilution Air Fan Discharge	795	E10	5.1	E10/A8	0.0	A18	800	E1	1.63E+03	E18	3.60E+03	E20	15	A58	59	E16			307	A50	764	E22	1,043	E25	0.004	E31	29.4%	N10	28.9	E56	0.922	E27	0.0575	E28	1.005	E52	0.240	E54								
41	AMR03	Ammonia					3.3	E62	3.3	E1	3.91	N12	8.62	E20	-31	E17	-23	A62			307	A50	764	E22	4	E25	0	R22	0%	R22	17.0	R24	0.645	E27	0.0403	E28	1.992	E8	0.476	E54								
42	LVP13	Diluted Ammonia Addition	795	E10	5.1	E10	3.3	E10	803.3	E1	1.64E+03	E18	3.61E+03	E20	15	E12	59	E16			307	A50	764	E22	1,046	E25	0.004	E31	29.7%	N10	28.8	E56	0.921	E27	0.0575	E28	1.005	E52	0.240	E54								
43	LVP23	SCR Input	1,761	E61	56	E61	5.2	E61	1,823	E1	3.69E+03	E18	8.14E+03	E20	238	E12	460	E16			307	E23	764	E22	4,214	E25	0.020	E31	0.07%	N10	28.7	E56	0.516	E27	0.0322	E28	1.056	E52	0.253	E54								
44	LVP14	SCR Discharge	1,762	E10/N13	61	E10/N13	0.4	E57	1,823	E1	3.69E+03	E18	8.14E+03	E20	258	E12/N13	496	E16	-1.1	R17	306	E23	762	E22	4,395	E25	0.021	E31	0.06%	N10	28.7	E56	0.495	E27	0.0309	E28	1.062	E52	0.254	E54								
45	LVP09	Catalyst Skid Discharge	1,762	E10	61	E10/A8	0.4	E57	1,823	E1	3.69E+03	E18	8.14E+03	E20	143	N23	289	E16	-0.6	A7	305	E23	760	E22	3,450	E25	0.021	E31	0.67%	N10	28.7	E56	0.630	E27	0.0393	E28	1.040	E52	0.249	E54								
46	Catalyst Skid Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
47	LVP09 Piping Pressure Drop										3.70E+03	E74	8.16E+03	E20					-2.0	A36	303	E23	755	E22																								
48	LVP18	Caustic Scrubber Discharge	1,911	E10/N27	191	E14	0.4	E57	2,103	E1	3.87E+03	E18	8.53E+03	E20	40	N26	103	E16	-5.0	A51	298	E23	743	E22	3,060	E25	0.067	E31	93.1%	N10	26.0	E56	0.744	E27	0.0464	E28	1.059	E52	0.253	E54								
49		Caustic Scrubber Inleakage	5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
50	LVP18 Piping Pressure Drop to Fans																		-2.0	A36	296	E23	738	E22																								
51	LVP08	Exhauster Discharge	1,916	E10	191	E10/A8	0.4	E57	2,108	E1	3.88E+03	E18	8.55E+03	E20	89	N5	192	E16	105	N7	401	E23	1000	E22	2,639	E25	0.067	E31	13.4%	N10	26.1	E56	0.865	E27	0.0540	E28	1.067	E52	0.255	E54								
52	Exhauster Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
53	LVP08 Piping Pressure Drop to Stack		1,921	E10	191	E10/A8	0.4	E57	2,113	E1	3.89E+03	E18	8.57E+03	E20	89	E32	192	E16	-4.0	A36	397	E23	990	E22	2,672	E25	0.067	E31	13.2%	N10	26.1	E56	0.857	E27	0.0535	E28	1.067	E52	0.255	E54								
54	Hanford Atmospheric Pressure (Pressure Balance)														25	A13	77	E16			397	E21	990	R14																								

By: Nancy Wilkins
Date: 11/15/2019

CALCULATION SHEET

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Subject: LAW Melter Offgas System Design Basis Flowsheets

	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ
1			🟩	Case Dependent Constant																										
2			🟦	Fixed Constant																										
3			N_2						O_2						CO_2						Ar						H_2O			
4	kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%	
5																														
6																														
7																														
8																									4.8E+02	E35	100.0%	E26	100.0%	E39
9	2.3E+02	E35	75%	E26	77.6%	E38	7.0E+01	E35	23%	E26	20.8%	E38	1.4E-01	E35	0.05%	E26	0.031%	E38	3.9E+00	E35	1.3%	E26	0.93%	E38	1.2E+00	E35	0.4%	E26	0.6%	E39
10	2.9E+01	E35	76%	E26	78.1%	E38	9.0E+00	E35	23%	E26	20.9%	E38	1.9E-02	E35	0.05%	E26	0.031%	E38	5.0E-01	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
11	2.6E+02	E2	30%	E36	23.3%	E37	7.9E+01	E2	9%	E36	6.2%	E37	2.9E+01	E11	3.4%	E36	1.7%	E37	4.4E+00	E2	0.5%	E36	0.28%	E37	4.9E+02	E2	56%	E26	68%	E39
12	2.9E+02	E35	76%	E26	78.1%	E38	8.8E+01	E35	23%	E26	20.9%	E38	1.8E-01	E35	0.05%	E26	0.031%	E38	4.9E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
13	5.4E+02	E3	44%	E36	36.9%	E37	1.7E+02	E3	13%	E36	9.9%	E37	2.9E+01	E24	2.4%	E36	1.3%	E37	9.3E+00	E3	0.7%	E36	0.44%	E37	4.9E+02	E3	39%	E26	51%	E39
14	3.1E+02	E35	76%	E26	78.1%	E38	9.5E+01	E35	23%	E26	20.9%	E38	2.0E-01	E35	0.05%	E26	0.031%	E38	5.3E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
15	8.5E+02	E4	52%	E36	45.6%	E37	2.6E+02	E4	16%	E36	12.2%	E37	2.9E+01	E35	1.8%	E26	1.0%	N4	1.5E+01	E4	0.9%	E36	0.55%	E37	4.9E+02	E4	29%	E26	40%	E39
16																														
17	8.5E+02	E5	70%	E36	70.3%	E37	2.6E+02	E5	21%	E36	18.9%	E37	2.9E+01	E5	2.4%	E36	1.5%	E37	1.5E+01	E5	1.2%	E36	0.84%	E37	6.4E+01	E35	5.2%	E26	8.2%	E39
18	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.05%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
19																														
20	5.4E+02	E35	76%	E26	78.1%	E38	1.6E+02	E35	23%	E26	20.9%	E38	3.4E-01	E35	0.05%	E26	0.031%	E38	9.1E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
21	1.4E+03	E6	72%	E36	73.1%	E37	4.3E+02	E6	22%	E36	19.6%	E37	3.0E+01	E6	1.5%	E36	1.0%	E37	2.4E+01	E6	1.2%	E36	0.87%	E37	6.4E+01	E6	3.3%	E26	5.2%	E39
22	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.05%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
23																														
24	1.4E+03	E10	72%	E36	73.1%	E37	4.3E+02	E10	22%	E36	19.6%	E37	3.0E+01	E10	1.5%	E36	1.0%	E37	2.4E+01	E10	1.2%	E36	0.87%	E37	6.4E+01	E10	3.3%	E26	5.2%	E39
25	6.0E+01	E35	75%	E26	77.4%	E38	1.8E+01	E35	23%	E26	20.8%	E38	3.8E-02	E35	0.05%	E26	0.031%	E38	1.0E+00	E35	1.3%	E26	0.93%	E38	4.2E-01	E35	0.5%	E26	0.8%	E39
26	1.5E+03	E9	72%	E36	73.3%	E37	4.5E+02	E9	22%	E36	19.7%	E37	3.0E+01	E9	1.5%	E36	0.9%	E37	2.5E+01	E9	1.2%	E36	0.88%	E37	6.5E+01	E9	3.2%	E26	5.0%	E39
27																														
28	1.5E+03	E10	72%	E36	73.3%	E37	4.5E+02	E10	22%	E36	19.7%	E37	3.0E+01	E10	1.5%	E36	0.9%	E37	2.5E+01	E10	1.2%	E36	0.88%	E37	6.5E+01	E10	3.2%	E26	5.0%	E39
29																														
30	1.5E+03	E10	72%	E36	73.3%	E37	4.5E+02	E10	22%	E36	19.7%	E37	3.0E+01	E10	1.5%	E36	0.9%	E37	2.5E+01	E10	1.2%	E36	0.88%	E37	6.5E+01	E10	3.2%	E26	5.0%	E39
31	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.05%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
32																														
33	1.5E+03	E10	72%	E36	73.3%	E37	4.5E+02	E10	22%	E36	19.7%	E37	3.0E+01	E10	1.5%	E36	0.9%	E37	2.5E+01	E10	1.2%	E36	0.88%	E37	6.5E+01	E10	3.2%	E26	5.0%	E39
34	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.05%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
35																														
36	1.5E+03	E10	72%	E36	73.3%	E37	4.5E+02	E10	22%	E36	19.7%	E37	3.0E+01	E10	1.4%	E36	0.9%	E37	2.5E+01	E10	1.2%	E36	0.88%	E37	6.5E+01	E10	3.2%	E26	5.0%	E39
37	1.5E+03	E10	72%	E36	73.3%	E37	4.5E+02	E10	22%	E36	19.7%	E37	3.0E+01	E10	1.4%	E36	0.9%	E37	2.5E+01	E10	1.2%	E36	0.88%	E37	6.5E+01	E10	3.2%	E26	5.0%	E39
38	1.5E+03	E10	72%	E36	73.3%	E37	4.5E+02	E10/N22	22%	E36	19.7%	E37	3.0E+01	E10/N22	1.5%	E36	0.9%	E37	2.5E+01	E10	1.2%	E36	0.88%	E37	6.5E+01	E10/N22	3.2%	E26	5.0%	E39
39	1.2E+03	E35	75%	E26	77.6%	E38	3.8E+02	E35	23%	E26	20.8%	E38	7.8E-01	E35	0.05%	E26	0.031%	E38	2.1E+01	E35	1.3%	E26	0.93%	E38	6.5E+00	E35	0.4%	E26	0.6%	E39
40	1.2E+03	E10	75%	E36	77.6%	E37	3.8E+02	E10	23%	E36	20.8%	E37	7.8E-01	E10	0.05%	E36	0.031%	E37	2.1E+01	E10	1.3%	E36	0.93%	E37	6.5E+00	E10	0.4%	E26	0.6%	E39
41																														
42	1.2E+03	E10	75%	E36	77.3%	E37	3.8E+02	E10	23%	E36	20.7%	E37	7.8E-01	E10	0.05%	E36	0.031%	E37	2.1E+01	E10	1.3%	E36	0.92%	E37	6.5E+00	E10	0.4%	E26	0.6%	E39
43	2.7E+03	E10	73%	E36	75.1%	E37	8.3E+02	E10	22%	E36	20.1%	E37	3.1E+01	E10	0.8%	E36	0.54%	E37	4.6E+01	E10	1.3%	E36	0.90%	E37	7.1E+01	E59	1.9%	E26	3.1%	E39
44	2.7E+03	E10/N13	73%	E36	75.2%	E37	8.3E+02	E10/N13	22%	E36	20.0%	E37	3.1E+01	E10	0.8%	E36	0.54%	E37	4.6E+01	E10	1.3%	E36	0.90%	E37	7.7E+01	E10/N13	2.1%	E26	3.3%	E39
45	2.7E+03	E10	73%	E36	75.2%	E37	8.3E+02	E10	22%	E36	20.0%	E37	3.1E+01	E10	0.8%	E36	0.54%	E37	4.6E+01	E10	1.3%	E36	0.90%	E37	7.7E+01	E10	2.1%	E26	3.3%	E39
46	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.05%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
47																									7.7E+01	E74				
48	2.7E+03	E10	70%	E36	65.4%	E37	8.3E+02	E10	21%	E36	17.4%	E37	3.0E+01	E10/N28	0.8%	E36	0.46%	E37	4.6E+01	E10	1.2%	E36	0.78%	E37	2.4E+02	N26	6.3%	E26	9%	E39
49	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.05%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
50																														
51	2.7E+03	E10	70%	E36	65.4%	E37	8.3E+02	E10	21%	E36	17.4%	E37	3.0E+01	E10	0.8%	E36	0.5%	E37	4.6E+01	E10	1.2%	E36	0.78%	E37	2.4E+02	E10	6.3%	E26	9.1%	E39
52	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.05%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
53	2.7E+03	E10	70%	E36	65.4%	E37	8.3E+02	E10	21%	E36	17.4%	E37	3.0E+01	E10	0.8%	E36	0.5%	E37	4.7E+01	E10	1.2%	E36	0.78%	E37	2.4E+02	E10	6.3%	E26	9.0%	E39
54																														

	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP
1			🟩	Case Dependent Constant																																						
2			🟦	Fixed Constant																																						
3	NO						N_2O						NO_2						NH_3						VOC						H_2						Hg					
4	kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5																																										
6																																										
7																																										
8																																										
9																																										
10																																										
11	4.85E+00	E47	2.50E+03	E45	4.08E+03	E51	7.00E-01	E47	3.60E+02	E45	4.01E+02	E51	5.42E-01	E47	2.79E+02	E45	2.98E+02	E51	5.66E-02	E47	29.1	E45	8.39E+01	E51	1.94E-04	E47	9.99E-02	E45	8.43E-02	E51	7.45E-03	E47	3.84E+00	E45	9.33E+01	E51	3.03E-03	E47	1.56E+00	E45	3.81E-01	E51
12																																										
13	4.85E+00	E46	2.10E+03	E45	3.07E+03	E51	7.00E-01	E46	3.02E+02	E45	3.02E+02	E51	5.42E-01	E46	2.34E+02	E45	2.24E+02	E51	5.66E-02	E46	24.5	E45	6.31E+01	E51	1.94E-04	E46	8.39E-02	E45	6.34E-02	E51	7.45E-03	E46	3.22E+00	E45	7.02E+01	E51	3.03E-03	E46	1.31E+00	E45	2.87E-01	E51
14																																										
15	4.85E+00	E50	1.80E+03	E45	2.42E+03	N4	7.00E-01	E50	2.60E+02	E45	2.38E+02	N4	5.42E-01	E50	2.01E+02	E45	1.76E+02	N4	5.66E-02	E50	21.0	E45	4.98E+01	N4	1.94E-04	E50	7.20E-02	E45	5.00E-02	N25	7.45E-03	E48	2.77E+00	E45	5.53E+01	E51	3.03E-03	R31	1.12E+00	E45	2.26E-01	E51
16																																										
17	2.57E+00	E50	2.05E+03	E45	1.97E+03	N4	4.41E-01	E50	3.53E+02	E45	2.31E+02	N4	4.46E-01	E50	3.56E+02	E45	2.24E+02	N4	0.00E+00	E50	0.0	E45	0.00E+00	N4	1.26E-04	E50	1.01E-01	E45	5.00E-02	A30	7.45E-03	E49	5.96E+00	E45	8.53E+01	E51	5.05E-04	E66/A55	4.04E-01	E45	5.81E-02	E51
18																																										
19																																										
20																																										
21	3.20E+00	E50	1.60E+03	E45	1.56E+03	N4	6.09E-01	E50	3.05E+02	E45	2.03E+02	N4	5.62E-01	E50	2.82E+02	E45	1.79E+02	N4	0.00E+00	E50	0.0	E45	0.00E+00	N4	1.98E-04	E50	9.94E-02	E45	5.00E-02	A30	7.45E-03	E50	3.74E+00	E45	7.72E+01	N4	5.05E-04	E53	2.53E-01	E45	3.69E-02	E51
22																																										
23																																										
24	3.20E+00	E10	1.46E+03	E45	1.55E+03	E51	6.09E-01	E10	2.78E+02	E45	2.02E+02	E51	5.62E-01	E10	2.57E+02	E45	1.78E+02	E51	0.00E+00	E10	0.0	E45	0.00E+00	E51	1.98E-04	E10	9.05E-02	E45	4.97E-02	E51	7.45E-03	E10	3.41E+00	E45	5.39E+01	E51	5.05E-04	E10	2.31E-01	E45	3.67E-02	E51
25	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.0	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	3.52E-03	E42	4.36E+01	E45	6.33E+02	E51	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	3.20E+00	E9	1.41E+03	E45	1.49E+03	E51	6.09E-01	E9	2.68E+02	E45	1.94E+02	E51	5.62E-01	E9	2.48E+02	E45	1.71E+02	E51	0.00E+00	E9	0.0	E45	0.00E+00	E51	1.98E-04	E9	8.73E-02	E45	4.78E-02	E51	1.10E-02	E9	4.84E+00	E45	7.63E+01	E51	5.05E-04	E9	2.23E-01	E45	3.53E-02	E51
27																																										
28	3.20E+00	E10	1.31E+03	E45	1.49E+03	E51	6.09E-01	E10	2.50E+02	E45	1.94E+02	E51	5.62E-01	E10	2.31E+02	E45	1.71E+02	E51	0.00E+00	E10	0.0	E45	0.00E+00	E51	1.98E-04	E10	8.14E-02	E45	4.78E-02	E51	1.10E-02	E10	4.51E+00	E45	7.63E+01	E51	5.05E-04	E10	2.08E-01	E45	3.53E-02	E51
29																																										
30	3.20E+00	E10	1.30E+03	E45	1.49E+03	E51	6.09E-01	E10	2.48E+02	E45	1.94E+02	E51	5.62E-01	E10	2.29E+02	E45	1.71E+02	E51	0.00E+00	E10	0.0	E45	0.00E+00	E51	1.98E-04	E10	8.07E-02	E45	4.78E-02	E51	1.10E-02	E10	4.47E+00	E45	7.63E+01	E51	5.05E-04	E10	2.06E-01	E45	3.53E-02	E51
31																																										
32																																										
33	3.20E+00	E10	1.27E+03	E45	1.49E+03	E51	6.09E-01	E10	2.42E+02	E45	1.93E+02	E51	5.62E-01	E10	2.24E+02	E45	1.71E+02	E51	0.00E+00	E10	0.0	E45	0.00E+00	E51	1.98E-04	E10	7.88E-02	E45	4.76E-02	E51	1.10E-02	E10	4.37E+00	E45	7.59E+01	E51	7.35E-05	R33	2.93E-02	E45	5.11E-03	E51
34																																										
35																																										
36	3.20E+00	E10	7.78E+02	E45	1.48E+03	E51	6.09E-01	E10	1.48E+02	E45	1.92E+02	E51	5.62E-01	E10	1.37E+02	E45	1.70E+02	E51	0.00E+00	E10	0.0	E45	0.00E+00	E51	1.98E-04	E10	4.82E-02	E45	4.73E-02	E51	1.10E-02	E10	2.67E+00	E45	7.56E+01	E51	7.35E-05	E10	1.79E-02	E45	5.09E-03	E51
37	3.20E+00	E10	6.11E+02	E45	1.48E+03	E51	6.09E-01	E10	1.16E+02	E45	1.92E+02	E51	5.62E-01	E10	1.08E+02	E45	1.70E+02	E51	0.00E+00	E10	0.0	E45	0.00E+00	E51	1.98E-04	E10	3.79E-02	E45	4.73E-02	E51	1.10E-02	E10	2.10E+00	E45	7.56E+01	E51	7.35E-05	E10	1.41E-02	E45	5.09E-03	E51
38	3.20E+00	E10	6.07E+02	E45	1.48E+03	E51	6.09E-01	E10	1.16E+02	E45	1.92E+02	E51	5.62E-01	E10	1.07E+02	E45	1.70E+02	E51	0.00E+00	E10	0.0	E45	0.00E+00	E51	9.90E-06	E43/R26	1.88E-03	E45	2.37E-03	E51	1.10E-02	E10	2.08E+00	E45	7.56E+01	E51	7.35E-05	E10	1.40E-02	E45	5.09E-03	E51
39																																										
40																																										
41																			3.91E+00	E44																						
42																			3.91E+00	E10	2199.6	E45	4.05E+03	E51																		
43	3.20E+00	E10	4.47E+02	E45	8.27E+02	E51	6.09E-01	E10	8.51E+01	E45	1.07E+02	E51	5.62E-01	E10	7.85E+01	E45	9.49E+01	E51	3.91E+00	E10	546.2	E45	1.78E+03	E51	9.90E-06	E10	1.38E-03	E45	1.32E-03	E51	1.10E-02	E10	1.53E+00	E45	4.23E+01	E51	7.35E-05	E10	1.03E-02	E45	2.85E-03	E51
44	6.39E-02	E67/R25	8.56E+00	E45	1.65E+01	E51	6.09E-01	E10	8.15E+01	E45	1.07E+02	E51	1.12E-02	E40/R25	1.51E+00	E45	1.90E+00	E51	7.80E-02	E41/N12	10.4	E45	3.56E+01	E51	9.90E-06	E10	1.33E-03	E45	1.32E-03	E51	1.10E-02	E10	1.47E+00	E45	4.22E+01	E51	7.35E-05	E10	9.84E-03	E45	2.84E-03	E51
45	6.39E-02	E10	1.09E+01	E45	1.65E+01	E51	6.09E-01	E10	1.04E+02	E45	1.07E+02	E51	1.12E-02	E10	1.92E+00	E45	1.90E+00	E51	7.80E-02	E10	13.3	E45	3.56E+01	E51	9.90E-06	E10	1.69E-03	E45	1.32E-03	E51	1.10E-02	E10	1.87E+00	E45	4.22E+01	E51	7.35E-05	E10	1.25E-02	E45	2.84E-03	E51
46																																										
47																																										
48	6.39E-02	E10	1.23E+01	E45	1.43E+01	E51	6.09E-01	E10	1.17E+02	E45	9.31E+01	E51	1.06E-02	E10/N28	2.04E+00	E45	1.55E+00	E51	7.80E-02	E10	15.0	E45	3.08E+01	E51	9.90E-06	E10	1.90E-03	E45	1.15E-03	E51	1.10E-02	E10	2.11E+00	E45	3.66E+01	E51	7.35E-05	E10	1.41E-02	E45	2.47E-03	E51
49																																										
50																																										
51	6.39E-02	E10	1.43E+01	E45	1.43E+01	E51	6.09E-01	E10	1.36E+02	E45	9.29E+01	E51	1.06E-02	E10	2.36E+00	E45	1.55E+00	E51	7.80E-02	E10	17.4	E45	3.08E+01	E51	9.90E-06	E10	2.21E-03	E45	1.14E-03	E51	1.10E-02	E10	2.45E+00	E45	3.65E+01	E51	7.35E-05	E10	1.64E-02	E45	2.46E-03	E51
52																																										
53	6.39E-02	E10	1.41E+01	E45	1.43E+01	E51	6.09E-01	E10	1.34E+02	E45	9.27E+01	E51	1.06E-02	E10	2.33E+00	E45	1.54E+00	E51	7.80E-02	E10	17.2	E45	3.07E+01	E51	9.90E-06	E10	2.18E-03	E45	1.14E-03	E51	1.10E-02	E10	2.42E+00	E45	3.65E+01	E51	7.35E-05	E10	1.62E-02	E45	2.46E-03	E51
54																																										

	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ
1			🟩	Case Dependent Constant																																
2			🟦	Fixed Constant																																
3	HCl						HF						I-129						SO_2						CO						Particulate					
4	kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5																																				
6																																				
7																																				
8																																				
9																																				
10																																				
11	1.22E-03	E47	6.27E-01	E45	8.43E-01	E51	4.73E-04	E47	2.43E-01	E45	5.96E-01	E51	1.11E-03	N20	5.72E-01	E45	2.18E-01	E51	0.00E+00	E47	0.00E+00	E45	0.00E+00	E51	1.71E-01	E47	8.82E+01	E45	1.54E+02	E51	1.46E-02	E47	7.49E+00	E45	5.11E+00	E51
12																																				
13	1.22E-03	E46	5.26E-01	E45	6.34E-01	E51	4.73E-04	E46	2.04E-01	E45	4.48E-01	E51	1.11E-03	E79	4.80E-01	E45	1.64E-01	E51	0.00E+00	E46	0.00E+00	E45	0.00E+00	E51	1.71E-01	E46	7.40E+01	E45	1.16E+02	E51	1.46E-02	E46	6.29E+00	E45	3.85E+00	E51
14																																				
15	1.22E-03	E50	4.52E-01	E45	5.00E-01	N4	4.73E-04	E50	1.75E-01	E45	3.54E-01	N4	1.11E-03	E79	4.12E-01	E45	1.29E-01	E51	0.00E+00	E50	0.00E+00	E45	0.00E+00	N4	1.71E-01	E50	6.36E+01	E45	9.15E+01	N4	1.46E-02	N8/E34	5.40E+00	E45	3.03E+00	E51
16																																				
17	6.43E-04	E50	5.15E-01	E45	4.07E-01	N4	2.85E-04	E50	2.28E-01	E45	3.29E-01	N4	3.09E-04	E78	2.47E-01	E45	5.53E-02	E51	1.25E-03	E50	1.00E+00	E45	4.52E-01	N4	3.79E-02	E50	3.03E+01	E45	3.12E+01	N4	2.51E-03	E69/N14	2.01E+00	E45	8.06E-01	E51
18																																				
19																																				
20																																				
21	0.00E+00	E50	0.00E+00	E45	0.00E+00	N4	4.82E-04	E50	2.42E-01	E45	3.54E-01	N4	6.43E-05	E78	3.23E-02	E45	7.32E-03	E51	1.78E-03	E50	8.95E-01	E45	4.09E-01	N4	4.17E-02	E50	2.09E+01	E45	2.18E+01	N4	1.26E-05	E69/N14	6.34E-03	E45	2.58E-03	E51
22																																				
23																																				
24	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	2.20E-01	E45	3.52E-01	E51	6.43E-05	E10	2.94E-02	E45	7.28E-03	E51	1.78E-03	E10	8.16E-01	E45	4.06E-01	E51	4.17E-02	E10	1.91E+01	E45	2.17E+01	E51	1.26E-05	E10	5.77E-03	E45	2.56E-03	E51
25	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	1.19E-05	N21	1.47E-01	E45	6.00E-02	E51
26	0.00E+00	E9	0.00E+00	E45	0.00E+00	E51	4.82E-04	E9	2.13E-01	E45	3.38E-01	E51	6.43E-05	E9	2.83E-02	E45	7.00E-03	E51	1.78E-03	E9	7.87E-01	E45	3.91E-01	E51	4.17E-02	E9	1.84E+01	E45	2.09E+01	E51	2.45E-05	E9	1.08E-02	E45	4.78E-03	E51
27																																				
28	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	1.98E-01	E45	3.38E-01	E51	6.43E-05	E10	2.64E-02	E45	7.00E-03	E51	1.78E-03	E10	7.34E-01	E45	3.91E-01	E51	4.17E-02	E10	1.71E+01	E45	2.09E+01	E51	2.45E-05	E10 / N2	1.01E-02	E45	4.78E-03	E51
29																																				
30	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	1.97E-01	E45	3.38E-01	E51	6.43E-05	E10	2.62E-02	E45	7.00E-03	E51	1.78E-03	E10	7.27E-01	E45	3.91E-01	E51	4.17E-02	E10	1.70E+01	E45	2.09E+01	E51	1.23E-08	R28	4.99E-06	E45	2.39E-06	E51
31																																				
32																																				
33	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	1.92E-01	E45	3.36E-01	E51	6.43E-05	E10~~/N19~~	2.56E-02	E45	6.96E-03	E51	1.78E-03	E10	7.10E-01	E45	3.89E-01	E51	4.17E-02	E10	1.66E+01	E45	2.08E+01	E51	1.23E-08	E10	4.88E-06	E45	2.38E-06	E51
34																																				
35																																				
36	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	1.17E-01	E45	3.35E-01	E51	6.43E-05	E10	1.56E-02	E45	6.93E-03	E51	1.78E-03	E10	4.34E-01	E45	3.87E-01	E51	4.17E-02	E10	1.01E+01	E45	2.07E+01	E51	1.23E-08	E10	2.98E-06	E45	2.37E-06	E51
37	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	9.22E-02	E45	3.35E-01	E51	6.43E-05	E10	1.23E-02	E45	6.93E-03	E51	1.78E-03	E10	3.41E-01	E45	3.87E-01	E51	4.17E-02	E10	7.97E+00	E45	2.07E+01	E51	1.23E-08	E10	2.34E-06	E45	2.37E-06	E51
38	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	9.16E-02	E45	3.35E-01	E51	6.43E-05	E10	1.22E-02	E45	6.93E-03	E51	1.78E-03	E10	3.39E-01	E45	3.87E-01	E51	1.54E-03	E50	2.93E-01	E45	7.66E-01	N15	1.23E-08	E10	2.33E-06	E45	2.37E-06	E51
39																																				
40																																				
41																																				
42																																				
43	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	6.74E-02	E45	1.87E-01	E51	6.43E-05	E10	8.98E-03	E45	3.87E-03	E51	1.78E-03	E10	2.49E-01	E45	2.16E-01	E51	1.54E-03	E10	2.16E-01	E45	4.28E-01	E51	1.23E-08	E10	1.71E-06	E45	1.32E-06	E51
44	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	6.46E-02	E45	1.87E-01	E51	6.43E-05	E10	8.61E-03	E45	3.87E-03	E51	1.78E-03	E10	2.39E-01	E45	2.16E-01	E51	1.54E-03	E10	2.07E-01	E45	4.28E-01	E51	1.23E-08	E10	1.64E-06	E45	1.32E-06	E51
45	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	8.23E-02	E45	1.87E-01	E51	6.43E-05	E10	1.10E-02	E45	3.87E-03	E51	1.78E-03	E10	3.04E-01	E45	2.16E-01	E51	1.54E-03	E10	2.63E-01	E45	4.28E-01	E51	1.23E-08	E10	2.09E-06	E45	1.32E-06	E51
46																																				
47																																				
48	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	6.43E-05	E10	1.24E-02	E45	3.36E-03	E51	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	1.54E-03	E10	2.97E-01	E45	3.71E-01	E51	1.23E-08	E10	2.36E-06	E45	1.15E-06	E51
49																																				
50																																				
51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	6.43E-05	E10	1.43E-02	E45	3.35E-03	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.54E-03	E10	3.44E-01	E45	3.70E-01	E51	1.23E-08	E10	2.73E-06	E45	1.15E-06	E51
52																																				
53	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	6.43E-05	E10	1.42E-02	E45	3.34E-03	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.54E-03	E10	3.40E-01	E45	3.69E-01	E51	1.23E-08	E10	2.70E-06	E45	1.14E-06	E51
54																																				

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV
1	***LAW Melter Offgas System Design Basis Flowrates, Physical Properties, and Compositional Information (LOP Air Balance)***																				🟩		Case Dependent Constant																									
2	***Minimum Flowsheet - 2 Melters***				Number of Operating LAW Melters =>					2											🟦		Fixed Constant																									
3	Stream Number	Stream Name	Dry Air		Steam		Others		Total		Mass Flow				Temperature				Diff. Press		Absolute Pressure				Total		Hum. Ratio		Relative Hum.		Mol. Weight		Density				Heat Capacity				Not Used				Not Used			
4			SCFM$^{(N1)}$		SCFM$^{(N1)}$		SCFM$^{(N1)}$		SCFM$^{(N1)}$		kg/hr		lb/hr		°C		°F		in. WG		in. WC		mbar-a		ACFM		lb H_2O/lb Air		%		g/mol		kg/m^3		lb/ft^3		KJ/kg-C		Btu/lb-F									
5	Hanford Atmospheric Pressure (Pressure Balance)																				397	E21	990	R14																								
6	C2/C3 Area Vacuum																		-0.4	R18	397	E23	989	E22																								
7	Melter Enclosure Relative to C3 Gallery																		-2.0	R19	395	E23	984	E22																								
8		Steam from LAW Melter Feed			381	R39			381	E1	4.84E+02	E18	1.07E+03	E20	N/A		N/A				N/A				N/A						18.0	E56																
9	LMP01	Melter Air Inleakage	148	E7	1.0	E19	0.0	A18	149	R2/A3	3.04E+02	E18	6.70E+02	E20	15	E17	59	N11			395	A23	984	E22	151	E25	0.004	N11	30%	A1	28.9	E56	1.187	E27	0.0741	E28	1.005	E52	0.240	E54								
10	LMP02/03	Melter Injected Air	19	R1	0	A2	0.0	A18	19	E1	3.89E+01	E18	8.57E+01	E20	16	E17	60	R7			390	A24	972	E22	20	E25	0	A2	0%	A2	29.0	E56	1.172	E27	0.0732	E28	1.001	E52	0.239	E54								
11	LMP06	Melter Offgas	176	E13	382	E2	2.9	E57	561	E1	8.62E+02	E18	1.90E+03	E20	300	A29	572	E16	-5.0	R15	390	E23	972	E22	1,144	E25	1.288	E31	0.8%	N10	21.8	E56	0.444	E27	0.0277	E28	1.591	E52	0.380	E54								
12	LMP11	Film Cooler Air	185	R3	0	A2	0.0	A18	185	E1	3.78E+02	E18	8.34E+02	E20	16	E17	60	R7			390	A25	970	E22	190	E25	0	A2	0%	A2	29.0	E56	1.171	E27	0.0731	E28	1.001	E52	0.239	E54								
13		Film Cooler Discharge	361	E3	382	E3	2.9	E57	746	E1	1.24E+03	E18	2.74E+03	E20	240	E12	463	E16	-0.5	R16	390	E23	970	E22	1,362	E25	0.643	E31	1.5%	N10	23.6	E56	0.536	E27	0.0335	E28	1.405	E52	0.336	E54								
14	LMP13	Pressure Control Air	200	A27	0	A2	0.0	A18	200	E1	4.09E+02	E18	9.02E+02	E20	16	E17	60	R7			390	A26	970	E22	206	E25	0	A2	0%	A2	29.0	E56	1.171	E27	0.0731	E28	1.001	E52	0.239	E54								
15	LMP14	Controlled Offgas	561	E4	382	E4	2.9	E57	946	E1	1.65E+03	E18	3.64E+03	E20	198	E12	388	E16			390	A26	970	E22	1,586	E25	0.417	E31	2.6%	N10	24.7	E56	0.612	E27	0.0382	E28	1.301	E52	0.311	E54								
16	LMP14 Piping Pressure Drop																		-0.9	R16	389	E23	968	E22																								
17	LOP02	SBS Discharge	561	E5	50.5	R8/A6	1.6	E57	613	E1	1.23E+03	E18	2.70E+03	E20	40	A53	104	E16	-26.4	N6	362	E23	902	E22	736	E25	0.055	E31	100.0%	N10	28.3	E56	0.981	E27	0.0612	E28	1.047	E52	0.250	E54								
18	FC/Jumper/SBS Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
19	LOP02 Piping Pressure Drop																		-2.0	A36	360	E23	897	E22																								
20	LOP06	WESP Bulge Air Purge	346	R5	0	A2	0.0	A18	346	E1	7.09E+02	E18	1.56E+03	E20	43	E17	109	R5			434	R5	1082	E22	350	E25	0	A2	0%	A2	29.0	E56	1.193	E27	0.0745	E28	1.005	E52	0.240	E54								
21	LOP08	WESP Discharge	913	E6	51	E6/A8	2.0	E57	965	E1	1.95E+03	E18	4.29E+03	E20	41	R10/E12	105	E16	-1.9	R20	358	E23	893	E22	1,173	E25	0.034	E31	60.4%	N10	28.5	E56	0.976	E27	0.0609	E28	1.032	E52	0.247	E54								
22		WESP Inleakage	5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
23	LOP08 Piping Pressure Drop																		-4.0	A36	354	E23	883	E22																								
24		Offgas Flow through Control Valve	918	E10	51	E10	2.0	E10	970.3	E1	1.96E+03	E18	4.31E+03	E20	41	E65	105	E16	-26.08	N24	328	E23	818	E22	1,288	E25	0.034	E31	55.1%	N10	28.5	E56	0.894	E27	0.0558	E28	1.032	E52	0.247	E54								
25	LVP01	Vessel Vent Offgas	39	E7	0.3	E19	0.02	E57	39	N3	7.95E+01	E18	1.75E+02	E20	15	E17	59	A14			328	A28	818	E22	48	E25	0.005	E63	50%	A22	28.9	E56	0.985	E27	0.0615	E28	1.006	E52	0.240	E54								
26	LVP03	Combined Offgas	1,874	E9	101	E9/A8	3.9	E57	1,980	E1	3.99E+03	E18	8.80E+03	E20	40	E12	104	E16			328	E55	818	E22	2,623	E25	0.033	E31	55.6%	N10	28.5	E56	0.896	E27	0.0559	E28	1.031	E52	0.246	E54								
27	LVP03 Piping Pressure Drop																		-2.0	A36	326	E23	813	E22																								
28	LVP04	HEPA Preheater Discharge	1,874	E10	101	E10/A8	3.9	E57	1,980	E1	3.99E+03	E18	8.80E+03	E20	60	A12	140	E16	-0.5	A20	326	E23	811	E22	2,811	E25	0.033	E31	20.6%	N10	28.5	E56	0.836	E27	0.0522	E28	1.035	E52	0.247	E54								
29	LVP04 Piping Pressure Drop																		-2.0	A36	324	E23	806	E22																								
30	LVP06	HEPA Discharge	1,874	E10	101	E10/A8	3.9	E57	1,980	E1	3.99E+03	E18	8.80E+03	E20	60	A11	140	E16	-1.0	A31	323	E23	804	E22	2,838	E25	0.033	E31	20.5%	N10	28.5	E56	0.828	E27	0.0517	E28	1.035	E52	0.247	E54								
31	HEPA Bank Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
32	LVP06 Piping Pressure Drop																		-2.0	A36	321	E23	799	E22																								
33	LVP26	S-AC Column Discharge	1,879	E10	101	E10/A8	3.9	E57	1,985	E1	4.00E+03	E18	8.82E+03	E20	55	A61	131	E16	-13.5	N16	307	E23	765	E22	2,944	E25	0.033	E31	24.6%	N10	28.5	E56	0.800	E27	0.0500	E28	1.034	E52	0.247	E54								
34	S-AC Column Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
35	LVP26 Piping Pressure Drop																		-2.0	A36	305	E23	760	E22																								
36	LVP10	Skid Preheater Discharge	1,884	E10	102	E10/A8	3.9	E57	1,990	E1	4.01E+03	E18	8.85E+03	E20	298	N23	569	E16	-0.5	R17	305	E23	759	E22	5,176	E25	0.033	E31	0.05%	N10	28.5	E56	0.456	E27	0.0285	E28	1.081	E52	0.258	E54								
37	LVP11	Skid Electric Heater Discharge	1,884	E10	102	E10/A8	3.9	E57	1,990	E1	4.01E+03	E18	8.85E+03	E20	399	E17	750	R11	-1.0	R17	304	E23	757	E22	6,109	E25	0.033	E31	0.01%	N10	28.5	E56	0.387	E27	0.0241	E28	1.102	E52	0.263	E54								
38	LVP12	TCO Discharge	1,884	E10/N22	102	E10/N22	3.9	E57	1,990	E1	4.01E+03	E18	8.85E+03	E20	399	N18	750	E16	-4.0	R17	300	E23	747	E22	6,192	E25	0.033	E31	0.01%	N10	28.5	E56	0.381	E27	0.0238	E28	1.102	E52	0.263	E54								
39		Ammonia Dilution Air	795	E7	5.1	E19	0.0	A18	800	A60	1.63E+03	E18	3.60E+03	E20	15	E17	59	N11			300	A50	747	E22	1,067	E25	0.004	N11	30%	A1	28.9	E56	0.900	E27	0.0562	E28	1.005	E52	0.240	E54								
40		Dilution Air Fan Discharge	795	E10	5.1	E10/A8	0.0	A18	800	E1	1.63E+03	E18	3.60E+03	E20	15	A58	59	E16			300	A50	747	E22	1,067	E25	0.004	E31	28.8%	N10	28.9	E56	0.900	E27	0.0562	E28	1.005	E52	0.240	E54								
41	AMR03	Ammonia					6.5	E62	6.5	E1	7.81	N12	17.2	E20	-31	E17	-23	A62			300	A50	747	E22	7	E25	0	R22	0%	R22	17.0	R24	0.630	E27	0.0394	E28	1.992	E8	0.476	E54								
42	LVP13	Diluted Ammonia Addition	795	E10	5.1	E10	6.5	E10	806.5	E1	1.64E+03	E18	3.62E+03	E20	15	E12	58	E16			300	A50	747	E22	1,075	E25	0.004	E31	29.3%	N10	28.8	E56	0.899	E27	0.0561	E28	1.005	E52	0.240	E54								
43	LVP23	SCR Input	2,679	E61	107	E61	10.4	E61	2,796	E1	5.65E+03	E18	1.25E+04	E20	295	E12	563	E16			300	E23	747	E22	7,357	E25	0.025	E31	0.04%	N10	28.6	E56	0.452	E27	0.0282	E28	1.072	E52	0.256	E54								
44	LVP14	SCR Discharge	2,681	E10/N13	116	E10/N13	0.7	E57	2,798	E1	5.65E+03	E18	1.25E+04	E20	320	E12/N13	608	E16	-2.1	R17	298	E23	741	E22	7,740	E25	0.027	E31	0.03%	N10	28.6	E56	0.430	E27	0.0268	E28	1.080	E52	0.258	E54								
45	LVP09	Catalyst Skid Discharge	2,681	E10	116	E10/A8	0.7	E57	2,798	E1	5.65E+03	E18	1.25E+04	E20	148	N23	298	E16	-0.6	R17	297	E23	740	E22	5,505	E25	0.027	E31	0.70%	N10	28.6	E56	0.604	E27	0.0377	E28	1.045	E52	0.250	E54								
46	Catalyst Skid Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
47	LVP09 Piping Pressure Drop										5.66E+03	E74	1.25E+04	E20					-2.0	A36	295	E23	735	E22																								
48	LVP18	Caustic Scrubber Discharge	2,830	E10/N27	327	E14	0.7	E57	3,158	E1	5.93E+03	E18	1.31E+04	E20	41	N26	106	E16	-5.0	A51	290	E23	722	E22	4,747	E25	0.075	E31	95.6%	N10	26.6	E56	0.735	E27	0.0459	E28	1.065	E52	0.255	E54								
49		Caustic Scrubber Inleakage	5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
50	LVP18 Piping Pressure Drop to Fans																		-2.0	A36	288	E23	717	E22																								
51	LVP08	Exhauster Discharge	2,835	E10	327	E10/A8	0.7	E57	3,163	E1	5.94E+03	E18	1.31E+04	E20	95	N5	203	E16	114	N7	402	E23	1000	E22	4,024	E25	0.075	E31	12.2%	N10	26.6	E56	0.869	E27	0.0542	E28	1.075	E52	0.257	E54								
52	Exhauster Inleakage		5	A21	0.0	E19	0.0	A18	5.0	E1	1.03E+01	E18	2.26E+01	E20			59	N11									0.004	N11	30%	A1	28.9	E56																
53	LVP08 Piping Pressure Drop to Stack		2,840	E10	327	E10/A8	0.7	E57	3,168	E1	5.95E+03	E18	1.31E+04	E20	95	E32	203	E16	-4.0	A36	398	E23	990	E22	4,071	E25	0.075	E31	12.1%	N10	26.6	E56	0.860	E27	0.0537	E28	1.075	E52	0.257	E54								
54	Hanford Atmospheric Pressure (Pressure Balance)														25	A13	77	E16			397	E21	990	R14																								

By: Nancy Wilkins
Date: 11/15/2019

Subject: LAW Melter Offgas System Design Basis Flowsheets

CALCULATION SHEET

Job No: 24590
Calc No: 24590-LAW-M4C-LOP-00001
Rev.: 6
Page: 1-7

	A	B	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant																										
2	***Minimum Flowsheet - 2 Melters***				🟦	Fixed Constant																										
3	Stream Number	Stream Name	N_2						O_2						CO_2						Ar						H_2O					
4			kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%	
5	Hanford Atmospheric Pressure (Pressure Balance)																															
6	C2/C3 Area Vacuum																															
7	Melter Enclosure Relative to C3 Gallery																															
8		Steam from LAW Melter Feed																									4.8E+02	E35	100.0%	E26	100.0%	E39
9	LMP01	Melter Air Inleakage	2.3E+02	E35	75%	E26	77.6%	E38	7.0E+01	E35	23%	E26	20.8%	E38	1.4E-01	E35	0.048%	E26	0.031%	E38	3.9E+00	E35	1.3%	E26	0.93%	E38	1.2E+00	E35	0.4%	E26	0.6%	E39
10	LMP02/03	Melter Injected Air	2.9E+01	E35	76%	E26	78.1%	E38	9.0E+00	E35	23%	E26	20.9%	E38	1.9E-02	E35	0.048%	E26	0.031%	E38	5.0E-01	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
11	LMP06	Melter Offgas	2.6E+02	E2	30%	E36	23.3%	E37	7.9E+01	E2	9%	E36	6.2%	E37	2.9E+01	E11	3.4%	E36	1.7%	E37	4.4E+00	E2	0.5%	E36	0.28%	E37	4.9E+02	E2	56%	E26	68%	E39
12	LMP11	Film Cooler Air	2.9E+02	E35	76%	E26	78.1%	E38	8.8E+01	E35	23%	E26	20.9%	E38	1.8E-01	E35	0.048%	E26	0.031%	E38	4.9E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
13		Film Cooler Discharge	5.4E+02	E3	44%	E36	36.9%	E37	1.7E+02	E3	13%	E36	9.9%	E37	2.9E+01	E24	2.4%	E36	1.3%	E37	9.3E+00	E3	0.7%	E36	0.44%	E37	4.9E+02	E3	39%	E26	51%	E39
14	LMP13	Pressure Control Air	3.1E+02	E35	76%	E26	78.1%	E38	9.5E+01	E35	23%	E26	20.9%	E38	2.0E-01	E35	0.048%	E26	0.031%	E38	5.3E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
15	LMP14	Controlled Offgas	8.5E+02	E4	52%	E36	45.6%	E37	2.6E+02	E4	16%	E36	12.2%	E37	2.9E+01	E35	1.8%	E26	1.0%	N4	1.5E+01	E4	0.9%	E36	0.55%	E37	4.9E+02	E4	29%	E26	40%	E39
16	LMP14 Piping Pressure Drop																															
17	LOP02	SBS Discharge	8.5E+02	E5	70%	E36	70.3%	E37	2.6E+02	E5	21%	E36	18.9%	E37	2.9E+01	E5	2.4%	E36	1.5%	E37	1.5E+01	E5	1.2%	E36	0.84%	E37	6.4E+01	E35	5.2%	E26	8.2%	E39
18	FC/Jumper/SBS Inleakage		7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.048%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
19	LOP02 Piping Pressure Drop																															
20	LOP06	WESP Bulge Air Purge	5.4E+02	E35	76%	E26	78.1%	E38	1.6E+02	E35	23%	E26	20.9%	E38	3.4E-01	E35	0.048%	E26	0.031%	E38	9.1E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
21	LOP08	WESP Discharge	1.4E+03	E6	72%	E36	73.1%	E37	4.3E+02	E6	22%	E36	19.6%	E37	3.0E+01	E6	1.5%	E36	1.0%	E37	2.4E+01	E6	1.2%	E36	0.87%	E37	6.4E+01	E6	3.3%	E26	5.2%	E39
22		WESP Inleakage	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.048%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
23	LOP08 Piping Pressure Drop																															
24		Offgas Flow through Control Valve	1.4E+03	E10	72%	E36	73.1%	E37	4.3E+02	E10	22%	E36	19.6%	E37	3.0E+01	E10	1.5%	E36	1.0%	E37	2.4E+01	E10	1.2%	E36	0.87%	E37	6.4E+01	E10	3.3%	E26	5.2%	E39
25	LVP01	Vessel Vent Offgas	6.0E+01	E35	75%	E26	77.4%	E38	1.8E+01	E35	23%	E26	20.8%	E38	3.8E-02	E35	0.047%	E26	0.031%	E38	1.0E+00	E35	1.3%	E26	0.93%	E38	4.2E-01	E35	0.5%	E26	0.8%	E39
26	LVP03	Combined Offgas	2.9E+03	E9	72%	E36	73.2%	E37	8.8E+02	E9	22%	E36	19.6%	E37	6.0E+01	E9	1.5%	E36	1.0%	E37	4.9E+01	E9	1.2%	E36	0.88%	E37	1.3E+02	E9	3.2%	E26	5.1%	E39
27	LVP03 Piping Pressure Drop																															
28	LVP04	HEPA Preheater Discharge	2.9E+03	E10	72%	E36	73.2%	E37	8.8E+02	E10	22%	E36	19.6%	E37	6.0E+01	E10	1.5%	E36	1.0%	E37	4.9E+01	E10	1.2%	E36	0.88%	E37	1.3E+02	E10	3.2%	E26	5.1%	E39
29	LVP04 Piping Pressure Drop																															
30	LVP06	HEPA Discharge	2.9E+03	E10	72%	E36	73.2%	E37	8.8E+02	E10	22%	E36	19.6%	E37	6.0E+01	E10	1.5%	E36	1.0%	E37	4.9E+01	E10	1.2%	E36	0.88%	E37	1.3E+02	E10	3.2%	E26	5.1%	E39
31	HEPA Bank Inleakage		7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.048%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
32	LVP06 Piping Pressure Drop																															
33	LVP26	S-AC Column Discharge	2.9E+03	E10	72%	E36	73.2%	E37	8.8E+02	E10	22%	E36	19.6%	E37	6.0E+01	E10	1.5%	E36	1.0%	E37	4.9E+01	E10	1.2%	E36	0.88%	E37	1.3E+02	E10	3.2%	E26	5.1%	E39
34	S-AC Column Inleakage		7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.048%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
35	LVP26 Piping Pressure Drop																															
36	LVP10	Skid Preheater Discharge	2.9E+03	E10	72%	E36	73.2%	E37	8.8E+02	E10	22%	E36	19.6%	E37	6.0E+01	E10	1.5%	E36	1.0%	E37	4.9E+01	E10	1.2%	E36	0.88%	E37	1.3E+02	E10	3.2%	E26	5.1%	E39
37	LVP11	Skid Electric Heater Discharge	2.9E+03	E10	72%	E36	73.2%	E37	8.8E+02	E10	22%	E36	19.6%	E37	6.0E+01	E10	1.5%	E36	1.0%	E37	4.9E+01	E10	1.2%	E36	0.88%	E37	1.3E+02	E10	3.2%	E26	5.1%	E39
38	LVP12	TCO Discharge	2.9E+03	E10	72%	E36	73.2%	E37	8.8E+02	E10/N22	22%	E36	19.6%	E37	6.0E+01	E10/N22	1.5%	E36	1.0%	E37	4.9E+01	E10	1.2%	E36	0.88%	E37	1.3E+02	E10/N22	3.2%	E26	5.1%	E39
39		Ammonia Dilution Air	1.2E+03	E35	75%	E26	77.6%	E38	3.8E+02	E35	23%	E26	20.8%	E38	7.8E-01	E35	0.048%	E26	0.031%	E38	2.1E+01	E35	1.3%	E26	0.93%	E38	6.5E+00	E35	0.4%	E26	0.6%	E39
40		Dilution Air Fan Discharge	1.2E+03	E10	75%	E36	77.6%	E37	3.8E+02	E10	23%	E36	20.8%	E37	7.8E-01	E10	0.048%	E36	0.031%	E37	2.1E+01	E10	1.3%	E36	0.93%	E37	6.5E+00	E10	0.4%	E26	0.6%	E39
41	AMR03	Ammonia																														
42	LVP13	Diluted Ammonia Addition	1.2E+03	E10	75%	E36	77.0%	E37	3.8E+02	E10	23%	E36	20.6%	E37	7.8E-01	E10	0.047%	E36	0.031%	E37	2.1E+01	E10	1.3%	E36	0.92%	E37	6.5E+00	E10	0.4%	E26	0.6%	E39
43	LVP23	SCR Input	4.1E+03	E10	73%	E36	74.3%	E37	1.3E+03	E10	22%	E36	19.9%	E37	6.0E+01	E10	1.1%	E36	0.70%	E37	7.0E+01	E10	1.2%	E36	0.89%	E37	1.4E+02	E59	2.4%	E26	3.8%	E39
44	LVP14	SCR Discharge	4.1E+03	E10/N13	73%	E36	74.4%	E37	1.3E+03	E10/N13	22%	E36	19.8%	E37	6.0E+01	E10	1.1%	E36	0.69%	E37	7.0E+01	E10	1.2%	E36	0.89%	E37	1.5E+02	E10/N13	2.6%	E26	4.2%	E39
45	LVP09	Catalyst Skid Discharge	4.1E+03	E10	73%	E36	74.4%	E37	1.3E+03	E10	22%	E36	19.8%	E37	6.0E+01	E10	1.1%	E36	0.69%	E37	7.0E+01	E10	1.2%	E36	0.89%	E37	1.5E+02	E10	2.6%	E26	4.2%	E39
46	Catalyst Skid Inleakage		7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.048%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
47	LVP09 Piping Pressure Drop																										1.5E+02	E74				
48	LVP18	Caustic Scrubber Discharge	4.1E+03	E10	70%	E36	66.1%	E37	1.3E+03	E10	21%	E36	17.6%	E37	5.9E+01	E10/N28	1.0%	E36	0.60%	E37	7.0E+01	E10	1.2%	E36	0.79%	E37	4.2E+02	N26	7.0%	E26	10%	E39
49		Caustic Scrubber Inleakage	7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.048%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
50	LVP18 Piping Pressure Drop to Fans																															
51	LVP08	Exhauster Discharge	4.1E+03	E10	70%	E36	66.1%	E37	1.3E+03	E10	21%	E36	17.6%	E37	5.9E+01	E10	1.0%	E36	0.6%	E37	7.0E+01	E10	1.2%	E36	0.79%	E37	4.2E+02	E10	7.0%	E26	10.3%	E39
52	Exhauster Inleakage		7.7E+00	E35	75%	E26	77.6%	E38	2.4E+00	E35	23%	E26	20.8%	E38	4.9E-03	E35	0.048%	E26	0.031%	E38	1.3E-01	E35	1.3%	E26	0.93%	E38	4.1E-02	E35	0.4%	E26	0.6%	E39
53	LVP08 Piping Pressure Drop to Stack		4.1E+03	E10	70%	E36	66.1%	E37	1.3E+03	E10	21%	E36	17.6%	E37	5.9E+01	E10	1.0%	E36	0.6%	E37	7.1E+01	E10	1.2%	E36	0.79%	E37	4.2E+02	E10	7.0%	E26	10.3%	E39
54	Hanford Atmospheric Pressure (Pressure Balance)																															

	A	B	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant								
2	***Minimum Flowsheet - 2 Melters***				🟦	Fixed Constant								
3	Stream Number	Stream Name	NO						N_2O					
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)													
6	C2/C3 Area Vacuum													
7	Melter Enclosure Relative to C3 Gallery													
8		Steam from LAW Melter Feed												
9	LMP01	Melter Air Inleakage												
10	LMP02/03	Melter Injected Air												
11	LMP06	Melter Offgas	4.85E+00	E47	2.50E+03	E45	4.08E+03	E51	7.00E-01	E47	3.60E+02	E45	4.01E+02	E51
12	LMP11	Film Cooler Air												
13		Film Cooler Discharge	4.85E+00	E46	2.10E+03	E45	3.07E+03	E51	7.00E-01	E46	3.02E+02	E45	3.02E+02	E51
14	LMP13	Pressure Control Air												
15	LMP14	Controlled Offgas	4.85E+00	E50	1.80E+03	E45	2.42E+03	N4	7.00E-01	E50	2.60E+02	E45	2.38E+02	N4
16	LMP14 Piping Pressure Drop													
17	LOP02	SBS Discharge	2.57E+00	E50	2.05E+03	E45	1.97E+03	N4	4.41E-01	E50	3.53E+02	E45	2.31E+02	N4
18	FC/Jumper/SBS Inleakage													
19	LOP02 Piping Pressure Drop													
20	LOP06	WESP Bulge Air Purge												
21	LOP08	WESP Discharge	3.20E+00	E50	1.60E+03	E45	1.56E+03	N4	6.09E-01	E50	3.05E+02	E45	2.03E+02	N4
22		WESP Inleakage												
23	LOP08 Piping Pressure Drop													
24		Offgas Flow through Control Valve	3.20E+00	E10	1.46E+03	E45	1.55E+03	E51	6.09E-01	E10	2.78E+02	E45	2.02E+02	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	LVP03	Combined Offgas	6.39E+00	E9	1.43E+03	E45	1.52E+03	E51	1.22E+00	E9	2.73E+02	E45	1.98E+02	E51
27	LVP03 Piping Pressure Drop													
28	LVP04	HEPA Preheater Discharge	6.39E+00	E10	1.34E+03	E45	1.52E+03	E51	1.22E+00	E10	2.55E+02	E45	1.98E+02	E51
29	LVP04 Piping Pressure Drop													
30	LVP06	HEPA Discharge	6.39E+00	E10	1.33E+03	E45	1.52E+03	E51	1.22E+00	E10	2.53E+02	E45	1.98E+02	E51
31	HEPA Bank Inleakage													
32	LVP06 Piping Pressure Drop													
33	LVP26	S-AC Column Discharge	6.39E+00	E10	1.28E+03	E45	1.52E+03	E51	1.22E+00	E10	2.43E+02	E45	1.97E+02	E51
34	S-AC Column Inleakage													
35	LVP26 Piping Pressure Drop													
36	LVP10	Skid Preheater Discharge	6.39E+00	E10	7.27E+02	E45	1.52E+03	E51	1.22E+00	E10	1.38E+02	E45	1.97E+02	E51
37	LVP11	Skid Electric Heater Discharge	6.39E+00	E10	6.16E+02	E45	1.52E+03	E51	1.22E+00	E10	1.17E+02	E45	1.97E+02	E51
38	LVP12	TCO Discharge	6.39E+00	E10	6.08E+02	E45	1.52E+03	E51	1.22E+00	E10	1.16E+02	E45	1.97E+02	E51
39		Ammonia Dilution Air												
40		Dilution Air Fan Discharge												
41	AMR03	Ammonia												
42	LVP13	Diluted Ammonia Addition												
43	LVP23	SCR Input	6.39E+00	E10	5.11E+02	E45	1.08E+03	E51	1.22E+00	E10	9.74E+01	E45	1.40E+02	E51
44	LVP14	SCR Discharge	1.28E-01	E67/R25	9.72E+00	E45	2.16E+01	E51	1.22E+00	E10	9.26E+01	E45	1.40E+02	E51
45	LVP09	Catalyst Skid Discharge	1.28E-01	E10	1.37E+01	E45	2.16E+01	E51	1.22E+00	E10	1.30E+02	E45	1.40E+02	E51
46	Catalyst Skid Inleakage													
47	LVP09 Piping Pressure Drop													
48	LVP18	Caustic Scrubber Discharge	1.28E-01	E10	1.59E+01	E45	1.91E+01	E51	1.22E+00	E10	1.51E+02	E45	1.24E+02	E51
49		Caustic Scrubber Inleakage												
50	LVP18 Piping Pressure Drop to Fans													
51	LVP08	Exhauster Discharge	1.28E-01	E10	1.87E+01	E45	1.91E+01	E51	1.22E+00	E10	1.78E+02	E45	1.24E+02	E51
52	Exhauster Inleakage													
53	LVP08 Piping Pressure Drop to Stack		1.28E-01	E10	1.85E+01	E45	1.90E+01	E51	1.22E+00	E10	1.76E+02	E45	1.24E+02	E51
54	Hanford Atmospheric Pressure (Pressure Balance)													

	A	B	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD
1	***LAW Melter Offgas System Design Basis***																			
2	***Minimum Flowsheet - 2 Melters***																			
3	Stream Number	Stream Name	NO_2						NH_3						VOC					
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)																			
6	C2/C3 Area Vacuum																			
7	Melter Enclosure Relative to C3 Gallery																			
8		Steam from LAW Melter Feed																		
9	LMP01	Melter Air Inleakage																		
10	LMP02/03	Melter Injected Air																		
11	LMP06	Melter Offgas	5.42E-01	E47	2.79E+02	E45	2.98E+02	E51	5.66E-02	E47	2.91E+01	E45	8.39E+01	E51	1.94E-04	E47	9.99E-02	E45	8.43E-02	E51
12	LMP11	Film Cooler Air																		
13		Film Cooler Discharge	5.42E-01	E46	2.34E+02	E45	2.24E+02	E51	5.66E-02	E46	2.45E+01	E45	6.31E+01	E51	1.94E-04	E46	8.39E-02	E45	6.34E-02	E51
14	LMP13	Pressure Control Air																		
15	LMP14	Controlled Offgas	5.42E-01	E50	2.01E+02	E45	1.76E+02	N4	5.66E-02	E50	2.10E+01	E45	4.98E+01	N4	1.94E-04	E50	7.20E-02	E45	5.00E-02	N25
16	LMP14 Piping Pressure Drop																			
17	LOP02	SBS Discharge	4.46E-01	E50	3.56E+02	E45	2.24E+02	N4	0.00E+00	E50	0.00E+00	E45	0.00E+00	N4	1.26E-04	E50	1.01E-01	E45	5.00E-02	A30
18	FC/Jumper/SBS Inleakage																			
19	LOP02 Piping Pressure Drop																			
20	LOP06	WESP Bulge Air Purge																		
21	LOP08	WESP Discharge	5.62E-01	E50	2.82E+02	E45	1.79E+02	N4	0.00E+00	E50	0.00E+00	E45	0.00E+00	N4	1.98E-04	E50	9.94E-02	E45	5.00E-02	A30
22		WESP Inleakage																		
23	LOP08 Piping Pressure Drop																			
24		Offgas Flow through Control Valve	5.62E-01	E10	2.57E+02	E45	1.78E+02	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.98E-04	E10	9.05E-02	E45	4.97E-02	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	LVP03	Combined Offgas	1.12E+00	E9	2.52E+02	E45	1.75E+02	E51	0.00E+00	E9	0.00E+00	E45	0.00E+00	E51	3.96E-04	E9	8.89E-02	E45	4.88E-02	E51
27	LVP03 Piping Pressure Drop																			
28	LVP04	HEPA Preheater Discharge	1.12E+00	E10	2.35E+02	E45	1.75E+02	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	3.96E-04	E10	8.29E-02	E45	4.88E-02	E51
29	LVP04 Piping Pressure Drop																			
30	LVP06	HEPA Discharge	1.12E+00	E10	2.33E+02	E45	1.75E+02	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	3.96E-04	E10	8.22E-02	E45	4.88E-02	E51
31	HEPA Bank Inleakage																			
32	LVP06 Piping Pressure Drop																			
33	LVP26	S-AC Column Discharge	1.12E+00	E10	2.25E+02	E45	1.74E+02	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	3.96E-04	E10	7.92E-02	E45	4.86E-02	E51
34	S-AC Column Inleakage																			
35	LVP26 Piping Pressure Drop																			
36	LVP10	Skid Preheater Discharge	1.12E+00	E10	1.28E+02	E45	1.74E+02	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	3.96E-04	E10	4.50E-02	E45	4.85E-02	E51
37	LVP11	Skid Electric Heater Discharge	1.12E+00	E10	1.08E+02	E45	1.74E+02	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	3.96E-04	E10	3.82E-02	E45	4.85E-02	E51
38	LVP12	TCO Discharge	1.12E+00	E10	1.07E+02	E45	1.74E+02	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.98E-05	E43/R26	1.88E-03	E45	2.43E-03	E51
39		Ammonia Dilution Air																		
40		Dilution Air Fan Discharge																		
41	AMR03	Ammonia							7.81E+00	E44										
42	LVP13	Diluted Ammonia Addition							7.81E+00	E10	4.28E+03	E45	8.05E+03	E51						
43	LVP23	SCR Input	1.12E+00	E10	9.00E+01	E45	1.24E+02	E51	7.81E+00	E10	6.25E+02	E45	2.32E+03	E51	1.98E-05	E10	1.58E-03	E45	1.73E-03	E51
44	LVP14	SCR Discharge	2.25E-02	E40/R25	1.71E+00	E45	2.47E+00	E51	1.56E-01	E41/N12	1.19E+01	E45	4.64E+01	E51	1.98E-05	E10	1.51E-03	E45	1.73E-03	E51
45	LVP09	Catalyst Skid Discharge	2.25E-02	E10	2.40E+00	E45	2.47E+00	E51	1.56E-01	E10	1.67E+01	E45	4.64E+01	E51	1.98E-05	E10	2.12E-03	E45	1.73E-03	E51
46	Catalyst Skid Inleakage																			
47	LVP09 Piping Pressure Drop																			
48	LVP18	Caustic Scrubber Discharge	2.12E-02	E10/N28	2.63E+00	E45	2.06E+00	E51	1.56E-01	E10	1.93E+01	E45	4.11E+01	E51	1.98E-05	E10	2.46E-03	E45	1.53E-03	E51
49		Caustic Scrubber Inleakage																		
50	LVP18 Piping Pressure Drop to Fans																			
51	LVP08	Exhauster Discharge	2.12E-02	E10	3.10E+00	E45	2.06E+00	E51	1.56E-01	E10	2.28E+01	E45	4.10E+01	E51	1.98E-05	E10	2.90E-03	E45	1.53E-03	E51
52	Exhauster Inleakage																			
53	LVP08 Piping Pressure Drop to Stack		2.12E-02	E10	3.06E+00	E45	2.06E+00	E51	1.56E-01	E10	22.6	E45	4.09E+01	E51	1.98E-05	E10	2.86E-03	E45	1.52E-03	E51
54	Hanford Atmospheric Pressure (Pressure Balance)																			

	A	B	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP
1	***LAW Melter Offgas System Design Basis***													
2	***Minimum Flowsheet - 2 Melters***													
3	Stream Number	Stream Name	H_2						Hg					
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)													
6	C2/C3 Area Vacuum													
7	Melter Enclosure Relative to C3 Gallery													
8		Steam from LAW Melter Feed												
9	LMP01	Melter Air Inleakage												
10	LMP02/03	Melter Injected Air												
11	LMP06	Melter Offgas	7.45E-03	E47	3.84E+00	E45	9.33E+01	E51	3.03E-03	E47	1.56E+00	E45	3.81E-01	E51
12	LMP11	Film Cooler Air												
13		Film Cooler Discharge	7.45E-03	E46	3.22E+00	E45	7.02E+01	E51	3.03E-03	E46	1.31E+00	E45	2.87E-01	E51
14	LMP13	Pressure Control Air												
15	LMP14	Controlled Offgas	7.45E-03	E48	2.77E+00	E45	5.53E+01	E51	3.03E-03	R31	1.12E+00	E45	2.26E-01	E51
16	LMP14 Piping Pressure Drop													
17	LOP02	SBS Discharge	7.45E-03	E49	5.96E+00	E45	8.53E+01	E51	5.05E-04	E66/A55	4.04E-01	E45	5.81E-02	E51
18	FC/Jumper/SBS Inleakage													
19	LOP02 Piping Pressure Drop													
20	LOP06	WESP Bulge Air Purge												
21	LOP08	WESP Discharge	7.45E-03	E50	3.74E+00	E45	7.72E+01	N4	5.05E-04	E53	2.53E-01	E45	3.69E-02	E51
22		WESP Inleakage												
23	LOP08 Piping Pressure Drop													
24		Offgas Flow through Control Valve	7.45E-03	E10	3.41E+00	E45	5.39E+01	E51	5.05E-04	E10	2.31E-01	E45	3.67E-02	E51
25	LVP01	Vessel Vent Offgas	3.52E-03	E42	4.36E+01	E45	6.33E+02	E51	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	LVP03	Combined Offgas	1.84E-02	E9	4.13E+00	E45	6.53E+01	E51	1.01E-03	E9	2.27E-01	E45	3.60E-02	E51
27	LVP03 Piping Pressure Drop													
28	LVP04	HEPA Preheater Discharge	1.84E-02	E10	3.86E+00	E45	6.53E+01	E51	1.01E-03	E10	2.11E-01	E45	3.60E-02	E51
29	LVP04 Piping Pressure Drop													
30	LVP06	HEPA Discharge	1.84E-02	E10	3.82E+00	E45	6.53E+01	E51	1.01E-03	E10	2.09E-01	E45	3.60E-02	E51
31	HEPA Bank Inleakage													
32	LVP06 Piping Pressure Drop													
33	LVP26	S-AC Column Discharge	1.84E-02	E10	3.68E+00	E45	6.52E+01	E51	1.44E-04	R33	2.88E-02	E45	5.12E-03	E51
34	S-AC Column Inleakage													
35	LVP26 Piping Pressure Drop													
36	LVP10	Skid Preheater Discharge	1.84E-02	E10	2.09E+00	E45	6.50E+01	E51	1.44E-04	E10	1.64E-02	E45	5.11E-03	E51
37	LVP11	Skid Electric Heater Discharge	1.84E-02	E10	1.77E+00	E45	6.50E+01	E51	1.44E-04	E10	1.39E-02	E45	5.11E-03	E51
38	LVP12	TCO Discharge	1.84E-02	E10	1.75E+00	E45	6.50E+01	E51	1.44E-04	E10	1.37E-02	E45	5.11E-03	E51
39		Ammonia Dilution Air												
40		Dilution Air Fan Discharge												
41	AMR03	Ammonia												
42	LVP13	Diluted Ammonia Addition												
43	LVP23	SCR Input	1.84E-02	E10	1.47E+00	E45	4.63E+01	E51	1.44E-04	E10	1.15E-02	E45	3.63E-03	E51
44	LVP14	SCR Discharge	1.84E-02	E10	1.40E+00	E45	4.62E+01	E51	1.44E-04	E10	1.10E-02	E45	3.63E-03	E51
45	LVP09	Catalyst Skid Discharge	1.84E-02	E10	1.97E+00	E45	4.62E+01	E51	1.44E-04	E10	1.54E-02	E45	3.63E-03	E51
46	Catalyst Skid Inleakage													
47	LVP09 Piping Pressure Drop													
48	LVP18	Caustic Scrubber Discharge	1.84E-02	E10	2.28E+00	E45	4.10E+01	E51	1.44E-04	E10	1.79E-02	E45	3.22E-03	E51
49		Caustic Scrubber Inleakage												
50	LVP18 Piping Pressure Drop to Fans													
51	LVP08	Exhauster Discharge	1.84E-02	E10	2.69E+00	E45	4.09E+01	E51	1.44E-04	E10	2.11E-02	E45	3.21E-03	E51
52	Exhauster Inleakage													
53	LVP08 Piping Pressure Drop to Stack		1.84E-02	E10	2.66E+00	E45	4.08E+01	E51	1.44E-04	E10	2.08E-02	E45	3.21E-03	E51
54	Hanford Atmospheric Pressure (Pressure Balance)													

	A	B	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant																																
2	***Minimum Flowsheet - 2 Melters***				🟦	Fixed Constant																																
3	Stream Number	Stream Name			HCl						HF						I-129						SO_2						CO						Particulate			
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)																																					
6	C2/C3 Area Vacuum																																					
7	Melter Enclosure Relative to C3 Gallery																																					
8		Steam from LAW Melter Feed																																				
9	LMP01	Melter Air Inleakage																																				
10	LMP02/03	Melter Injected Air																																				
11	LMP06	Melter Offgas	1.22E-03	E47	6.27E-01	E45	8.43E-01	E51	4.73E-04	E47	2.43E-01	E45	5.96E-01	E51	1.11E-03	N20	5.72E-01	E45	2.18E-01	E51	0.00E+00	E47	0.00E+00	E45	0.00E+00	E51	1.71E-01	E47	8.82E+01	E45	1.54E+02	E51	1.46E-02	E47	7.49E+00	E45	5.11E+00	E51
12	LMP11	Film Cooler Air																																				
13		Film Cooler Discharge	1.22E-03	E46	5.26E-01	E45	6.34E-01	E51	4.73E-04	E46	2.04E-01	E45	4.48E-01	E51	1.11E-03	E79	4.80E-01	E45	1.64E-01	E51	0.00E+00	E46	0.00E+00	E45	0.00E+00	E51	1.71E-01	E46	7.40E+01	E45	1.16E+02	E51	1.46E-02	E46	6.29E+00	E45	3.85E+00	E51
14	LMP13	Pressure Control Air																																				
15	LMP14	Controlled Offgas	1.22E-03	E50	4.52E-01	E45	5.00E-01	N4	4.73E-04	E50	1.75E-01	E45	3.54E-01	N4	1.11E-03	E79	4.12E-01	E45	1.29E-01	E51	0.00E+00	E50	0.00E+00	E45	0.00E+00	N4	1.71E-01	E50	6.36E+01	E45	9.15E+01	N4	1.46E-02	N8/E34	5.40E+00	E45	3.03E+00	E51
16	LMP14 Piping Pressure Drop																																					
17	LOP02	SBS Discharge	6.43E-04	E50	5.15E-01	E45	4.07E-01	N4	2.85E-04	E50	2.28E-01	E45	3.29E-01	N4	3.09E-04	E78	2.47E-01	E45	5.53E-02	E51	1.25E-03	E50	1.00E+00	E45	4.52E-01	N4	3.79E-02	E50	3.03E+01	E45	3.12E+01	N4	2.51E-03	E69/N14	2.01E+00	E45	8.06E-01	E51
18	FC/Jumper/SBS Inleakage																																					
19	LOP02 Piping Pressure Drop																																					
20	LOP06	WESP Bulge Air Purge																																				
21	LOP08	WESP Discharge	0.00E+00	E50	0.00E+00	E45	0.00E+00	N4	4.82E-04	E50	2.42E-01	E45	3.54E-01	N4	6.43E-05	E78	3.23E-02	E45	7.32E-03	E51	1.78E-03	E50	8.95E-01	E45	4.09E-01	N4	4.17E-02	E50	2.09E+01	E45	2.18E+01	N4	1.26E-05	E69/N14	6.34E-03	E45	2.58E-03	E51
22		WESP Inleakage																																				
23	LOP08 Piping Pressure Drop																																					
24		Offgas Flow through Control Valve	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	4.82E-04	E10	2.20E-01	E45	3.52E-01	E51	6.43E-05	E10	2.94E-02	E45	7.28E-03	E51	1.78E-03	E10	8.16E-01	E45	4.06E-01	E51	4.17E-02	E10	1.91E+01	E45	2.17E+01	E51	1.26E-05	E10	5.77E-03	E45	2.56E-03	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	1.19E-05	N21	1.47E-01	E45	6.00E-02	E51
26	LVP03	Combined Offgas	0.00E+00	E9	0.00E+00	E45	0.00E+00	E51	9.65E-04	E9	2.16E-01	E45	3.45E-01	E51	1.29E-04	E9	2.89E-02	E45	7.13E-03	E51	3.57E-03	E9	8.01E-01	E45	3.98E-01	E51	8.34E-02	E9	1.87E+01	E45	2.13E+01	E51	3.71E-05	E9	8.33E-03	E45	3.70E-03	E51
27	LVP03 Piping Pressure Drop																																					
28	LVP04	HEPA Preheater Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	2.02E-01	E45	3.45E-01	E51	1.29E-04	E10	2.69E-02	E45	7.13E-03	E51	3.57E-03	E10	7.47E-01	E45	3.98E-01	E51	8.34E-02	E10	1.75E+01	E45	2.13E+01	E51	3.71E-05	E10/N2	7.77E-03	E45	3.70E-03	E51
29	LVP04 Piping Pressure Drop																																					
30	LVP06	HEPA Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	2.00E-01	E45	3.45E-01	E51	1.29E-04	E10	2.67E-02	E45	7.13E-03	E51	3.57E-03	E10	7.40E-01	E45	3.98E-01	E51	8.34E-02	E10	1.73E+01	E45	2.13E+01	E51	1.86E-08	R28	3.85E-06	E45	1.85E-06	E51
31	HEPA Bank Inleakage																																					
32	LVP06 Piping Pressure Drop																																					
33	LVP26	S-AC Column Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	1.93E-01	E45	3.44E-01	E51	1.29E-04	E10/~~N19~~	2.57E-02	E45	7.12E-03	E51	3.57E-03	E10	7.14E-01	E45	3.97E-01	E51	8.34E-02	E10	1.67E+01	E45	2.12E+01	E51	1.86E-08	E10	3.71E-06	E45	1.84E-06	E51
34	S-AC Column Inleakage																																					
35	LVP26 Piping Pressure Drop																																					
36	LVP10	Skid Preheater Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	1.10E-01	E45	3.43E-01	E51	1.29E-04	E10	1.46E-02	E45	7.10E-03	E51	3.57E-03	E10	4.06E-01	E45	3.96E-01	E51	8.34E-02	E10	9.48E+00	E45	2.12E+01	E51	1.86E-08	E10	2.11E-06	E45	1.84E-06	E51
37	LVP11	Skid Electric Heater Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	9.29E-02	E45	3.43E-01	E51	1.29E-04	E10	1.24E-02	E45	7.10E-03	E51	3.57E-03	E10	3.44E-01	E45	3.96E-01	E51	8.34E-02	E10	8.04E+00	E45	2.12E+01	E51	1.86E-08	E10	1.79E-06	E45	1.84E-06	E51
38	LVP12	TCO Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	9.17E-02	E45	3.43E-01	E51	1.29E-04	E10	1.22E-02	E45	7.10E-03	E51	3.57E-03	E10	3.39E-01	E45	3.96E-01	E51	3.09E-03	E50	2.94E-01	E45	7.85E-01	N15	1.86E-08	E10	1.76E-06	E45	1.84E-06	E51
39		Ammonia Dilution Air																																				
40		Dilution Air Fan Discharge																																				
41	AMR03	Ammonia																																				
42	LVP13	Diluted Ammonia Addition																																				
43	LVP23	SCR Input	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	7.72E-02	E45	2.44E-01	E51	1.29E-04	E10	1.03E-02	E45	5.05E-03	E51	3.57E-03	E10	2.86E-01	E45	2.82E-01	E51	3.09E-03	E10	2.47E-01	E45	5.58E-01	E51	1.86E-08	E10	1.49E-06	E45	1.31E-06	E51
44	LVP14	SCR Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	7.34E-02	E45	2.44E-01	E51	1.29E-04	E10	9.78E-03	E45	5.05E-03	E51	3.57E-03	E10	2.71E-01	E45	2.82E-01	E51	3.09E-03	E10	2.35E-01	E45	5.58E-01	E51	1.86E-08	E10	1.41E-06	E45	1.31E-06	E51
45	LVP09	Catalyst Skid Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	9.65E-04	E10	1.03E-01	E45	2.44E-01	E51	1.29E-04	E10	1.37E-02	E45	5.05E-03	E51	3.57E-03	E10	3.82E-01	E45	2.82E-01	E51	3.09E-03	E10	3.30E-01	E45	5.58E-01	E51	1.86E-08	E10	1.99E-06	E45	1.31E-06	E51
46	Catalyst Skid Inleakage																																					
47	LVP09 Piping Pressure Drop																																					
48	LVP18	Caustic Scrubber Discharge	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	1.29E-04	E10	1.59E-02	E45	4.47E-03	E51	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	3.09E-03	E10	3.83E-01	E45	4.94E-01	E51	1.86E-08	E10	2.30E-06	E45	1.16E-06	E51
49		Caustic Scrubber Inleakage																																				
50	LVP18 Piping Pressure Drop to Fans																																					
51	LVP08	Exhauster Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.29E-04	E10	1.88E-02	E45	4.47E-03	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	3.09E-03	E10	4.52E-01	E45	4.94E-01	E51	1.86E-08	E10	2.72E-06	E45	1.16E-06	E51
52	Exhauster Inleakage																																					
53	LVP08 Piping Pressure Drop to Stack		0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.29E-04	E10	1.86E-02	E45	4.46E-03	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	3.09E-03	E10	4.47E-01	E45	4.93E-01	E51	1.86E-08	E10	2.68E-06	E45	1.15E-06	E51
54	Hanford Atmospheric Pressure (Pressure Balance)																																					

Subject: LAW Melter Offgas System Design Basis Flowsheets

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV
1	***LAW Melter Offgas System Design Basis Flowrates, Physical Properties, and Compositional Information (LOP Air Balance)***																				🟩		Case Dependent Constant																									
2	***Nominal Flowsheet - 2 Melters***				Number of Operating LAW Melters =>					2											🟦		Fixed Constant																									
3	Stream Number	Stream Name	Dry Air		Steam		Others		Total		Mass Flow				Temperature				Diff. Press		Absolute Pressure				Total		Hum. Ratio		Relative Hum.		Mol. Weight		Density				Heat Capacity				Not Used				Not Used			
4			SCFM$^{(N1)}$		SCFM$^{(N1)}$		SCFM$^{(N1)}$		SCFM$^{(N1)}$		kg/hr		lb/hr		°C		°F		in. WG		in. WC		mbar-a		ACFM		lb H_2O/lb Air		%		g/mol		kg/m^3		lb/ft^3		KJ/kg-C		Btu/lb-F									
5	Hanford Atmospheric Pressure (Pressure Balance)																				397	E21	990	R14																								
6	C2/C3 Area Vacuum																		-0.4	R18	397	E23	989	E22																								
7	Melter Enclosure Relative to C3 Gallery																		-2.0	R19	395	E23	984	E22																								
8		Steam from LAW Melter Feed			401	R39			401	E1	5.10E+02	E18	1.12E+03	E20	N/A		N/A				N/A				N/A						18.0	E56																
9	LMP01	Melter Air Inleakage	221	E7	3.2	E19	0.0	A18	224	R2/A3	4.56E+02	E18	1.00E+03	E20	27	E17	80	N11			395	A23	984	E22	236	E25	0.009	N11	40%	A1	28.8	E56	1.137	E27	0.0710	E28	1.011	E52	0.242	E54								
10	LMP02/03	Melter Injected Air	19	R1	0	A2	0.0	A18	19	E1	3.89E+01	E18	8.57E+01	E20	16	E17	60	R7			390	A24	972	E22	20	E25	0	A2	0%	A2	29.0	E56	1.172	E27	0.0732	E28	1.001	E52	0.239	E54								
11	LMP06	Melter Offgas	252	E13	404	E2	5.5	E57	662	E1	1.06E+03	E18	2.33E+03	E20	400	R6	752	E16	-5.0	R15	390	E23	972	E22	1,585	E25	0.948	E31	0.2%	N10	22.6	E56	0.392	E27	0.0245	E28	1.562	E52	0.373	E54								
12	LMP11	Film Cooler Air	185	R3	0	A2	0.0	A18	185	E1	3.78E+02	E18	8.34E+02	E20	16	E17	60	R7			389	A25	969	E22	191	E25	0	A2	0%	A2	29.0	E56	1.169	E27	0.0730	E28	1.001	E52	0.239	E54								
13		Film Cooler Discharge	437	E3	404	E3	5.5	E57	847	E1	1.43E+03	E18	3.16E+03	E20	330	E12	626	E16	-1.1	R16	389	E23	969	E22	1,822	E25	0.558	E31	0.4%	N10	24.0	E56	0.463	E27	0.0289	E28	1.406	E52	0.336	E54								
14	LMP13	Pressure Control Air	300	A27	0	A2	0.0	A18	300	E1	6.14E+02	E18	1.35E+03	E20	16	E17	60	R7			389	A26	969	E22	309	E25	0	A2	0%	A2	29.0	E56	1.169	E27	0.0730	E28	1.001	E52	0.239	E54								
15	LMP14	Controlled Offgas	737	E4	404	E4	5.5	E57	1,147	E1	2.05E+03	E18	4.52E+03	E20	258	E12	496	E16			389	A26	969	E22	2,172	E25	0.335	E31	0.8%	N10	25.3	E56	0.555	E27	0.0347	E28	1.279	E52	0.306	E54								
16	LMP14 Piping Pressure Drop																		-1.9	R16	387	E23	964	E22																								
17	LOP02	SBS Discharge	737	E5	120.5	R8/A6	5.0	E57	863	E1	1.69E+03	E18	3.72E+03	E20	50	A53	122	E16	-32.2	N6	355	E23	884	E22	1,090	E25	0.100	E31	100.0%	N10	27.7	E56	0.911	E27	0.0569	E28	1.083	E52	0.259	E54								
18	FC/Jumper/SBS Inleakage		10	A21	0.1	E19	0.0	A18	10.1	E1	2.06E+01	E18	4.55E+01	E20			80	N11									0.009	N11	40%	A1	28.8	E56																
19	LOP02 Piping Pressure Drop																		-3.0	A36	352	E23	876	E22																								
20	LOP06	WESP Bulge Air Purge	336	R5	0	A2	0.0	A18	336	E1	6.87E+02	E18	1.51E+03	E20	53	E17	127	R5			434	R5	1082	E22	350	E25	0	A2	0%	A2	29.0	E56	1.157	E27	0.0722	E28	1.007	E52	0.241	E54								
21	LOP08	WESP Discharge	1,083	E6	121	E6/A8	6.7	E57	1,210	E1	2.40E+03	E18	5.29E+03	E20	51	R10/E12	125	E16	-2.6	R20	349	E23	870	E22	1,561	E25	0.068	E31	65.4%	N10	28.1	E56	0.905	E27	0.0565	E28	1.061	E52	0.254	E54								
22		WESP Inleakage	10	A21	0.1	E19	0.0	A18	10.1	E1	2.06E+01	E18	4.55E+01	E20			80	N11									0.009	N11	40%	A1	28.8	E56																
23	LOP08 Piping Pressure Drop																		-5.0	A36	344	E23	857	E22																								
24		Offgas Flow through Control Valve	1,093	E10	121	E10	6.7	E10	1,220.6	E1	2.42E+03	E18	5.34E+03	E20	51	E65	125	E16	-16.1	N24	328	E23	817	E22	1,675	E25	0.068	E31	61.0%	N10	28.1	E56	0.850	E27	0.0531	E28	1.060	E52	0.253	E54								
25	LVP01	Vessel Vent Offgas	70	E7	2.3	E19	0.02	E57	72	N3	1.45E+02	E18	3.21E+02	E20	30	E17	86	A9			328	A28	817	E22	92	E25	0.021	E63	75%	A22	28.6	E56	0.928	E27	0.0579	E28	1.021	E52	0.244	E54								
26	LVP03	Combined Offgas	2,256	E9	244	E9/A8	13.4	E57	2,513	E1	4.99E+03	E18	1.10E+04	E20	51	E12	124	E16			328	E55	817	E22	3,443	E25	0.066	E31	61.6%	N10	28.1	E56	0.852	E27	0.0532	E28	1.059	E52	0.253	E54								
27	LVP03 Piping Pressure Drop																		-3.0	A36	325	E23	810	E22																								
28	LVP04	HEPA Preheater Discharge	2,256	E10	244	E10/A8	13.4	E57	2,513	E1	4.99E+03	E18	1.10E+04	E20	71	A12	160	E16	-1.0	A20	324	E23	807	E22	3,701	E25	0.066	E31	24.2%	N10	28.1	E56	0.793	E27	0.0495	E28	1.063	E52	0.254	E54								
29	LVP04 Piping Pressure Drop																		-3.0	A36	321	E23	800	E22																								
30	LVP06	HEPA Discharge	2,256	E10	244	E10/A8	13.4	E57	2,513	E1	4.99E+03	E18	1.10E+04	E20	71	A11	160	E16	-2.0	A31	319	E23	795	E22	3,759	E25	0.066	E31	23.9%	N10	28.1	E56	0.781	E27	0.0487	E28	1.063	E52	0.254	E54								
31	HEPA Bank Inleakage		10	A21	0.1	E19	0.0	A18	10.1	E1	2.06E+01	E18	4.55E+01	E20			80	N11									0.009	N11	40%	A1	28.8	E56																
32	LVP06 Piping Pressure Drop																		-3.0	A36	316	E23	788	E22																								
33	LVP26	S-AC Column Discharge	2,266	E10	244	E10/A8	13.4	E57	2,523	E1	5.01E+03	E18	1.10E+04	E20	76	A61	169	E16	-17.3	N16	299	E23	744	E22	4,089	E25	0.066	E31	18.0%	N10	28.1	E56	0.721	E27	0.0450	E28	1.064	E52	0.254	E54								
34	S-AC Column Inleakage		10	A21	0.1	E19	0.0	A18	10.1	E1	2.06E+01	E18	4.55E+01	E20			80	N11									0.009	N11	40%	A1	28.8	E56																
35	LVP26 Piping Pressure Drop																		-3.0	A36	296	E23	737	E22																								
36	LVP10	Skid Preheater Discharge	2,276	E10	244	E10/A8	13.4	E57	2,533	E1	5.03E+03	E18	1.11E+04	E20	337	N23	639	E16	-0.7	R17	295	E23	735	E22	7,267	E25	0.066	E31	0.05%	N10	28.1	E56	0.407	E27	0.0254	E28	1.118	E52	0.267	E54								
37	LVP11	Skid Electric Heater Discharge	2,276	E10	244	E10/A8	13.4	E57	2,533	E1	5.03E+03	E18	1.11E+04	E20	399	E17	750	R11	-1.0	R17	294	E23	733	E22	8,032	E25	0.066	E31	0.02%	N10	28.1	E56	0.368	E27	0.0230	E28	1.132	E52	0.271	E54								
38	LVP12	TCO Discharge	2,276	E10/N22	245	E10/N22	12.9	E57	2,533	E1	5.03E+03	E18	1.11E+04	E20	403	N18	757	E16	-5.3	R17	289	E23	719	E22	8,227	E25	0.066	E31	0.02%	N10	28.1	E56	0.360	E27	0.0225	E28	1.133	E52	0.271	E54								
39		Ammonia Dilution Air	789	E7	11	E19	0.0	A18	800	A60	1.63E+03	E18	3.59E+03	E20	27	E17	80	N11			289	A50	719	E22	1,152	E25	0.009	N11	40%	A1	28.8	E56	0.831	E27	0.0519	E28	1.011	E52	0.242	E54								
40		Dilution Air Fan Discharge	789	E10	11	E10/A8	0.0	A18	800	E1	1.63E+03	E18	3.59E+03	E20	27	A58	80	E16			289	A50	719	E22	1,152	E25	0.009	E31	29.1%	N10	28.8	E56	0.831	E27	0.0519	E28	1.011	E52	0.242	E54								
41	AMR03	Ammonia					19.2	E62	19.2	E1	23.13	N12	50.99	E20	25	E17	77	A63			289	A50	719	E22	28	E25	0	R22	0%	R22	17.0	R24	0.494	E27	0.0309	E28	2.091	E8	0.500	E54								
42	LVP13	Diluted Ammonia Addition	789	E10	11	E10	19.2	E10	819.2	E1	1.65E+03	E18	3.64E+03	E20	27	E12	81	E16			289	A50	719	E22	1,181	E25	0.009	E31	27.8%	N10	28.5	E56	0.823	E27	0.0513	E28	1.011	E52	0.242	E54								
43	LVP23	SCR Input	3,064	E61	256	E61	32.1	E61	3,352	E1	6.68E+03	E18	1.47E+04	E20	318	E12	605	E16			289	E23	719	E22	9,524	E25	0.051	E31	0.05%	N10	28.2	E56	0.413	E27	0.0258	E28	1.101	E52	0.263	E54								
44	LVP14	SCR Discharge	3,074	E10/N13	284	E10/N13	2.1	E57	3,360	E1	6.68E+03	E18	1.47E+04	E20	377	E12/N13	711	E16	-3.1	R17	286	E23	712	E22	10,611	E25	0.057	E31	0.03%	N10	28.1	E56	0.370	E27	0.0231	E28	1.119	E52	0.268	E54								
45	LVP09	Catalyst Skid Discharge	3,074	E10	284	E10/A8	2.1	E57	3,360	E1	6.68E+03	E18	1.47E+04	E20	183	N23	361	E16	-1.1	R17	285	E23	709	E22	7,472	E25	0.057	E31	0.55%	N10	28.1	E56	0.526	E27	0.0328	E28	1.078	E52	0.258	E54								
46	Catalyst Skid Inleakage		10	A21	0.1	E19	0.0	A18	10.1	E1	2.06E+01	E18	4.55E+01	E20			80	N11									0.009	N11	40%	A1	28.8	E56																
47	LVP09 Piping Pressure Drop										6.70E+03	E74	1.48E+04	E20					-3.0	A36	282	E23	701	E22																								
48	LVP18	Caustic Scrubber Discharge	3,228	E10/N27	606	E14	2.0	E57	3,835	E1	7.11E+03	E18	1.57E+04	E20	48	N26	118	E16	-10.0	A51	272	E23	677	E22	6,288	E25	0.122	E31	96.5%	N10	26.2	E56	0.665	E27	0.0415	E28	1.099	E52	0.263	E54								
49		Caustic Scrubber Inleakage	10	A21	0.1	E19	0.0	A18	10.1	E1	2.06E+01	E18	4.55E+01	E20			80	N11									0.009	N11	40%	A1	28.8	E56																
50	LVP18 Piping Pressure Drop to Fans																		-3.0	A36	269	E23	669	E22																								
51	LVP08	Exhauster Discharge	3,238	E10	606	E10/A8	2.0	E57	3,845	E1	7.13E+03	E18	1.57E+04	E20	116	N5	241	E16	134	N7	403	E23	1003	E22	5,157	E25	0.121	E31	9.6%	N10	26.2	E56	0.813	E27	0.0508	E28	1.113	E52	0.266	E54								
52	Exhauster Inleakage		10	A21	0.1	E19	0.0	A18	10.1	E1	2.06E+01	E18	4.55E+01	E20			80	N11									0.009	N11	40%	A1	28.8	E56																
53	LVP08 Piping Pressure Drop to Stack		3,248	E10	606	E10/A8	2.0	E57	3,855	E1	7.15E+03	E18	1.58E+04	E20	116	E32	241	E16	-5.0	A36	398	E23	990	E22	5,236	E25	0.121	E31	9.5%	N10	26.2	E56	0.803	E27	0.0502	E28	1.112	E52	0.266	E54								
54	Hanford Atmospheric Pressure (Pressure Balance)														25	A13	77	E16			397	E21	990	R14																								

	A	B	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant																										
2	***Nominal Flowsheet - 2 Melters***				🟦	Fixed Constant																										
3	Stream Number	Stream Name	N_2						O_2						CO_2						Ar						H_2O					
4			kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%	
5	Hanford Atmospheric Pressure (Pressure Balance)																															
6	C2/C3 Area Vacuum																															
7	Melter Enclosure Relative to C3 Gallery																															
8		Steam from LAW Melter Feed																									5.1E+02	E35	100.0%	E26	100.0%	E39
9	LMP01	Melter Air Inleakage	3.4E+02	E35	75%	E26	77.0%	E38	1.0E+02	E35	22.9%	E26	20.6%	E38	2.2E-01	E35	0.05%	E26	0.031%	E38	5.8E+00	E35	1.3%	E26	0.92%	E38	4.1E+00	E35	0.9%	E26	1.4%	E39
10	LMP02/03	Melter Injected Air	2.9E+01	E35	76%	E26	78.1%	E38	9.0E+00	E35	23.1%	E26	20.9%	E38	1.9E-02	E35	0.05%	E26	0.031%	E38	5.0E-01	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
11	LMP06	Melter Offgas	3.7E+02	E2	35%	E36	28.3%	E37	1.1E+02	E2	10.7%	E36	7.6%	E37	3.9E+01	E11	3.7%	E36	1.883%	E37	6.3E+00	E2	0.6%	E36	0.34%	E37	5.1E+02	E2	48.7%	E26	61.0%	E39
12	LMP11	Film Cooler Air	2.9E+02	E35	76%	E26	78.1%	E38	8.8E+01	E35	23.1%	E26	20.9%	E38	1.8E-01	E35	0.05%	E26	0.031%	E38	4.9E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
13		Film Cooler Discharge	6.6E+02	E3	46%	E36	39.2%	E37	2.0E+02	E3	14.0%	E36	10.5%	E37	3.9E+01	E24	2.7%	E36	1.479%	E37	1.1E+01	E3	0.8%	E36	0.47%	E37	5.1E+02	E3	35.8%	E26	47.7%	E39
14	LMP13	Pressure Control Air	4.6E+02	E35	76%	E26	78.1%	E38	1.4E+02	E35	23.1%	E26	20.9%	E38	2.9E-01	E35	0.05%	E26	0.031%	E38	7.9E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
15	LMP14	Controlled Offgas	1.1E+03	E4	55%	E36	49.4%	E37	3.4E+02	E4	16.8%	E36	13.2%	E37	3.9E+01	E35	1.9%	E26	1.1%	N4	1.9E+01	E4	0.9%	E36	0.59%	E37	5.1E+02	E4	25.1%	E26	35.2%	E39
16	LMP14 Piping Pressure Drop																															
17	LOP02	SBS Discharge	1.1E+03	E5	66%	E36	65.6%	E37	3.4E+02	E5	20.3%	E36	17.6%	E37	3.9E+01	E5	2.3%	E36	1.462%	E37	1.9E+01	E5	1.1%	E36	0.78%	E37	1.5E+02	E35	9.1%	E26	14.0%	E39
18	FC/Jumper/SBS Inleakage		1.5E+01	E35	75%	E26	77.0%	E38	4.7E+00	E35	22.9%	E26	20.6%	E38	9.8E-03	E35	0.05%	E26	0.031%	E38	2.6E-01	E35	1.3%	E26	0.92%	E38	1.8E-01	E35	0.9%	E26	1.4%	E39
19	LOP02 Piping Pressure Drop																															
20	LOP06	WESP Bulge Air Purge	5.2E+02	E35	76%	E26	78.1%	E38	1.6E+02	E35	23.1%	E26	20.9%	E38	3.3E-01	E35	0.05%	E26	0.031%	E38	8.8E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
21	LOP08	WESP Discharge	1.7E+03	E6	69%	E36	69.1%	E37	5.1E+02	E6	21.1%	E36	18.5%	E37	4.0E+01	E6	1.6%	E36	1.051%	E37	2.8E+01	E6	1.2%	E36	0.83%	E37	1.5E+02	E6	6.4%	E26	10.0%	E39
22		WESP Inleakage	1.5E+01	E35	75%	E26	77.0%	E38	4.7E+00	E35	22.9%	E26	20.6%	E38	9.8E-03	E35	0.05%	E26	0.031%	E38	2.6E-01	E35	1.3%	E26	0.92%	E38	1.8E-01	E35	0.9%	E26	1.4%	E39
23	LOP08 Piping Pressure Drop																															
24		Offgas Flow through Control Valve	1.7E+03	E10	69%	E36	69.1%	E37	5.1E+02	E10	21.1%	E36	18.5%	E37	4.0E+01	E10	1.6%	E36	1.043%	E37	2.8E+01	E10	1.2%	E36	0.83%	E37	1.5E+02	E10	6.3%	E26	9.9%	E39
25	LVP01	Vessel Vent Offgas	1.1E+02	E35	74%	E26	75.6%	E38	3.3E+01	E35	22.7%	E26	20.3%	E38	6.8E-02	E35	0.05%	E26	0.030%	E38	1.8E+00	E35	1.3%	E26	0.90%	E38	2.9E+00	E35	2.0%	E26	3.2%	E39
26	LVP03	Combined Offgas	3.4E+03	E9	69%	E36	69.3%	E37	1.1E+03	E9	21.2%	E36	18.6%	E37	7.9E+01	E9	1.6%	E36	1.014%	E37	5.9E+01	E9	1.2%	E36	0.83%	E37	3.1E+02	E9	6.2%	E26	9.7%	E39
27	LVP03 Piping Pressure Drop																															
28	LVP04	HEPA Preheater Discharge	3.4E+03	E10	69%	E36	69.3%	E37	1.1E+03	E10	21.2%	E36	18.6%	E37	7.9E+01	E10	1.6%	E36	1.014%	E37	5.9E+01	E10	1.2%	E36	0.83%	E37	3.1E+02	E10	6.2%	E26	9.7%	E39
29	LVP04 Piping Pressure Drop																															
30	LVP06	HEPA Discharge	3.4E+03	E10	69%	E36	69.3%	E37	1.1E+03	E10	21.2%	E36	18.6%	E37	7.9E+01	E10	1.6%	E36	1.014%	E37	5.9E+01	E10	1.2%	E36	0.83%	E37	3.1E+02	E10	6.2%	E26	9.7%	E39
31	HEPA Bank Inleakage		1.5E+01	E35	75%	E26	77.0%	E38	4.7E+00	E35	22.9%	E26	20.6%	E38	9.8E-03	E35	0.05%	E26	0.031%	E38	2.6E-01	E35	1.3%	E26	0.92%	E38	1.8E-01	E35	0.9%	E26	1.4%	E39
32	LVP06 Piping Pressure Drop																															
33	LVP26	S-AC Column Discharge	3.5E+03	E10	69%	E36	69.3%	E37	1.1E+03	E10	21.2%	E36	18.6%	E37	7.9E+01	E10	1.6%	E36	1.010%	E37	5.9E+01	E10	1.2%	E36	0.83%	E37	3.1E+02	E10	6.2%	E26	9.7%	E39
34	S-AC Column Inleakage		1.5E+01	E35	75%	E26	77.0%	E38	4.7E+00	E35	22.9%	E26	20.6%	E38	9.8E-03	E35	0.05%	E26	0.031%	E38	2.6E-01	E35	1.3%	E26	0.92%	E38	1.8E-01	E35	0.9%	E26	1.4%	E39
35	LVP26 Piping Pressure Drop																															
36	LVP10	Skid Preheater Discharge	3.5E+03	E10	69%	E36	69.4%	E37	1.1E+03	E10	21.2%	E36	18.6%	E37	7.9E+01	E10	1.6%	E36	1.006%	E37	5.9E+01	E10	1.2%	E36	0.83%	E37	3.1E+02	E10	6.2%	E26	9.6%	E39
37	LVP11	Skid Electric Heater Discharge	3.5E+03	E10	69%	E36	69.4%	E37	1.1E+03	E10	21.2%	E36	18.6%	E37	7.9E+01	E10	1.6%	E36	1.006%	E37	5.9E+01	E10	1.2%	E36	0.83%	E37	3.1E+02	E10	6.2%	E26	9.6%	E39
38	LVP12	TCO Discharge	3.5E+03	E10	69%	E36	69.4%	E37	1.1E+03	E10/N22	21.2%	E36	18.6%	E37	8.2E+01	E10/N22	1.6%	E36	1.037%	E37	5.9E+01	E10	1.2%	E36	0.83%	E37	3.1E+02	E10/N22	6.2%	E26	9.7%	E39
39		Ammonia Dilution Air	1.2E+03	E35	75%	E26	77.0%	E38	3.7E+02	E35	22.9%	E26	20.6%	E38	7.7E-01	E35	0.05%	E26	0.031%	E38	2.1E+01	E35	1.3%	E26	0.92%	E38	1.5E+01	E35	0.9%	E26	1.4%	E39
40		Dilution Air Fan Discharge	1.2E+03	E10	75%	E36	77.0%	E37	3.7E+02	E10	22.9%	E36	20.6%	E37	7.7E-01	E10	0.05%	E36	0.031%	E37	2.1E+01	E10	1.3%	E36	0.92%	E37	1.5E+01	E10	0.9%	E26	1.4%	E39
41	AMR03	Ammonia																														
42	LVP13	Diluted Ammonia Addition	1.2E+03	E10	74%	E36	75.2%	E37	3.7E+02	E10	22.6%	E36	20.2%	E37	7.7E-01	E10	0.05%	E36	0.030%	E37	2.1E+01	E10	1.3%	E36	0.90%	E37	1.5E+01	E10	0.9%	E26	1.4%	E39
43	LVP23	SCR Input	4.7E+03	E10	70%	E36	70.8%	E37	1.4E+03	E10	21.5%	E36	19.0%	E37	8.2E+01	E10	1.2%	E36	0.791%	E37	8.0E+01	E10	1.2%	E36	0.85%	E37	3.3E+02	E59	4.9%	E26	7.6%	E39
44	LVP14	SCR Discharge	4.7E+03	E10/N13	71%	E36	71.1%	E37	1.4E+03	E10/N13	21.3%	E36	18.8%	E37	8.2E+01	E10	1.2%	E36	0.789%	E37	8.0E+01	E10	1.2%	E36	0.84%	E37	3.6E+02	E10/N13	5.4%	E26	8.5%	E39
45	LVP09	Catalyst Skid Discharge	4.7E+03	E10	71%	E36	71.1%	E37	1.4E+03	E10	21.3%	E36	18.8%	E37	8.2E+01	E10	1.2%	E36	0.789%	E37	8.0E+01	E10	1.2%	E36	0.84%	E37	3.6E+02	E10	5.4%	E26	8.5%	E39
46	Catalyst Skid Inleakage		1.5E+01	E35	75%	E26	77.0%	E38	4.7E+00	E35	22.9%	E26	20.6%	E38	9.8E-03	E35	0.05%	E26	0.031%	E38	2.6E-01	E35	1.3%	E26	0.92%	E38	1.8E-01	E35	0.9%	E26	1.4%	E39
47	LVP09 Piping Pressure Drop																										3.6E+02	E74				
48	LVP18	Caustic Scrubber Discharge	4.7E+03	E10	67%	E36	62.5%	E37	1.4E+03	E10	20.1%	E36	16.5%	E37	8.1E+01	E10/N28	1.1%	E36	0.679%	E37	8.0E+01	E10	1.1%	E36	0.74%	E37	7.7E+02	N26	10.8%	E26	15.8%	E39
49		Caustic Scrubber Inleakage	1.5E+01	E35	75%	E26	77.0%	E38	4.7E+00	E35	22.9%	E26	20.6%	E38	9.8E-03	E35	0.05%	E26	0.031%	E38	2.6E-01	E35	1.3%	E26	0.92%	E38	1.8E-01	E35	0.9%	E26	1.4%	E39
50	LVP18 Piping Pressure Drop to Fans																															
51	LVP08	Exhauster Discharge	4.8E+03	E10	67%	E36	62.5%	E37	1.4E+03	E10	20.1%	E36	16.5%	E37	8.1E+01	E10	1.1%	E36	0.677%	E37	8.1E+01	E10	1.1%	E36	0.74%	E37	7.7E+02	E10	10.8%	E26	15.8%	E39
52	Exhauster Inleakage		1.5E+01	E35	75%	E26	77.0%	E38	4.7E+00	E35	22.9%	E26	20.6%	E38	9.8E-03	E35	0.05%	E26	0.031%	E38	2.6E-01	E35	1.3%	E26	0.92%	E38	1.8E-01	E35	0.9%	E26	1.4%	E39
53	LVP08 Piping Pressure Drop to Stack		4.8E+03	E10	67%	E36	62.6%	E37	1.4E+03	E10	20.1%	E36	16.5%	E37	8.1E+01	E10	1.1%	E36	0.675%	E37	8.1E+01	E10	1.1%	E36	0.74%	E37	7.7E+02	E10	10.8%	E26	15.7%	E39
54	Hanford Atmospheric Pressure (Pressure Balance)																															

	A	B	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant														
2	***Nominal Flowsheet - 2 Melters***				🟦	Fixed Constant														
3	Stream Number	Stream Name			NO						N_2O						NO_2			
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)																			
6	C2/C3 Area Vacuum																			
7	Melter Enclosure Relative to C3 Gallery																			
8		Steam from LAW Melter Feed																		
9	LMP01	Melter Air Inleakage																		
10	LMP02/03	Melter Injected Air																		
11	LMP06	Melter Offgas	8.17E+00	E47	3.03E+03	E45	5.82E+03	E51	1.16E+00	E47	4.30E+02	E45	5.62E+02	E51	1.88E+00	E47	6.97E+02	E45	8.73E+02	E51
12	LMP11	Film Cooler Air																		
13		Film Cooler Discharge	8.17E+00	E46	2.64E+03	E45	4.55E+03	E51	1.16E+00	E46	3.74E+02	E45	4.39E+02	E51	1.88E+00	E46	6.06E+02	E45	6.82E+02	E51
14	LMP13	Pressure Control Air																		
15	LMP14	Controlled Offgas	8.17E+00	E50	2.21E+03	E45	3.36E+03	N4	1.16E+00	E50	3.13E+02	E45	3.25E+02	N4	1.88E+00	E50	5.09E+02	E45	5.04E+02	N4
16	LMP14 Piping Pressure Drop																			
17	LOP02	SBS Discharge	6.11E+00	E50	3.30E+03	E45	3.34E+03	N4	1.29E+00	E50	6.98E+02	E45	4.82E+02	N4	4.44E+00	E50	2.40E+03	E45	1.58E+03	N4
18	FC/Jumper/SBS Inleakage																			
19	LOP02 Piping Pressure Drop																			
20	LOP06	WESP Bulge Air Purge																		
21	LOP08	WESP Discharge	6.47E+00	E50	2.44E+03	E45	2.52E+03	N4	1.72E+00	E50	6.49E+02	E45	4.57E+02	N4	8.59E+00	E50	3.24E+03	E45	2.18E+03	N4
22		WESP Inleakage																		
23	LOP08 Piping Pressure Drop																			
24		Offgas Flow through Control Valve	6.47E+00	E10	2.27E+03	E45	2.50E+03	E51	1.72E+00	E10	6.05E+02	E45	4.54E+02	E51	8.59E+00	E10	3.02E+03	E45	2.17E+03	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	LVP03	Combined Offgas	1.29E+01	E9	2.21E+03	E45	2.43E+03	E51	3.44E+00	E9	5.88E+02	E45	4.41E+02	E51	1.72E+01	E9	2.94E+03	E45	2.10E+03	E51
27	LVP03 Piping Pressure Drop																			
28	LVP04	HEPA Preheater Discharge	1.29E+01	E10	2.06E+03	E45	2.43E+03	E51	3.44E+00	E10	5.47E+02	E45	4.41E+02	E51	1.72E+01	E10	2.73E+03	E45	2.10E+03	E51
29	LVP04 Piping Pressure Drop																			
30	LVP06	HEPA Discharge	1.29E+01	E10	2.03E+03	E45	2.43E+03	E51	3.44E+00	E10	5.39E+02	E45	4.41E+02	E51	1.72E+01	E10	2.69E+03	E45	2.10E+03	E51
31	HEPA Bank Inleakage																			
32	LVP06 Piping Pressure Drop																			
33	LVP26	S-AC Column Discharge	1.29E+01	E10	1.86E+03	E45	2.42E+03	E51	3.44E+00	E10	4.95E+02	E45	4.39E+02	E51	1.72E+01	E10	2.47E+03	E45	2.10E+03	E51
34	S-AC Column Inleakage																			
35	LVP26 Piping Pressure Drop																			
36	LVP10	Skid Preheater Discharge	1.29E+01	E10	1.05E+03	E45	2.41E+03	E51	3.44E+00	E10	2.79E+02	E45	4.37E+02	E51	1.72E+01	E10	1.39E+03	E45	2.09E+03	E51
37	LVP11	Skid Electric Heater Discharge	1.29E+01	E10	9.48E+02	E45	2.41E+03	E51	3.44E+00	E10	2.52E+02	E45	4.37E+02	E51	1.72E+01	E10	1.26E+03	E45	2.09E+03	E51
38	LVP12	TCO Discharge	1.29E+01	E10	9.26E+02	E45	2.41E+03	E51	3.44E+00	E10	2.46E+02	E45	4.37E+02	E51	1.72E+01	E10	1.23E+03	E45	2.09E+03	E51
39		Ammonia Dilution Air																		
40		Dilution Air Fan Discharge																		
41	AMR03	Ammonia																		
42	LVP13	Diluted Ammonia Addition																		
43	LVP23	SCR Input	1.29E+01	E10	8.00E+02	E45	1.82E+03	E51	3.44E+00	E10	2.13E+02	E45	3.30E+02	E51	1.72E+01	E10	1.06E+03	E45	1.58E+03	E51
44	LVP14	SCR Discharge	2.59E-01	E67/R25	1.44E+01	E45	3.63E+01	E51	3.44E+00	E10	1.91E+02	E45	3.30E+02	E51	3.44E-01	E40/R25	1.91E+01	E45	3.15E+01	E51
45	LVP09	Catalyst Skid Discharge	2.59E-01	E10	2.04E+01	E45	3.63E+01	E51	3.44E+00	E10	2.71E+02	E45	3.30E+02	E51	3.44E-01	E10	2.71E+01	E45	3.15E+01	E51
46	Catalyst Skid Inleakage																			
47	LVP09 Piping Pressure Drop																			
48	LVP18	Caustic Scrubber Discharge	2.59E-01	E10	2.42E+01	E45	3.18E+01	E51	3.44E+00	E10	3.22E+02	E45	2.89E+02	E51	3.24E-01	E10/N28	3.03E+01	E45	2.60E+01	E51
49		Caustic Scrubber Inleakage																		
50	LVP18 Piping Pressure Drop to Fans																			
51	LVP08	Exhauster Discharge	2.59E-01	E10	2.95E+01	E45	3.18E+01	E51	3.44E+00	E10	3.93E+02	E45	2.88E+02	E51	3.24E-01	E10	3.69E+01	E45	2.59E+01	E51
52	Exhauster Inleakage																			
53	LVP08 Piping Pressure Drop to Stack		2.59E-01	E10	2.91E+01	E45	3.17E+01	E51	3.44E+00	E10	3.87E+02	E45	2.87E+02	E51	3.24E-01	E10	3.64E+01	E45	2.58E+01	E51
54	Hanford Atmospheric Pressure (Pressure Balance)																			

	A	B	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP
1	***LAW Melter Offgas System Design Basis***																									
2	***Nominal Flowsheet - 2 Melters***																									
3	Stream Number	Stream Name			NH_3						VOC						H_2						Hg			
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)																									
6	C2/C3 Area Vacuum																									
7	Melter Enclosure Relative to C3 Gallery																									
8		Steam from LAW Melter Feed																								
9	LMP01	Melter Air Inleakage																								
10	LMP02/03	Melter Injected Air																								
11	LMP06	Melter Offgas	2.72E-01	E47	1.01E+02	E45	3.42E+02	E51	2.31E-01	E47	8.58E+01	E45	8.51E+01	E51	1.44E-02	E47	5.36E+00	E45	1.53E+02	E51	8.08E-03	E47	3.00E+00	E45	8.62E-01	E51
12	LMP11	Film Cooler Air																								
13		Film Cooler Discharge	2.72E-01	E46	8.79E+01	E45	2.67E+02	E51	2.31E-01	E46	7.46E+01	E45	6.65E+01	E51	1.44E-02	E46	4.66E+00	E45	1.20E+02	E51	8.08E-03	E46	2.61E+00	E45	6.73E-01	E51
14	LMP13	Pressure Control Air																								
15	LMP14	Controlled Offgas	2.72E-01	E50	7.37E+01	E45	1.97E+02	N4	2.31E-01	E50	6.26E+01	E45	4.91E+01	N25	1.44E-02	E48	3.91E+00	E45	8.84E+01	E51	8.08E-03	R31	2.19E+00	E45	4.97E-01	E51
16	LMP14 Piping Pressure Drop																									
17	LOP02	SBS Discharge	2.90E-02	E50	1.56E+01	E45	2.79E+01	N4	1.74E-01	E50	9.39E+01	E45	4.91E+01	A30	1.44E-02	E49	7.80E+00	E45	1.18E+02	E51	1.35E-03	E66/A55	7.27E-01	E45	1.10E-01	E51
18	FC/Jumper/SBS Inleakage																									
19	LOP02 Piping Pressure Drop																									
20	LOP06	WESP Bulge Air Purge																								
21	LOP08	WESP Discharge	1.34E-02	E50	5.07E+00	E45	9.24E+00	N4	2.44E-01	E50	9.20E+01	E45	4.91E+01	A30	1.44E-02	E50	5.44E+00	E45	1.08E+02	N4	1.35E-03	E53	5.08E-01	E45	7.85E-02	E51
22		WESP Inleakage																								
23	LOP08 Piping Pressure Drop																									
24		Offgas Flow through Control Valve	1.34E-02	E10	4.72E+00	E45	9.16E+00	E51	2.44E-01	E10	8.57E+01	E45	4.87E+01	E51	1.44E-02	E10	5.07E+00	E45	8.31E+01	E51	1.35E-03	E10	4.73E-01	E45	7.79E-02	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	3.52E-03	E42	2.24E+01	E45	3.43E+02	E51	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	LVP03	Combined Offgas	2.69E-02	E9	4.60E+00	E45	8.90E+00	E51	4.88E-01	E9	8.34E+01	E45	4.73E+01	E51	3.24E-02	E9	5.54E+00	E45	9.05E+01	E51	2.69E-03	E9	4.60E-01	E45	7.56E-02	E51
27	LVP03 Piping Pressure Drop																									
28	LVP04	HEPA Preheater Discharge	2.69E-02	E10	4.28E+00	E45	8.90E+00	E51	4.88E-01	E10	7.76E+01	E45	4.73E+01	E51	3.24E-02	E10	5.15E+00	E45	9.05E+01	E51	2.69E-03	E10	4.28E-01	E45	7.56E-02	E51
29	LVP04 Piping Pressure Drop																									
30	LVP06	HEPA Discharge	2.69E-02	E10	4.21E+00	E45	8.90E+00	E51	4.88E-01	E10	7.64E+01	E45	4.73E+01	E51	3.24E-02	E10	5.07E+00	E45	9.05E+01	E51	2.69E-03	E10	4.22E-01	E45	7.56E-02	E51
31	HEPA Bank Inleakage																									
32	LVP06 Piping Pressure Drop																									
33	LVP26	S-AC Column Discharge	2.69E-02	E10	3.87E+00	E45	8.86E+00	E51	4.88E-01	E10	7.02E+01	E45	4.71E+01	E51	3.24E-02	E10	4.66E+00	E45	9.02E+01	E51	1.73E-04	R33	2.49E-02	E45	4.84E-03	E51
34	S-AC Column Inleakage																									
35	LVP26 Piping Pressure Drop																									
36	LVP10	Skid Preheater Discharge	2.69E-02	E10	2.18E+00	E45	8.83E+00	E51	4.88E-01	E10	3.95E+01	E45	4.69E+01	E51	3.24E-02	E10	2.62E+00	E45	8.98E+01	E51	1.73E-04	E10	1.40E-02	E45	4.82E-03	E51
37	LVP11	Skid Electric Heater Discharge	2.69E-02	E10	1.97E+00	E45	8.83E+00	E51	4.88E-01	E10	3.57E+01	E45	4.69E+01	E51	3.24E-02	E10	2.37E+00	E45	8.98E+01	E51	1.73E-04	E10	1.27E-02	E45	4.82E-03	E51
38	LVP12	TCO Discharge	2.69E-02	E10	1.92E+00	E45	8.83E+00	E51	2.44E-02	E43/R26	1.75E+00	E45	2.35E+00	E51	3.24E-02	E10	2.32E+00	E45	8.98E+01	E51	1.73E-04	E10	1.24E-02	E45	4.82E-03	E51
39		Ammonia Dilution Air																								
40		Dilution Air Fan Discharge																								
41	AMR03	Ammonia	2.31E+01	E44																						
42	LVP13	Diluted Ammonia Addition	2.31E+01	E10	1.15E+04	E45	2.35E+04	E51																		
43	LVP23	SCR Input	2.32E+01	E10	1.43E+03	E45	5.74E+03	E51	2.44E-02	E10	1.51E+00	E45	1.77E+00	E51	3.24E-02	E10	2.00E+00	E45	6.79E+01	E51	1.73E-04	E10	1.07E-02	E45	3.64E-03	E51
44	LVP14	SCR Discharge	4.90E-01	E41/N12	2.72E+01	E45	1.21E+02	E51	2.44E-02	E10	1.35E+00	E45	1.77E+00	E51	3.24E-02	E10	1.80E+00	E45	6.77E+01	E51	1.73E-04	E10	9.60E-03	E45	3.63E-03	E51
45	LVP09	Catalyst Skid Discharge	4.90E-01	E10	3.86E+01	E45	1.21E+02	E51	2.44E-02	E10	1.92E+00	E45	1.77E+00	E51	3.24E-02	E10	2.55E+00	E45	6.77E+01	E51	1.73E-04	E10	1.36E-02	E45	3.63E-03	E51
46	Catalyst Skid Inleakage																									
47	LVP09 Piping Pressure Drop																									
48	LVP18	Caustic Scrubber Discharge	4.90E-01	E10	4.59E+01	E45	1.06E+02	E51	2.44E-02	E10	2.28E+00	E45	1.55E+00	E51	3.24E-02	E10	3.03E+00	E45	5.93E+01	E51	1.73E-04	E10	1.62E-02	E45	3.18E-03	E51
49		Caustic Scrubber Inleakage																								
50	LVP18 Piping Pressure Drop to Fans																									
51	LVP08	Exhauster Discharge	4.90E-01	E10	5.59E+01	E45	1.06E+02	E51	2.44E-02	E10	2.78E+00	E45	1.55E+00	E51	3.24E-02	E10	3.70E+00	E45	5.92E+01	E51	1.73E-04	E10	1.97E-02	E45	3.18E-03	E51
52	Exhauster Inleakage																									
53	LVP08 Piping Pressure Drop to Stack		4.90E-01	E10	55.1	E45	1.06E+02	E51	2.44E-02	E10	2.74E+00	E45	1.54E+00	E51	3.24E-02	E10	3.64E+00	E45	5.90E+01	E51	1.73E-04	E10	1.94E-02	E45	3.17E-03	E51
54	Hanford Atmospheric Pressure (Pressure Balance)																									

	A	B	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant																																
2	***Nominal Flowsheet - 2 Melters***				🟦	Fixed Constant																																
3	Stream Number	Stream Name	HCl						HF						I-129						SO_2						CO						Particulate					
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)																																					
6	C2/C3 Area Vacuum																																					
7	Melter Enclosure Relative to C3 Gallery																																					
8		Steam from LAW Melter Feed																																				
9	LMP01	Melter Air Inleakage																																				
10	LMP02/03	Melter Injected Air																																				
11	LMP06	Melter Offgas	1.48E-03	E47	5.48E-01	E45	8.66E-01	E51	1.13E-03	E47	4.21E-01	E45	1.21E+00	E51	1.11E-03	N20	4.13E-01	E45	1.84E-01	E51	2.16E-02	E47	8.01E+00	E45	7.20E+00	E51	2.14E-01	E47	7.93E+01	E45	1.63E+02	E51	1.20E+00	E47	4.46E+02	E45	3.57E+02	E51
12	LMP11	Film Cooler Air																																				
13		Film Cooler Discharge	1.48E-03	E46	4.77E-01	E45	6.77E-01	E51	1.13E-03	E46	3.66E-01	E45	9.48E-01	E51	1.11E-03	E79	3.59E-01	E45	1.44E-01	E51	2.16E-02	E46	6.97E+00	E45	5.63E+00	E51	2.14E-01	E46	6.90E+01	E45	1.27E+02	E51	1.20E+00	E46	3.88E+02	E45	2.79E+02	E51
14	LMP13	Pressure Control Air																																				
15	LMP14	Controlled Offgas	1.48E-03	E50	4.00E-01	E45	5.00E-01	N4	1.13E-03	E50	3.07E-01	E45	7.00E-01	N4	1.11E-03	E79	3.01E-01	E45	1.06E-01	E51	2.16E-02	E50	5.84E+00	E45	4.16E+00	N4	2.14E-01	E50	5.79E+01	E45	9.41E+01	N4	1.20E+00	N8/E34	3.25E+02	E45	2.06E+02	E51
16	LMP14 Piping Pressure Drop																																					
17	LOP02	SBS Discharge	1.39E-03	E50	7.52E-01	E45	6.27E-01	N4	8.94E-04	E50	4.83E-01	E45	7.33E-01	N4	3.09E-04	E78	1.67E-01	E45	3.93E-02	E51	8.43E-03	E50	4.55E+00	E45	2.16E+00	N4	3.61E-01	E50	1.95E+02	E45	2.12E+02	N4	1.56E-01	E69/N14	8.41E+01	E45	3.56E+01	E51
18	FC/Jumper/SBS Inleakage																																					
19	LOP02 Piping Pressure Drop																																					
20	LOP06	WESP Bulge Air Purge																																				
21	LOP08	WESP Discharge	2.20E-02	E50	8.29E+00	E45	7.06E+00	N4	1.20E-03	E50	4.51E-01	E45	7.00E-01	N4	6.43E-05	E78	2.42E-02	E45	5.83E-03	E51	1.39E-02	E50	5.24E+00	E45	2.54E+00	N4	4.62E-01	E50	1.74E+02	E45	1.93E+02	N4	6.23E-03	E69/N14	2.35E+00	E45	1.01E+00	E51
22	WESP Inleakage																																					
23	LOP08 Piping Pressure Drop																																					
24		Offgas Flow through Control Valve	2.20E-02	E10	7.73E+00	E45	7.00E+00	E51	1.20E-03	E10	4.21E-01	E45	6.94E-01	E51	6.43E-05	E10	2.26E-02	E45	5.79E-03	E51	1.39E-02	E10	4.88E+00	E45	2.52E+00	E51	4.62E-01	E10	1.62E+02	E45	1.91E+02	E51	6.23E-03	E10	2.19E+00	E45	1.01E+00	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	1.78E-04	N21	1.13E+00	E45	4.86E-01	E51
26	LVP03	Combined Offgas	4.40E-02	E9	7.52E+00	E45	6.80E+00	E51	2.39E-03	E9	4.09E-01	E45	6.74E-01	E51	1.29E-04	E9	2.20E-02	E45	5.62E-03	E51	2.78E-02	E9	4.75E+00	E45	2.44E+00	E51	9.25E-01	E9	1.58E+02	E45	1.86E+02	E51	1.26E-02	E9	2.16E+00	E45	9.91E-01	E51
27	LVP03 Piping Pressure Drop																																					
28	LVP04	HEPA Preheater Discharge	4.40E-02	E10	7.00E+00	E45	6.80E+00	E51	2.39E-03	E10	3.81E-01	E45	6.74E-01	E51	1.29E-04	E10	2.05E-02	E45	5.62E-03	E51	2.78E-02	E10	4.42E+00	E45	2.44E+00	E51	9.25E-01	E10	1.47E+02	E45	1.86E+02	E51	2.15E-02	E10/N2	3.42E+00	E45	1.69E+00	E51
29	LVP04 Piping Pressure Drop																																					
30	LVP06	HEPA Discharge	4.40E-02	E10	6.89E+00	E45	6.80E+00	E51	2.39E-03	E10	3.75E-01	E45	6.74E-01	E51	1.29E-04	E10	2.01E-02	E45	5.62E-03	E51	2.78E-02	E10	4.35E+00	E45	2.44E+00	E51	9.25E-01	E10	1.45E+02	E45	1.86E+02	E51	1.08E-05	R28	1.68E-03	E45	8.43E-04	E51
31	HEPA Bank Inleakage																																					
32	LVP06 Piping Pressure Drop																																					
33	LVP26	S-AC Column Discharge	4.40E-02	E10	6.33E+00	E45	6.77E+00	E51	2.39E-03	E10	3.45E-01	E45	6.72E-01	E51	1.29E-04	E10	1.85E-02	E45	5.60E-03	E51	2.78E-02	E10	4.00E+00	E45	2.43E+00	E51	9.25E-01	E10	1.33E+02	E45	1.85E+02	E51	1.08E-05	E10	1.55E-03	E45	8.40E-04	E51
34	S-AC Column Inleakage																																					
35	LVP26 Piping Pressure Drop																																					
36	LVP10	Skid Preheater Discharge	4.40E-02	E10	3.56E+00	E45	6.74E+00	E51	2.39E-03	E10	1.94E-01	E45	6.69E-01	E51	1.29E-04	E10	1.04E-02	E45	5.57E-03	E51	2.78E-02	E10	2.25E+00	E45	2.42E+00	E51	9.25E-01	E10	7.49E+01	E45	1.85E+02	E51	1.08E-05	E10	8.71E-04	E45	8.36E-04	E51
37	LVP11	Skid Electric Heater Discharge	4.40E-02	E10	3.22E+00	E45	6.74E+00	E51	2.39E-03	E10	1.75E-01	E45	6.69E-01	E51	1.29E-04	E10	9.42E-03	E45	5.57E-03	E51	2.78E-02	E10	2.04E+00	E45	2.42E+00	E51	9.25E-01	E10	6.78E+01	E45	1.85E+02	E51	1.08E-05	E10	7.88E-04	E45	8.36E-04	E51
38	LVP12	TCO Discharge	4.40E-02	E10	3.15E+00	E45	6.74E+00	E51	2.39E-03	E10	1.71E-01	E45	6.69E-01	E51	1.29E-04	E10	9.20E-03	E45	5.57E-03	E51	2.78E-02	E10	1.99E+00	E45	2.42E+00	E51	1.38E-01	E50	9.87E+00	E45	2.75E+01	N15	1.08E-05	E10	7.69E-04	E45	8.36E-04	E51
39		Ammonia Dilution Air																																				
40		Dilution Air Fan Discharge																																				
41	AMR03	Ammonia																																				
42	LVP13	Diluted Ammonia Addition																																				
43	LVP23	SCR Input	4.40E-02	E10	2.72E+00	E45	5.09E+00	E51	2.39E-03	E10	1.48E-01	E45	5.05E-01	E51	1.29E-04	E10	7.95E-03	E45	4.21E-03	E51	2.78E-02	E10	1.72E+00	E45	1.83E+00	E51	1.38E-01	E10	8.53E+00	E45	2.08E+01	E51	1.08E-05	E10	6.65E-04	E45	6.32E-04	E51
44	LVP14	SCR Discharge	4.40E-02	E10	2.44E+00	E45	5.08E+00	E51	2.39E-03	E10	1.33E-01	E45	5.04E-01	E51	1.29E-04	E10	7.13E-03	E45	4.20E-03	E51	2.78E-02	E10	1.54E+00	E45	1.83E+00	E51	1.38E-01	E10	7.66E+00	E45	2.08E+01	E51	1.08E-05	E10	5.96E-04	E45	6.31E-04	E51
45	LVP09	Catalyst Skid Discharge	4.40E-02	E10	3.47E+00	E45	5.08E+00	E51	2.39E-03	E10	1.89E-01	E45	5.04E-01	E51	1.29E-04	E10	1.01E-02	E45	4.20E-03	E51	2.78E-02	E10	2.19E+00	E45	1.83E+00	E51	1.38E-01	E10	1.09E+01	E45	2.08E+01	E51	1.08E-05	E10	8.47E-04	E45	6.31E-04	E51
46	Catalyst Skid Inleakage																																					
47	LVP09 Piping Pressure Drop																																					
48	LVP18	Caustic Scrubber Discharge	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	1.29E-04	E10	1.20E-02	E45	3.68E-03	E51	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	1.38E-01	E10	1.29E+01	E45	1.82E+01	E51	1.08E-05	E10	1.01E-03	E45	5.53E-04	E51
49		Caustic Scrubber Inleakage																																				
50	LVP18 Piping Pressure Drop to Fans																																					
51	LVP08	Exhauster Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.29E-04	E10	1.47E-02	E45	3.67E-03	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.38E-01	E10	1.58E+01	E45	1.81E+01	E51	1.08E-05	E10	1.23E-03	E45	5.51E-04	E51
52	Exhauster Inleakage																																					
53	LVP08 Piping Pressure Drop to Stack		0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.29E-04	E10	1.45E-02	E45	3.66E-03	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	1.38E-01	E10	1.55E+01	E45	1.81E+01	E51	1.08E-05	E10	1.21E-03	E45	5.50E-04	E51
54	Hanford Atmospheric Pressure (Pressure Balance)																																					

By: Nancy Wilkins
Date: 11/15/2019

CALCULATION SHEET

Subject: LAW Melter Offgas System Design Basis Flowsheets

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV
1	***LAW Melter Offgas System Design Basis Flowrates, Physical Properties, and Compositional Information (LOP Air Balance)***																				🟩		Case Dependent Constant																									
2	***Maximum Flowsheet - 2 Melters***				Number of Operating LAW Melters =>					2											🟦		Fixed Constant																									
3	Stream Number	Stream Name	Dry Air		Steam		Others		Total		Mass Flow				Temperature				Diff. Press		Absolute Pressure				Total		Hum. Ratio		Relative Hum.		Mol. Weight		Density				Heat Capacity				Not Used				Not Used			
4			SCFM$^{(N1)}$		SCFM$^{(N1)}$		SCFM$^{(N1)}$		SCFM$^{(N1)}$		kg/hr		lb/hr		°C		°F		in. WG		in. WC		mbar-a		ACFM		lb H_2O/lb Air		%		g/mol		kg/m^3		lb/ft^3		KJ/kg-C		Btu/lb-F									
5	Hanford Atmospheric Pressure (Pressure Balance)																				397	E21	990	R14																								
6	C2/C3 Area Vacuum																		-0.4	R18	397	E23	989	E22																								
7	Melter Enclosure Relative to C3 Gallery																		-2.0	R19	395	E23	984	E22																								
8		Steam from LAW Melter Feed			421	R39			421	E1	5.36E+02	E18	1.18E+03	E20	N/A		N/A				N/A				N/A						18.0	E56																
9	LMP01	Melter Air Inleakage	270	E7	28.2	E19	0.0	A18	298	R2/A3	5.88E+02	E18	1.30E+03	E20	45	E17	113	N11			395	A23	984	E22	333	E25	0.065	N11	100%	A1	27.9	E56	1.039	E27	0.0649	E28	1.059	E52	0.253	E54								
10	LMP02/03	Melter Injected Air	19	R1	0	A2	0.0	A18	19	E1	3.89E+01	E18	8.57E+01	E20	16	E17	60	R7			390	A24	972	E22	20	E25	0	A2	0%	A2	29.0	E56	1.172	E27	0.0732	E28	1.001	E52	0.239	E54								
11	LMP06	Melter Offgas	304	E13	449	E2	14.9	E57	768	E1	1.25E+03	E18	2.75E+03	E20	500	R6	932	E16	-5.0	R15	390	E23	972	E22	2,112	E25	0.848	E31	0.07%	N10	23.0	E56	0.347	E27	0.0217	E28	1.584	E52	0.379	E54								
12	LMP11	Film Cooler Air	185	R3	0	A2	0.0	A18	185	E1	3.78E+02	E18	8.34E+02	E20	16	E17	60	R7			388	A25	967	E22	191	E25	0	A2	0%	A2	29.0	E56	1.167	E27	0.0729	E28	1.001	E52	0.239	E54								
13		Film Cooler Discharge	489	E3	449	E3	14.9	E57	953	E1	1.62E+03	E18	3.58E+03	E20	425	E12	797	E16	-1.8	R16	388	E23	967	E22	2,377	E25	0.543	E31	0.1%	N10	24.1	E56	0.402	E27	0.0251	E28	1.438	E52	0.344	E54								
14	LMP13	Pressure Control Air	300	A27	0	A2	0.0	A18	300	E1	6.14E+02	E18	1.35E+03	E20	16	E17	60	R7			388	A26	967	E22	310	E25	0	A2	0%	A2	29.0	E56	1.167	E27	0.0729	E28	1.001	E52	0.239	E54								
15	LMP14	Controlled Offgas	789	E4	449	E4	14.9	E57	1,253	E1	2.24E+03	E18	4.93E+03	E20	342	E12	647	E16			388	A26	967	E22	2,752	E25	0.343	E31	0.2%	N10	25.3	E56	0.479	E27	0.0299	E28	1.311	E52	0.313	E54								
16	LMP14 Piping Pressure Drop																		-2.9	R16	385	E23	960	E22																								
17	LOP02	SBS Discharge	789	E5	175.9	R8/A6	11.6	E57	976	E1	1.88E+03	E18	4.15E+03	E20	55	A53	131	E16	-34.7	N6	351	E23	873	E22	1,268	E25	0.135	E31	100.0%	N10	27.3	E56	0.874	E27	0.0546	E28	1.109	E52	0.265	E54								
18	FC/Jumper/SBS Inleakage		10	A21	1.0	E19	0.0	A18	11.0	E1	2.18E+01	E18	4.80E+01	E20			113	N11									0.065	N11	100%	A1	27.9	E56																
19	LOP02 Piping Pressure Drop																		-4.0	A36	347	E23	863	E22																								
20	LOP06	WESP Bulge Air Purge	331	R5	0	A2	0.0	A18	331	E1	6.77E+02	E18	1.49E+03	E20	58	E17	136	R5			434	R5	1082	E22	350	E25	0	A2	0%	A2	29.0	E56	1.139	E27	0.0711	E28	1.008	E52	0.241	E54								
21	LOP08	WESP Discharge	1,130	E6	177	E6/A8	9.7	E57	1,316	E1	2.58E+03	E18	5.68E+03	E20	58	R10/E12	136	E16	-3.3	R20	343	E23	855	E22	1,761	E25	0.096	E31	63.9%	N10	27.7	E56	0.861	E27	0.0538	E28	1.082	E52	0.259	E54								
22	WESP Inleakage		10	A21	1.0	E19	0.0	A18	11.0	E1	2.18E+01	E18	4.80E+01	E20			113	N11									0.065	N11	100%	A1	27.9	E56																
23	LOP08 Piping Pressure Drop																		-6.0	A36	337	E23	840	E22																								
24		Offgas Flow through Control Valve	1,140	E10	178	E10	9.7	E10	1,327.3	E1	2.60E+03	E18	5.73E+03	E20	58	E65	136	E16	-11.84	N24	326	E23	811	E22	1,873	E25	0.095	E31	60.4%	N10	27.7	E56	0.817	E27	0.0510	E28	1.082	E52	0.259	E54								
25	LVP01	Vessel Vent Offgas	126	E7	13.2	E19	0.03	E57	139	N3	2.74E+02	E18	6.04E+02	E20	45	E17	113	A10			326	A28	811	E22	189	E25	0.065	E63	100%	A22	27.9	E56	0.856	E27	0.0534	E28	1.059	E52	0.253	E54								
26	LVP03	Combined Offgas	2,405	E9	369	E9/A8	19.3	E57	2,794	E1	5.47E+03	E18	1.21E+04	E20	57	E12	135	E16			326	E55	811	E22	3,934	E25	0.094	E31	61.3%	N10	27.7	E56	0.819	E27	0.0511	E28	1.081	E52	0.258	E54								
27	LVP03 Piping Pressure Drop																		-4.0	A36	322	E23	801	E22																								
28	LVP04	HEPA Preheater Discharge	2,405	E10	369	E10/A8	19.3	E57	2,794	E1	5.47E+03	E18	1.21E+04	E20	77	A12	171	E16	-5.0	A20	317	E23	788	E22	4,291	E25	0.094	E31	24.6%	N10	27.7	E56	0.751	E27	0.0469	E28	1.085	E52	0.259	E54								
29	LVP04 Piping Pressure Drop																		-4.0	A36	313	E23	778	E22																								
30	LVP06	HEPA Discharge	2,405	E10	369	E10/A8	19.3	E57	2,794	E1	5.47E+03	E18	1.21E+04	E20	77	A11	171	E16	-10.0	A31	303	E23	754	E22	4,490	E25	0.094	E31	23.5%	N10	27.7	E56	0.717	E27	0.0448	E28	1.085	E52	0.259	E54								
31	HEPA Bank Inleakage		10	A21	0.6	E19	0.0	A18	10.6	E1	2.12E+01	E18	4.67E+01	E20			95	N11									0.036	N11	100%	A1	28.4	E56																
32	LVP06 Piping Pressure Drop																		-4.0	A36	299	E23	744	E22																								
33	LVP26	S-AC Column Discharge	2,415	E10	370	E10/A8	19.3	E57	2,804	E1	5.49E+03	E18	1.21E+04	E20	97	A61	207	E16	-20.9	N16	278	E23	691	E22	5,192	E25	0.094	E31	9.9%	N10	27.7	E56	0.623	E27	0.0389	E28	1.089	E52	0.260	E54								
34	S-AC Column Inleakage		10	A21	0.6	E19	0.0	A18	10.6	E1	2.12E+01	E18	4.67E+01	E20			95	N11									0.036	N11	100%	A1	28.4	E56																
35	LVP26 Piping Pressure Drop																		-4.0	A36	274	E23	681	E22																								
36	LVP10	Skid Preheater Discharge	2,425	E10	370	E10/A8	19.3	E57	2,815	E1	5.51E+03	E18	1.22E+04	E20	357	N23	675	E16	-0.9	R17	272.7	E23	679	E22	9,026	E25	0.093	E31	0.05%	N10	27.7	E56	0.360	E27	0.0224	E28	1.146	E52	0.274	E54								
37	LVP11	Skid Electric Heater Discharge	2,425	E10	370	E10/A8	19.3	E57	2,815	E1	5.51E+03	E18	1.22E+04	E20	399	E17	750	R11	-1.0	R17	272	E23	677	E22	9,663	E25	0.093	E31	0.03%	N10	27.7	E56	0.336	E27	0.0210	E28	1.156	E52	0.276	E54								
38	LVP12	TCO Discharge	2,425	E10/N22	372	E10/N22	18.2	E57	2,815	E1	5.51E+03	E18	1.22E+04	E20	409	N18	769	E16	-6.4	R17	265	E23	661	E22	10,052	E25	0.094	E31	0.03%	N10	27.7	E56	0.323	E27	0.0202	E28	1.159	E52	0.277	E54								
39		Ammonia Dilution Air	756	E7	43.8	E19	0.0	A18	800	A60	1.60E+03	E18	3.53E+03	E20	35	E17	95	N11			265	A50	661	E22	1,290	E25	0.036	N11	100%	A1	28.4	E56	0.731	E27	0.0457	E28	1.034	E52	0.247	E54								
40		Dilution Air Fan Discharge	756	E10	43.8	E10/A8	0.0	A18	800	E1	1.60E+03	E18	3.53E+03	E20	35	A58	95	E16			265	A50	661	E22	1,290	E25	0.036	E31	63.7%	N10	28.4	E56	0.731	E27	0.0457	E28	1.034	E52	0.247	E54								
41	AMR03	Ammonia					26.6	E62	27	E1	31.97	N12	70.48	E20	45	E17	113	A62			265	A50	661	E22	44	E25	0	R22	0%	R22	17.0	R24	0.425	E27	0.0266	E28	2.128	E8	0.509	E54								
42	LVP13	Diluted Ammonia Addition	756	E10	43.8	E10	26.6	E10	827	E1	1.63E+03	E18	3.60E+03	E20	36	E12	97	E16			265	A50	661	E22	1,337	E25	0.035	E31	58.0%	N10	28.0	E56	0.719	E27	0.0449	E28	1.035	E52	0.247	E54								
43	LVP23	SCR Input	3,181	E61	415	E61	44.8	E61	3,641	E1	7.15E+03	E18	1.58E+04	E20	332	E12	629	E16			265	E23	661	E22	11,525	E25	0.080	E31	0.06%	N10	27.8	E56	0.365	E27	0.0228	E28	1.129	E52	0.270	E54								
44	LVP14	SCR Discharge	3,193	E10/N13	455	E10/N13	3.4	E57	3,651	E1	7.15E+03	E18	1.58E+04	E20	406	E12/N13	762	E16	-4.0	R17	261	E23	651	E22	13,163	E25	0.088	E31	0.03%	N10	27.7	E56	0.320	E27	0.0200	E28	1.153	E52	0.275	E54								
45	LVP09	Catalyst Skid Discharge	3,193	E10	455	E10/A8	3.4	E57	3,651	E1	7.15E+03	E18	1.58E+04	E20	208	N23	406	E16	-1.5	R17	259.7	E23	647	E22	9,387	E25	0.088	E31	0.44%	N10	27.7	E56	0.448	E27	0.0280	E28	1.107	E52	0.265	E54								
46	Catalyst Skid Inleakage		10	A21	0.6	E19	0.0	A18	10.6	E1	2.12E+01	E18	4.67E+01	E20			95	N11									0.036	N11	100%	A1	28.4	E56																
47	LVP09 Piping Pressure Drop										7.17E+03	E74	1.58E+04	E20					-4.0	A36	256	E23	637	E22																								
48	LVP18	Caustic Scrubber Discharge	3,347	E10/N27	868	E14	3.3	E57	4,219	E1	7.69E+03	E18	1.70E+04	E20	51	N26	123	E16	-15.0	A51	241	E23	600	E22	7,875	E25	0.168	E31	96.8%	N10	25.8	E56	0.575	E27	0.0359	E28	1.131	E52	0.270	E54								
49		Caustic Scrubber Inleakage	10	A21	0.6	E19	0.0	A18	10.6	E1	2.12E+01	E18	4.67E+01	E20			95	N11									0.036	N11	100%	A1	28.4	E56																
50	LVP18 Piping Pressure Drop to Fans																		-4.0	A36	237	E23	590	E22																								
51	LVP08	Exhauster Discharge	3,357	E10	869	E10/A8	3.3	E57	4,230	E1	7.72E+03	E18	1.70E+04	E20	143	N5	289	E16	167	N7	404	E23	1005	E22	6,052	E25	0.167	E31	5.4%	N10	25.8	E56	0.750	E27	0.0468	E28	1.150	E52	0.275	E54								
52	Exhauster Inleakage		10	A21	0.6	E19	0.0	A18	10.6	E1	2.12E+01	E18	4.67E+01	E20			95	N11									0.036	N11	100%	A1	28.4	E56																
53	LVP08 Piping Pressure Drop to Stack		3,367	E10	869	E10/A8	3.3	E57	4,240	E1	7.74E+03	E18	1.71E+04	E20	143	E32	289	E16	-6.0	A36	398	E23	990	E22	6,158	E25	0.167	E31	5.3%	N10	25.8	E56	0.739	E27	0.0462	E28	1.150	E52	0.275	E54								
54	Hanford Atmospheric Pressure (Pressure Balance)														25	A13	77	E16			397	E21	990	R14																								

	A	B	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant																										
2	***Maximum Flowsheet - 2 Melters***				🟦	Fixed Constant																										
3	Stream Number	Stream Name	N_2						O_2						CO_2						Ar						H_2O					
4			kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%		kg/hr		wt%		vol%	
5	Hanford Atmospheric Pressure (Pressure Balance)																															
6	C2/C3 Area Vacuum																															
7	Melter Enclosure Relative to C3 Gallery																															
8		Steam from LAW Melter Feed																									5.4E+02	E35	100.0%	E26	100.0%	E39
9	LMP01	Melter Air Inleakage	4.2E+02	E35	71%	E26	70.7%	E38	1.3E+02	E35	22%	E26	19.0%	E38	2.6E-01	E35	0.045%	E26	0.028%	E38	7.1E+00	E35	1.2%	E26	0.85%	E38	3.6E+01	E35	6.1%	E26	9.5%	E39
10	LMP02/03	Melter Injected Air	2.9E+01	E35	76%	E26	78.1%	E38	9.0E+00	E35	23%	E26	20.9%	E38	1.9E-02	E35	0.048%	E26	0.031%	E38	5.0E-01	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
11	LMP06	Melter Offgas	4.5E+02	E2	36%	E36	29.4%	E37	1.4E+02	E2	11%	E36	7.9%	E37	4.6E+01	E11	3.7%	E36	1.938%	E37	7.6E+00	E2	0.6%	E36	0.35%	E37	5.7E+02	E2	46%	E26	58.5%	E39
12	LMP11	Film Cooler Air	2.9E+02	E35	76%	E26	78.1%	E38	8.8E+01	E35	23%	E26	20.9%	E38	1.8E-01	E35	0.048%	E26	0.031%	E38	4.9E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
13		Film Cooler Discharge	7.3E+02	E3	45%	E36	38.8%	E37	2.2E+02	E3	14%	E36	10.4%	E37	4.6E+01	E24	2.9%	E36	1.568%	E37	1.2E+01	E3	0.8%	E36	0.46%	E37	5.7E+02	E3	35%	E26	47.2%	E39
14	LMP13	Pressure Control Air	4.6E+02	E35	76%	E26	78.1%	E38	1.4E+02	E35	23%	E26	20.9%	E38	2.9E-01	E35	0.048%	E26	0.031%	E38	7.9E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
15	LMP14	Controlled Offgas	1.2E+03	E4	53%	E36	48.2%	E37	3.7E+02	E4	16%	E36	12.9%	E37	4.7E+01	E35	2.1%	E26	1.2%	N4	2.0E+01	E4	0.9%	E36	0.58%	E37	5.7E+02	E4	26%	E26	35.9%	E39
16	LMP14 Piping Pressure Drop																															
17	LOP02	SBS Discharge	1.2E+03	E5	64%	E36	61.9%	E37	3.7E+02	E5	19%	E36	16.6%	E37	4.7E+01	E5	2.5%	E36	1.540%	E37	2.0E+01	E5	1.1%	E36	0.74%	E37	2.2E+02	E35	11.9%	E26	18.0%	E39
18	FC/Jumper/SBS Inleakage		1.5E+01	E35	71%	E26	70.7%	E38	4.7E+00	E35	22%	E26	19.0%	E38	9.8E-03	E35	0.045%	E26	0.028%	E38	2.6E-01	E35	1.2%	E26	0.85%	E38	1.3E+00	E35	6.1%	E26	9.5%	E39
19	LOP02 Piping Pressure Drop																															
20	LOP06	WESP Bulge Air Purge	5.1E+02	E35	76%	E26	78.1%	E38	1.6E+02	E35	23%	E26	20.9%	E38	3.2E-01	E35	0.048%	E26	0.031%	E38	8.7E+00	E35	1.3%	E26	0.93%	E38	0.0E+00	E35	0.0%	E26	0.0%	E39
21	LOP08	WESP Discharge	1.7E+03	E6	67%	E36	66.1%	E37	5.3E+02	E6	20%	E36	17.7%	E37	4.7E+01	E6	1.8%	E36	1.150%	E37	2.9E+01	E6	1.1%	E36	0.79%	E37	2.3E+02	E6	8.7%	E26	13.4%	E39
22		WESP Inleakage	1.5E+01	E35	71%	E26	70.7%	E38	4.7E+00	E35	22%	E26	19.0%	E38	9.8E-03	E35	0.045%	E26	0.028%	E38	2.6E-01	E35	1.2%	E26	0.85%	E38	1.3E+00	E35	6.1%	E26	9.5%	E39
23	LOP08 Piping Pressure Drop																															
24		Offgas Flow through Control Valve	1.7E+03	E10	67%	E36	66.2%	E37	5.3E+02	E10	20%	E36	17.8%	E37	4.7E+01	E10	1.8%	E36	1.141%	E37	3.0E+01	E10	1.1%	E36	0.79%	E37	2.3E+02	E10	8.7%	E26	13.4%	E39
25	LVP01	Vessel Vent Offgas	1.9E+02	E35	71%	E26	70.7%	E38	6.0E+01	E35	22%	E26	19.0%	E38	1.2E-01	E35	0.045%	E26	0.028%	E38	3.3E+00	E35	1.2%	E26	0.85%	E38	1.7E+01	E35	6.1%	E26	9.5%	E39
26	LVP03	Combined Offgas	3.7E+03	E9	67%	E36	66.4%	E37	1.1E+03	E9	21%	E36	17.8%	E37	9.4E+01	E9	1.7%	E36	1.086%	E37	6.3E+01	E9	1.1%	E36	0.79%	E37	4.7E+02	E9	8.6%	E26	13.2%	E39
27	LVP03 Piping Pressure Drop																															
28	LVP04	HEPA Preheater Discharge	3.7E+03	E10	67%	E36	66.4%	E37	1.1E+03	E10	21%	E36	17.8%	E37	9.4E+01	E10	1.7%	E36	1.086%	E37	6.3E+01	E10	1.1%	E36	0.79%	E37	4.7E+02	E10	8.6%	E26	13.2%	E39
29	LVP04 Piping Pressure Drop																															
30	LVP06	HEPA Discharge	3.7E+03	E10	67%	E36	66.4%	E37	1.1E+03	E10	21%	E36	17.8%	E37	9.4E+01	E10	1.7%	E36	1.086%	E37	6.3E+01	E10	1.1%	E36	0.79%	E37	4.7E+02	E10	8.6%	E26	13.2%	E39
31	HEPA Bank Inleakage		1.5E+01	E35	73%	E26	73.8%	E38	4.7E+00	E35	22%	E26	19.8%	E38	9.8E-03	E35	0.046%	E26	0.030%	E38	2.6E-01	E35	1.2%	E26	0.88%	E38	7.4E-01	E35	3.5%	E26	5.5%	E39
32	LVP06 Piping Pressure Drop																															
33	LVP26	S-AC Column Discharge	3.7E+03	E10	67%	E36	66.4%	E37	1.1E+03	E10	21%	E36	17.8%	E37	9.4E+01	E10	1.7%	E36	1.082%	E37	6.3E+01	E10	1.1%	E36	0.79%	E37	4.7E+02	E10	8.6%	E26	13.2%	E39
34	S-AC Column Inleakage		1.5E+01	E35	73%	E26	73.8%	E38	4.7E+00	E35	22%	E26	19.8%	E38	9.8E-03	E35	0.046%	E26	0.030%	E38	2.6E-01	E35	1.2%	E26	0.88%	E38	7.4E-01	E35	3.5%	E26	5.5%	E39
35	LVP26 Piping Pressure Drop																															
36	LVP10	Skid Preheater Discharge	3.7E+03	E10	67%	E36	66.5%	E37	1.1E+03	E10	21%	E36	17.8%	E37	9.4E+01	E10	1.7%	E36	1.078%	E37	6.3E+01	E10	1.1%	E36	0.79%	E37	4.7E+02	E10	8.5%	E26	13.2%	E39
37	LVP11	Skid Electric Heater Discharge	3.7E+03	E10	67%	E36	66.5%	E37	1.1E+03	E10	21%	E36	17.8%	E37	9.4E+01	E10	1.7%	E36	1.078%	E37	6.3E+01	E10	1.1%	E36	0.79%	E37	4.7E+02	E10	8.5%	E26	13.2%	E39
38	LVP12	TCO Discharge	3.7E+03	E10	67%	E36	66.4%	E37	1.1E+03	E10/N22	20%	E36	17.7%	E37	1.0E+02	E10/N22	1.8%	E36	1.152%	E37	6.3E+01	E10	1.1%	E36	0.79%	E37	4.7E+02	E10/N22	8.6%	E26	13.2%	E39
39		Ammonia Dilution Air	1.2E+03	E35	73%	E26	73.8%	E38	3.6E+02	E35	22%	E26	19.8%	E38	7.4E-01	E35	0.046%	E26	0.030%	E38	2.0E+01	E35	1.2%	E26	0.88%	E38	5.6E+01	E35	3.5%	E26	5.5%	E39
40		Dilution Air Fan Discharge	1.2E+03	E10	73%	E36	73.8%	E37	3.6E+02	E10	22%	E36	19.8%	E37	7.4E-01	E10	0.046%	E36	0.030%	E37	2.0E+01	E10	1.2%	E36	0.88%	E37	5.6E+01	E10	3.5%	E26	5.5%	E39
41	AMR03	Ammonia																														
42	LVP13	Diluted Ammonia Addition	1.2E+03	E10	71%	E36	71.4%	E37	3.6E+02	E10	22%	E36	19.2%	E37	7.4E-01	E10	0.045%	E36	0.029%	E37	2.0E+01	E10	1.2%	E36	0.85%	E37	5.6E+01	E10	3.4%	E26	5.3%	E39
43	LVP23	SCR Input	4.9E+03	E10	68%	E36	67.6%	E37	1.5E+03	E10	21%	E36	18.1%	E37	1.0E+02	E10	1.4%	E36	0.897%	E37	8.3E+01	E10	1.2%	E36	0.81%	E37	5.3E+02	E59	7.4%	E26	11.4%	E39
44	LVP14	SCR Discharge	4.9E+03	E10/N13	69%	E36	68.0%	E37	1.5E+03	E10/N13	21%	E36	17.8%	E37	1.0E+02	E10	1.4%	E36	0.895%	E37	8.3E+01	E10	1.2%	E36	0.81%	E37	5.8E+02	E10/N13	8.1%	E26	12.4%	E39
45	LVP09	Catalyst Skid Discharge	4.9E+03	E10	69%	E36	68.0%	E37	1.5E+03	E10	21%	E36	17.8%	E37	1.0E+02	E10	1.4%	E36	0.895%	E37	8.3E+01	E10	1.2%	E36	0.81%	E37	5.8E+02	E10	8.1%	E26	12.4%	E39
46	Catalyst Skid Inleakage		1.5E+01	E35	73%	E26	73.8%	E38	4.7E+00	E35	22%	E26	19.8%	E38	9.8E-03	E35	0.046%	E26	0.030%	E38	2.6E-01	E35	1.2%	E26	0.88%	E38	7.4E-01	E35	3.5%	E26	5.5%	E39
47	LVP09 Piping Pressure Drop																										5.8E+02	E74				
48	LVP18	Caustic Scrubber Discharge	4.9E+03	E10	64%	E36	59.0%	E37	1.5E+03	E10	19%	E36	15.4%	E37	1.0E+02	E10/N28	1.3%	E36	0.761%	E37	8.3E+01	E10	1.1%	E36	0.70%	E37	1.1E+03	N26	14%	E26	20.6%	E39
49		Caustic Scrubber Inleakage	1.5E+01	E35	73%	E26	73.8%	E38	4.7E+00	E35	22%	E26	19.8%	E38	9.8E-03	E35	0.046%	E26	0.030%	E38	2.6E-01	E35	1.2%	E26	0.88%	E38	7.4E-01	E35	3.5%	E26	5.5%	E39
50	LVP18 Piping Pressure Drop to Fans																															
51	LVP08	Exhauster Discharge	4.9E+03	E10	64%	E36	59.0%	E37	1.5E+03	E10	19%	E36	15.5%	E37	1.0E+02	E10	1.3%	E36	0.759%	E37	8.4E+01	E10	1.1%	E36	0.70%	E37	1.1E+03	E10	14.3%	E26	20.5%	E39
52	Exhauster Inleakage		1.5E+01	E35	73%	E26	73.8%	E38	4.7E+00	E35	22%	E26	19.8%	E38	9.8E-03	E35	0.046%	E26	0.030%	E38	2.6E-01	E35	1.2%	E26	0.88%	E38	7.4E-01	E35	3.5%	E26	5.5%	E39
53	LVP08 Piping Pressure Drop to Stack		5.0E+03	E10	64%	E36	59.1%	E37	1.5E+03	E10	19%	E36	15.5%	E37	1.0E+02	E10	1.3%	E36	0.757%	E37	8.4E+01	E10	1.1%	E36	0.70%	E37	1.1E+03	E10	14.3%	E26	20.5%	E39
54	Hanford Atmospheric Pressure (Pressure Balance)																															

By: Nancy Wilkins
Date: 11/15/2019

Subject: LAW Melter Offgas System Design Basis Flowsheets

CALCULATION SHEET

Job No: 24590
Calc No: 24590-LAW-M4C-LOP-00001
Rev: 6
Page: 1-16

	A	B	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant																																						
2	***Maximum Flowsheet - 2 Melters***				🟦	Fixed Constant																																						
3	Stream Number	Stream Name	NO						N_2O						NO_2						NH_3						VOC						H_2						Hg					
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)																																											
6	C2/C3 Area Vacuum																																											
7	Melter Enclosure Relative to C3 Gallery																																											
8		Steam from LAW Melter Feed																																										
9	LMP01	Melter Air Inleakage																																										
10	LMP02/03	Melter Injected Air																																										
11	LMP06	Melter Offgas	1.71E+01	E77	4.77E+03	E45	1.05E+04	E51	1.60E+00	E47	4.46E+02	E45	6.71E+02	E51	1.14E+01	E77	3.17E+03	E45	4.56E+03	E51	5.20E-01	E47	1.45E+02	E45	5.63E+02	E51	9.34E-01	E75	2.60E+02	E45	2.96E+02	E51	2.08E-02	E47	5.81E+00	E45	1.91E+02	E51	2.02E-02	E47	5.63E+00	E45	1.86E+00	E51
12	LMP11	Film Cooler Air																																										
13		Film Cooler Discharge	1.71E+01	E76	4.24E+03	E45	8.48E+03	E51	1.60E+00	E46	3.96E+02	E45	5.41E+02	E51	1.14E+01	E76	2.82E+03	E45	3.67E+03	E51	5.20E-01	E46	1.29E+02	E45	4.53E+02	E51	9.34E-01	E76	2.31E+02	E45	2.39E+02	E51	2.08E-02	E46	5.16E+00	E45	1.54E+02	E51	2.02E-02	E46	5.00E+00	E45	1.50E+00	E51
14	LMP13	Pressure Control Air																																										
15	LMP14	Controlled Offgas	1.71E+01	E76	3.66E+03	E45	6.45E+03	E51	1.60E+00	E50	3.42E+02	E45	4.11E+02	N4	1.14E+01	E76	2.43E+03	E45	2.79E+03	E51	5.20E-01	E50	1.11E+02	E45	3.45E+02	N4	9.34E-01	E76	2.00E+02	E45	1.82E+02	E51	2.08E-02	E48	4.45E+00	E45	1.17E+02	E51	2.02E-02	R31	4.32E+00	E45	1.14E+00	E51
16	LMP14 Piping Pressure Drop																																											
17	LOP02	SBS Discharge	1.32E+01	E78	6.11E+03	E45	6.36E+03	E51	2.22E+00	E50	1.03E+03	E45	7.33E+02	N4	1.14E+01	E76	5.28E+03	E45	3.59E+03	E51	7.77E-02	E50	3.61E+01	E45	6.62E+01	N4	9.34E-01	E76	4.34E+02	E45	2.33E+02	E51	2.08E-02	E49	9.67E+00	E45	1.50E+02	E51	3.37E-03	E66/A55	1.56E+00	E45	2.43E-01	E51
18	FC/Jumper/SBS Inleakage																																											
19	LOP02 Piping Pressure Drop																																											
20	LOP06	WESP Bulge Air Purge																																										
21	LOP08	WESP Discharge	9.14E+00	E78/E10	3.06E+03	E45	3.28E+03	E51	2.91E+00	E50	9.74E+02	E45	7.12E+02	N4	1.14E+01	E76/E10	3.80E+03	E45	2.66E+03	E51	2.99E-02	E50	9.99E+00	E45	1.89E+01	N4	9.34E-01	E76/E10	3.12E+02	E45	1.73E+02	E51	2.08E-02	E50	6.96E+00	E45	1.39E+02	N4	3.37E-03	E53	1.13E+00	E45	1.81E-01	E51
22	WESP Inleakage																																											
23	LOP08 Piping Pressure Drop																																											
24		Offgas Flow through Control Valve	9.14E+00	E10	2.87E+03	E45	3.25E+03	E51	2.91E+00	E10	9.15E+02	E45	7.06E+02	E51	1.14E+01	E10	3.57E+03	E45	2.64E+03	E51	2.99E-02	E10	9.39E+00	E45	1.87E+01	E51	9.34E-01	E10	2.93E+02	E45	1.71E+02	E51	2.08E-02	E10	6.55E+00	E45	1.10E+02	E51	3.37E-03	E10	1.06E+00	E45	1.79E-01	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	3.52E-03	E42	1.10E+01	E45	1.78E+02	E51	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	LVP03	Combined Offgas	1.83E+01	E9	2.74E+03	E45	3.09E+03	E51	5.83E+00	E9	8.72E+02	E45	6.71E+02	E51	2.27E+01	E9	3.40E+03	E45	2.51E+03	E51	5.98E-02	E9	8.94E+00	E45	1.78E+01	E51	1.87E+00	E9	2.79E+02	E45	1.63E+02	E51	4.52E-02	E9	6.76E+00	E45	1.14E+02	E51	6.73E-03	E9	1.01E+00	E45	1.70E-01	E51
27	LVP03 Piping Pressure Drop																																											
28	LVP04	HEPA Preheater Discharge	1.83E+01	E10	2.51E+03	E45	3.09E+03	E51	5.83E+00	E10	7.99E+02	E45	6.71E+02	E51	2.27E+01	E10	3.12E+03	E45	2.51E+03	E51	5.98E-02	E10	8.20E+00	E45	1.78E+01	E51	1.87E+00	E10	2.56E+02	E45	1.63E+02	E51	4.52E-02	E10	6.20E+00	E45	1.14E+02	E51	6.73E-03	E10	9.23E-01	E45	1.70E-01	E51
29	LVP04 Piping Pressure Drop																																											
30	LVP06	HEPA Discharge	1.83E+01	E10	2.40E+03	E45	3.09E+03	E51	5.83E+00	E10	7.64E+02	E45	6.71E+02	E51	2.27E+01	E10	2.98E+03	E45	2.51E+03	E51	5.98E-02	E10	7.83E+00	E45	1.78E+01	E51	1.87E+00	E10	2.45E+02	E45	1.63E+02	E51	4.52E-02	E10	5.92E+00	E45	1.14E+02	E51	6.73E-03	E10	8.83E-01	E45	1.70E-01	E51
31	HEPA Bank Inleakage																																											
32	LVP06 Piping Pressure Drop																																											
33	LVP26	S-AC Column Discharge	1.83E+01	E10	2.07E+03	E45	3.08E+03	E51	5.83E+00	E10	6.60E+02	E45	6.68E+02	E51	2.27E+01	E10	2.58E+03	E45	2.50E+03	E51	5.98E-02	E10	6.77E+00	E45	1.77E+01	E51	1.87E+00	E10	2.12E+02	E45	1.62E+02	E51	4.52E-02	E10	5.12E+00	E45	1.13E+02	E51	1.85E-04	R33	2.10E-02	E45	4.66E-03	E51
34	S-AC Column Inleakage																																											
35	LVP26 Piping Pressure Drop																																											
36	LVP10	Skid Preheater Discharge	1.83E+01	E10	1.19E+03	E45	3.06E+03	E51	5.83E+00	E10	3.80E+02	E45	6.66E+02	E51	2.27E+01	E10	1.48E+03	E45	2.49E+03	E51	5.98E-02	E10	3.90E+00	E45	1.76E+01	E51	1.87E+00	E10	1.22E+02	E45	1.62E+02	E51	4.52E-02	E10	2.95E+00	E45	1.13E+02	E51	1.85E-04	E10	1.21E-02	E45	4.64E-03	E51
37	LVP11	Skid Electric Heater Discharge	1.83E+01	E10	1.11E+03	E45	3.06E+03	E51	5.83E+00	E10	3.55E+02	E45	6.66E+02	E51	2.27E+01	E10	1.39E+03	E45	2.49E+03	E51	5.98E-02	E10	3.64E+00	E45	1.76E+01	E51	1.87E+00	E10	1.14E+02	E45	1.62E+02	E51	4.52E-02	E10	2.75E+00	E45	1.13E+02	E51	1.85E-04	E10	1.13E-02	E45	4.64E-03	E51
38	LVP12	TCO Discharge	1.83E+01	E10	1.07E+03	E45	3.06E+03	E51	5.83E+00	E10	3.41E+02	E45	6.66E+02	E51	2.27E+01	E10	1.33E+03	E45	2.49E+03	E51	5.98E-02	E10	3.50E+00	E45	1.76E+01	E51	9.34E-02	E43/R26	5.47E+00	E45	8.08E+00	E51	4.52E-02	E10	2.65E+00	E45	1.13E+02	E51	1.85E-04	E10	1.08E-02	E45	4.64E-03	E51
39		Ammonia Dilution Air																																										
40		Dilution Air Fan Discharge																																										
41	AMR03	Ammonia																			3.20E+01	E44																						
42	LVP13	Diluted Ammonia Addition																			3.20E+01	E10	1.41E+04	E45	3.22E+04	E51																		
43	LVP23	SCR Input	1.83E+01	E10	9.34E+02	E45	2.37E+03	E51	5.83E+00	E10	2.98E+02	E45	5.15E+02	E51	2.27E+01	E10	1.16E+03	E45	1.92E+03	E51	3.20E+01	E10	1.64E+03	E45	7.31E+03	E51	9.34E-02	E10	4.77E+00	E45	6.25E+00	E51	4.52E-02	E10	2.31E+00	E45	8.71E+01	E51	1.85E-04	E10	9.45E-03	E45	3.59E-03	E51
44	LVP14	SCR Discharge	3.66E-01	E67/R25	1.64E+01	E45	4.73E+01	E51	5.83E+00	E10	2.60E+02	E45	5.13E+02	E51	4.55E-01	E40/R25	2.03E+01	E45	3.83E+01	E51	6.99E-01	E41/N12	3.12E+01	E45	1.59E+02	E51	9.34E-02	E10	4.17E+00	E45	6.23E+00	E51	4.52E-02	E10	2.02E+00	E45	8.69E+01	E51	1.85E-04	E10	8.27E-03	E45	3.58E-03	E51
45	LVP09	Catalyst Skid Discharge	3.66E-01	E10	2.29E+01	E45	4.73E+01	E51	5.83E+00	E10	3.65E+02	E45	5.13E+02	E51	4.55E-01	E10	2.85E+01	E45	3.83E+01	E51	6.99E-01	E10	4.38E+01	E45	1.59E+02	E51	9.34E-02	E10	5.85E+00	E45	6.23E+00	E51	4.52E-02	E10	2.83E+00	E45	8.69E+01	E51	1.85E-04	E10	1.16E-02	E45	3.58E-03	E51
46	Catalyst Skid Inleakage																																											
47	LVP09 Piping Pressure Drop																																											
48	LVP18	Caustic Scrubber Discharge	3.66E-01	E10	2.73E+01	E45	4.09E+01	E51	5.83E+00	E10	4.35E+02	E45	4.44E+02	E51	4.50E-01	E10/N28	3.36E+01	E45	3.28E+01	E51	6.99E-01	E10	5.22E+01	E45	1.38E+02	E51	9.34E-02	E10	6.98E+00	E45	5.39E+00	E51	4.52E-02	E10	3.38E+00	E45	7.52E+01	E51	1.85E-04	E10	1.38E-02	E45	3.09E-03	E51
49		Caustic Scrubber Inleakage																																										
50	LVP18 Piping Pressure Drop to Fans																																											
51	LVP08	Exhauster Discharge	3.66E-01	E10	3.56E+01	E45	4.08E+01	E51	5.83E+00	E10	5.67E+02	E45	4.43E+02	E51	4.50E-01	E10	4.38E+01	E45	3.27E+01	E51	6.99E-01	E10	6.80E+01	E45	1.37E+02	E51	9.34E-02	E10	9.08E+00	E45	5.38E+00	E51	4.52E-02	E10	4.39E+00	E45	7.50E+01	E51	1.85E-04	E10	1.80E-02	E45	3.09E-03	E51
52	Exhauster Inleakage																																											
53	LVP08 Piping Pressure Drop to Stack		3.66E-01	E10	3.49E+01	E45	4.07E+01	E51	5.83E+00	E10	5.57E+02	E45	4.42E+02	E51	4.50E-01	E10	4.30E+01	E45	3.27E+01	E51	6.99E-01	E10	66.8	E45	1.37E+02	E51	9.34E-02	E10	8.92E+00	E45	5.37E+00	E51	4.52E-02	E10	4.32E+00	E45	7.48E+01	E51	1.85E-04	E10	1.77E-02	E45	3.08E-03	E51
54	Hanford Atmospheric Pressure (Pressure Balance)																																											

11/14/2019 1:53 PM

By: Nancy Wilkins
Date: 11/15/2019

CALCULATION SHEET

Job No: 24590
Calc No: 24590-LAW-M4C-LOP-00001
Rev: 6
Page: 1-17

Subject: LAW Melter Offgas System Design Basis Flowsheets

	A	B	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB
1	***LAW Melter Offgas System Design Basis***				🟩	Case Dependent Constant								
2	***Maximum Flowsheet - 2 Melters***				🟦	Fixed Constant								
3	Stream Number	Stream Name	HCl						HF					
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)													
6	C2/C3 Area Vacuum													
7	Melter Enclosure Relative to C3 Gallery													
8		Steam from LAW Melter Feed												
9	LMP01	Melter Air Inleakage												
10	LMP02/03	Melter Injected Air												
11	LMP06	Melter Offgas	7.94E-02	E77	2.21E+01	E45	4.02E+01	E51	1.00E+00	E77	2.80E+02	E45	9.25E+02	E51
12	LMP11	Film Cooler Air												
13		Film Cooler Discharge	7.94E-02	E76	1.97E+01	E45	3.24E+01	E51	1.00E+00	E76	2.49E+02	E45	7.45E+02	E51
14	LMP13	Pressure Control Air												
15	LMP14	Controlled Offgas	7.94E-02	E76	1.70E+01	E45	2.46E+01	E51	1.00E+00	E76	2.15E+02	E45	5.67E+02	E51
16	LMP14 Piping Pressure Drop													
17	LOP02	SBS Discharge	4.18E-02	E78	1.94E+01	E45	1.66E+01	E51	3.72E-01	E78	1.73E+02	E45	2.69E+02	E51
18	FC/Jumper/SBS Inleakage													
19	LOP02 Piping Pressure Drop													
20	LOP06	WESP Bulge Air Purge												
21	LOP08	WESP Discharge	1.18E-02	E78/E10	3.96E+00	E45	3.49E+00	E51	4.98E-02	E78/E10	1.67E+01	E45	2.68E+01	E51
22		WESP Inleakage												
23	LOP08 Piping Pressure Drop													
24		Offgas Flow through Control Valve	1.18E-02	E10	3.72E+00	E45	3.46E+00	E51	4.98E-02	E10	1.57E+01	E45	2.66E+01	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	LVP03	Combined Offgas	2.37E-02	E9	3.54E+00	E45	3.29E+00	E51	9.97E-02	E9	1.49E+01	E45	2.52E+01	E51
27	LVP03 Piping Pressure Drop													
28	LVP04	HEPA Preheater Discharge	2.37E-02	E10	3.25E+00	E45	3.29E+00	E51	9.97E-02	E10	1.37E+01	E45	2.52E+01	E51
29	LVP04 Piping Pressure Drop													
30	LVP06	HEPA Discharge	2.37E-02	E10	3.10E+00	E45	3.29E+00	E51	9.97E-02	E10	1.31E+01	E45	2.52E+01	E51
31	HEPA Bank Inleakage													
32	LVP06 Piping Pressure Drop													
33	LVP26	S-AC Column Discharge	2.37E-02	E10	2.68E+00	E45	3.28E+00	E51	9.97E-02	E10	1.13E+01	E45	2.52E+01	E51
34	S-AC Column Inleakage													
35	LVP26 Piping Pressure Drop													
36	LVP10	Skid Preheater Discharge	2.37E-02	E10	1.54E+00	E45	3.27E+00	E51	9.97E-02	E10	6.50E+00	E45	2.51E+01	E51
37	LVP11	Skid Electric Heater Discharge	2.37E-02	E10	1.44E+00	E45	3.27E+00	E51	9.97E-02	E10	6.07E+00	E45	2.51E+01	E51
38	LVP12	TCO Discharge	2.37E-02	E10	1.39E+00	E45	3.27E+00	E51	9.97E-02	E10	5.84E+00	E45	2.51E+01	E51
39		Ammonia Dilution Air												
40		Dilution Air Fan Discharge												
41	AMR03	Ammonia												
42	LVP13	Diluted Ammonia Addition												
43	LVP23	SCR Input	2.37E-02	E10	1.21E+00	E45	2.52E+00	E51	9.97E-02	E10	5.09E+00	E45	1.94E+01	E51
44	LVP14	SCR Discharge	2.37E-02	E10	1.06E+00	E45	2.52E+00	E51	9.97E-02	E10	4.46E+00	E45	1.93E+01	E51
45	LVP09	Catalyst Skid Discharge	2.37E-02	E10	1.48E+00	E45	2.52E+00	E51	9.97E-02	E10	6.25E+00	E45	1.93E+01	E51
46	Catalyst Skid Inleakage													
47	LVP09 Piping Pressure Drop													
48	LVP18	Caustic Scrubber Discharge	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51
49		Caustic Scrubber Inleakage												
50	LVP18 Piping Pressure Drop to Fans													
51	LVP08	Exhauster Discharge	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51
52	Exhauster Inleakage													
53	LVP08 Piping Pressure Drop to Stack		0.00E+00	E10	0.00E+00	E45	0.00E+00	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51
54	Hanford Atmospheric Pressure (Pressure Balance)													

	A	B	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN
1	***LAW Melter Offgas System Design Basis***													
2	***Maximum Flowsheet - 2 Melters***													
3	Stream Number	Stream Name	I-129						SO_2					
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)													
6	C2/C3 Area Vacuum													
7	Melter Enclosure Relative to C3 Gallery													
8		Steam from LAW Melter Feed												
9	LMP01	Melter Air Inleakage												
10	LMP02/03	Melter Injected Air												
11	LMP06	Melter Offgas	1.11E-03	N20	3.10E-01	E45	1.59E-01	E51	1.37E+00	E77	3.81E+02	E45	3.93E+02	E51
12	LMP11	Film Cooler Air												
13		Film Cooler Discharge	1.11E-03	E79	2.75E-01	E45	1.28E-01	E51	1.37E+00	E76	3.38E+02	E45	3.17E+02	E51
14	LMP13	Pressure Control Air												
15	LMP14	Controlled Offgas	1.11E-03	E79	2.38E-01	E45	9.74E-02	E51	1.37E+00	E76	2.92E+02	E45	2.41E+02	E51
16	LMP14 Piping Pressure Drop													
17	LOP02	SBS Discharge	3.09E-04	E78	1.43E-01	E45	3.47E-02	E51	3.17E-02	E78	1.47E+01	E45	7.18E+00	E51
18	FC/Jumper/SBS Inleakage													
19	LOP02 Piping Pressure Drop													
20	LOP06	WESP Bulge Air Purge												
21	LOP08	WESP Discharge	6.43E-05	E78	2.15E-02	E45	5.36E-03	E51	3.17E-02	E78/E10	1.06E+01	E45	5.32E+00	E51
22		WESP Inleakage												
23	LOP08 Piping Pressure Drop													
24		Offgas Flow through Control Valve	6.43E-05	E10	2.02E-02	E45	5.32E-03	E51	3.17E-02	E10	9.97E+00	E45	5.28E+00	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16
26	LVP03	Combined Offgas	1.29E-04	E9	1.92E-02	E45	5.06E-03	E51	6.34E-02	E9	9.49E+00	E45	5.02E+00	E51
27	LVP03 Piping Pressure Drop													
28	LVP04	HEPA Preheater Discharge	1.29E-04	E10	1.76E-02	E45	5.06E-03	E51	6.34E-02	E10	8.70E+00	E45	5.02E+00	E51
29	LVP04 Piping Pressure Drop													
30	LVP06	HEPA Discharge	1.29E-04	E10	1.69E-02	E45	5.06E-03	E51	6.34E-02	E10	8.32E+00	E45	5.02E+00	E51
31	HEPA Bank Inleakage													
32	LVP06 Piping Pressure Drop													
33	LVP26	S-AC Column Discharge	1.29E-04	E10/~~N19~~	1.46E-02	E45	5.04E-03	E51	6.34E-02	E10	7.19E+00	E45	5.00E+00	E51
34	S-AC Column Inleakage													
35	LVP26 Piping Pressure Drop													
36	LVP10	Skid Preheater Discharge	1.29E-04	E10	8.38E-03	E45	5.02E-03	E51	6.34E-02	E10	4.14E+00	E45	4.98E+00	E51
37	LVP11	Skid Electric Heater Discharge	1.29E-04	E10	7.83E-03	E45	5.02E-03	E51	6.34E-02	E10	3.86E+00	E45	4.98E+00	E51
38	LVP12	TCO Discharge	1.29E-04	E10	7.53E-03	E45	5.02E-03	E51	6.34E-02	E10	3.71E+00	E45	4.98E+00	E51
39		Ammonia Dilution Air												
40		Dilution Air Fan Discharge												
41	AMR03	Ammonia												
42	LVP13	Diluted Ammonia Addition												
43	LVP23	SCR Input	1.29E-04	E10	6.57E-03	E45	3.88E-03	E51	6.34E-02	E10	3.24E+00	E45	3.85E+00	E51
44	LVP14	SCR Discharge	1.29E-04	E10	5.75E-03	E45	3.87E-03	E51	6.34E-02	E10	2.84E+00	E45	3.84E+00	E51
45	LVP09	Catalyst Skid Discharge	1.29E-04	E10	8.06E-03	E45	3.87E-03	E51	6.34E-02	E10	3.98E+00	E45	3.84E+00	E51
46	Catalyst Skid Inleakage													
47	LVP09 Piping Pressure Drop													
48	LVP18	Caustic Scrubber Discharge	1.29E-04	E10	9.61E-03	E45	3.35E-03	E51	0.00E+00	E10/N28	0.00E+00	E45	0.00E+00	E51
49		Caustic Scrubber Inleakage												
50	LVP18 Piping Pressure Drop to Fans													
51	LVP08	Exhauster Discharge	1.29E-04	E10	1.25E-02	E45	3.34E-03	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51
52	Exhauster Inleakage													
53	LVP08 Piping Pressure Drop to Stack		1.29E-04	E10	1.23E-02	E45	3.33E-03	E51	0.00E+00	E10	0.00E+00	E45	0.00E+00	E51
54	Hanford Atmospheric Pressure (Pressure Balance)													

	A	B	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ
1	***LAW Melter Offgas System Design Basis***													
2	***Maximum Flowsheet - 2 Melters***													
3	Stream Number	Stream Name	CO						Particulate					
4			kg/hr		mg/m^3		ppmv		kg/hr		mg/m^3		ppmv	
5	Hanford Atmospheric Pressure (Pressure Balance)													
6	C2/C3 Area Vacuum													
7	Melter Enclosure Relative to C3 Gallery													
8		Steam from LAW Melter Feed												
9	LMP01	Melter Air Inleakage												
10	LMP02/03	Melter Injected Air												
11	LMP06	Melter Offgas	8.34E-01	E77	2.32E+02	E45	5.49E+02	E51	2.55E+00	E47	7.10E+02	E45	6.54E+02	E51
12	LMP11	Film Cooler Air												
13		Film Cooler Discharge	8.34E-01	E76	2.06E+02	E45	4.42E+02	E51	2.55E+00	E46	6.31E+02	E45	5.27E+02	E51
14	LMP13	Pressure Control Air												
15	LMP14	Controlled Offgas	8.34E-01	E76	1.78E+02	E45	3.36E+02	E51	2.55E+00	N8/E34	5.45E+02	E45	4.01E+02	E51
16	LMP14 Piping Pressure Drop													
17	LOP02	SBS Discharge	8.34E-01	E76	3.87E+02	E45	4.32E+02	E51	2.31E-01	E69/N14	1.07E+02	E45	4.67E+01	E51
18	FC/Jumper/SBS Inleakage													
19	LOP02 Piping Pressure Drop													
20	LOP06	WESP Bulge Air Purge												
21	LOP08	WESP Discharge	8.34E-01	E76/E10	2.79E+02	E45	3.20E+02	E51	2.23E-02	E69/N14	7.44E+00	E45	3.33E+00	E51
22		WESP Inleakage												
23	LOP08 Piping Pressure Drop													
24		Offgas Flow through Control Valve	8.34E-01	E10	2.62E+02	E45	3.17E+02	E51	2.23E-02	E10	7.00E+00	E45	3.30E+00	E51
25	LVP01	Vessel Vent Offgas	0.00E+00	E50	0.00E+00	E45	0.00E+00	A16	5.91E-03	N21	1.84E+01	E45	8.37E+00	E51
26	LVP03	Combined Offgas	1.67E+00	E9	2.49E+02	E45	3.02E+02	E51	5.04E-02	E9	7.54E+00	E45	3.56E+00	E51
27	LVP03 Piping Pressure Drop													
28	LVP04	HEPA Preheater Discharge	1.67E+00	E10	2.29E+02	E45	3.02E+02	E51	6.14E-02	E10/N2	8.42E+00	E45	4.33E+00	E51
29	LVP04 Piping Pressure Drop													
30	LVP06	HEPA Discharge	1.67E+00	E10	2.19E+02	E45	3.02E+02	E51	3.07E-05	R28	4.03E-03	E45	2.17E-03	E51
31	HEPA Bank Inleakage													
32	LVP06 Piping Pressure Drop													
33	LVP26	S-AC Column Discharge	1.67E+00	E10	1.89E+02	E45	3.00E+02	E51	3.07E-05	E10	3.48E-03	E45	2.16E-03	E51
34	S-AC Column Inleakage													
35	LVP26 Piping Pressure Drop													
36	LVP10	Skid Preheater Discharge	1.67E+00	E10	1.09E+02	E45	2.99E+02	E51	3.07E-05	E10	2.00E-03	E45	2.15E-03	E51
37	LVP11	Skid Electric Heater Discharge	1.67E+00	E10	1.02E+02	E45	2.99E+02	E51	3.07E-05	E10	1.87E-03	E45	2.15E-03	E51
38	LVP12	TCO Discharge	4.39E-01	E50	2.57E+01	E45	7.88E+01	N15	3.07E-05	E10	1.80E-03	E45	2.15E-03	E51
39		Ammonia Dilution Air												
40		Dilution Air Fan Discharge												
41	AMR03	Ammonia												
42	LVP13	Diluted Ammonia Addition												
43	LVP23	SCR Input	4.39E-01	E10	2.24E+01	E45	6.09E+01	E51	3.07E-05	E10	1.57E-03	E45	1.66E-03	E51
44	LVP14	SCR Discharge	4.39E-01	E10	1.96E+01	E45	6.07E+01	E51	3.07E-05	E10	1.37E-03	E45	1.66E-03	E51
45	LVP09	Catalyst Skid Discharge	4.39E-01	E10	2.75E+01	E45	6.07E+01	E51	3.07E-05	E10	1.93E-03	E45	1.66E-03	E51
46	Catalyst Skid Inleakage													
47	LVP09 Piping Pressure Drop													
48	LVP18	Caustic Scrubber Discharge	4.39E-01	E10	3.28E+01	E45	5.26E+01	E51	3.07E-05	E10	2.30E-03	E45	1.43E-03	E51
49		Caustic Scrubber Inleakage												
50	LVP18 Piping Pressure Drop to Fans													
51	LVP08	Exhauster Discharge	4.39E-01	E10	4.27E+01	E45	5.24E+01	E51	3.07E-05	E10	2.99E-03	E45	1.43E-03	E51
52	Exhauster Inleakage													
53	LVP08 Piping Pressure Drop to Stack		4.39E-01	E10	4.19E+01	E45	5.23E+01	E51	3.07E-05	E10	2.94E-03	E45	1.43E-03	E51
54	Hanford Atmospheric Pressure (Pressure Balance)													

Data Discussions via Notes:

1. SCFM flowrates are defined at standard conditions of 20°C and 1 atm.
2. The particulate flowrate in HEPA Discharge (LVP06) is equal to the particulate flowrate in upstream HEPA preheater discharge (LVP04) plus the predicted ammonium nitrate formed before the HEPA filters, calculated in Attachment 32.
3. The vessel ventilation offgas volumetric flowrate for the minimum, nominal, and maximum cases is calculated in Attachment 4.
4. Offgas gaseous contaminant concentrations for the melter, SBS, and WESP discharges are calculated in Attachment 28. The nominal case uses average data from melter runs based only on prototypical feed vectors (not spiked with organics). The maximum and minimum cases used the average concentration defined for the nominal case plus or minus, respectively, the standard deviation of the prototypical data. Since carbon dioxide will not be removed by any of the primary offgas equipment (i.e., acid scrubbing), it is defined at the SBS inlet (cell BM-15) to preserve the downstream mass balance [CO_2 vol% taken from Attachment 28 (Melter), Column U].
5. Due to compression heating, the melter offgas temperature will increase as it is pulled through the fans. This temperature increase is calculated for the four cases in Attachment 7.
6. The pressure drop across the SBS for the minimum, nominal, and maximum cases are determined to be 26.4, 32.2, and 34.7 in. WG respectively, based on data from VSL reports listed in Attachment 10.
7. Per LAW Process Flow Diagram 24590-LAW-M5-V17T-00010 (Ref. 9.16), the offgas system exhausters are driven by "variable speed drive" motors and will be controlled by the same speed controller. This will result in extraction fans operating at approximately the same RPMs. Therefore, to determine the motive force required by the fans for the minimum, nominal, and maximum cases, the pressure increase across the fan set defined in cell [S-51] is manually adjusted until the absolute pressure in cell [W-53] equals the site atmospheric pressure defined in cell [W-54]. The pressure increase defined in cell [S-51] provides the exhauster discharge pressure in cell [W-51] used in Attachment 7 to calculate the temperature increase across the fans.
8. Offgas particulate concentrations for the DM-1200 melter discharge are defined and analyzed in Attachment 33. The average particulate mass concentration out of the melter was calculated to be 27.1 mg/dscf. Taking into account the calculated standard deviation of the data, the minimum and maximum particulate mass concentrations were calculated as 0.4 and 53.8 mg/dscf.
9. The Caustic Scrubber steam flowrate is adjusted until the relative humidity is 100%.
10. Offgas relative humidities are calculated per Equation 9a & 9b using the offgas temperature in Column O, the offgas pressure in Column W, and the offgas water volume percentage (i.e., mole fraction) in Column BY.
11. The steam content (i.e., humidity ratio) in the melter offgas or offgas inleakage will follow Assumption 1. The contamination zone from which the inleakage air originates was determined from general arrangement drawings 24590-LAW-P1-P01T-00002 & -00005 (Ref. 9.26 & 9.27). SBS and WESP inleakages are from C5; the melter inleakage is primarily from the C5 ventilation supply (see footnote 3 of Table 1); all other inleakages or air addition are from C3 areas. The minimum case temperature is set at 59°F which is the minimum C3/C5 temperature per Table 12-4 of the Basis of Design (Input 52), with a relative humidity of 30% (Assumption 1). The nominal case temperature is set at 80°F (Assumption 66) with a relative humidity of 40% (Assumption 1). The maximum case temperature is set at 95°F for C3 areas (Input 53) and 113°F for C5 areas (Input 12). These are the maximum temperatures allowed in these areas per Table 12-1 of the Basis of Design (Inputs 53 & 12). The relative humidity is defined at 100% for the maximum case for bounding conservatism. A psychrometric chart from Perry's (Ref. 10.2.14, Fig. 12-2b) was used to determine the corresponding absolute humidity: 0.004 lb water/lb dry air for the minimum case, 0.009 lb water/lb dry air for the nominal case, and 0.036 lb water/lb dry air for the maximum case for the C3 air, and 0.065 lb water/lb dry air for the maximum case for the C5 air.

12.	The SCR ammonia addition flowrates (AMR03) and the ammonia flowrates in SCR discharge are calculated in Attachment 8.	
13.	The SCR discharge stream temperature, air flowrate, water flowrate, and other flowrates have been adjusted to account for the reaction of NO_x with NH_3 to form N_2 and H_2O as discussed in Attachment 8. See Section 5.23 for the methodology regarding the final temperature of the stream exiting the SCR.	
14.	Overall SBS and WESP decontamination factors (DF) are calculated in Attachment 34 based on LAW pilot melter runs, feed vectors, and operating conditions. The maximum SBS DF will be used in the maximum cases because this case is associated with the high melter particulate emissions (i.e., minimum melter DF). There is an inverse relationship between melter and SBS DFs (i.e, in case of high melter particulate emission (low melter DF), the SBS captures more particulates (high SBS DF). Conversely, the minimum SBS DF will be used in both minimum cases when there is low melter particulate emission. For similar reasons, the minimum WESP DF will be used in the maximum cases to maximize the particulates and the maximum WESP DF used in the minimum case. The nominal SBS and WESP DFs will be used in the nominal case.	
15.	The catalyst skid decontamination factors based on concentration (ppmv) are calculated in Attachment 42 for the TCO. The minimum DF is used for the maximum cases. The maximum DF is used for the minimum cases, and the average DF is used in the nominal case.	
16.	The pressure drop across the Activated Carbon column is determined from the equation developed in Attachment 25.	
17.	Equal to the hydrogen generation rate calculation in Attachment 4. This generation rate is constant due to radiolysis of the waste.	
18.	See Section 5.17 for the methodology. The temperature increase due to the heat of reaction in the TCO is calculated in Attachment 20.	
19.	Deleted	|
20.	An Iodine-129 emission rate from the LAW melter is determined in Attachment 36. The amount of iodine available for the offgas is based on contract maximum values. A DF of 2.5 is applied (Input 54) to split some iodine to the glass product and some to the offgas. This value is used for all cases for the I-129 emission rate~~.~~	|
21.	The vessel ventilation particulate mass flowrate is defined from Attachment 4, Section A4.8.2, using the unit conversion of 1,000,000 mg per kg.	
22.	The air, water, and other component flowrates in the TCO discharge have been adjusted to account for the CO_2 and H_2O formed from the reaction of VOC/CO, and O_2 consumed as discussed in Attachment 20.	
23.	The catalytic skid recuperative heat exchanger cold-side and hot-side outlet temperatures are calculated in Attachment 40.	
24.	The pressure drop across the control valve is calculated based on the equation developed in Attachment 41.	
25.	The VOC concentrations (ppm) are taken from VSL data and averaged in Attachment 24.	
26.	The Caustic Scrubber outlet temperature and outlet steam mass flow are calculated in Attachment 39.	
27.	The Caustic Scrubber outlet dry air flow (SCFM) includes the spray nozzle air addition calculated in Attachment 39, Section A39.1.	
28.	HCl, HF, SO_2, NO_2 and CO_2 mass flowrates in the caustic scrubber discharge are determined by multiplying the corresponding component mass flow at the scrubber inlet by (1 - removal efficiency). See Inputs 16, 17, and 18 in Section 2.1 for caustic scrubber HCl, HF, SO_2, NO_2 and CO_2 removal efficiency.	

Data Discussions via Equations:	
1.	Offgas vol flowrate is the total flowrates of dry air, steam and others (total of Columns C, E, and G).
2.	Stream flowrate is the sum of all contributing flowrates (Sum of Rows 8, 9, and 10).
3.	Flowrate of film cooler discharge (and its gas components) is the sum of melter offgas and film cooler air addition corresponding flowrates (sum of Rows 11 and 12).
4.	Controlled offgas (and its gas components) flowrates is the sum of film cooler discharge and control air flowrates (Sum of Rows 13 and 14).
5.	The flowrates of primary offgas components (N_2, O_2, CO_2, Ar) / dry air in the SBS discharge (LOP02) are equal to those in the Controlled offgas stream (LMP14).
6.	The volumetric flow of gas components in WESP discharge (LOP08) is determined by combining the volumetric flow of corresponding gas components in SBS discharge, SBS inleakage and WESP Bulge Purge Air (Sum of Rows 17, 18, and 20).
7.	The standard volumetric flowrate of dry air is calculated by subtracting the vol flowrate of steam and other components (Columns E and G) from the total stream vol flowrate (Column I).
8.	The temperature dependent heat capacity of Ammonia is determined using Equation (16b) in Section 5.
9.	Gas component mass flow in Combined Offgas (LVP03) is the sum of component mass flow in the vessel vent (LVP01) and the component mass flow in the WESP Discharge Offgas flow thru control valve multiplied by the number of melters.
10.	The cell's flowrate is equal to the flowrate defined in the previous unit's discharge plus the previous unit's defined inleakage (if applicable).
11.	Equal to Row 13 minus Row 12. The CO_2 vol% from the controlled offgas is fixed (LMP14, cell BM-15). Working backwards to the start of the offgas train, the CO_2 mass flow in the film cooler air is subtracted from the CO_2 mass flow in the film cooler discharge to determine what the CO_2 level would be in the melter offgas.
12.	Combined offgas temperature is calculated from a heat balance of inlet and outlet streams using Equation (17a) for non-reactive streams and Equation (17b) for reactive streams around TCO & SCR).
13.	Sum of Rows 8, 9, and 10 plus the additional carbon dioxide generated from cold cap decomposition which is calculated by multiplying the defined carbon dioxide volume percentage by the overall offgas standard volumetric flowrate.
14.	Equation (1b) is used to convert the gas mass flowrates (kg/hr) to standard volumetric flowrates in SCFM.
15.	Deleted.
16.	Column Q is calculated from Column O using Equation (2a) which converts degree Celsius to Fahrenheit.
17.	Column O is calculated from Column Q using Equation (2b) which converts degree Fahrenheit to degree Celsius.
18.	Equation (1a) in the methodology (calculation Section 5) is used to convert the SCFM flowrates to a mass flowrate (kg/hr).
19.	Use Equation (8) in Section 5 to determine the water vapor volumetric flowrate from dry air vol flowrate (column C), absolute humidity (column O) and molecular weight ratio between air and water.
20.	The mass flowrate in kg/hr is converted to lb/hr using the conversion factor of 2.20462 lb/kg.
21.	Pressure in units of "mbar" is converted to "in. WC" using unit conversion factors of (33.9 ft WC / 1013.25 mbar) *(12 in/ft).

22.	Pressure in units of "in. WC" is converted to "mbar" using unit conversion factors of (1013.25 mbar / 33.9 ft WC)*(ft/12 in).
23.	The offgas absolute pressure is calculated by adding the defined pressure change in Column S to the absolute pressure upstream (i.e., the previous row).
24.	Equal to Row 15 minus Row 14. The CO_2 vol% from the controlled offgas is fixed (LMP14, cell BM-15). Working backwards to the film cooler discharge, the CO_2 mass flow in pressure control air is subtracted from the CO_2 mass flow in the controlled offgas to determine the CO_2 mass flow in the film cooler discharge.
25.	The "actual" offgas flowrates in ft^3/min (ACFM) is calculated from the "standard" offgas flowrate in Column I and offgas temperatures and absolute pressure in Columns O and W, respectively (using Equation 6a).
26.	Weight % of components in the offgas streams are calculated using Equation (14a) to solve for mass fractions based on component volume fraction and the ratio between the molecular weight of components (defined in Input 2.2) and overall calculated offgas stream molecular weight in Column AE.
27.	Offgas density is calculated using Equation (7) and the defined offgas temperatures and absolute pressure defined in Columns O and W, respectively, and the average offgas molecular weight defined in Column AE.
28.	Offgas density is converted from "kg/m^3" to units of "lb/ft^3" using a conversion factor of 2.20462 lb/kg and 35.3145 ft^3/m^3.
29.	Deleted
30.	Deleted
31.	The offgas humidity ratio (lb H_2O / lb Air) is calculated by dividing the water weight percent (Column BW) by "1" minus the water weight percent. See Equation (11) in Section 5.
32.	No temperature change in LVP08 piping to stack (Equal to O51).
33.	Deleted
34.	The particulate mass flow (kg/hr) is calculated from concentration (mg/dscf) by multiplying the concentration by the dry air SCFM in column C and using conversion factors 60 min/hr and $1x10^6$ mg/kg .
35.	The component mass flowrate is calculated by multiplying the associated weight fraction by the overall mass flowrate defined in Column K.
36.	Component wt% is calculated by dividing the gas component mass flowrate by the overall stream mass flowrate defined in Column K.
37.	Equation (14b) is used to convert mass fraction to volume fraction.
38.	Component dry air volume fractions for pure air additions to the offgas streams are defined based on the US standard atmosphere from CRC, Page 14-20 (Input 2.6). The dry air component volume % are adjusted to account for the realized gas humidity by multiplying the dry air component vol% by the ratio of dry air to total air volumetric flowrates defined in Columns C and I, respectively.
39.	The water volumetric fraction is calculated by dividing the water volumetric flowrate in Column E by the overall volumetric flowrate in Column I.
40.	Defined equal to Row 43 multiplied by (1-DF), with the DF of 98% per Input 15 in Section 2.1.
41.	NH_3 mass flow in the SCR discharge stream (LVP14) is equal to the NH_3 mass flow in SCR input stream (LVP23) plus the Ammonia addition calculated in Attachment 8.

42.	The vessel ventilation hydrogen volumetric flowrate is obtained from Attachment 4, Section A4.8.3 and converted to a mass flowrate using the unit conversions 28.32 L/ ft^3, 22.4 L/mol, 1000 g/kg, 60 min/hr and the MW of H_2 (2.01588 g/mol).
43.	The VOC mass flow in TCO discharge is reduced 95% based on the TCO VOC DRE (Input 13).
44.	Defined equal to the overall ammonia addition mass flowrate defined in cell [K-41].
45.	Offgas contaminant mass concentrations (mg/m^3) are calculated by dividing the contaminant mass flowrate by the overall volumetric flowrate in Column Y and then applying unit conversion factors of 35.3145 ft^3/m^3, 60 min/hr, and 10^6 mg/kg (see Equation 4).
46.	Gas contaminant mass flow in Film Cooler discharge is equal to that in Controlled Offgas (Equal to Row 15)
47.	Gas contaminant mass flow in melter offgas discharge is equal to that in film cooler discharge (Equal to Row 13).
48.	H_2 mass flow in Controlled Offgas is equal to that in SBS discharge (Equal to Row 17).
49.	H_2 mass flow in SBS discharge is equal to that in WESP discharge (Equal to Row 21).
50.	Offgas contaminant mass flowrates are calculated using Equation 1a. The contaminant volumetric flowrate is calculated using the overall actual volumetric flowrate defined in Column Y multiplied by the contaminant volumetric concentration (ppm_v) and then applying unit conversion factors of 35.3145 ft^3/m^3, 60 min/hr, and 1,000,000/ppm_v. The offgas pressure (mbar) is defined in Column W and converted to Pa by applying the unit conversion factor of 100 Pa/mbar. The contaminant molecular weight is defined from Table 2. The offgas temperature is defined in Column O and then converted to absolute temperature by adding 273.15 K. The final unit conversion factor is 1000 g/kg.
51.	Offgas contaminant volumetric concentrations (i.e., ppm_v) are calculated from the component mass flowrate, temperature, pressure, molecular weight and total stream volumetric flowrate using Equation (5).
52.	Offgas heat capacity is calculated from Equation (16a), using the temperature dependent equations for the primary offgas components defined in Attachment 15. The overall offgas heat capacity is determined as the weighted average of outputs from these equations, based on the gas component weight percent defined in Columns AY, BE, BK, BQ, and BW.
53.	Hg mass flow in WESP discharge is equal to Hg mass flow in SBS Discharge (no removal of Hg in WESP).
54.	Offgas heat capacity is converted from "KJ/kg-C" to unit of "Btu/lb-F" using conversion factors of 9.486E-4 Btu/J, 5°C/9°F, 1000 J/KJ, and 2.20462 lb/kg.
55.	The absolute pressure of the combined offgas (LVP03) is equal to the pressure of the upstream offgas flow through control valve, assuming the vessel vent being at the same pressure (Assumption 28).
56.	Offgas molecular weights are calculated using Equation (12) based on a weighted average of the individual component molecular weights defined in Table 2 (Input 2.2) and the component volumetric percentages of primary gas components (Columns BA, BG, BM, etc.) or the volumetric concentration, ppm_v, for the contaminants, (i.e, Columns CE, CK, CQ, CW, etc.).
57.	Offgas contaminant (i.e., others) standard vol. flowrates (Col G) are calculated by multiplying the sum of contaminant volumetric concentrations (i.e., ppmv from Columns CE, CK, CQ, CW, etc.) by the stream overall standard volumetric flowrate and dividing by 10^6.
58.	Deleted
59.	The water mass flow in LVP23 is the sum of water mass flow in LVP12 & LVP13 (Sum of Rows 41 and 45)

60.	Deleted
61.	The SCR input stream (LVP23) volumetric flowrate is the TCO discharge flowrate plus the diluted ammonia addition flowrate.
62.	The mass flowrate (kg/hr) is converted to standard flowrate (SCFM) by using Equation (1b) and conversion factors of 35.3145 ft^3/m^3, 1000 g/kg, hr/60 min, and 1000 mbar/bar.
63.	The steam content (i.e., humidity ratio) in the vessel vent offgas is determined from a psychrometric chart (Perry's, Ref. 10.2.14, Figure 12-2b) based on the stream temperature and relative humidity.
64.	Deleted
65.	The temperature of the WESP discharge flow through the control valve is the same as that of the WESP discharge offgas; the air inleakage flow is insignificant compared to the offgas flow and thus does not affect the offgas stream temperature.
66.	Hg mass flow in SBS discharge is equal to Hg mass flow in controlled Offgas divided by the DF of 6 (Assumption 55).
67.	The NO mass flow in the SCR discharge stream (LVP14) is the NO mass flow in the SCR input stream (LVP23) multiplied by (1 - reduction efficiency), with the reduction efficiency of 98% per Input 15.
68.	Deleted
69.	Mass flow out is equal to the mass flow in divided by the DF in Attachment 34.
70.	Deleted
71.	Deleted
72.	Deleted
73.	Deleted
74	Total mass flow of LVP09 (cell K-47) is the sum of catalyst skid discharge mass flow and air inleakage mass flow (Sum of K-45 and K-46).
75	Mass fraction is from APPS data: LMP06 total VOC and SVOC mass flow divided by total stream mass flow (See Input 2.14). This fraction is then multiplied by cell K-11, the total stream mass flow in this flowsheet to give the total VOC/SVOC mass flow.
76	Gas contaminant mass flow in Film Cooler discharge, Controlled Offgas, SBS discharge & WESP discharge streams is equal to that in Melter Offgas (no change in mass flow from melter through the WESP).
77	Mass fraction is from APPS data: LMP06 constituent mass flow is divided by total stream mass flow (See Input 2.14). This fraction is then multiplied by cell K-11, the total stream mass flow in this flowsheet to give the total constituent mass flow.
78	For the maximum case, the mass flow of NO, HCl, HF, and SO_2 at the SBS and WESP discharge is determined by using Equation (3a) and applying the DF across the SBS and WESP (Input 2.15). This is done for all cases for iodine.
79	Mass flow equal to mass flow in melter offgas discharge

Data Discussions via References:	
1.	Section 2.1, Table 1 (Input 2)
2.	Section 2.1, Table 1 (Input 3)
3.	Section 2.1, Table 1 (Input 5)
4.	Deleted.
5.	The WESP Bulge Air purge flowrate is defined as 350 ACFM at 1 psig (434.5 in WC using conversion factor of 33.9 ft/14.7 psi and 12 in/ft) per Vendor P&ID 24590-QL-POA-MKE0-00001-06-33 (Input 6). This flowrate is realized in this calculation by manually adjusting the SCFM flowrate in cell C-20 until the related ACFM flowrate defined in Column Y equals the specified flowrate. The purge air temperature is also defined as 5°F above the WESP inlet temperature per the same Vendor P&ID (Section 2.1, Input 7).
6.	In melter tests on the DM3300 melter described in 24590-101-TSA-W000-0009-87-00019 (Ref. 9.6, pg. T-3), the DM3300 melter was operated to maintain a target plenum temperature of 400°C. To provide a range of temperatures, the minimum temperature is set at 300°C, and the maximum is set at 500°C. See Assumption 29 and Input 10.
7.	Section 2.1, Table 1 (Input 11).
8.	The steam standard flowrate in cell E-17 is manually adjusted until the relative humidity in cell AC-17 is 100% per Assumption 6.
9.	Not Used.
10.	Due to resistance heating, the melter offgas will normally increase in temperature as it passes through the WESP. Per Attachment 6, the average temperature increase was 1.7°C over several melter runs. Taking into account the standard deviation of the data, the minimum and maximum temperature rise are 0°C and 3.4°C, respectively, also per Attachment 6.
11.	Section 2.1, Table 1 (Input 19)
12.	Not Used.
13.	Not Used.
14.	Section 2.1, Table 1 (Input 1)
15.	Section 2.1, Table 1 (Input 27)
16.	The average (i.e., normal) film cooler pressure drop and transfer line pressure drop are calculated in Attachment 9 to be 1.1 in. WG and 1.9 in. WG. Taking into account the calculated standard deviation of the data, the minimum and maximum pressure drop is defined as 0.5 and 1.8 in WG (film cooler) and 0.9 and 2.9 in. WG (transfer line), respectively.
17	The pressure drops across units within the catalyst skid are determined based on pressure drop equations developed in Attachment 37.
18.	Per Table 1, Inputs 28 and 29, the pressure set points in the C2 area and the C3 area will be established to maintain a cascade differential pressure of -0.1 and -0.3 inch WG relative to the preceding area, resulting in a total pressure drop of -0.4 in. w.g.
19.	The melter annulus is held to a 2 inch WC vacuum relative to the C3 melter gallery (Section 2.1, Table 1, Input 30).
20.	The average (i.e., normal) WESP pressure drop is calculated in Attachment 11 to be 2.6 in. WG. Taking into account the calculated standard deviation of the data, the minimum and maximum pressure drop is defined as 1.9 and 3.3 in. WG.
21.	Deleted.
22.	The anhydrous ammonia system contains no humidity by definition.

23.	Not Used.
24.	The anhydrous ammonia molecular weight is per CRC as defined in Table 2, Section 2 (Input 2.2).
25.	Nitric Oxide (NO) mass flowrate is reduced by the SCR NOx abatement efficiency of 98% per Input 15.
26.	VOC mass flow in LVP12 is reduced by the TCO VOC abatement efficiency of 95% per Input 13.
27.	Not Used.
28.	The dual HEPA filter particulate removal efficiency of 99.95% is defined per Input 14. Therefore the particulate flowrate in the HEPA discharge (LVP06) is equal to the particulate mass flow at the HEPA inlet multiplied by (1-removal efficiency).
29.	Not Used.
30.	Not Used.
31.	See methodology section 5.19 (Equation 21) and assumptions 49 and 57 for the determination of Hg mass flow in minimum, nominal and maximum cases.
32.	Not Used.
33.	The mass rate of Hg leaving the activated carbon bed unit is determined in Attachment 35 based on the permit mercury limit of <45 micrograms / dry std. cubic meter (Input 31) and the carbon bed dry air volumetric flow.
34.	Not Used.
35.	Not Used.
36.	Not Used.
37.	Not Used.
38.	Deleted.
39.	The steam flowrate (SCFM) from the LAW melter feed to the melter is calculated in Attachment 2 and Attachment 5.
40.	Deleted.

Attachment 2 Melter Steam Generation Determination

Attachment 2 - Melter Steam Generation Determination

Attachment 2 converts mass flowrate of steam generated to volumetric flowrates for use in Attachment 1 main flowsheets.

Unit Definition:

Length

$mm \equiv \frac{m}{1000}$

$in \equiv 25.4 \cdot mm$

$ft \equiv 12 \cdot in$

$cm \equiv \frac{m}{100}$

$\mu m \equiv \frac{mm}{1000}$

Energy

$J \equiv \frac{kg \cdot m^2}{s^2}$

$KJ \equiv 1000 \cdot J$

$Btu \equiv 1055.1 \cdot J$

Temperature

$C \equiv K$

$F \equiv \frac{5}{9} \cdot C$

$F \equiv R$

Power

$W \equiv \frac{J}{s}$

$mW \equiv \frac{W}{1000}$

$kW \equiv 1000 \cdot W$

$Hp \equiv 745.71 \cdot W$

Volume

$L \equiv \frac{m^3}{1000}$

$gal \equiv \frac{ft^3}{7.4805}$

$ml \equiv \frac{L}{1000}$

Pressure

$Pa \equiv \frac{kg}{m \cdot s^2}$

$\mu Pa \equiv \frac{Pa}{1000000}$

$bar \equiv 100000 \cdot Pa$

$mbar \equiv \frac{bar}{1000}$

$atm \equiv 1.01325 \cdot bar$

$psi \equiv \frac{atm}{14.696}$

$inWC \equiv \frac{psi}{27.681}$

$mmWC \equiv \frac{inWC}{25.4}$

Force

$N \equiv kg \cdot \frac{m}{s^2}$

$mN := \frac{N}{1000}$

Viscosity

$cP \equiv 1000 \cdot \mu Pa \cdot s$

$P \equiv 100 \cdot cP$

Time

$min \equiv 60 \cdot s$

$hr \equiv 3600 \cdot s$

$day \equiv 24 \cdot hr$

$year \equiv 365.25 \cdot day$

Substance

$kmol \equiv 1000 \cdot mole$

$lbmole \equiv \frac{kmol}{2.20462}$

$mmol \equiv \frac{mole}{1000}$

Mass

$g \equiv \frac{kg}{1000}$

$lb \equiv \frac{kg}{2.20462}$

$\mu g \equiv \frac{g}{1000000}$

$MT \equiv 1000 \cdot kg$

Gravity

$g_n := 9.81 \cdot \frac{m}{s^2}$

Gas Constant

$R_G := 8.314 \cdot \frac{J}{mol \cdot K}$

The range of steam flowrates into the melter offgas in SCFM is calculated as follows using the steam mass flowrates defined in *Attachment 5*. The mass flowrate is converted to a volumetric flowrate using Equation 1b from Section 5 of the main calculation body (Methodology).
The minimum case uses the minimum water rate, the nominal case uses the average water rate, and the maximum case uses the maximum water rate (*Column H* from the spreadsheet in Attachment 5).

$i := 1 .. 4$

Steam Mass Flowrates =>

$$m_S := \begin{pmatrix} 1180.8 \\ 1124 \\ 1067.3 \\ 1067.3 \end{pmatrix} \cdot \frac{lb}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

Standard Temperature =>

$T_S := 293.15 \cdot K$

Standard Pressure =>

$P_S := 1 \cdot atm$

Water Molecular Weight => $MW_S := 18.01 \cdot \frac{g}{mol}$ per CRC (Ref. 10.2.6, Page 4-111)

Steam SCFM Flowrate (Equation 1b) =>

$$V_{S_i} := \frac{\left(\frac{m_{S_i}}{MW_S}\right) \cdot R_G \cdot T_S}{P_S} \qquad V_S = \begin{pmatrix} 421 \\ 400.8 \\ 380.6 \\ 380.6 \end{pmatrix} \cdot \frac{ft^3}{min} \qquad \begin{matrix} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{matrix}$$

These steam flowrates are entered into **cell E-8** in Attachment 1 flowsheets.

Attachment 3 Mercury Concentration in TFCOUP6 Feed Batches

Attachment 3 provides the graph of mercury concentration in TFCOUP6 feed batches extracted from calculation 24590-WTP-M4C-V11T-00037 and associated RMVD-03212 (Ref. 9.64(a), TFCOUP6 Batch Evaluation.xls, worksheet "Contract – LAW").

In cell AQ-4, select "Hg+2" in the drop-down list, then hit F9 to obtain the resulting graph shown as Figure 1 in this Attachment. This graph shows the ratio of mercury to sodium in each batch in feed vector TFCOUP6. Figure 2 is the same plot with the y-axis decreased to the mercury contract maximum of 1.4E-05 mol Hg/mol Na (Input 36) to provide more mercury concentration details in this range.

Figure 1 – Mercury Concentration Distributed over TFCOUP6 Batches

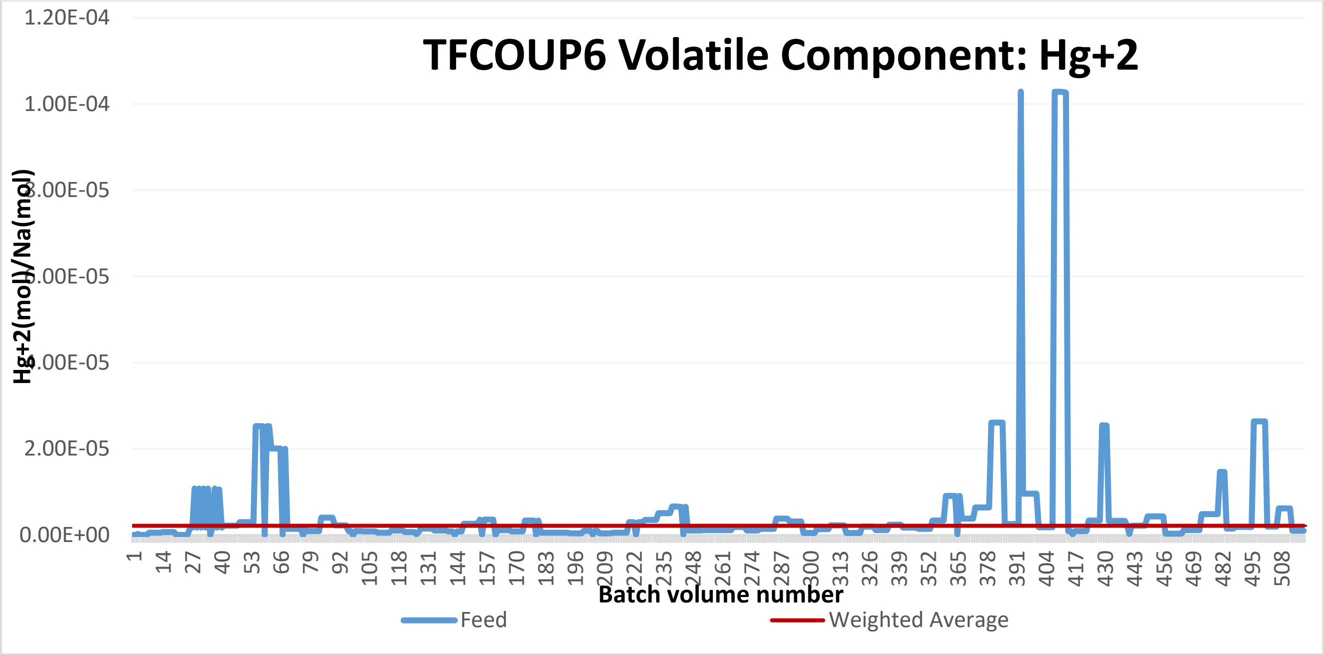
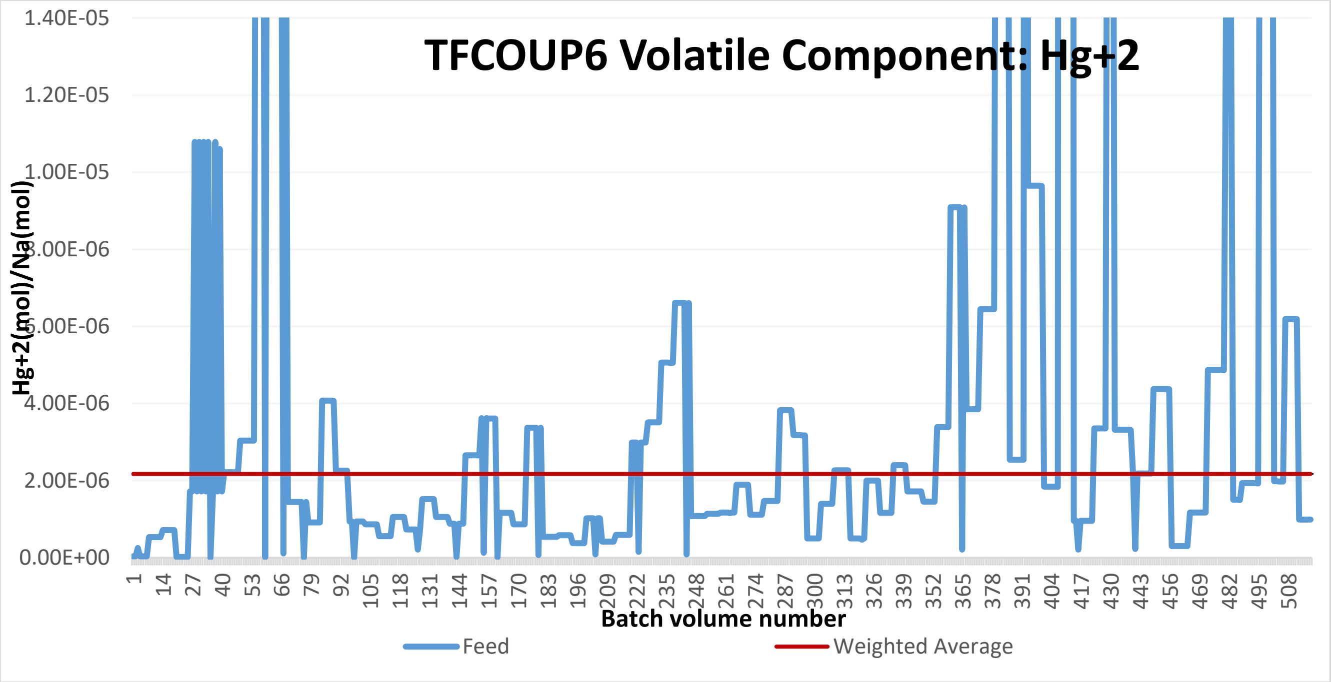


Figure 2 – Mercury Concentration Distributed over TFCOUP6 Batches, Y-Axis Scaled to Contract Maximum



Attachment 4 LAW Vessel Ventilation Design Basis Flowsheets

Contents

Page Number

A4.1 Objective

A vessel ventilation system is in place for the LAW Vitrification Facility. The purpose of this calculation is to:

- Define the hydrogen generation rate into the vessel ventilation system.
- Determine the total minimum, nominal, and maximum volumetric flowrate of air into the vessel ventilation system.
- Determine the minimum, nominal, and maximum mass flowrate of particulates into the vessel ventilation system

A4.2 Inputs

A4.2.1 Vessel Inleakage

The molecular weight of dry air is 29.0 lb/lbmole (Ref. A4.10.3, pg. 142).

A4.2.2 Jet Particulate Entrainment

I.1 The TCP vessel (TCP-VSL-00001) transfers to LCP-VSL-00001/2 at a nominal rate of 88 gpm (Ref. A4.9.45, pg. 1). The inlet pipe to LCP-VSL-00001/2 is 3" and Schedule 40S (Ref. A4.9.9 & A4.9.49, pg. 2). The pipe inside diameter is 3.068" (Ref. A4.10.1, pg. B-16).

I.2 LCP-VSL-00001/2 transfer to LFP-VSL-00001/3 (normal operation) at a nominal rate of 88 gpm via LCP-PMP-00001A/B & -00002A/B (Ref. A4.9.37, Section 8). The pump discharge pipe to LFP-VSL-00001/3 is 2" and Schedule 80S (Ref. A4.9.31, pg. 14; Ref. A4.9.11 & A4.9.13; Ref. A4.9.49). The pipe inside diameter is 1.939" (Ref. A4.10.1, pg. B-16).

I.3 LFP-VSL-00001/3 transfer to LFP-VSL-00002/4 at a nominal flowrate of 50 gpm via LFP-PMP-00001A/B & -00003A/B (Ref. A4.9.38, Section 8; Ref. A4.9.32, pg. 12). The pump discharge pipe to LFP-VSL-00002/4 is 2" and Schedule 80S (Ref. A4.9.32, pg. 11; Ref. A4.9.44/A4.9.22; Ref. A4.9.49). The pipe inside diameter is 1.939" (Ref. A4.10.1, pg. B-16).

I.4 Transfers into RLD-VSL-00003: Pumps NLD-PMP-00003A/B transfer C1/C2 effluent into RLD-VSL-00003 at a nominal rate of 100 gpm (Ref. A4.9.35). LCP-VSL-00001/2 transfer at a nominal rate of 88 gpm (Ref. A4.9.37, Section 8). LFP-VSL-00001/3 transfer at a nominal rate of 50 gpm (Ref. A4.9.32, pg. 12). LFP-VSL-00002/4 transfer at a nominal rate of 50 gpm (Ref. A4.9.40, pg. 12). RLD-PMP-00004 transfers sump effluent to RLD-VSL-00003 at a nominal rate of 30 gpm (Ref. A4.9.36, pg. 7 & 9). The highest flowrate, 100 gpm, will be used in the particulate entrainment calculation section A4.7.4 because it will result in the highest jet velocity.

I.5 The smallest inlet pipe diameter leading to RLD-VSL-00003 is 2 inches (Ref. A4.9.23). This pipe is Schedule 40S (Ref. A4.9.48, pg. 3). The pipe has an inside diameter of 2.067 inches (Ref. A4.10.1, pg. B-16).

I.6 Transfers into RLD-VSL-00005: The LOP submerged bed scrubbers transfer the SBS condensate to RLD-VSL-00005 at a nominal rate of 48 gpm via LOP-PMP-00003A/B & -00006A/B (Ref. A4.9.34, Section 8.1) through a 2", Schedule 40S pipe (Ref. A4.9.42 & A4.9.43, Ref. A4.9.47, pg. 2).
The LOP SBS condensate vessels (LOP-VSL-00001/2) transfer the SBS condensate at a nominal rate of 124 gpm via LOP-PUMP-00001/2/4/5 through the same entry nozzle (Ref. A4.9.33, Section 8; Ref. A4.9.42 & A4.9.43). Pumps RLD-PMP-00002A/B normally transfer C3/C5 effluent from RLD-VSL-00004 to RLD-VSL-00005 at a rate of 75 gpm. The pump discharge line to RLD-VSL-00005 is 2 inch, Schedule 40S (Ref. A4.9.39, pg. 15; Ref. A4.9.41, Section 8.1, pg. 16; Ref. A4.9.29 & A4.9.30; Ref. A4.9.46, pg. 3 of Attachment 1). The highest flowrate, 124 gpm, will be used in the particulate entrainment calculation section A4.7.4 because it will result in the highest jet velocity. The inside diameter of a 2" Sch. 40S pipe is 2.067 in (Ref. A4.10.1, pg. B-16).

I.7 For jet entrainment, the bubble burst entrainment coefficient for waste liquid has a value of $2 \cdot 10^{-7}$ (Ref. A4.10.2, pg. 2-6 & 6-5 as included in Section A4.11 of this Attachment).

I.8 The Z dimension of LCP-VSL-00001/2, nozzle 3 (feed concentrate inlet) is 15'-1" or 181 in (Ref. A4.9.7 & A4.9.8).

I.9 The Z dimension of LFP-VSL-00001/3, nozzles 5 & 6 (feed concentrate inlet) is 12'-2" or 146 in (Ref. A4.9.5 & A4.9.6).

I.10 The Z dimension of LFP-VSL-00002/4, nozzle 3 (melter feed inlet) is 12'-2" or 146 in (Ref. A4.9.3 & A4.9.4).

I.11 The Z dimension of RLD-VSL-00003, nozzles 7 (sump effluent inlet), 8, 11, 12, 13 (vessel wash inlet), 10 & 14 (C3/C5 & C1/C2 effluent inlet) is 199 in (Ref. A4.9.1).

I.12 The Z dimension of RLD-VSL-00005, nozzles 12 & 13 (SBS condensate inlet) is 190.75 inches (Ref. A4.9.2).

I.13 For the waste in LCP, the minimum density is 1.0 g/mL, the nominal density is 1.38 g/mL, and the maximum density is 1.46 g/mL (Ref. A4.9.37, Section 8).

I.14 For the waste in LFP-VSL-00002/4, the minimum density is 1.0 g/mL, the nominal density is 1.70 g/mL, and the maximum density is 1.80 g/mL (Ref. A4.9.38, Section 8).

I.15 The minimum and nominal density of RLD-VSL-00003 effluent is 61.7 (Ref. A4.9.50, Table A-43, pg. A-44, stream RLD25) and 63.0 lb/ft^3 (Ref. A4.9.54, Section 8), (0.988 and 1.0 g/mL) respectively .

I.16 The nominal density of RLD-VSL-00005 effluent is 62.5 lb/ft^3 (1.0 g/mL) (Ref. A4.9.55, Section 8 and Ref. A4.9.50, Table A-19, pg. A-20, stream LOP05).

I.17 The percent of design life (%DL) that LCP receives LAW concentrate from Pretreatment is 2.7% (Ref. A4.9.37, Section 8).

I.18 The percent of design life (%DL) that LFP-VSL-00001/3 receives LAW concentrate from LCP is 2.7% (Ref. A4.9.38, Section 8).

I.19 The percent of design life (%DL) that LFP-VSL-00002/4 receives melter feed from LFP-VSL-00001/3 is 7.2% (Ref. A4.9.38, Section 8).

I.20 The acceleration due to gravity is 9.8066 m/s^2 (Ref. A4.10.3, pg. 15).

I.21 The gas constant is 0.7302 (ft^3*atm)/(lb-mol*R) (Ref. A4.10.3, back cover).

A4.3 Background

Not Applicable

A4.4 Applicable Codes and Standards

Not Applicable

A4.5 Methodology

Vessels LCP-VSL-00001/2, LFP-VSL-00001/2/3/4, and RLD-VSL-00003/4/5 contribute offgas to the LVP (secondary offgas) system. The different sources and quantity of gas flow are defined in this methodology.

A4.5.1 Vessel Vent Air Addition

The sources into the vessel ventilation system are identified from the P&IDs. Inleakage rates through flanged connections were found in engineering literature. These inleakage rates are multiplied by the number of flanged connections on the vessel to determine the total inleakage rate.

The flowrates for the minimum, nominal, and maximum operating scenarios are defined as follows:

Minimum:	Half of the nominal estimated vessel inleakage
Nominal:	Nominal vessel inleakage through flanged connections
Maximum:	Twice the nominal vessel inleakage

A4.5.2 Individual Hydrogen Purge Rate and Total Hydrogen Generation Rate

The following vessels have an air purge to disperse hydrogen from the vessel headspace: LCP-VSL-00001/2, LFP-VSL-00001/2/3/4, RLD-VSL-00004. The hydrogen generation rate for these vessels is available from calculation 24590-WTP-M4C-V11T-00011 (Ref. A4.9.51, see Assumption A3.2).

Per Assumption A3.2, the hydrogen generation rate is doubled for conservatism. The purge air rate is determined to be 200 times the generation rate (Assumption A3.1). The calculation is performed using Mathcad.

The volumetric flow of purge air is determined at 140°F and 1 atm condition (Assumption A3.2). To provide a conservative value that does not depend on temperature, this calculated flow rate will be used as the value at standard conditions (68 °F and 1 atm).

The hydrogen generation rates from the different vessels are summed to give a total generation rate. This rate is converted to SCFM using Mathcad. For conservatism, this rate is used as the value at standard conditions (68 °F and 1 atm).

A4.5.3 Vessel Vent Air Addition Summary

The vessel inleakage and the hydrogen purge air are totaled to give the total vessel vent flow. The total vessel vent flowrate in SCFM is used in **Cell I-25** in the Attachment 1 main flowsheets.

A4.5.4 Particulate Entrainment

A4.5.4.1 Jet Entrainment

Aerosol formation occurs during pouring and filling operations in the LAW vessels.

The bubble burst entrainment coefficient, E_{mfg}, is given by Ref. A4.10.2 (Input I.7). For each vessel, the highest flowrate into the vessel, the inlet pipe diameter, and the height from nozzle to liquid level are used. First, the jet velocity at the nozzle outlet, v_0, is determined by this common equation:

$$v_0 = \frac{Fl}{\pi \cdot \left(\frac{D}{2}\right)^2}$$

Equation A4-1

v_0 = Jet velocity at the nozzle outlet (m/s)
Fl = Maximum inlet flowrate to vessel (m^3/s)
D = Diameter of inlet pipe (m)

The jet velocity at the point of impact is determined using the jet velocity at the nozzle outlet (Ref. A4.10.2, pg. 6-2):

$$v_j = \left(v_0^{\,2} + 2 \cdot g_n \cdot H\right)^{.5}$$

Equation A4-2

v_j = Jet velocity at impact with liquid (m/s)
v_0 = Jet velocity at the nozzle outlet (m/s)
g_n = Acceleration of gravity (m/s^2)
H = Height from nozzle outlet to liquid level (m). The Z dimension (distance from top of nozzle to the lower vessel tangent length) is used for conservatism.

The jet velocity at impact is used to determine the Froude number (Ref. A4.10.2, pg. 6-4).

$$Fr_j = \frac{v_j^{\,2}}{g_n \cdot D}$$

Equation A4-3

Fr_j = Froude number (dimensionless)
v_j = Jet velocity at impact with liquid (m/s)
g_n = Acceleration of gravity (m/s^2)
D = Diameter of nozzle (m)

The Froude number is then used to calculate the volumetric flowrate of entrained gas (Ref. A4.10.2, pg. 6-4).

$$V_{eg} = Fl \cdot 0.04 Fr_j^{\,.28} \cdot \left(\frac{H}{D}\right)^{0.4}$$

Equation A4-4

V_{eg} = Volumetric flowrate of entrained gas (m^3/s)
Fl = Maximum inlet liquid volumetric flowrate to vessel (m^3/s)

Fr_j = Froude number (dimensionless)
H = Height from nozzle outlet to liquid level (m). The Z dimension (distance from the nozzle flange to the lower vessel tangent length) is used for conservatism.
D = Diameter of nozzle (m)

This equation is based on experiments with $H/D \leq 100$ and $V_{eg}/Fl \geq 0.4$. Ratios H/D and V_{eg}/Fl will be checked in calculation section A4.7.4.

The aerosol generation mass flowrate is determined by multiplying the volumetric flowrate of entrained gas by the bubble burst entrainment coefficient using the bubble burst formula (Epstein, Ref. A4.10.2, pg. 6-5) and the density of the vessel contents.

$$L = E_{vfg} \cdot V_{eg} \cdot \rho$$

Equation A4-5

L = Mass flowrate of aerosol (kg/s)
E_{vfg} = Volumetric bubble burst entrainment coefficient (dimensionless)
V_{eg} = Volumetric flowrate of entrained gas (m^3/s)
ρ = Density of vessel contents (kg/m^3)

The mass flowrate of aerosol entering the vessel vent is multiplied by the solids percent in the vessel content to determine the amount of solids that enter the vessel vent system.

$$M = L \cdot \%sol$$

Equation A4-6

M = Mass of solids entering the vent system (g/hr)
L = Mass flowrate of aerosol (g/hr)
%sol = Solids percent of the vessel contents (%)

The solids content of the feed into LCP is calculated in Attachment 5. The water content and glass former content of several types of melter feed was available in several R&T reports. Anything in the waste that was not water or glass formers is assumed to be solids.

The water content of the melter feed is also calculated in Attachment 5.

The density and solids content of RLD-VSL-00003 will vary depending on what is sent to the vessel. The vessel is intended to receive plant wash, but off-specification feed from LCP and LFP can also be sent here.

A4.5.4.2 Solids Removal in the SBS and WESP

The particulate emission concentration from the melter is calculated in Attachment 33. The dry offgas volumetric flowrate (SCFM) from the melter is calculated in Attachment 1 nominal flowsheet, Cell C11. The solids removal efficiency by the SBS and WESP is calculated in Attachment 34.

The particulate emission mass flowrate from the melter is determined by multiplying the melter particulate emission concentration and the dry offgas volumetric flowrate.

$P_{Melter} = E_{Melter} * M_{Melter}$ **Equation A4-7**

P_{Melter} = Particulate emission mass flowrate from melter (mg/min)

E_{Melter} = particulate emission concentration from melter (mg/ft^3), calculated in Attachment 33

M_{Melter} = Dry offgas volumetric flowrate from melter (ft^3/min), calculated in Attachment 1 nominal flowsheet, cell C11

The mass flow of particulates captured in the SBS is calculated by multiplying the particulate emission mass flow from the melter and the SBS removal efficiency.

$P_{SBScond} = P_{Melter} * Rem_{SBS}$ **Equation A4-8**

$P_{SBScond}$ = Particulates removed in SBS (g/min)

Rem_{SBS} = Removal efficiency of SBS (%), calculated in Attachment 34

The mass flow of particulates captured in the WESP is calculated by multiplying the mass flow of the particulates remaining in the offgas stream (post-SBS) by the WESP removal efficiency.

$P_{WESPcond} = (P_{Melter} - P_{SBScond}) * Rem_{WESP}$ **Equation A4-9**

$P_{SBScond}$ = Particulates removed in WESP (g/min)

Rem_{SBS} = Removal efficiency of WESP (%), calculated in Attachment 34

The particulates removed in the SBS and WESP contribute to the solids content of the LCP feed.

A4.5.4.3 Time-Weighting Particulate Flowrates

The particulate mass flowrate calculation shown in Section A4.5.4.1 determines the particulate mass flowrate when a vessel is filled. Vessels are only filled during brief periods of time, and this rate overstates the amount of particulate traveling to the HEPA filters if it is used as a constant rate. The percentage of a vessel's design life spent receiving feed has been calculated in other calculations (see Inputs I.17 - I.19). This percentage is multiplied by the particulate mass flowrate (due to jet entrainment) to result in a time-weighted average particulate mass flowrate.

A4.6 Assumptions

A4.6.1 Assumptions Not Requiring Verification

A4.6.1.1 Vessel Inleakage

The following vessel inleakage are assumed and included in the flowsheet calculations in Attachment 1 for completeness. For additional justification of vessel inleakage assumptions, see Assumption 6.7 of the main calculation. Since the inleakage through pin-hole leaks in fittings and penetrations to the vessel are relatively small compared to the overall offgas flowrate and the maximum inleakage is conservatively doubled, variations in the inleakage rates have minimal impact to the overall flowrate and therefore the assumed inleakages do not need verification.

A1.1 The minimum vessel inleakage is defined as half of the nominal vessel inleakage based on the vessels, connections, and lines being brand new and therefore having less inleakage than an older system.

A1.2 The maximum vessel inleakage is twice the nominal predicted vessel inleakage for conservatism.

A1.3 Flanged fittings are found to have an inleakage rate of 0.5 lb/hr for connections up to 6" and 0.8 lb/hr for connections 6" - 24" (Ref. A4.10.4, Table 2 for flanged fittings). An inleakage rate of 0.5 SCFM per flange is assumed. See Section A4.7.1 for calculations showing that 0.5 SCFM per flange is conservative.

A1.4 The LCP vessels (Concentrate Receipt Vessels) have 11 flanged connections each (Refs. A4.9.10, A4.9.11, A4.9.12, & A4.9.13); 13 flanged connections are conservatively assumed for each vessel, resulting in a nominal inleakage rate of 6.5 SCFM.

A1.5 The LFP vessels (Melter Feed Preparation Vessels and Melter Feed Vessels) have 19 flanged connections per vessel (Refs. A.4.9.14 - A4.9.21); 20 flanged connections are conservatively assumed for each vessel, resulting in a nominal inleakage rate of 10 SCFM.

A1.6 RLD-VSL-00003 (Plant Wash Vessel) has 10 flanged connections (Refs. A4.9.23 & A4.9.24), resulting in a nominal inleakage rate of 5 SCFM.

A1.7 RLD-VSL-00004 (C3/C5 Drains/Sump Collection Vessel) has 8 flanged connections (Refs. A4.9.27 & A4.9.28), resulting in an inleakage rate of 4 SCFM.

A1.8 RLD-VSL-00005 (SBS Condensate Collection Vessel) has 10 flanged connections (Refs. A4.9.25 & A4.9.26), resulting in an inleakage rate of 5 SCFM.

A1.9 Standard temperature and pressure for this calculation is defined at 1 atm and 68 ^{o}F or 528 ^{o}R (per Note 1 in Attachment 1 of main calculation). This is a typical standard condition and thus does not need verification.

A4.6.1.2 Particulate Entrainment

A2.1 A larger drop produces more particulates during transfers. The Z dimension, which is the height of the nozzle at the flange to the lower tangent line of the vessel, is conservatively used as the height from nozzle to liquid level in Equation A4-2 to determine the jet velocity at impact and particulate flowrate. During normal operations, all of the vessels will have at least a heel of liquid within them which shorten the distance to the liquid level. Therefore, this assumption is conservative and does not need verification.

A2.2 The minimum solids content of RLD-VSL-00003 is assumed to be 0 wt% solids. This vessel will most likely contain vessel washes which is primarily water, and thus the solids content is expected to be negligible.
The nominal solids content of RLD-VSL-00003 is assumed to be 5 wt% solids. 5 wt % solids is expected to be much higher than what is contained in the vessel washes. In the calculations supporting the PIBOD, stream RLD25 has a range of suspended solids from 0.01 - 3.4 wt% (Ref. A4.9.56, within each APPS run, see "APPS Main USER INTERFACE v(3)(0)LAW_PIBOD_RUN_XX.xlsm", worksheet APPS_VIT_Streams_1, cell IX-12 and Ref. A4.9.57, within each MRQ, see "APPS Main USER INTERFACE v(3)(0)DFLAW_PIBOD_RUN_XX.xlsm", worksheet APPS_VIT_Streams_1, cell IX-12).
The maximum solids content of RLD-VSL-00003 is assumed to be the same as the solids content of LFP-VSL-00002/4 determined in Attachment 5 for bounding conservatism. Off-specification melter feed from LFP-VSL-00002/4 may be transferred to RLD-VSL-00003 but will be diluted prior to transfer back to Pretreatment; therefore the solids content in RLD-VSL-00003 should be much lower than the solids content of LFP vessels. Using a higher solids content will result in a larger particulate entrainment.
This assumption is very conservative and therefore does not require verification.

A2.3 The maximum density of RLD-VSL-00003 vessel content is assumed to be the same as the bounding maximum density of LFP-VSL-00002/4 content (1.8 g/mL per Input I.14). Transfer of LFP feed to RLD-VSL-00003 may occur in off-specification feed case; however this will require dilution of the feed and thus lower the feed density before transferring back to Pretreatment. This assumption is bounding and therefore does not require verification.

A2.4 The waste in RLD-VSL-00005 is condensate from the Submerged Bed Scrubber, which is essentially water (SBS condensate, LOP05, contains 0.1 - 1 wt% suspended solids per Ref. A4.9.50, Table A-19, pg A-20). Therefore the density of liquid within the vessel is assumed to be 1 g/mL which is the density of water (Ref. A4.10.3, pg. 44). This assumption is reasonable and does not require verification.

A4.6.1.3 Hydrogen Air Purge Rates

A3.1 LCP-VSL-00001/2, LFP-VSL-00001/2/3/4 & RLD-VSL-00004 have air purges to prevent flammable gas accumulation (Ref. A4.9.52, pgs. 2-60, 2-64, and 2-137). The purge rate required is assumed to be the same as that required for HLW (which has more potential for hydrogen generation), 200 times the maximum calculated hydrogen generation rate (Ref. A4.9.53, Section 4.4.2.3.4). This assumption is conservative and therefore does not require verification.

A3.2 The hydrogen generation rates for the following LAW vessels at 140°F and 1 atm are listed in Table 8-2 of Ref. A4.9.51, which is a committed calculation. For conservatism, the hydrogen generation rate will be doubled in this calculation to yield a sufficient air purge rate. An air purge for RLD-VSL-00004 exists because LCP or LFP vessels may overflow into the RLD vessel. The generation rate for RLD-VSL-00004 is assumed to be the same as that of an LFP vessel because LFP has a higher hydrogen generation rate than LCP. Since the hydrogen generation rates are doubled to compensate for potential variations in hydrogen generation rates at the vessel maximum temperatures pending confirmation of the referenced calculation, this assumption does not require verification.

Table 1: Maximum Hydrogen Generation Rates

Vessel Number	Maximum Hydrogen Generation Rate at 140°F and 1 atm (L/hr)	Hydrogen Generation Rate Doubled (L/hr)
LCP-VSL-00001/2	1.3	2.6
LFP-VSL-00001/2/3/4	3.4	6.8
RLD-VSL-00004	3.4	6.8

A4.6.1.4 General Assumptions

None

A4.6.2 Assumptions Requiring Verification

None

A4.7 Calculations

Unit Definitions

Pressure

$$\text{Pa} \equiv \frac{\text{kg}}{\text{m}\cdot\text{s}^2}$$

$$\mu\text{Pa} \equiv \frac{\text{Pa}}{1000000}$$

$$\text{inWC} \equiv \frac{\text{psi}}{27.681}$$

$$\text{inWG} \equiv \text{inWC}$$

Substance

$$\text{kmol} \equiv 1000\cdot\text{mole}$$

$$\text{lbmole} \equiv \frac{\text{kmol}}{2.20462}$$

$$\text{mmol} \equiv \frac{\text{mole}}{1000}$$

Viscosity

$$\text{cP} \equiv 1000\cdot\mu\text{Pa}\cdot\text{s}$$

$$\text{P} \equiv 100\cdot\text{cP}$$

Acceleration of Gravity

$$g_n := 9.8066\cdot\frac{\text{m}}{\text{s}^2}$$ [Input I.20]

Gas Constant:

$$\text{GasC} := 0.7302\cdot\frac{\text{ft}^3\cdot\text{atm}}{\text{lbmole}\cdot\text{R}}$$ [Input I.21]

A4.7.1 Vessel Vent Air Addition due to Vessel Inleakage

The following calculation is to show that a nominal inleakage rate of 0.5 SCFM per flanged connection is conservative (Assumption A1.3).

Based on Assumption A1.3, use 0.8 lb/hr inleakage rate per flanged connection for conservatism. Converting 0.8 lb/hr of air to SCFM as follows:

Molecular weight of air: $\mathrm{MWair} := 29.0\cdot\frac{\mathrm{lb}}{\mathrm{lbmole}}$ (Input A4.2.1)

Nominal Inleakage rate for flanged connection: $\mathrm{RATEair} := 0.8\cdot\frac{\mathrm{lb}}{\mathrm{hr}}$ (Assumption A1.3)

Nominal molar rate of inleakage air per flanged connection: $n := \frac{\mathrm{RATEair}}{\mathrm{MWair}}$

$$n = 4.598 \times 10^{-4}\cdot\frac{\mathrm{lbmole}}{\mathrm{min}}$$

Standard Pressure: $\mathrm{StdP} := 1\cdot\mathrm{atm}$ (Assumption A1.9)

Standard Temperature: $\mathrm{StdT} := 528\cdot\mathrm{R}$ (Assumption A1.9)

Calculate nominal standard volume inleakage air per flanged connection: $\mathrm{StdV} := n\cdot\mathrm{GasC}\cdot\frac{\mathrm{StdT}}{\mathrm{StdP}}$ (Ideal gas law)

$$\mathrm{StdV} = 0.177\cdot\frac{\mathrm{ft}^3}{\mathrm{min}}$$

0.5 SCFM is over 2.8 times larger than the literature value. Therefore, Assumption A1.3 is conservative.

Using the number of vessels and their estimated inleakage values per vessel, the total vessel nominal inleakage is determined in Table 2:

Table 2: Vessel Inleakage Rates

Vessel Description	Vessel Number	Estimated Inleakage Rate (SCFM)	Number of Vessels	Total Estimated Inleakage Rate (SCFM)
Concentrate Receipt Vessel	LCP-VSL-00001/2	6.5 [1]	2	13
Feed Prep & Melter Feed Vessel	LFP-VSL-00001/2/3/4	10 [2]	4	40
Plant Wash Vessel	RLD-VSL-00003	5 [3]	1	5
C3/C5 Drains/Sump Collection Vessel	RLD-VSL-00004	4 [4]	1	4
SBS Condensate Collection Vessel	RLD-VSL-00005	5 [5]	1	5
Total				**67**

[1] Assumption A1.4.
[2] Assumption A1.5.
[3] Assumption A1.6.
[4] Assumption A1.7.
[5] Assumption A1.8.

A4.7.2 Hydrogen Purge Rate and Total Hydrogen Generation Rate

The nominal hydrogen purge rate must be enough to dilute any hydrogen generated in the waste. In this calculation, the purge air rate is assumed to be 200 times the hydrogen generation rate within each vessel (Assumptions A3.1 & A3.2).

Table 3: Maximum Hydrogen Generation Rates

Vessel Number	Maximum Hydrogen Generation Rate (L/hr at 140°F & 1 atm)
LCP-VSL-00001/2	2.6
LFP-VSL-00001/2/3/4	6.8
RLD-VSL-00004	6.8

The purge air flowrates for the vessels are calculated below.

$$\left(2.6\cdot\frac{\text{L}}{\text{hr}}\right)\cdot 200 = 0.306\cdot\frac{\text{ft}^3}{\text{min}}$$ for LCP-VSL-00001/2

$$\left(6.8\cdot\frac{\text{L}}{\text{hr}}\right)\cdot 200 = 0.8\cdot\frac{\text{ft}^3}{\text{min}}$$ for LFP-VSL-00001/2/3/4 & RLD-VSL-00004

The resulting volumetric flow of purge air is at 140 °F and 1 atm. To provide a conservative value that does not depend on temperature, the actual flow rates will be used as standard flowrates at standard conditions (68 °F and 1 atm). Based on the Ideal Gas Law equation to convert SCFM to ACFM and vice versa (Equation 6 in Section 5 of the main calculation), using the ACFM at 140 °F and 1 atm as SCFM at 68 °F and 1 atm will give more conservative purge air flowrate values as shown below. V_{S_LCP} and V_{S_LFP} represent flows at standard conditions.

$$T_a := (140 + 460)\cdot R \qquad T_a = 600\cdot R$$

$$P_a := 1\cdot atm$$

$$V_{s\_LCP} := 0.33\,\frac{ft^3}{min}\cdot\frac{StdT}{T_a}\cdot\frac{P_a}{StdP} \qquad V_{s\_LCP} = 0.29\cdot\frac{ft^3}{min}$$

$$V_{s\_LFP} := 0.8\,\frac{ft^3}{min}\cdot\frac{StdT}{T_a}\cdot\frac{P_a}{StdP} \qquad V_{s\_LFP} = 0.704\cdot\frac{ft^3}{min}$$

Using the actual flow at standard conditions results in a 14% higher flow through the vessels.

The vessels hydrogen generation rates and required air purge rates are summarized in Table 4:

Table 4: Hydrogen Purge Air Rates

Vessel Number	Maximum Hydrogen Generation Rate (L/hr)	Air Purge Rate (SCFM)
LCP-VSL-00001	2.6	0.31
LCP-VSL-00002	2.6	0.31
LFP-VSL-00001	6.8	0.8
LFP-VSL-00002	6.8	0.8
LFP-VSL-00003	6.8	0.8
LFP-VSL-00004	6.8	0.8
RLD-VSL-00004	6.8	0.8
Totals	39.6	**4.62**

The total hydrogen purge air flowrate is rounded up to 5 SCFM.

The total hydrogen generation rate in SCFM (again assuming the actual flow rate to be equal to the standard flow rate at 68°F for conservatism) is as follows:

$$H2_{gen} := 39.6\cdot\frac{L}{hr} \qquad H2_{gen} = 0.023\cdot\frac{ft^3}{min}$$

A4.7.3 Vessel Vent Air Addition Summary

The total vessel nominal inleakage rate is listed in Table 2 in Section A4.7.1. The inleakage rate should be small when the system is new. Therefore, the minimum vessel inleakage rate is assumed to be half of the nominal vessel inleakage rate (Assumption A1.1). The maximum vessel inleakage rate is determined as twice the nominal inleakage rate (Assumption A1.2). The air inleakage and the purge air to the vessel will be vented to the vessel vent system. The minimum, nominal and maximum vessel vent flowrates are summarized in Table 5 below.

Table 5: Vessel Vent Flow Rates

Addition Type	**Estimated Flowrate (SCFM)**		
	Minimum	Nominal	Maximum
Vessel Inleakage (total)	34(1)	67(3)	134(2)
Hydrogen Purge Air	5	5	5
Total Addition	**39**	**72**	**139**

(1) Assumption A1.1
(2) Assumption A1.2.
(3) Table 2, Section A4.7.1

A4.7.4 Jet Entrainment

For jet entrainment, the particulate flowrate increases with increasing fluid density. The following cases are defined:

Minimum Case: Use minimum fluid density and minimum solids content.
Nominal Case: Use nominal fluid density and nominal solids content.
Maximum Case: Use maximum fluid density and maximum solids content.

$E_{vfg} := 2 \cdot 10^{-7}$ (Ref. A4.10.2, pg. 6-5, Input I.7)

Transfers to LCP-VSL-00001/2

Inlet Volumetric Flowrate: $Fl_{LCP1\_2} := 88 \frac{gal}{min}$ (Input I.1)

Inlet Pipe Size: $D_{LCP1\_2} := 3.068 in$ (Input I.1)

Vessel Height: $Ht_{LCP1\_2} := 181 in$ (Input I.8)

Waste density:

$\rho_{LCPmin} := 1.0 \cdot \frac{gm}{mL}$ $\rho_{LCPnom} := 1.38 \cdot \frac{gm}{mL}$ $\rho_{LCPmax} := 1.46 \cdot \frac{gm}{mL}$ (Input I.13)

Solids wt% Content:

$Sol_{LCPmin} := 14.1 \cdot \%$ $Sol_{LCPnom} := 26.7 \cdot \%$ $Sol_{LCPmax} := 39.2 \cdot \%$ (*Attachment 5*)

Total Solids Mass Flowrate:

$TS_{min} := Fl_{LCP1\_2} \cdot \rho_{LCPmin} \cdot Sol_{LCPmin}$ $TS_{min} = 4.697 \times 10^{4} \cdot \frac{gm}{min}$

$TS_{nom} := Fl_{LCP1\_2} \cdot \rho_{LCPnom} \cdot Sol_{LCPnom}$ $TS_{nom} = 1.227 \times 10^{5} \cdot \frac{gm}{min}$

$TS_{max} := Fl_{LCP1\_2} \cdot \rho_{LCPmax} \cdot Sol_{LCPmax}$ $TS_{max} = 1.906 \times 10^{5} \cdot \frac{gm}{min}$

Particulates that are cleaned from the melter offgas in the SBS and WESP are sent back to Pretreatment and end up in the LCP feed.

Average particulate emissions from melter: $E_{Melter} := 26.8 \cdot \left(\frac{mg}{ft^3}\right)$ (*Attachment 33*)

Dry offgas flowrate from melter: $M_{Melter} := 252 \cdot \frac{ft^3}{min}$ (*Attachment 1,* nominal case, Cell C-11)

Average SBS solids capture efficiency: $Rem_{SBS} := 87\%$ (*Attachment 34*)

Average WESP solids capture efficiency: $Rem_{WESP} := 96\%$ (*Attachment 34*)

Mass flow of particulates emitted from melter (Eq. A4-7): $P_{Melter} := E_{Melter} \cdot M_{Melter}$ $P_{Melter} = 6.754 \cdot \frac{gm}{min}$

Mass flow of particulates captured in SBS (Eq. A4-8): $P_{SBScond} := P_{Melter} \cdot \left(Rem_{SBS}\right)$ $P_{SBScond} = 5.876 \cdot \frac{gm}{min}$

Mass flow of particulates captured in WESP (Eq. A4-9): $P_{WESPcond} := \left(P_{Melter} - P_{SBScond}\right) \cdot \left(Rem_{WESP}\right)$

$P_{WESPcond} = 0.843 \cdot \frac{gm}{min}$

Total mass flow of particulates removed: $P_{removed} := P_{SBScond} + P_{WESPcond}$ $P_{removed} = 6.718 \cdot \frac{gm}{min}$

The amount of solids being washed out of the offgas is not significant compared to the total solids content of the feed (see total solids flowrate above) and will be neglected.

Calculate the jet velocity at nozzle outlet and jet velocity at impact with liquid using Equation A4-1 and A4-2:

$$v_{0LCP1\_2} := \frac{Fl_{LCP1\_2}}{\pi \cdot \left(\frac{D_{LCP1\_2}}{2}\right)^2} \qquad v_{0LCP1\_2} = 1.164\,\frac{m}{s}$$

$$v_{jLCP1\_2} := \left(v_{0LCP1\_2}{}^2 + 2 \cdot g_n \cdot Ht_{LCP1\_2}\right)^{.5} \qquad v_{jLCP1\_2} = 9.567\,\frac{m}{s}$$

Determine the Froud number using Equation A4-3:

$$Fr_{jLCP1\_2} := \frac{v_{jLCP1\_2}{}^2}{g_n \cdot D_{LCP1\_2}} \qquad Fr_{jLCP1\_2} = 119.765$$

The volumetric flowrate of entrained gas is calculated using Equation A4-4:

$$V_{egLCP1\_2} := Fl_{LCP1\_2} \cdot .04 \cdot Fr_{jLCP1\_2}{}^{.28} \cdot \left(\frac{Ht_{LCP1\_2}}{D_{LCP1\_2}}\right)^{.4} \qquad V_{egLCP1\_2} = 4.333 \times 10^{-3}\,\frac{m^3}{s}$$

Verify the H/D ratio and the ratio between Volumetric Flow of entrained gas and Froude number:

$$\frac{Ht_{LCP1\_2}}{D_{LCP1\_2}} = 58.996$$ H/D ratio < 100

$$\frac{V_{egLCP1\_2}}{Fl_{LCP1\_2}} = 0.78$$ This ratio is greater than 0.4, so this equation is appropriate. (See Eq. A4-4 in Section A4.5.4.1)

The minimum, nominal and maximum entrained gas mass flowrate is determined using Equation A4-5:

$$L_{LCP1\_2min} := E_{vfg} \cdot V_{egLCP1\_2} \cdot \rho_{LCPmin} \qquad L_{LCP1\_2min} = 3.12 \cdot \frac{gm}{hr}$$

$$L_{LCP1\_2nom} := E_{vfg} \cdot V_{egLCP1\_2} \cdot \rho_{LCPnom} \qquad L_{LCP1\_2nom} = 4.305 \cdot \frac{gm}{hr}$$

$$L_{LCP1\_2max} := E_{vfg} \cdot V_{egLCP1\_2} \cdot \rho_{LCPmax} \qquad L_{LCP1\_2max} = 4.555 \cdot \frac{gm}{hr}$$

The minimum, nominal and maximum particulate mass flowrate is calculated using Equation A4-6:

$$M_{LCP1\_2min} := L_{LCP1\_2min} \cdot Sol_{LCPmin} \qquad M_{LCP1\_2min} = 0.44 \cdot \frac{gm}{hr}$$

$$M_{LCP1\_2nom} := L_{LCP1\_2nom} \cdot Sol_{LCPnom} \qquad M_{LCP1\_2nom} = 1.149 \cdot \frac{gm}{hr}$$

$$M_{LCP1\_2max} := L_{LCP1\_2max} \cdot Sol_{LCPmax} \qquad M_{LCP1\_2max} = 1.785 \cdot \frac{gm}{hr}$$

Transfers to LFP-VSL-00001/3

Inlet Volumetric Flowrate:	$Fl_{LFP1\_3} := 88 \frac{gal}{min}$	(Input I.2)
Inlet Pipe Size:	$D_{LFP1\_3} := 1.939in$	(Input I.2)
Vessel Height:	$Ht_{LFP1\_3} := 146in$	(Input I.9)

Waste density and Solids Content:	The amount of liquid entrainment is driven by the liquid sent to the vessel, the liquid jet. The waste is the same as that in LCP. No glass formers have been added yet. The density and solids content will be the same as that in LCP.

Calculate the jet velocity at nozzle outlet and jet velocity at impact with liquid using Equation A4-1 and A4-2:

$$v_{0LFP1\_3} := \frac{Fl_{LFP1\_3}}{\pi \cdot \left(\frac{D_{LFP1\_3}}{2}\right)^2} \qquad v_{0LFP1\_3} = 2.914 \frac{m}{s}$$

$$v_{jLFP1\_3} := \left(v_{0LFP1\_3}{}^2 + 2 \cdot g_n \cdot Ht_{LFP1\_3}\right)^{.5} \qquad v_{jLFP1\_3} = 9.013 \frac{m}{s}$$

Determine the Froud number using Equation A4-3:

$$Fr_{jLFP1\_3} := \frac{v_{jLFP1\_3}{}^2}{g_n \cdot D_{LFP1\_3}} \qquad Fr_{jLFP1\_3} = 168.178$$

The volumetric flowrate of entrained gas is calculated using Equation A4-4:

$$V_{egLFP1\_3} := Fl_{LFP1\_3} \cdot 0.04 \cdot Fr_{jLFP1\_3}{}^{.28} \cdot \left(\frac{Ht_{LFP1\_3}}{D_{LFP1\_3}}\right)^{.4} \qquad V_{egLFP1\_3} = 5.253 \times 10^{-3} \frac{m^3}{s}$$

Verify the H/D ratio and the ratio between Volumetric Flow of entrained gas and Froude number:

$$\frac{Ht_{LFP1\_3}}{D_{LFP1\_3}} = 75.297$$ H/D ratio < 100

$$\frac{V_{egLFP1\_3}}{Fl_{LFP1\_3}} = 0.946$$ This ratio is greater than 0.4, so this equation is appropriate. (See Eq. A4-4 in Section A4.5.4.1)

The minimum, nominal and maximum entrained gas mass flowrate is calculated using Equation A4-5:

$L_{LFP1\_3min} := E_{vfg} \cdot V_{egLFP1\_3} \cdot \rho_{LCPmin}$ $L_{LFP1\_3min} = 3.782 \cdot \frac{gm}{hr}$

$L_{LFP1\_3nom} := E_{vfg} \cdot V_{egLFP1\_3} \cdot \rho_{LCPnom}$ $L_{LFP1\_3nom} = 5.22 \cdot \frac{gm}{hr}$

$L_{LFP1\_3max} := E_{vfg} \cdot V_{egLFP1\_3} \cdot \rho_{LCPmax}$ $L_{LFP1\_3max} = 5.522 \cdot \frac{gm}{hr}$

The minimum, nominal and maximum solids mass flowrate is calculated using Equation A4-6:

$M_{LFP1\_3min} := L_{LFP1\_3min} \cdot Sol_{LCPmin}$ $M_{LFP1\_3min} = 0.533 \cdot \frac{gm}{hr}$

$M_{LFP1\_3nom} := L_{LFP1\_3nom} \cdot Sol_{LCPnom}$ $M_{LFP1\_3nom} = 1.394 \cdot \frac{gm}{hr}$

$M_{LFP1\_3max} := L_{LFP1\_3max} \cdot Sol_{LCPmax}$ $M_{LFP1\_3max} = 2.165 \cdot \frac{gm}{hr}$

<u>Transfers to LFP-VSL-00002/4</u>

Inlet Volumetric Flowrate: $Fl_{LFP2\_4} := 50 \frac{gal}{min}$ (Input I.3)

Inlet Pipe Size: $D_{LFP2\_4} := 1.939 in$ (Input I.3)

Vessel Height: $Ht_{LFP2\_4} := 146 in$ (Input I.10)

Waste density: Glass formers have been added.

$\rho_{LFP2min} := 1.0 \cdot \frac{gm}{mL}$ $\rho_{LFP2nom} := 1.70 \cdot \frac{gm}{mL}$ $\rho_{LFP2max} := 1.80 \cdot \frac{gm}{mL}$ (Input I.14)

Solids mass fraction is determined from the water wt% obtained from Attachment 5 (use maximum water wt% to calculate the minimum solids % and vice versa):

$Sol_{LFPmin} := 1 - 38.4 \cdot \%$ $\qquad$ $Sol_{LFPmin} = 0.616$

$Sol_{LFPnom} := 1 - 36.7 \cdot \%$ $\qquad$ $Sol_{LFPnom} = 0.633$

$Sol_{LFPmax} := 1 - 34.9 \cdot \%$ $\qquad$ $Sol_{LFPmax} = 0.651$

Calculate the jet velocity at nozzle outlet and jet velocity at impact with liquid using Equation A4-1 and A4-2:

$$v_{0LFP2\_4} := \frac{Fl_{LFP2\_4}}{\pi \cdot \left(\frac{D_{LFP2\_4}}{2}\right)^2} \qquad v_{0LFP2\_4} = 1.656 \frac{m}{s}$$

$$v_{jLFP2\_4} := \left(v_{0LFP2\_4}^{\;2} + 2 \cdot g_n \cdot Ht_{LFP2\_4}\right)^{.5} \qquad v_{jLFP2\_4} = 8.688 \frac{m}{s}$$

Determine the Froud number using Equation A4-3:

$$Fr_{jLFP2\_4} := \frac{v_{jLFP2\_4}^{\;2}}{g_n \cdot D_{LFP2\_4}} \qquad Fr_{jLFP2\_4} = 156.27$$

The volumetric flowrate of entrained gas is calculated using Equation A4-4:

$$V_{egLFP2\_4} := Fl_{LFP2\_4} \cdot .04 \cdot Fr_{jLFP2\_4}^{\;.28} \cdot \left(\frac{Ht_{LFP2\_4}}{D_{LFP2\_4}}\right)^{.4} \qquad V_{egLFP2\_4} = 2.924 \times 10^{-3} \frac{m^3}{s}$$

Verify the H/D ratio and the ratio between Volumetric Flow of entrained gas and Froude number:

$$\frac{Ht_{LFP2\_4}}{D_{LFP2\_4}} = 75.297$$

H/D ratio < 100

$$\frac{V_{egLFP2\_4}}{Fl_{LFP2\_4}} = 0.927$$

This ratio is greater than 0.4, so this equation is appropriate. (See Eq. A4-4 in Section A4.5.4.1)

The minimum, nominal and maximum entrained gas mass flowrate is calculated using Equation A4-5:

$L_{LFP2\_4min} := E_{vfg} \cdot V_{egLFP2\_4} \cdot \rho_{LFP2min}$ $\qquad L_{LFP2\_4min} = 2.105 \cdot \frac{gm}{hr}$

$L_{LFP2\_4nom} := E_{vfg} \cdot V_{egLFP2\_4} \cdot \rho_{LFP2nom}$ $\qquad L_{LFP2\_4nom} = 3.579 \cdot \frac{gm}{hr}$

$L_{LFP2\_4max} := E_{vfg} \cdot V_{egLFP2\_4} \cdot \rho_{LFP2max}$ $\qquad L_{LFP2\_4max} = 3.79 \cdot \frac{gm}{hr}$

The minimum, nominal and maximum solids mass flowrate is calculated using Equation A4-6:

$M_{LFP2\_4min} := L_{LFP2\_4min} \cdot Sol_{LFPmin}$ $\qquad M_{LFP2\_4min} = 1.297 \cdot \frac{gm}{hr}$

$M_{LFP2\_4nom} := L_{LFP2\_4nom} \cdot Sol_{LFPnom}$ $\qquad M_{LFP2\_4nom} = 2.266 \cdot \frac{gm}{hr}$

$M_{LFP2\_4max} := L_{LFP2\_4max} \cdot Sol_{LFPmax}$ $\qquad M_{LFP2\_4max} = 2.467 \cdot \frac{gm}{hr}$

Transfer to RLD-VSL-00003

RLD-VSL-00003 may receive the following transfers (Input I.4):
- C1/C2 effluent transfer at a nominal rate of 100 gpm
- sump effluent via RLD-PMP-00004 at a nominal rate of 30 gpm
- vessel wash transfer from LCP-VSL-00001/2 at a nominal rate of 88 gpm
- off-spec transfer from LFP-VSL-00001/2/3/4 at a nominal rate of 50 gpm via LFP bulge

The highest flowrate (100 gpm) will be used for conservatism since this will produce the highest jet velocity.

The smallest inlet pipe diameter to RLD-VSL-00003 is 2 inches (Input I.5).

Inlet Volumetric Flowrate:	$Fl_{RLD3} := 100 \frac{gal}{min}$	(Input I.4)
Inlet Pipe Size:	$D_{RLD3} := 2.067 in$	(Input I.5)

Waste Density and Solids Content:

The density and solids content will vary depending on what is sent to the vessel. The vessel is intended to receive plant wash, but off-specification feed from LCP and LFP can also be sent here.

Minimum case:	$\rho_{RLD3min} := 0.988 \frac{gm}{mL}$	$Sol_{RLD3min} := 0.0$	(Input I.15, Assumption A2.2)
Nominal case:	$\rho_{RLD3nom} := 1.0 \frac{gm}{mL}$	$Sol_{RLD3nom} := 0.05$	(Input I.15, Assumption A2.2)
Maximum case:	$\rho_{RLD3max} := 1.80 \frac{gm}{mL}$	$Sol_{RLD3max} := 0.651$	(Assumption A2.3)
Vessel Height:	$Ht_{RLD3} := 199in$		(Input I.11)

Calculate the jet velocity at nozzle outlet and jet velocity at impact with liquid using Equation A4-1 and A4-2:

$$v_{0RLD3} := \frac{Fl_{RLD3}}{\pi \cdot \left(\frac{D_{RLD3}}{2}\right)^2} \qquad v_{0RLD3} = 2.914 \frac{m}{s}$$

$$v_{jRLD3} := \left(v_{0RLD3}^{\ 2} + 2 \cdot g_n \cdot Ht_{RLD3}\right)^{.5} \qquad v_{jRLD3} = 10.374 \frac{m}{s}$$

Determine the Froud number using Equation A4-3:

$$Fr_{jRLD3} := \frac{v_{jRLD3}^{\ 2}}{g_n \cdot D_{RLD3}}$$

$$Fr_{jRLD3} = 209.045$$

The volumetric flowrate of entrained gas is calculated using Equation A4-4:

$$V_{egRLD3} := Fl_{RLD3} \cdot .04 \cdot Fr_{jRLD3}^{\ .28} \cdot \left(\frac{Ht_{RLD3}}{D_{RLD3}}\right)^{.4} \qquad V_{egRLD3} = 7 \times 10^{-3} \frac{m^3}{s}$$

Verify the H/D ratio and the ratio between Volumetric Flow of entrained gas and Froude number:

$\frac{Ht_{RLD3}}{D_{RLD3}} = 96.275$ H/D ratio is < 100

$\frac{V_{egRLD3}}{Fl_{RLD3}} = 1.11$ This ratio is greater than 0.4, so this equation is appropriate. (See Eq. A4-4 in Section A4.5.4.1)

The minimum, nominal and maximum entrained gas mass flowrate is calculated using Equation A4-5:

$L_{RLD3min} := E_{vfg} \cdot V_{egRLD3} \cdot \rho_{RLD3min}$ $L_{RLD3min} = 4.979 \cdot \frac{gm}{hr}$

$L_{RLD3nom} := E_{vfg} \cdot V_{egRLD3} \cdot \rho_{RLD3nom}$ $L_{RLD3nom} = 5.04 \cdot \frac{gm}{hr}$

$L_{RLD3max} := E_{vfg} \cdot V_{egRLD3} \cdot \rho_{RLD3max}$ $L_{RLD3max} = 9.072 \cdot \frac{gm}{hr}$

The minimum, nominal and maximum solids mass flowrate is calculated using Equation A4-6:

$M_{RLD3min} := L_{RLD3min} \cdot Sol_{RLD3min}$ $M_{RLD3min} = 0 \cdot \frac{gm}{hr}$

$M_{RLD3nom} := L_{RLD3nom} \cdot Sol_{RLD3nom}$ $M_{RLD3nom} = 0.252 \cdot \frac{gm}{hr}$

$M_{RLD3max} := L_{RLD3max} \cdot Sol_{RLD3max}$ $M_{RLD3max} = 5.906 \cdot \frac{gm}{hr}$

Transfers to RLD-VSL-00004
No jet entrainment calculation is needed. All inlet piping is dipped.
(24590-LAW-M6-RLD-00002001/2)

Transfers to RLD-VSL-00005

RLD-VSL-00005 receives the following transfers (Input I.6):

- SBS condensate transfer from the SBS at a nominal rate of 48 gpm
- SBS condensate transfer from the SBS condensate vessels at a nominal rate of 124 gpm
- Effluent transfer from RLD-VSL-00004 at a nominal rate of 75 gpm

The highest flowrate (124 gpm) will be used for conservatism since this will produce the highest jet velocity.

Inlet Volumetric Flowrate: $Fl_{RLD5} := 124 \cdot \frac{gal}{min}$ (Input I.6)

Inlet Pipe Size: $D_{RLD5} := 2.067 \cdot in$ (Input I.6)

Vessel Height: $Ht_{RLD5} := 190.75 \cdot in$ (Input I.12)

Waste Density: $\rho_{RLD5} := 1.0 \cdot \frac{gm}{mL}$ (Input I.16)

The amount of solids in RLD-VSL-00005 comes from what SBS removes from the offgas. (See LCP section)

Solids mass flow $Sol_{RLD} := P_{Melter} \cdot Rem_{SBS}$ $Sol_{RLD} = 352.538 \cdot \frac{gm}{hr}$

wt% solids: $\%Sol_{RLD} := \frac{Sol_{RLD}}{Fl_{RLD5} \cdot \rho_{RLD5} + Sol_{RLD}}$ $\%Sol_{RLD} = 1.252 \times 10^{-3} \cdot \%$

Calculate the jet velocity at nozzle outlet and jet velocity at impact with liquid using Equation A4-1 and A4-2:

$$v_{0RLD5} := \frac{Fl_{RLD5}}{\pi \cdot \left(\frac{D_{RLD5}}{2}\right)^2} \qquad v_{0RLD5} = 3.614 \frac{m}{s}$$

$$v_{jRLD5} := \left(v_{0RLD5}^{\ 2} + 2 \cdot g_n \cdot Ht_{RLD5}\right)^{.5} \qquad v_{jRLD5} = 10.396 \frac{m}{s}$$

Determine the Froude number using Equation A4-3:

$$Fr_{jRLD5} := \frac{v_{jRLD5}^{\ 2}}{g_n \cdot D_{RLD5}} \qquad Fr_{jRLD5} = 209.93$$

The volumetric flowrate of entrained gas is calculated using Equation A4-4:

$$V_{egRLD5} := Fl_{RLD5} \cdot .04 \cdot Fr_{jRLD5}^{\ .28} \cdot \left(\frac{Ht_{RLD5}}{D_{RLD5}}\right)^{.4} \qquad V_{egRLD5} = 8.544 \times 10^{-3} \frac{m^3}{s}$$

Verify the H/D ratio and the ratio between Volumetric Flow of entrained gas and Froude number:

$\frac{Ht_{RLD5}}{D_{RLD5}} = 92.284$ H/D ratio < 100

$\frac{V_{egRLD5}}{Fl_{RLD5}} = 1.092$ This ratio is greater than 0.4, so this equation is appropriate. (See Eq. A4-4 in Section A4.5.4.1)

The nominal entrained gas mass flowrate is calculated using Equation A4-5:

$L_{RLD5} := E_{vfg} \cdot V_{egRLD5} \cdot \rho_{RLD5}$ $L_{RLD5} = 6.152 \cdot \frac{gm}{hr}$

The nominal solids mass flowrate is calculated using Equation A4-6:

$M_{RLD5} := L_{RLD5} \cdot \%Sol_{RLD}$ $M_{RLD5} = 7.701 \times 10^{-5} \cdot \frac{gm}{hr}$

A4.7.5 Final Particulate Flowrates Summary

This section determines the final mass flowrates of particulates entrained to the offgas for minimum, nominal and maximum flowsheet calculations in Attachment 1. Particulate entrainment typically occurs during filling of the vessels. The following four cases are considered:

Case 1: Filling LCP (contribution from jet entrainment, tank waste with few solids)
Case 2: Filling LFP-VSL-00001/3 (contribution from jet entrainment, tank waste with few solids)
Case 3: Filling LFP-VSL-00002/4 (contribution from jet entrainment, melter feed with glass formers)
Case 4: Filling RLD-VSL-00003 (contribution from jet entrainment, melter feed with glass formers)
Filling RLD-VSL-00005 is bounded by these other cases and is omitted.

To provide the minimum, nominal and maximum particulate mass flowrates for the flowsheet calculations in Attachment 1, the following particulate flowrates are defined for the 4 cases:

Case 1: $M_{LCP1\_2min} = 0.44 \cdot \frac{gm}{hr}$ Case 2: $M_{LFP1\_3nom} = 1.394 \cdot \frac{gm}{hr}$

Case 3: $M_{LFP2\_4max} = 2.467 \cdot \frac{gm}{hr}$ Case 4: $M_{RLD3max} = 5.906 \cdot \frac{gm}{hr}$

However, this rate of particulate entrainment only occurs during filling of the vessels. These values will be time-weighted to calculate an average result of particulate emissions between transfers.

The percentage of time that LCP will receive waste from PTF is 2.7%. (Input I.17)

So the particulate rate from jet entrainment will occur 2.7% of the time.

$DL_{LCP} := 2.7\%$

$M_{LCP1\_2minTS} := M_{LCP1\_2min} \cdot DL_{LCP}$ $M_{LCP1\_2minTS} = 11.876 \cdot \frac{mg}{hr}$

The percentage of time that the MFPVs will receive waste from LCP is 2.7%. (Input I.18)

$DL_{LFP1\_3} := 2.7\%$

$M_{LFP1\_3nomTS} := M_{LFP1\_3nom} \cdot DL_{LFP1\_3}$ $\quad M_{LFP1\_3nomTS} = 37.628 \cdot \frac{mg}{hr}$

The percentage of time that the MFVs will receive waste from the MFPVs is 7.2%. (Input I.19)

$DL_{LFP2\_4} := 7.2\%$

$M_{LFP2\_4maxTS} := M_{LFP2\_4max} \cdot DL_{LFP2\_4}$ $\quad M_{LFP2\_4maxTS} = 177.626 \cdot \frac{mg}{hr}$

The bounding RLD case will be left as it is. $\quad M_{RLD3max} = 5.906 \cdot \frac{gm}{hr}$

A4.8 Results and Conclusion

The results for each objective are summarized in the following sections.

A4.8.1 Vessel Vent Air Additions

The following vessel vent air addition rates were calculated in Section A.4.7.3.

Table 6: Vessel Vent Flow Rates

Addition Type	Estimated Flowrate (SCFM)		
	Minimum	Nominal	Maximum
Vessel Inleakage (total)	34	67	134
Hydrogen Purge Air	5	5	5
Total Addition	**39**	**72**	**139**

The minimum vessel vent flowrate is used for the minimum case of the main flowsheets in Attachment 1, the nominal flowrate is used for the nominal case, and the maximum flowrate are used in the maximum case. These values are entered into Cell **I-25** in the main flowsheets.

A4.8.2 Particulate Entrainment

The following entrained particulate mass flowrates were calculated in Section A.4.7.5.

Case 1: $M_{LCP1\_2minTS} = 11.876 \cdot \frac{mg}{hr}$

Case 2: $M_{LFP1\_3nomTS} = 37.628 \cdot \frac{mg}{hr}$

Case 3: $M_{LFP2\_4maxTS} = 177.626 \cdot \frac{mg}{hr}$

Case 4: $M_{RLD3max} = 5.906 \times 10^{3} \cdot \frac{mg}{hr}$

The Case 1 particulate flowrate will be used for the minimum case of the main flowsheets in Attachment 1, Case 3 will be used for the nominal case (to account for glass formers), and Case 4 will be used in the maximum case. These values are input into Cell **EU-25** of the main flowsheets.

A4.8.3 Hydrogen Generation Rate

The hydrogen generation rate is 0.023 SCFM (Section A4.7.2).

A4.8.4 Margin and Conservatism

Margin is typically not added for process calculations. Conservatism is applied througout the calculations as listed in the following summary:

- In Assumption A1.3, the higher literature inleakage rate of 0.8 lb/hr is assumed as 0.5 SCFM. This is 2.8 times larger than the equivalent standard flow (SCFM) of 0.8 lb/hr, which is 0.177 SCFM per Section A4.7.1.

- In Assumption A1.4 and A1.5, the number of flanged connections for LCP and LFP vessels are increased to maximize the air inleakage rates.

- In Assumption A.2.1, the Z dimension between the transfer inlet nozzle and the vessel's lower tangent line is used instead of the distance from the nozzle to the liquid level. During normal operations, all of the vessels will have at least a heel which shortens the distance. This assumption maximizes the distance of the drop in liquid level and thus maximizes the potential for aerosols.

- In Assumption A2.2, the maximum solids content of RLD-VSL-00003 is assumed to be the same as the solids content of LFP-VSL-0002/4; this is much higher than what is expected because the transfer of LFP feed to RLD only occurs in off-normal case and the feed will be diluted prior to transfer to Pretreatment.

- In Assumption A3.1, the air purge rate for LCP, LFP and RLD-VSL-00003 vessels are assumed to be the same as the required purge rate for HLW which has much more potential for hydrogen generation.

- In Assumption A3.2, the hydrogen generation rate is doubled. The calculated hydrogen purge rate and hydrogen generation rate are assumed to be at standard conditions instead of actual conditions. When these rates are used in the main calculation and converted back to ACFM, this drives the values to be higher in ACFM than they would be otherwise (see Section A4.7.2).

- In Section A4.7.4, the highest flowrates of 100 gpm and 124 gpm is used to calculate the jet velocity for RLD-VSL-00003 & -00005 respectively. Higher jet velocity will result in higher particulate entrainment and give conservative results.

A4.9 Tracked References

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A4.9.4 24590-CM-POA-MVA0-00002-03-42, Rev. B00, *Drawing - General Arrangement - Melter 2 Feed Vessel*

A4.9.5 24590-CM-POA-MVA0-00002-03-11, Rev. F, *Drawing - General Arrangement - Melter 2 Feed Preparation Vessel*

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A4.9.15 24590-LAW-M6-LFP-00001002, Rev. 1, *P&ID - LAW - LAW Melter Feed Process System Melter 1 Feed Preparation LFP-VSL-00001*

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A4.9.18 24590-LAW-M6-LFP-00003001, Rev. 1, *P&ID - LAW - LAW Melter Feed Process System Melter 2 Feed Preparation LFP-VSL-00003*

A4.9.19 24590-LAW-M6-LFP-00003002, Rev. 1, *P&ID - LAW - LAW Melter Feed Process System Melter 2 Feed Preparation LFP-VSL-00003*

A4.9.20 24590-LAW-M6-LFP-00003003, Rev. 1, *P&ID - LAW - LAW Melter Feed Process System Melter 2 Feed Vessel LFP-VSL-00004*

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A4.9.34 24590-LAW-MPC-LOP-00003, Rev. 0, *Sizing of Pump LOP-PMP-00003A/B and LOP-PMP-00006A/B*

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A4.9.38 24590-LAW-MVC-LFP-00001, Rev. 1, *LAW Melter Feed Process System (LFP) Data*

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A4.9.40 24590-LAW-MPC-LFP-00002, Rev. 0, *Melter 1 Feed Vessel Pump LFP-PMP-00002 and Melter 2 Feed Vessel Pump LFP-PMP-00004*

A4.9.41 24590-LAW-MPC-RLD-00002, Rev 1, *Sizing of Pump RLD-PMP-00002A and RLD-PMP-00002B*

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A4.10 References

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A4.11 Attachments

Attachment A - Aerosol Generation During Select Normal and Off-Normal Waste Treatment Plant Processes (Ref. A4.10.2)

return to:
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Ronald Graves

Attachment A

FAI/01-07

AEROSOL GENERATION DURING SELECT NORMAL AND OFF-NORMAL WASTE TREATMENT PLANT PROCESSES

Operability and Safety Evaluation, Tasks 3 and 4

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2.0 MECHANICAL AEROSOL PRODUCTION ABOVE SELF-BOILING OR BUBBLING WASTE IN VESSELS

2.1 Entrainment Coefficient and Bubbling Flow Regimes

When boiling or bubbling occurs in a liquid pool, droplets are ejected from the pool surface by bursting of bubbles or by intense liquid agitation, depending on the magnitude of the bubble flow rate. The droplets ejected from the surface have various diameters. Here we are interested in those droplets whose diameters are small enough to be carried away by the streaming gas or vapor to any height above the liquid pool. The process of separation of liquid from the pool and subsequent transport by the flowing gas is referred to as liquid entrainment. The volume or flow rate of liquid aerosol that is carried upward is related to the volume or flow rate of gas or vapor by the definition of the entrainment coefficient E:

$$\frac{V_a}{V_g} = \frac{j_a}{j_g} = E \qquad (2\text{-}1)$$

In the above equation V_a is the volume of liquid drops (aerosol) produced at the surface due to the passage of volume V_g of gas (vapor) through the surface, j_f is the upward superficial velocity of liquid flowing as droplets and j_g is the superficial velocity of gas (vapor).

At low superficial gas velocities discrete bubbles rise through the pool uniformly and steadily. This flow pattern has been classified as the bubbly flow regime. When the superficial gas velocity exceeds the threshold value $j_{g,t}$ the flow regime transitions from bubbly flow to churn turbulent flow which is characterized by nonuniformed sized bubbles rising unsteadily and chaotically. The transition superficial velocity is (Wallis, 1962)

$$j_{g,t} = 0.3\left(\frac{\sigma g}{\rho_f}\right)^{1/4} \qquad (2\text{-}2)$$

Wallis, 1969 $j_{gf} = 1.53(\alpha)\left[\frac{\sigma g(\rho_f - \rho_g)}{\rho_f^2}\right]^{1/4}$

for $\alpha \sim 20\%$ & $\rho_f >> \rho_g \longrightarrow 0.3\left(\frac{\sigma g}{\rho_f}\right)^{1/2}$

where σ is the liquid surface tension, ρ_f is the liquid density, and g is the gravitational constant. For an air-water system ($\sigma = 0.07$ kg s^{-2}, $\rho_f = 10^3$ kg m^{-3}) the transition from bubbly to churn turbulent flow occurs at about $j_{g,t} \approx 5.0$ cm s^{-1}.

2.2 Bubbly Flow Regime and Bubble Burst Mechanism of Aerosol Production

In the bubbly flow regime, discrete bubbles rise up to the surface of the pool and collapse there. The mechanism of aerosol generation is the rupture of the dome-shaped lamina that forms above the bubble as it passes through the pool surface. The discussion which follows focuses on the entrainment coefficient E for the bubble burst process. The estimates of E which are suggested by the available information are empirical rather than based on first principles.

Tomaides and Whitby (1976) reported a water aerosol size distribution measurement resulting from the collapse of an isolated 0.55-cm diameter bubble at the surface of a 0.1% aqueous solution of NaCl. About 200 droplets were observed. The droplet size distribution data were presented by plotting the droplet number frequency $\Delta N/(N \cdot \Delta d)$ versus the drop diameter d, where ΔN is the number of droplets in the size range d to d + Δd and N is the total number of droplets ($\approx$ 200). Most of the contribution to the distribution comes from the size range 1.0 to 10.0 μm and over this range the present author found that the distribution is well-represented by the power law

$$\frac{\Delta N}{N \cdot \Delta d} = \frac{0.3}{d^{0.825}} \quad \text{for} \quad 1.0 \leq d \leq 10.0\ \mu\text{m} \tag{2-3}$$

Letting ΔN and Δd approach zero the total volume of the aerosol is

$$V_a = \sum_i \Delta N_i \frac{4}{3}\pi\left(\frac{d_i}{2}\right)^3 \simeq \int_{1.0}^{10.0\,\mu m} \frac{4\pi}{3}\left(\frac{d}{2}\right)^3 \frac{0.3}{d^{0.825}} Nd(d)$$

(2-4)

$$= 0.049\, N \int_{1.0}^{10.0\,\mu m} d^{3.175} = 1.47 \times 10^4\ \mu m^3$$

The volume of the 0.55-cm diameter bubble is $V_g = 8.71 \times 10^{10}\ \mu m^3$. Thus the entrainment coefficient inferred from the measurements of Tomaides and Whitby (1976) is, from Eq. (2-1),

$$E = \frac{1.47 \times 10^4}{8.71 \times 10^{10}} = 1.7 \times 10^{-7} \quad \text{(0.1\% NaCl solution)} \qquad (2\text{-}5)$$

Garner et al. (1954) measured the volume of the aerosol drops produced above single bursting bubbles in the 6.0 to 12.0 mm range in water containing a suspension of calcium carbonate and in a 12% aqueous kNO_2 solution. The measured entrainment coefficients were in he range

$$E = 1.3 \times 10^{-7} - 2.3 \times 10^{-7} \quad (CaCO_3 \text{ suspension in water}) \qquad (2\text{-}6)$$

$$E = 3 \times 10^{-7} - 10^{-6} \quad (12\%\ kNO_3 \text{ solution}) \qquad (2\text{-}7)$$

In the same laboratory study Garner et al. (1954) also measured entrainment coefficients for single bubbles in pure water, ethyl alcohol and benzene. The results were

$$E = 2 \times 10^{-5} \text{ to } 5 \times 10^{-5} \quad \text{(pure liquids)} \qquad (2\text{-}8)$$

Cipriano and Blanchard (1981) performed a multi-bubble experiment in sea water (≃ 3.5% NaCl). A continuous waterfall plunged through the surface of a pool of sea water thereby producing a plume of bubbles within the sea water. This multi-bubbling situation produced a wide droplet size distribution relative to the distribution observed by Tomaides and Whitby (1976) in their single-bubble/salt solution experiment, 1.0 to 50 μm versus 1.0 to 10 μm, respectively. When summed over the entire 1.0-50 μm distribution, the drop volume production rate is 5.08 x 10^{-4} cm^3 s^{-1}. By capturing the air contributed by all the bursting bubbles, Cipriano and Blanchard determined that the total rate of air entrainment was 128 cm^3 s^{-1}; therefore (see Eq. 2-1)

$$E = 4.0 \times 10^{-6} \qquad \text{(multi-bubble/3.5\% NaCl solution)} \qquad (2\text{-}9)$$

Interestingly enough, if only the drops in the interval 1.0-10 μm are counted the entrainment coefficient becomes E = 1.5 x 10^{-7} which is about equal to that measured by Tomaides and Whitby (see Eq. 2-5).

Azbel (1978) developed a model to predict the mass of the liquid film which surrounds the gas bubble at the instant of bubble break-through at the pool surface. The effect of impurities is not included in Azbel's model, yet for no apparent reason his theoretical formula for E agrees with the Garner et al. (1954) water/$CaCO_3$ suspension data and the Tomaides and Whitby (1976) salt solution data.

It is clear from the available empirical information on aerosol production by bubble burst that entrainment rates for pure liquids are about two orders of magnitude larger than those for liquids containing foreign substances (see Fig. 2-1). For pure liquids the measure entrainment coefficient is in the range E = 2 x 10^{-5} to 5 x 10^{-5}. When impurities are present in the liquid and only ejected droplets of size < 10 μm are considered, E = 10^{-7} to 10^{-6} depending on the type of impurity. The bubble burst data obtained with $CaCO_3$ suspension and rather dilute NaCl solutions yielded E ≈ 2 x 10^{-7} while the data obtained with kNO_3 solutions resulted in E ≈ 3 x 10^{-7} to 10^{-6}. Effects of impurities on aerosol generation have also been observed by MacIntyre (1974) and Day (1964). It is worth mentioning that tests with pure glycerol (Garner et al., 1954) showed very low droplet production. This was attributed to the high viscosity of the glycerol. In clean inviscid liquids bubbles burst immediately upon arrival at the surface. High viscosity, the presence of dissolved or suspended particles results in stabilizing the bubble at the surface. The delay before rupture appears to reduce drop production relative to drop production above clean liquids. Additional bubble burst data is needed using fluids more nearly prototypic of process-

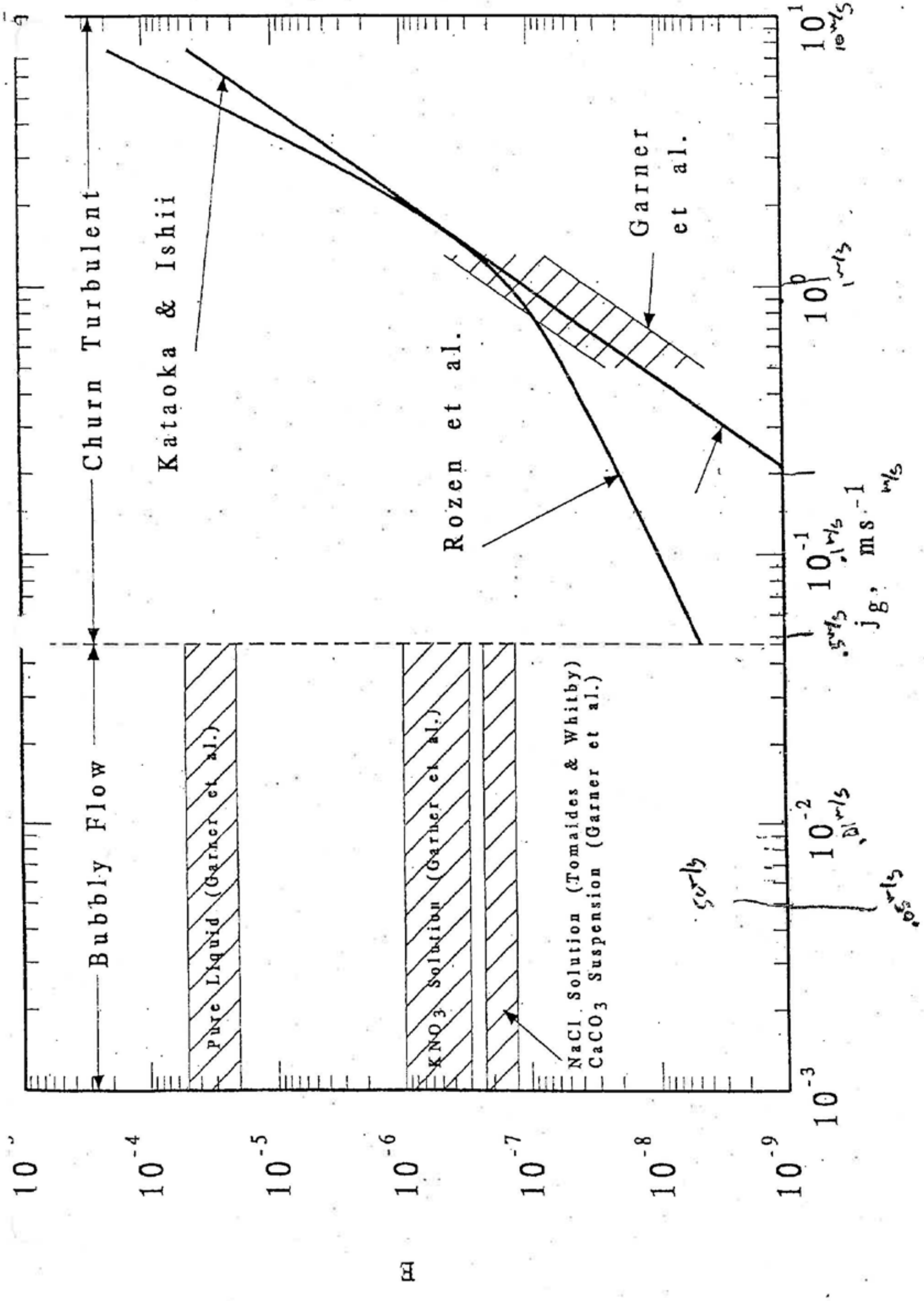


Fig. 2-1 Entrainment coefficient versus superficial vapor velocity for the steam-water system.

waste liquid. Until such data becomes available, the value E = 2 x 10^{-7} is recommended for waste liquid. This is a best estimate value that reflects the high concentrations of impurities that are likely to be dissolved and/or suspended in the waste liquid.

2.3 Churn Turbulent Regime and Momentum Exchange Mechanism of Aerosol Production

In the churn turbulent flow regime the droplets are not generated by the bubble burst mechanism, but by a momentum exchange mechanism. Rozen et al. (1974) measured the aerosol flux in a water-air system for air superficial velocities in the range $0.6 < j_g < 3.0$ m s^{-1}. The data is clearly representative of churn flow conditions. The entrainment coefficient just above the pool surface was shown experimentally to be independent of gas flux and given by $E = 4\rho_g/\rho_f$. Rozen et al. (1976) suggested a correlation for the entrainment coefficient E in terms of the superficial gas velocity and the diameter of the largest drop which can be carried upward by the gas flow. Kataoka and Ishii (1984) used a momentum balance to relate this drop size to the superficial gas velocity and expressed the Rozen et al. correlation in the form

conservative for flow. below ≈1 m/s

$$E = 7.6 \times 10^{-5}\left(\frac{\rho_g}{\rho_f}\right)^{1/2}\left[j_g^{*} N_{\mu g}^{1/6} + 4870\,(j_g^{*})^{4.2}\, N_{\mu g}^{0.7}\right] \qquad (2\text{-}10)$$

where j_g^{*} is a dimensionless superficial gas velocity defined as

$$j_g^{*} = j_g\left(\frac{\rho_g^2}{\sigma g \rho_f}\right)^{1/4} \qquad (2\text{-}11)$$

and $N_{\mu g}$ is a dimensionless gas viscosity defined by

$$N_{\mu g} = \mu_g\left(\frac{g\rho_f}{\rho_g^2\,\sigma^3}\right)^{1/4} \qquad (2\text{-}12)$$

In the above definitions μ_g and ρ_g are, respectively, the gas viscosity and density.

Kataoka and Ishii (1984) developed their own correlation of aerosol production in the churn turbulent regime, which is

$$\boxed{E = 7.13 \times 10^{-4} (j_g^*)^3 N_{\mu g}^{1/2}} \qquad (2\text{-}13)$$

The numerical coefficient was obtained by a best fit of Eq.(7) to the steam-water data of Garner et al. (1954) for $0.5 < j_g < 1.3$ m s^{-1} and the air-water data of Golub (1970) for $0.5 < j_g < 2.0$ m s^{-1}. Note that Garner et al. reported entrainment data taken in both the bubble and churn turbulent regimes.

2.4 Entrainment Coefficient for Steam-Water System

The relevant physical properties for a boiling pool of water at 0.1 MPa are $\sigma = 0.059$ kg s^{-2}, $\rho_f = 960$ kg m^{-3}, $\rho_g = 0.6$ kg m^{-3}, and $\mu_g = 1.2 \times 10^{-5}$ kg m^{-1} s^{-1}. Substituting these property values into the definitions given by Eqs. (2-11) and (2-12) yields the relations

$$j_g^* = 0.16\, j_g \qquad (2\text{-}14)$$

$$N_{\mu g} = 12.7 \times 10^{-3} \qquad (2\text{-}15)$$

where j_g is in units of m s^{-1}. Combining Eqs. (2-10), (2-14), and (2-15) yields the following dimensional form of the Rozen et al. (1976) correlation for the steam-water system:

$$E = 10^{-7}\, j_g + 3.95 \times 10^{-8}\, j_g^{4.2} \quad \text{(Rosen et al.)} \qquad (2\text{-}16)$$

From Eqs. (2-13) to (2-15), the Kataoka and Ishii (1984) correlation for the steam-water system becomes

$$E = 1.04 \times 10^{-7}\ j_g^3 \qquad \text{(Kataoka and Ishii)} \qquad (2\text{-}17)$$

In Eqs. (2-16) and (2-17) j_g is in units of m s^{-1}. Recall that for superficial steam velocities less than $j_{g,t}$ the two-phase pool behavior is in the bubbly flow regime. For the steam-water system $j_{g,t} = 0.047$ m s^{-1}.

The entrainment coefficient for the bubbly flow regime and Eqs. (2-16) and (2-17) for the churn-turbulent flow regime are plotted in Fig. 2-1. The bubble burst data of Garner et al. (1954) and Tomaides and Whitby (1976) are indicated in the figure. Also the steam-water data reported by Garner et al. for the churn turbulent regime are presented in the figure. The semi-empirical correlations as well as the data suggest that the entrainment coefficient undergoes a dramatic reduction upon transition from the bubbly flow regime to the churn turbulent flow regime. Ginsberg (1983) constructed a plot similar to the one in Fig. 2-1 and first noted this behavior. He speculated that the E versus j_g trend exhibited in the figure is a result of bubble coalescence and reduction of liquid-vapor interfacial surface area with change in flow regime. An alternative explanation is that in the low gas flux regime (bubbly flow) the entrainment is small but the entrained liquid consists of very fine drops which are all carried away by the gas flow. In the churn turbulent regime a considerable amount of liquid is entrained but larger drops are ejected from the pool and most of these entrained drops fall back to the surface.

The Rosen et al. (1976) and Kataoka and Ishii (1984) correlations give similar results for E in the range of j_g values for which there is data. Unfortunately, as the bubbly flow regime is approached by decreasing j_g the two correlations diverge, and there is no data to provide support for one correlation relative to the other. Obviously the safe (conservative) choice in this region is the correlation of Rozen et al. (1976).

2.5 Example Problems

We shall illustrate the results reviewed in the foregoing by two examples, first referring to a process tank with a volumetric self heat rate of $\dot{Q}''' = 100$ W m^{-3} in sludge with water-like interstitial liquid. Assuming that all the power generated is converted to water vapor, the superficial vapor velocity at the pool surface is given by the equation

$$j_g = \frac{\dot{Q}''' H}{\rho_g h_{fg}} \qquad (2\text{-}18)$$

where H is the depth of the liquid and h_{fg} is the latent heat of evaporation of water (2.3×10^6 J kg^{-1}). Taking a liquid depth H = 3.0 m we get from Eq. (2-18) $j_g = 2 \times 10^{-4}$ m s^{-1}. This low superficial vapor velocity clearly lies in the bubbly flow regime (see Fig. 2-1) and the appropriate (best estimate) entrainment coefficient for the rather impure waste liquid is $E \approx 2 \times 10^{-7}$. Consequently, the aerosol superficial velocity at any height above the pool is $j_f = Ej_g = 4 \times 10^{-11}$ m s^{-1}. The total aerosol production rate in kg s^{-1} is obtained by simply multiplying j_f by the product $\rho_f A$ where "A" is the cross-sectional area of the process tank.

Since the self-heat rate $\dot{Q}''' = 100$ W m^{-3} probably represents an upper bound value for the process tanks, it is reasonable to infer from the previous example that the entrainment coefficient for bubbly flow ($E \approx 2 \times 10^{-7}$) should be used for prediction of the aerosol generation rate above a process liquid (sludge) pool undergoing steady-state boiling. The churn turbulent flow regime may materialize during transient events involving the sudden release of gas and/or vapor from the waste material (e.g., during a steam bump).

As a second example, we consider aerosols generated by air sparging of liquid waste (pneumercator flow). The aerosol production rate Q_a (in m^3 s^{-1}) may be written as

$$Q_a = EQ_g \qquad (2\text{-}19)$$

where Q_g is the gas volumetric flow rate. If the pneumercator flow is $Q_g = 0.068$ m^3 hr^{-1}, the aerosol generation rate using $E = 2 \times 10^{-7}$ for very impure liquids is $Q_a = 1.4 \times 10^{-8}$ m^3 hr^{-1}.

2.6 Concluding Remarks

With respect to boiling waste, aerosol generation in addition to that produced by bubble burst may occur via condensation of the flowing vapor (i.e., fog formation) as it mixes with cool air some distance above the surface of the pool. Future work should be devoted to this issue.

In closing this section, the need for droplet production data obtained with bubble burst experiments in near-prototypic waste liquids is re-emphasized. The high concentrations of dissolved and suspended materials suggest very low entrainment coefficients for liquid waste.

6.0 PROCESS LIQUOR AEROSOL CONCENTRATION DUE TO STREAM FALLING ONTO LIQUOR SURFACE

6.1 Mechanism of Aerosol Generation

Aerosol formation can occur during pouring and filling process vessels with liquor. Two different mechanisms of airborne droplet formation may be associated with plunging liquid streams (jets). The first mechanism involves disturbances on the surfaces of the jet and the receiving pool. Waves of increasing amplitude form on the surfaces and periodically break away from the surface and form droplets. Unless the pouring velocity is high (> 10 m s^{-1}), the droplets formed by this "atomization" mechanism are likely to be too large to be carried by purge air flows into the vent system. The second mechanism is also due to disturbances on the liquid surfaces. When disturbances on the jet surface hit the depression on the surface of the receiving pool, the interacting surface deformations lead to gas entrainment at the jet plunging point. Gas bubbles are produced that ultimately rise to the surface. The bubble bursting process at the surface results in fine droplets which may be readily transported to the vessel vent system. The approach described below for the prediction of the aerosol release fraction RF (see Section 5.3) due to plunging liquid jets is based on the assumption that gas entrainment (followed by bubble burst) is the primary cause of aerosol production.

Unless otherwise stated, all the formulas given below for calculation of the gas entrainment rate by a plunging liquid jet were obtained from a review article on the subject by Bin (1993).

6.2 Jet Velocity and Diameter

Two important parameters that enter into the calculation of the gas entrainment rate are the jet velocity V_j and the jet diameter d_j at the plunging point. Prediction of these quantities is complicated by jet contraction or expansion at the nozzle outlet and the loss of jet energy due to developing jet turbulence. In view of these complications it seems best to identify the jet diameter with the nozzle diameter d_0 and to calculate jet velocity at impact with the following formula based on ideal (frictionless) jet flow

$$V_j = (V_0^2 + 2gL_j)^{1/2} \tag{6-1}$$

where V_0 is the jet velocity at the nozzle outlet, g is the gravitational constant and L_j is the vertical height of the nozzle outlet above the pool surface level.

6.3 Jet Breakup Length

Long jets and high velocity jets may break up before they reach the surface of the pool. The correlations for air entrainment by individual drops are different than those for air entrainment by coherent jets. Therefore it is important to be able to predict the breakup length L_b of liquid jets. An equation that correlates data on the breakup length of turbulent jets is

$$\frac{L_b}{d_0} = 2.7\,(We_0)^{1/2} \tag{6-2}$$

where We_0 is the jet Weber number evaluated at the nozzle outlet:

$$We_0 = \frac{\rho_f\, d_0\, V_0^2}{\sigma} \tag{6-3}$$

In the above definition ρ_f and σ are the liquid density and surface tension, respectively. A close examination of the L_b versus We_0 data summarized graphically by Bin (1993) reveals that the data departs from Eq. (6-2) for $We_0 \gtrsim 2000$ and appears to level off and become insensitive to We_0. In the high Weber number (atomization) regime, we recommend the Taylor (1940) formula for the breakup length; namely,

$$\frac{L_b}{d_0} = 5.0\left(\frac{\rho_f}{\rho_g}\right)^{1/2} \qquad (6\text{-}4)$$

where ρ_g is the density of the surrounding gas. By setting Eq. (6-2) equal to Eq. (6-4) we obtain the following critical Weber number for the transition from the Weber number regime to the atomization regime of jet breakup

$$(We_0)_{crit} = 3.4\,\frac{\rho_f}{\rho_g} \qquad (6\text{-}5)$$

Equation (6-2) or (6-4) should be used to calculate L_b depending on whether We_0 is less than or greater than $(We_0)_{crit}$.

6.4 Onset of Gas Entrainment

A liquid jet penetrating a liquid surface in a pool will entrain gas only if the jet velocity at impact exceeds a certain critical value denoted by the symbol V_e. From the summary given by Bin (1993) it is evident that there is no successful theoretical or semi-empirical approach to predict V_e for all conditions of interest. However the formula

$$V_e = 20\left(\frac{\sigma}{\rho_f d_0}\right)^{1/2}, \qquad (6\text{-}6)$$

which is based on a jet Weber number principle, correlates data for coherent turbulent water and aqueous solution jets. For broken up jets (the droplet regime) the data points for V_e can be approximated by the dimensional correlation

$$V_e = 389\left(\frac{\sigma}{\rho_f}\right)^{1/2}\frac{L_j^{0.534}}{d_0^{0.0786}} \qquad (6\text{-}7)$$

where all the symbols are in SI units. The data base for Eq. (6-7) covers nozzles with diameters ranging from 2 to 10.2 mm and jet Weber numbers (We_j) ranging from 10 to 10^3. Equation (6-7) may have to be extrapolated beyond the available data base when applied to process vessel conditions.

6.5 Air Entrainment Rate

The following empirical expression for the gas entrainment rate by a plunging, coherent liquid jet gives satisfactory agreement with experiments:

$$\frac{Q_g}{Q_f} = 0.04\, Fr_j^{0.28} \left(\frac{L_j}{d_0}\right)^{0.4} \qquad (6\text{-}8)$$

where Q_g is the volumetric flow rate of entrained gas, Q_f is the volumetric flow rate of liquid ($V_j\ \pi\ d_0^2/4$) and Fr_j is the jet Froude number defined by

$$Fr_j = \frac{V_j^2}{g\, d_0} \qquad (6\text{-}9)$$

Equation (6-8) is based on experiments with $L_j/d_0 \leq 100$ and $Q_g/Q_f \geq 0.4$. Again extrapolations may have to be made for plant-vent-aerosol concentration assessments.

For disrupted jets the experimental data suggests a direct relationship between the gas entrainment rate and jet power N_j, where

$$N_j = \frac{1}{2} Q_f\, \rho_f\, V_j^2 \qquad (6\text{-}10)$$

A dimensional formula that approximates the upper limit of the data base is

$$Q_g = \begin{cases} 1.3 \times 10^{-4}\, N_j^{0.61} & 10^{-2} < N_j < 0.51 \\ \\ 1.5 \times 10^{-4}\, N_j^{0.825} & 0.51 < N_j < 10^2 \end{cases} \tag{6-11}$$

where all quantities are in SI units. Conditions produced from nozzles with $N_j > 10^2$ will require extrapolation of Eq. (11).

6.6 Aerosol Generation Rate

Once Q_g is calculated the aerosol generation rate Q_a (in $m^3\ s^{-1}$) is obtained immediately from the bubble burst formula (Eq. 2-1):

$$Q_a = E\, Q_g \tag{6-12}$$

where E (~ 2×10^{-7}) is the bubble burst entrainment coefficient (see Section 2.2). Let Q_p denote the volume flow of purge gas. Then the suspended aerosol mass concentration c_a carried by the purge flow is

$$c_a = \frac{\rho_f Q_a}{Q_p} = \frac{\rho_f E Q_g}{Q_p} \tag{6-13}$$

The aerosol release fraction RF is defined as the ratio of the suspended aerosol density to the process liquor density (see Section 5.3); so that

$$RF = \frac{c_a}{\rho_f} = \frac{EQ_g}{Q_p} \tag{6-14}$$

Attachment 5 DM-1200 LAW Feed Solids Weight Percent and Water Rate to Melter

This spreadsheet is used to determine the percentage of solids present in LAW feed and the mass rate of water in the feed to the melter based on VSL data.

Spreadsheet Explanation:

1. References for each data set (water wt%, glass formers wt% and densities) are defined in Column I.
2. To calculate the weight percent of water and glass formers in the melter feed:
   a. The weight percent of water and glass formers for each feed vector were manually entered into Columns B & C, respectively.
   b. Whatever in the feed that is not water or glass formers is considered as other solids. Subtracting Columns B plus C from 100 wt % results in the weight percent of other solids, Column D.
   c. The weight percent of solids in the untreated feed vector (before glass formers are added) is calculated by dividing Column D by the sum of Columns B & D. The result is in column E.

$$wt\%\ feed\ solids = \frac{wt\%\ other\ solids}{wt\%\ other\ solids + wt\%\ water}$$

3. To calculate the water rate to the melter:
   a. The batch volume of the melter feed vessel (MFV) is entered into cell C-7 (Input 2.10).
   b. The cycle time (processing time for a MFV batch) in the melter is entered into Cell C-8 (Input 2.10).

      It is assumed that an entire MFV feed batch is processed in the melter every 16 hours (cycle time) and that the feed batch is always the same size.

   c. The volumetric flowrate rate of the feed to the melter is calculated in cell G-10 (MFV batch size divided by cycle time, gal/hr).
   d. The densities of each feed vector were manually entered into Column F.
   e. The mass rate of feed into the melter for each feed vector is calculated in Column G by multiplying the density (Column F) by the feed volumetric rate (Cell G-9).

$$Mass\ rate\ of\ feed\ \left(\frac{lb}{hr}\right) = \frac{density\ \left(\frac{g}{mL}\right)}{453.593\,\frac{g}{lb}} * melter\ feed\ rate\left(\frac{gal}{hr}\right) * \frac{1{,}000{,}000\ mL}{264.17\ gal}$$

   f. The mass rate of water to the melter for each feed vector is calculated by multiplying the mass feed rate (Column G) by the water wt% (Column B).

4. The average for each column is calculated in Row 21 using Excel's AVERAGE function.
5. The standard deviation of each column is calculated in Row 22 using Excel's STDEV function.
6. The statistical minimum of each column is calculated in Row 23 by subtracting the standard deviation from the average value.

7. The statistical maximum of each column is calculated in Row 24 by adding the standard deviation to the average value.

The LAW feed wt% solids results (Column E) are used in **Attachment 4**, Section A4.7.4 to determine the solids mass flowrates in LCP-VSL-00001/2.

The melter feed water wt% results (Column B) are used in **Attachment 4**, Section A4.7.4 to determine the solids wt% in LFP-VSL-00002/4.

The mass rate of water to the melter (Column H) is used in **Attachment 2** to calculate the steam volumetric flowrate generated.

As a basis for Assumption 5, the percentage of glass formers in the glass made during testing is entered in cells B-30 and B-31. This percentage is then subtracted from 100% to determine the waste loading in the glass in cells C-30 and C-31. Envelope A wastes are used because more waste can be loaded into the glass (as opposed to Envelopes B & C) due to its chemical makeup (see Column D, “wt% solids in melter feed that aren’t GFCs”, Envelopes B & C have much lower percentages of waste solids in the feed).

Attachment 5
DM-1200 LAW Feed Solids Weight Percent and Water Rate to Melter

	[Input 2.10]	
Batch volume of MFV	3465	(gal)
Cycle time per batch of melter feed	16	(hr)

	Feed rate	
The flowrate of melter feed to the melter per hour is 3465 gal / 16 hr.	216.5625	gal/hr

Feed Vector	Water Weight % [Input 2.4]	Glass Former Weight % [Input 2.4]	wt% solids in melter feed that aren't GFCs	wt% solids in LAW feed concentrate	Density (g/mL) [Input 2.4]	Mass rate of melter feed (lb/hr)	Mass rate of water to melter (lb/hr)	Reference (Ref. 9.1 - 9.5)
A1	37.6%	42.2%	20.2%	34.9%	1.72	3108.6	1170.1	24590-101-TSA-W000-0009-111-02, Table 2.3, Page T-5
A2	34.0%	44.0%	22.0%	39.3%	1.7	3072.4	1044.6	24590-101-TSA-W000-0009-166-00001, Table 2.7, Page T-7
B1	37.2%	60.1%	2.7%	6.8%	1.7	3072.4	1142.9	24590-101-TSA-W000-0009-143-01, Table 2.3, Page T-5
C1	38.5%	49.0%	12.5%	24.5%	1.69	3054.4	1175.9	24590-101-TSA-W000-0009-111-01, Table 2.4, Page T-6
C1	36.0%	50.0%	14.0%	28.0%	1.67	3018.2	1086.6	24590-101-TSA-W000-0009-105-00006, Table 2.5, Page T-

	Water Weight %	Glass Former Weight %	wt% solids in melter feed that aren't GFCs	wt% solids in LAW feed concentrate
Average =>	**36.7%**	49.1%	14.3%	**26.7%**
STDEV =>	1.7%	7.0%	7.6%	12.5%
Min =>	**34.9%**	42.1%	6.7%	**14.1%**
Max =>	**38.4%**	56.0%	21.9%	**39.2%**

	Mass rate of water to melter (lb/hr)
Average =>	**1124.0**
STDEV =>	56.74
Min =>	**1067.3**
Max =>	**1180.8**

Bold solids wt% values are used in Attachment 4, section A4.7.4.
Bold water wt% values are used in Attachment 4, , section A4.7.4.
Bold water mass rate values are used in Attachment 2.

Feed Vector	Additives in Glass (glass formers) [Input 2.4] (wt%)	Waste Loading in Glass (wt%)	Reference (Ref. 9.3 & 9.5)
A1	74.15%	25.85%	24590-101-TSA-W000-0009-111-02, Table 2.3, Page T-5
A2	75.34%	24.66%	24590-101-TSA-W000-0009-166-00001, Table 2.7, Page T-7

Attachment 6 WESP Average Differential Temperature

Attachment 6 calculates the minimum, average, and maximum differential temperatures across the WESP based on VSL testing data (Ref. 9.1 - 9.5).

Spreadsheet Explanation:

1. References for each data set are defined in Columns A through F.
2. The average inlet and outlet temperatures for the VSL-DM-1200 WESP in each run are manually entered into Columns G and H, respectively.
3. The WESP average differential temperature for each run is calculated in Column I by subtracting Column G from Column H.
4. The average differential temperature is calculated in cell [I-31] using Excel's AVERAGE function.
5. The maximum differential temperature is calculated in cell [I-32] using Excel's MAX function.
6. The standard deviation of the differential temperature is calculated in cell [I-33] using Excel's STDEV function.
7. The statistical maximum WESP differential temperature is calculated in cell [I-34] by adding the standard deviation to the average value.
8. The statistical minimum WESP differential temperature is calculated in cell [I-35] by subtracting the standard deviation from the average value.

The differential temperature results are used in cell **O-21** of Attachment 1 flowsheets. The minimum differential temperature is used in the minimum flowsheet cases, the average is used in the nominal case, and the maximum is used in the maximum cases.

Attachment 6

VSL DM-1200 WESP Average Differential Temperature (°C)

Report Number	Report Revision	Report Table	Report Page	Feed Vector	Run Number	Average Temperature (^{o}C)		
						in [Input 2.4]	out [Input 2.4]	ΔT
24590-101-TSA-W000-0009-111-01 (VSL-02R8800-1) [Ref. 9.2]	B	4.1	T-12	Sub-envelope C1 (AN-107 simulant)	1	37.4	41.1	3.7
24590-101-TSA-W000-0009-111-02 (VSL-02R8800-2) [Ref. 9.3]	B	4.1	T-11	Sub-envelope A1 (AN-105 simulant)	1	38	42.2	4.2
24590-101-TSA-W000-0009-143-01 (VSL-03R3851-1) [Ref. 9.4]	B	4.1	T-9	Sub-envelope B1 (AZ-101 simulant)	1	39.2	41.9	2.7
24590-101-TSA-W000-0009-105-00006 (VSL-04R4851-1) [Ref. 9.1]	A	5.2	T-27	Sub-envelope C1 (AN-107 simulant)	A	40.0	45.5	5.5
					B	38.6	39.3	0.7
					C	39.1	38.3	-0.8
					D	37.6	37.1	-0.5
			T-28		E	40.9	42.7	1.8
24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1) [Ref. 9.5]	B	4.2	T-35	Bounding Sub-envelope A2 (AP-101 simulant)	1 - AA	49.3	50.8	1.5
					1 - Naph/MeOH	49.2	50.9	1.7
					1 - No Spike	49.4	51.2	1.8
					2A - AA/Naph	49.1	49.9	0.8
			T-37		2A - Naph/MeOH	49.4	50.3	0.9
					2A - No Spike	49.1	49.6	0.5
			T-36		2B	49.4	50.9	1.5

Average =>	**1.7**
Maximum =>	5.5
Standard Deviation =>	1.7
Average + SDev =>	**3.4**
Average - SDev =>	**0.0**

Values in Bold are used in cell **O-21** of Attachment 1 flowsheets.

Attachment 7 Temperature Increase Across Offgas Exhausters

The temperature increase across the offgas exhausters are determined based on the methodology described in Section 5.15, using Equation (15a) and (15c). The calculations are done in MathCAD.

Attachment 7 - Temperature Increase Across Offgas Exhausters

Unit Definition:

Length

$$mm \equiv \frac{m}{1000}$$
$$in \equiv 25.4 \cdot mm$$
$$ft \equiv 12 \cdot in$$
$$cm \equiv \frac{m}{100}$$
$$\mu m \equiv \frac{mm}{1000}$$

Energy

$$J \equiv \frac{kg \cdot m^2}{s^2}$$
$$KJ \equiv 1000 \cdot J$$
$$Btu \equiv 1055.1 \cdot J$$

Temperature

$$C \equiv K$$
$$F \equiv \frac{5}{9} \cdot C$$
$$F \equiv R$$

Power

$$W \equiv \frac{J}{s}$$
$$mW \equiv \frac{W}{1000}$$
$$kW \equiv 1000 \cdot W$$
$$Hp \equiv 745.71 \cdot W$$

Volume

$$L \equiv \frac{m^3}{1000}$$
$$gal \equiv \frac{ft^3}{7.4805}$$
$$ml \equiv \frac{L}{1000}$$

Pressure

$$Pa \equiv \frac{kg}{m \cdot s^2}$$
$$\mu Pa \equiv \frac{Pa}{1000000}$$
$$bar \equiv 100000 \cdot Pa$$
$$mbar \equiv \frac{bar}{1000}$$
$$atm \equiv 1.01325 \cdot bar$$
$$psi \equiv \frac{atm}{14.696}$$
$$inWC \equiv \frac{psi}{27.681}$$
$$mmWC \equiv \frac{inWC}{25.4}$$

Force

$$N \equiv kg \cdot \frac{m}{s^2}$$

Viscosity

$$cP \equiv 1000 \cdot \mu Pa \cdot s$$
$$P \equiv 100 \cdot cP$$

Time

$$min \equiv 60 \cdot s$$
$$hr \equiv 3600 \cdot s$$
$$day \equiv 24 \cdot hr$$
$$year \equiv 365.25 \cdot day$$

Substance

$$kmol \equiv 1000 \cdot mole$$
$$lbmole \equiv \frac{kmol}{2.20462}$$
$$mmol \equiv \frac{mole}{1000}$$

Mass

$$g \equiv \frac{kg}{1000}$$
$$lb \equiv \frac{kg}{2.20462}$$
$$\mu g \equiv \frac{g}{1000000}$$
$$MT \equiv 1000 \cdot kg$$

Gravity

$$g_n := 9.81 \cdot \frac{m}{s^2}$$

Gas Constant

$$R_G := 8.314 \cdot \frac{J}{mol \cdot K}$$

A7.1 The ratio of specific heats of air is 1.40 (Input 37, Section 2.1).

$$\gamma := 1.40$$

The exhauster operating efficiency, η, is 58% per Input 25 in Section 2.1.

$$\eta := 0.58$$

A7.2 The inlet temperatures of the exhausters for the five cases are obtained from cell [O-48] in Attachment 1 flowsheets. These temperatures were determined in Attachment 39, Section A39.5.

$$T_{i.} := \begin{pmatrix} 51 \\ 48 \\ 41 \\ 40 \end{pmatrix} \cdot C \quad \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array}$$

The exhauster inlet temperatures are converted from °C to absolute temperature K as follows:

$$T_{ia} := T_{i.} + 273.15K \qquad T_{ia} = \begin{pmatrix} 324.15 \\ 321.15 \\ 314.15 \\ 313.15 \end{pmatrix} K$$

A7.3 The inlet and discharge pressures for the exhausters are defined below from cells [W-50] and [W-51] in Attachment 1 flowsheets:

$$P_{i.} := \begin{pmatrix} 590 \\ 669 \\ 717 \\ 738 \end{pmatrix} \cdot \text{mbar} \qquad \begin{matrix} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{matrix}$$

$$P_{d.} := \begin{pmatrix} 1005 \\ 1003 \\ 1000 \\ 1000 \end{pmatrix} \cdot \text{mbar} \qquad \begin{matrix} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{matrix}$$

A7.4 Calculating the exhauster ideal discharge temperatures for the five cases using Equation (15a):

$$i := 1 .. 4$$

$$T_{d._i} := T_{ia_i} \cdot \left(\frac{P_{d._i}}{P_{i._i}} \right)^{\frac{\gamma - 1}{\gamma}} \qquad T_{d.} = \begin{pmatrix} 377.429 \\ 360.544 \\ 345.476 \\ 341.547 \end{pmatrix} K$$

A7.5 Calculating the exhauster final actual temperatures and converting temperatures back to ^{o}C (Eq. 15c):

$$T_{f_i} := \frac{\left[T_{ia_i} \cdot \left(\frac{P_{d._i}}{P_{i._i}}\right)^{\frac{\gamma-1}{\gamma}} - T_{ia_i}\right]}{\eta} + T_{ia_i} - 273.15 \cdot K \qquad T_f = \begin{pmatrix} 143 \\ 116 \\ 95 \\ 89 \end{pmatrix} \cdot C$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

These temperatures are entered into Cell **O-51** of Attachment 1 main flowsheets as the exhauster discharge temperatures.

Attachment 8 SCR Temperature Increase, SCR Ammonia Addition Flowrate Determination, and Residual SCR Gas Discharge Mass Flowrate Calculation

Attachment 8 calculates the temperature rise across the Selective Catalytic Reducer (SCR), the ammonia addition flowrate and the residual SCR gas discharge flowrate using MathCAD.

Attachment 8 - SCR Temperature Increase, SCR Ammonia Addition Flowrate Determination, and Residual SCR Gas Discharge Mass Flowrate Calculation

Unit Definition:

Length

$\mathrm{mm} \equiv \frac{\mathrm{m}}{1000}$

$\mathrm{in} \equiv 25.4\cdot\mathrm{mm}$

$\mathrm{ft} \equiv 12\cdot\mathrm{in}$

$\mathrm{cm} \equiv \frac{\mathrm{m}}{100}$

$\mu\mathrm{m} \equiv \frac{\mathrm{mm}}{1000}$

Energy

$\mathrm{J} \equiv \frac{\mathrm{kg}\cdot\mathrm{m}^2}{\mathrm{s}^2}$

$\mathrm{KJ} \equiv 1000\cdot\mathrm{J}$

$\mathrm{Btu} \equiv 1055.1\cdot\mathrm{J}$

Temperature

$\mathrm{C} \equiv \mathrm{K}$

$\mathrm{F} \equiv \frac{5}{9}\cdot\mathrm{C}$

$\mathrm{F} \equiv \mathrm{R}$

Power

$\mathrm{W} \equiv \frac{\mathrm{J}}{\mathrm{s}}$

$\mathrm{mW} \equiv \frac{\mathrm{W}}{1000}$

$\mathrm{kW} \equiv 1000\cdot\mathrm{W}$

$\mathrm{Hp} \equiv 745.71\cdot\mathrm{W}$

Volume

$\mathrm{L} \equiv \frac{\mathrm{m}^3}{1000}$

$\mathrm{gal} \equiv \frac{\mathrm{ft}^3}{7.4805}$

$\mathrm{ml} \equiv \frac{\mathrm{L}}{1000}$

Pressure

$\mathrm{Pa} \equiv \frac{\mathrm{kg}}{\mathrm{m}\cdot\mathrm{s}^2}$

$\mu\mathrm{Pa} \equiv \frac{\mathrm{Pa}}{1000000}$

$\mathrm{bar} \equiv 100000\cdot\mathrm{Pa}$

$\mathrm{mbar} \equiv \frac{\mathrm{bar}}{1000}$

$\mathrm{atm} \equiv 1.01325\cdot\mathrm{bar}$

$\mathrm{psi} \equiv \frac{\mathrm{atm}}{14.696}$

$\mathrm{inWC} \equiv \frac{\mathrm{psi}}{27.681}$

$\mathrm{mmWC} \equiv \frac{\mathrm{inWC}}{25.4}$

Force

$\mathrm{N} \equiv \mathrm{kg}\cdot\frac{\mathrm{m}}{\mathrm{s}^2}$

$\mathrm{mN} := \frac{\mathrm{N}}{1000}$

Viscosity

$\mathrm{cP} \equiv 1000\cdot\mu\mathrm{Pa}\cdot\mathrm{s}$

$\mathrm{P} \equiv 100\cdot\mathrm{cP}$

Time

$\mathrm{min} \equiv 60\cdot\mathrm{s}$

$\mathrm{hr} \equiv 3600\cdot\mathrm{s}$

$\mathrm{day} \equiv 24\cdot\mathrm{hr}$

$\mathrm{year} \equiv 365.25\cdot\mathrm{day}$

Substance

$\mathrm{kmol} \equiv 1000\cdot\mathrm{mole}$

$\mathrm{lbmole} \equiv \frac{\mathrm{kmol}}{2.20462}$

$\mathrm{mmol} \equiv \frac{\mathrm{mole}}{1000}$

Mass

$\mathrm{g} \equiv \frac{\mathrm{kg}}{1000}$

$\mathrm{lb} \equiv \frac{\mathrm{kg}}{2.20462}$

$\mu\mathrm{g} \equiv \frac{\mathrm{g}}{1000000}$

$\mathrm{MT} \equiv 1000\cdot\mathrm{kg}$

Gravity

$g_n := 9.81\cdot\frac{\mathrm{m}}{\mathrm{s}^2}$

Gas Constant

$R_G := 8.314\cdot\frac{\mathrm{J}}{\mathrm{mol}\cdot\mathrm{K}}$

This attachment is used to calculate the temperature rise across the SCR. It also determines what components are added or subtracted from the gas as the gas reacts in the SCR.

A8.1 The molecular weights of the different chemical species used in this calculation (NO, NO_2, NH_3, H_2O, O_2 & N_2) are identified per Table 2 in Section 2 (Input 2.2):

$MW_{NO} := 30.01\cdot\frac{\mathrm{g}}{\mathrm{mol}}$ $MW_{NO2} := 46.01\cdot\frac{\mathrm{g}}{\mathrm{mol}}$ $MW_{O2} := 32.0\cdot\frac{\mathrm{g}}{\mathrm{mol}}$

$MW_{NH3} := 17.03\cdot\frac{\mathrm{g}}{\mathrm{mol}}$ $MW_{H2O} := 18.01\cdot\frac{\mathrm{g}}{\mathrm{mol}}$ $MW_{N2} := 28.01\cdot\frac{\mathrm{g}}{\mathrm{mol}}$

A8.2 The heat of reaction (ΔH_r) is the difference between the enthalpy of the products and the enthalpy of the reactants at a given temperature and pressure (Felder, Ref. 10.2.9, pg. 422).

Possible NO_x/NH_3 reactions for a selective catalytic reduction were evaluated by Bradford (Ref. 10.2.3, pg 39). These reactions and their associated heats of reactions are defined below based on defined component enthalpies per Barin (Ref. 10.2.2) at 700 K (427°C).

There are 2 possible reactions for NO and one reaction for NO_2:

$2\ NO + 4\ NH_3 + 2\ O_2 \rightarrow 3\ N_2 + 6\ H_2O$

$6\ NO + 4\ NH_3 \rightarrow 5\ N_2 + 6\ H_2O$

$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$

Enthalpies for various chemical species used in the reactions are listed below (Inputs 43 - 48, Section 2.1 of the main calculation):

$H_{H2O} := -227.635 \cdot \frac{KJ}{mol}$ Ref. 10.2.2, pg 650

$H_{NH3} := -29.071 \cdot \frac{KJ}{mol}$ Ref. 10.2.2, pg 942

$H_{N2} := 11.937 \cdot \frac{KJ}{mol}$ Ref. 10.2.2, pg 935

$H_{NO} := 102.599 \cdot \frac{KJ}{mol}$ Ref. 10.2.2, pg 946

$H_{O2} := 12.499 \cdot \frac{KJ}{mol}$ Ref. 10.2.2, pg 1093

$H_{NO2} := 50.456 \cdot \frac{KJ}{mol}$ Ref. 10.2.2, pg 947

The heat of reactions for NO and NO_2 reactions are evaluated below.

Based on Equation (22a) & (22b) in Section 5:

$$\Delta H_r = \Sigma\, (\nu^*\Delta H)_{products} - \Sigma\, (\nu^*\Delta H)_{reactants}$$

$\Delta H = \Delta H_r(T)^*n/\nu$ Where $\Delta H_r(T)$ = heat of reaction at temperature T, in this case 700K (kJ/mol)

ΔH = enthalpy change of reactants or products at temperature T (kJ/mol)

n = moles of reactant or product

ν = stoichiometric coefficient

NO Reaction 1: $2\ NO + 4\ NH_3 + 2\ O_2 \rightarrow 3\ N_2 + 6\ H_2O$

$$H_{rNO} := \frac{3 \cdot H_{N2} + 6 \cdot H_{H2O} - 2 \cdot H_{NO} - 4 \cdot H_{NH3} - 2H_{O2}}{2}$$

$H_{rNO} = -721.956 \cdot \frac{KJ}{mol}$ (per mol of NO reacted)

NO Reaction 2: $6\ NO + 4\ NH_3 \rightarrow 5\ N_2 + 6\ H_2O$

$$H_{rNOb} := \frac{5 \cdot H_{N2} + 6 \cdot H_{H2O} - 6 \cdot H_{NO} - 4 \cdot H_{NH3}}{6} \qquad H_{rNOb} = -300.906 \cdot \frac{KJ}{mol}$$ (per mol of NO reacted)

NO reaction 1 will be used since it has a larger heat of reaction.

NO_2 Reaction: $6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$

$$H_{rNO2} := \frac{7 \cdot H_{N2} + 12 \cdot H_{H2O} - 6 \cdot H_{NO2} - 8 \cdot H_{NH3}}{6} \qquad H_{rNO2} = -453.038 \cdot \frac{KJ}{mol}$$ (per mol of NO_2 reacted)

Calculating the total energy change by introducing mass flowrate.

A8.3 The total mass flowrate at the SCR inlet for the four cases are defined below from cell [K-43] of Attachment 1 flowsheets:

$$i := 1 .. 4$$

$$m_T := \begin{pmatrix} 7150 \\ 6680 \\ 5650 \\ 3690 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A8.4 The mass flowrate of NO_x compounds in the melter offgas for the five cases are defined below from cells [CA-43] and [CM-43] of Attachment 1 flowsheets:

$$m_{NO} := \begin{pmatrix} 18.3 \\ 12.9 \\ 6.39 \\ 3.20 \end{pmatrix} \cdot \frac{kg}{hr} \qquad m_{NO2} := \begin{pmatrix} 22.7 \\ 17.2 \\ 1.12 \\ 0.562 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A8.5 Based on the contaminant mass flowrates, molecular weights, and reaction energies, the total energy change for the four cases is calculated as follows:

$$Q_{rNOx_i} := \frac{m_{NO_i}}{MW_{NO}} \cdot H_{rNO} + \frac{m_{NO2_i}}{MW_{NO2}} \cdot H_{rNO2} \qquad -Q_{rNOx} = \begin{pmatrix} 6.64 \times 10^{5} \\ 4.8 \times 10^{5} \\ 1.65 \times 10^{5} \\ 8.25 \times 10^{4} \end{pmatrix} \cdot \frac{KJ}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A8.6 The heat capacity of the offgas for the five cases at the SCR discharge is defined per cell [AK-44] of Attachment 1 flowsheets:

$$Cp_{offgas} := \begin{pmatrix} 1.153 \\ 1.119 \\ 1.080 \\ 1.062 \end{pmatrix} \cdot \frac{KJ}{kg \cdot C}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A8.7 The temperature rise across the SCR is calculated by using Equation (22d) in Section 5:

$$\Delta T_{SCR_i} := \frac{\left(-Q_{rNOx}\right)_i}{m_{T_i} \cdot Cp_{offgas_i}} \qquad \Delta T_{SCR} = \begin{pmatrix} 80.5 \\ 64.2 \\ 27 \\ 21.1 \end{pmatrix} \cdot C$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

This temperature increase is added to the inlet temperature in cell **O-44** of Attachment 1 main flowsheets.

A8.8 The SCR ammonia addition molar flowrate is calculated below based on the calculated NOx molar flowrates and the defined stoichiometric ratio between NO_x and ammonia (See Section A8.2 & A8.4):

$$n_{NH3_i} := \left(\frac{m_{NO_i}}{MW_{NO}} \cdot \frac{4}{2} + \frac{m_{NO2_i}}{MW_{NO2}} \cdot \frac{8}{6} \right) \qquad n_{NH3} = \begin{pmatrix} 1.9 \times 10^{3} \\ 1.4 \times 10^{3} \\ 458.3 \\ 229.5 \end{pmatrix} \cdot \frac{mol}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A8.9 The stoichiometric NH_3 standard volumetric flowrate is calculated as follows, using the defined molar flowrate in Section A8.8 above, the ideal gas equation (Equation 1b) and the defined standard temperatures and pressures:

$T_S := 293.15 \cdot K$
$P_S := 1 \cdot atm$

$$V_{NH3_i} := \frac{n_{NH3_i} \cdot R_G \cdot T_S}{P_S} \qquad V_{NH3} = \begin{pmatrix} 26.58 \\ 19.23 \\ 6.49 \\ 3.25 \end{pmatrix} \cdot \frac{ft^3}{min} \quad \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array}$$

A8.10 The molar flowrate of nitrogen gas (i.e., dry gas component) resulting from the NO_x/NH_3 reactions is calculated based on a 98% reduction efficiency (Input 15), the calculated NOx molar flowrates, and the defined stoichiometric ratio between NOx and nitrogen (See Section A8.2 & A8.4):

$$n_{N2_i} := \left(\frac{m_{NO_i}}{MW_{NO}} \cdot \frac{3}{2} + \frac{m_{NO2_i}}{MW_{NO2}} \cdot \frac{7}{6} \right) \cdot 98\% \qquad n_{N2} = \begin{pmatrix} 1.46 \times 10^3 \\ 1.06 \times 10^3 \\ 340.84 \\ 170.71 \end{pmatrix} \cdot \frac{mol}{hr} \quad \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array}$$

A8.11 The molar flowrate of steam generated from the NO_x/NH_3 reactions is calculated based on a 98% reduction efficiency (Input 15), the calculated NO_x molar flowrates, and the defined stoichiometric ratio between NO_x and H_2O (See Section A8.2 & A8.4):

$$n_{H2O_i} := \left(\frac{m_{NO_i}}{MW_{NO}} \cdot \frac{6}{2} + \frac{m_{NO2_i}}{MW_{NO2}} \cdot \frac{12}{6} \right) \cdot 98\% \qquad n_{H2O} = \begin{pmatrix} 2.76 \times 10^3 \\ 2 \times 10^3 \\ 673.72 \\ 337.44 \end{pmatrix} \cdot \frac{mol}{hr} \quad \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array}$$

A8.12 The standard volumetric flowrate of the additional steam from Section A8.11 is calculated as follows using the defined molar flowrate above, the ideal gas equation and the defined standard temperatures and pressures:

$$T_S = 293.15\,K$$

$$P_S = 1\cdot atm$$

$$V_{H2O_i} := \frac{n_{H2O_i}\cdot R_G\cdot T_S}{P_S} \qquad V_{H2O} = \begin{pmatrix}39.07\\28.27\\9.54\\4.78\end{pmatrix}\cdot\frac{ft^3}{min}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

The additional steam standard flowrates (SCFM) are added to the steam flowrates in the SCR inlet stream to determine the steam standard volumetric flowrates in the SCR discharge in cell **E-44** of Attachment 1 flowsheets.

A8.13 The molar flowrate of oxygen gas consumed from the NO_x/NH_3 reactions is calculated based on a 98% reduction efficiency (Input 15), the calculated NO_x molar flowrates, and the defined stoichiometric ratio between NO_x and oxygen (See Section A8.2 & A8.4):

$$n_{O2_i} := \left(\frac{m_{NO_i}}{MW_{NO}}\cdot\frac{2}{2}\right)\cdot 98\% \qquad n_{O2} = \begin{pmatrix}597.6\\421.26\\208.67\\104.5\end{pmatrix}\cdot\frac{mol}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A8.14 The mass flowrate of additional N_2 based on the molar flowrate from Section A8.10 is calculated:

$$m_{N2_i} := n_{N2_i}\cdot MW_{N2} \qquad m_{N2} = \begin{pmatrix}40.91\\29.67\\9.55\\4.78\end{pmatrix}\cdot\frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

These flowrates are added in cell **AW-44** of Attachment 1 main flowsheets.

A8.15 The mass flowrate of consumed O_2 based on the molar flowrate from Section A8.13 is calculated:

$$m_{O2_i} := n_{O2_i} \cdot MW_{O2}$$

$$m_{O2} = \begin{pmatrix} 19.12 \\ 13.48 \\ 6.68 \\ 3.34 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

The flowrates of O_2 consumed are subtracted from the O_2 inlet flowrates to determine the residual O_2 flowrates in the SCR discharge in cell **BC-44** of Attachment 1 main flowsheets.

A8.16 The standard volumetric flowrate of the additional net dry air (from produced N_2 and consumed O_2 determined in Sections A8.10 and A8.13 is calculated by using the defined molar flowrate above, the ideal gas equation (Equation 1b) and the defined standard temperatures and pressures:

$$T_S = 293.15\,K$$

$$P_S = 1 \cdot atm$$

$$V_{Air_i} := \frac{\left(n_{N2_i} - n_{O2_i}\right) \cdot R_G \cdot T_S}{P_S}$$

$$V_{Air} = \begin{pmatrix} 12.22 \\ 9.03 \\ 1.87 \\ 0.94 \end{pmatrix} \cdot \frac{ft^3}{min}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

These flowrates are added in cell **C-44** of Attachment 1 main flowsheets.

A8.17 The mass flowrate of additional steam (H_2O) based on the molar flowrate from Section A8.11 is calculated:

$$m_{H2O_i} := n_{H2O_i} \cdot MW_{H2O}$$

$$m_{H2O} = \begin{pmatrix} 49.7 \\ 35.96 \\ 12.13 \\ 6.08 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

These flowrates are added in cell **BU-44** of Attachment 1 main flowsheets.

A8.18 The mass flowrate of ammonia (NH_3) added into the SCR based on the molar flowrate from Section A8.8 is calculated as follows:

$$m_{NH3f\_in_i} := n_{NH3_i} \cdot MW_{NH3} \qquad m_{NH3f\_in} = \begin{array}{cl} \begin{pmatrix} 31.97 \\ 23.13 \\ 7.81 \\ 3.91 \end{pmatrix} \cdot \dfrac{kg}{hr} & \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array} \end{array}$$

These ammonia flowrates are entered into cell **K-41** of Attachment 1 main flowsheets.

A8.19 The mass flowrate of residual ammonia (NH_3) based on the molar flowrate from Section A8.8 is calculated below:

$$m_{NH3f\_out_i} := n_{NH3_i} \cdot MW_{NH3} \cdot (1 - 98\%) \qquad m_{NH3f\_out} = \begin{array}{cl} \begin{pmatrix} 0.639 \\ 0.463 \\ 0.156 \\ 0.078 \end{pmatrix} \cdot \dfrac{kg}{hr} & \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array} \end{array}$$

These flowrates are added in cell **CS-44** of Attachment 1 main flowsheets.

Attachment 9 Film Cooler and Transition Line (i.e., Offgas Jumper) Average Pressure Drop

Attachment 9 provides the pressure drop across the film cooler and offgas jumper transition line based on data from VSL testing. These pressure drops are used in Attachment 1 flowsheets (cell **S-13** for film cooler and cell **S-16** for transition line).

Spreadsheet Explanation:

1. References for each data set are defined in Columns A through F.
2. The average differential pressures for the VSL DM-1200 film cooler and transition line was manually entered into Columns G and H, respectively.
3. The average differential pressure for all runs is calculated in cells [G-34] and [H-34] using Excel's AVERAGE function.
4. The maximum differential pressure is calculated in cells [G-35] and [H-35] using Excel's MAX function.
5. The standard deviation of the differential pressures is calculated in cells [G-36] and [H-36] using Excel's STDEV function
6. The statistical maximum differential pressures are calculated in cells [G-37] and [H-37] by adding the standard deviation to the average value.
7. The statistical minimum differential pressures are calculated in cells [G-38] and [H-38] by subtracting the standard deviation to the average value.

Attachment 9

VSL DM-1200 Film Cooler and Transition Line (i.e., Offgas Jumper) Average Pressure Drops (in. WG)

The average pressure drops across the film cooler and transition line are obtained from Ref. 9.2, 9.3, 9.4, 9.1 & 9.5.

The min, average and max pressure drops are used in Attachment 1 flowsheets (cells S-13 for film cooler and S-16 for transition line).

Report Number	Report Revision	Report Table	Report Page	Feed Vector	Run Number	Film Cooler ΔP (Input 2.4)	Transition Line ΔP (Input 2.4)
24590-101-TSA-W000-0009-111-01 (VSL-02R8800-1) [Ref. 9.2]	B	3.1	T-11	Sub-envelope C1 (AN-107 simulant)	1	2.43	0.85
24590-101-TSA-W000-0009-111-02 (VSL-02R8800-2) [Ref. 9.3]	B	3.1	T-10	Sub-envelope A1 (AN-105 simulant)	1	2.07	1.77
24590-101-TSA-W000-0009-143-01 (VSL-03R3851-1) [Ref. 9.4]	B	3.1	T-8	Sub-envelope B1	1	1.75	2.51
24590-101-TSA-W000-0009-105-00006 (VSL-04R4851-1) [Ref. 9.1]	A	5.2	T-27 T-28	Sub-envelope C1 (AN-107 simulant)	A	1.3	0.9
					B	0.6	0.3
					C	0.7	0.6
					D	0.9	1.3
					E	1.3	1.8
24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1) [Ref. 9.5]	B	4.2	T-35 T-37 T-36	Sub-envelope A2 (AP-101 simulant)	1 - AA	N/A	1.7
					1 - Naph	N/A	1.9
					1 - No Spike	N/A	1.9
					2A - AA/Naph	0.42	3.3
					2A - Naph/MeOH	0.39	3.3
					2A - No Spike	0.60	3.1
					2B	1.22	3.2

Average =>	**1.1**	**1.9**
Maximum =>	2.4	3.3
Standard Deviation =>	0.7	1.0
Average + SDev =>	**1.8**	**2.9**
Average - SDev =>	**0.5**	**0.9**

Attachment 10 SBS Average Pressure Drop

Attachment 10 estimates the pressure drop across the SBS based on VSL testing data (Ref 9.5). The design of the SBS was altered as testing progressed. The configuration used in Ref 9.5 is the most similar to what was procured for use in WTP.

Spreadsheet Explanation:

1. The differential pressures for the VSL DM-1200 SBS were manually entered into Column C. Average, minimum, and maximum measurements are recorded. References for the data are shown in Columns D, E & F.
2. The average differential pressure is calculated in cell [C-18] using Excel's AVERAGE function.
3. The smallest minimum differential pressure is calculated in cell [C-31] using Excel's MIN function.
4. The largest maximum differential pressure is calculated in cell [C-43] using Excel's MAX function.

The SBS estimated differential pressures are entered in cell **S-17** of Attachment 1 flowsheets. The minimum differential pressure is used in the minimum flowsheet cases, the average is used in the nominal case, and the maximum is used in the maximum cases. Figures 4.65 and 4.72 of Ref. 9.5 show that the SBS differential pressure was relatively steady during testing.

	A	B	C	D	E	F
2						
3	**Attachment 10**					
4	**Average SBS Pressure Drop (in. WG)**					
5						
6						
7		VSL DM-1200 SBS ΔP				
8			Average			
9		Test	ΔP (in. WC) [Input 2.4]	Source		
10		1	32.4	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
11		1	32.5	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
12		1	32.5	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
13		2B	32.1	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
14		2A	32.0	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
15		2A	31.7	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
16		2A	31.9	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
17						
18	Average ΔP =>		**32.2**		Values in Bold are entered in cell **S-17** of Attachment 1 flowsheets.	
19						
20						
21			Minimum			
22		Test	ΔP (in. WC) [Input 2.4]	Source		
23		1	30.8	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
24		1	30.6	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
25		1	28.6	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
26		2B	26.4	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
27		2A	27.8	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
28		2A	26.8	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
29		2A	27.2	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
30						
31	Minimum ΔP =>		**26.4**			
32						
33			Maximum			
34		Test	ΔP (in. WC) [Input 2.4]	Source		
35		1	33.6	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
36		1	33.8	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
37		1	33.9	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
38		2B	34.7	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
39		2A	33.1	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
40		2A	32.9	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
41		2A	33.9	Table 4.2	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1)	[Ref. 9.5]
42						
43	Maximum ΔP =>		**34.7**			
44						
45	The minimum, average and maximum pressure drop values in Bold are entered in cell **S-17** of Attachment 1 flowsheets.					

Attachment 11 WESP Average Pressure Drop

Attachment 11 determines the minimum, average, and maximum pressure drops across the WESP based on VSL testing data (Ref. 9.1 - 9.5).

Spreadsheet Explanation:

1. References for each data set are defined in Columns A through F.
2. The average differential pressures for the VSL DM-1200 WESP in all test runs are manually entered into Column G.
3. The overall average differential pressure is calculated in cell [G-32] using Excel's AVERAGE function.
4. The maximum differential pressure is calculated in cell [G-33] using Excel's MAX function.
5. The standard deviation of the differential pressures is calculated in cell [G-34] using Excel's STDEV function.
6. The statistical maximum differential pressure is calculated in cell [G-35] by adding the standard deviation to the average value.
7. The statistical minimum differential pressure is calculated in cell [G-36] by subtracting the standard deviation to the average value.

The results are entered into cell **S-21** of Attachment 1 flowsheets. The minimum pressure drops are used in the minimum flowsheet cases, the average is used in the nominal case, and the maximum is used in the maximum cases.

	A	B	C	D	E	F	G
1	**Attachment 11**						
2	**VSL DM-1200 WESP Average Pressure Drops (in. WG)**						
4 5	Report Number	Report Revision	Report Table	Report Page	Feed Vector	Run Number	WESP ΔP [Input 2.4] (in. WC)
6 7 8 9 10	24590-101-TSA-W000-0009-111-01 (VSL-02R8800-1) [Ref. 9.2]	B	4.1	T-12	Sub-envelope C1 (AN-107 simulant)	1	2.7
11 12 13 14	24590-101-TSA-W000-0009-111-02 (VSL-02R8800-2) [Ref. 9.3]	B	4.1	T-11	Sub-envelope A1 (AN-105 simulant)	1	2.2
15 16 17 18	24590-101-TSA-W000-0009-143-01 (VSL-03R3851-1) [Ref. 9.4]	B	4.1	T-9	Sub-envelope B1 (AZ-101 simulant)	1	2.9
19	24590-101-TSA-W000-0009-105-00006 (VSL-04R4851-1) [Ref. 9.1]	A	5.2		Sub-envelope C1 (AN-107 simulant)	A	4.6
20				T-27		B	3.8
21						C	2.7
22						D	2.4
23				T-28		E	2.5
24	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1) [Ref. 9.5]	B	4.2		Bounding Sub-envelope A2 (AP-101 simulant)	1 - AA	2.2
25				T-35		1 - Naph/MeOH	2.4
26						1 - No Spike	2.4
27						2A - AA/Naph	2.2
28				T-37		2A - Naph/MeOH	2.2
29						2A - No Spike	2.2
30				T-36		2B	2.1
31							
32					Average =>		**2.6**
33					Maximum =>		4.6
34					Standard Deviation =>		0.7
35					Average + SDev =>		**3.3**
36					Average - SDev =>		**1.9**
37							
38	Values in Bold are entered in cell **S-21** of Attachment 1 flowsheets.						

Attachment 12 Deleted

Attachment 13 Deleted

Attachment 14 Water Vapor Pressure Equation Determination

Attachment 14 provides the equation to determine the water vapor pressure at a specific temperature for use in the calculation of the offgas relative humidity in Attachment 1 flowsheets. The equation is derived from plotting the vapor pressure data versus temperatures and using the Excel trendline feature.

Spreadsheet Explanation:

1. The vapor pressure of water was manually entered into Column C for temperatures ranging from 0 to 100°C (Column B) obtained from CRC (Ref. 10.2.20, Page 6-5). Similarly, the vapor pressure data corresponding to temperatures above 100°C was entered into Columns M (Ref. 10.2.20, Page 6-5 & 6-6).
2. The vapor pressure data defined in Column C & M are converted from kPa to mbar units in Column D & N respectively, using conversion factor 10 mbar/1 kPa.
3. The converted water vapor pressure data (mbar) is plotted against temperatures (°C) in the provided figures.
4. Excel's trendline feature was used to define a fourth order equation for the data set as shown on the figure.
5. The equation is used to re-predict the water vapor pressures at temperatures ≤ 100°C in Column E and at temperatures above 100°C in Column O.
6. The differential percentage between the equation predicted values and the actual data is determined in Column F and Column P.
   These comparisons show that the equation is very accurate at reproducing the vapor pressure data.

The vapor pressure equations are used in **Column AC** of Attachment 1 worksheets to determine the offgas relative humidity based on Equation 9a & 9b in Section 5 of this calculation.

Attachment 14

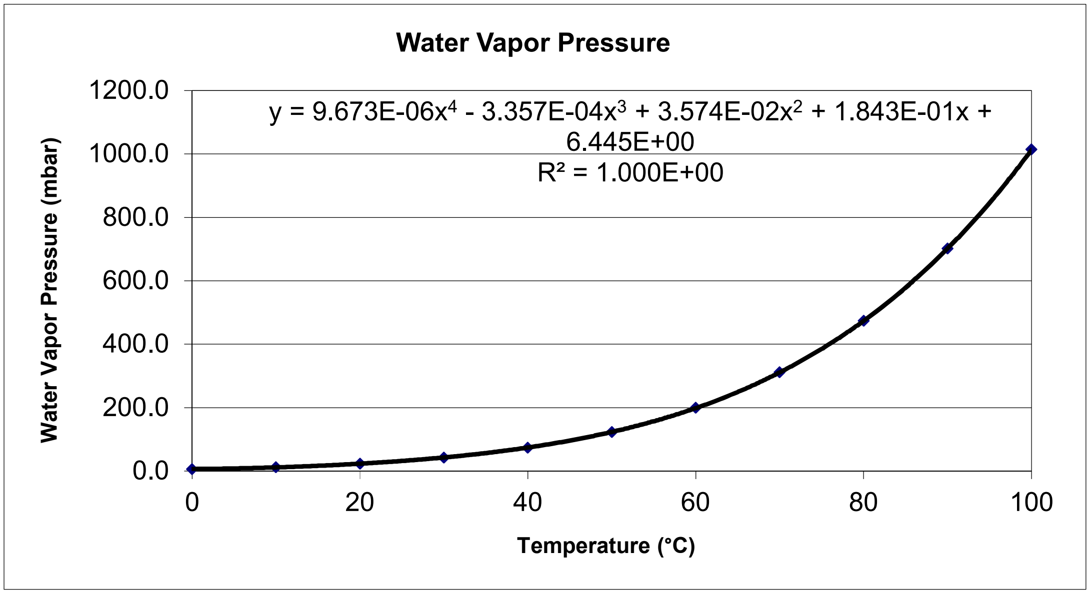
Water Vapor Pressure

From CRC (Ref. 10.2.20, Page 6-5) [Input 2.11]

Temperature Range 0 - 100°C

Temp. °C	Vapor Pressure kPa	Vapor Pressure mbar	Equation Comparison Predicted value mbar	Equation Comparison Error
0	0.61165	6.1165	6.4	-5.4%
10	1.2282	12.282	11.6	5.4%
20	2.3393	23.393	23.3	0.4%
30	4.247	42.47	42.9	-1.0%
40	7.3849	73.849	74.3	-0.6%
50	12.352	123.52	123.5	0.0%
60	19.946	199.46	199.0	0.2%
70	31.201	312.01	311.6	0.1%
80	47.414	474.14	474.3	0.0%
90	70.182	701.82	702.4	-0.1%
100	101.42	1014.2	1013.9	0.0%

Overall Error => 0.0%



Attachment 14 - page 2

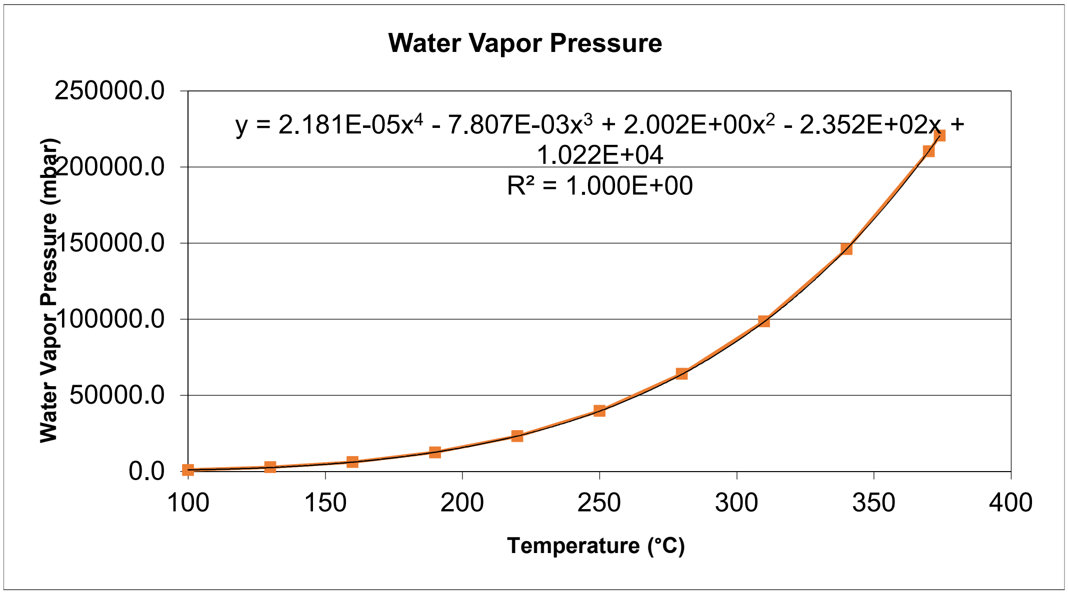
Water Vapor Pressure

From CRC (Ref. 10.2.20, Page 6-5 & 6-6) [Input 2.11]

Temperature Range 100 - 374°C

Temp. °C	Vapor Pressure kPa	Vapor Pressure mbar	Equation Comparison Predicted value mbar	Equation Comparison Error
100	101.42	1,014.2	1,094.0	-7.9%
130	270.28	2,702.8	2,555.0	5.5%
160	618.23	6,182.3	6,155.1	0.4%
190	1,255.20	12,552.0	12,679.0	-1.0%
220	2,319.60	23,196.0	23,335.1	-0.6%
250	3,976.20	39,762.0	39,755.9	0.0%
280	6,416.60	64,166.0	63,998.0	0.3%
310	9,865.10	98,651.0	98,541.8	0.1%
340	14,601.00	146,010.0	146,291.8	-0.2%
370	21,044.00	210,440.0	210,576.3	-0.1%
373.95	22,064.00	220,640.0	220,466.1	0.1%

Overall Error => 0.0%



Attachment 15 Heat Capacity Equations for Primary Air Components

This attachment provides the temperature dependent equations to determine heat capacities for the primary air components used in Attachment 1 flowsheets.

Spreadsheet Explanation:

1. The coefficients for molar heat capacity equations based on gas temperature for dry air, nitrogen, oxygen, carbon dioxide, and water vapor are manually entered into Columns B, C, D, and E [Felder, Table B.2 (Ref. 10.2.9, pages 622 and 624)]. The heat capacity of Argon does not vary significantly with the range of temperature change in the flowsheets, therefore the Argon heat capacity of 20.8 J/mol·C (Ref. 10.2.6, pg C-133) is used in the calculation of the overall heat capacity of the offgas.
2. The molecular weight of the different gases is manually entered into Column F (Ref. 10.2.9, Table B.2).
3. The heat capacity equation coefficients are converted from a molar basis to a mass basis in Columns, G, H, I, and J by dividing the coefficients by the molecular weight in Column F.

These coefficients are used to calculate the overall heat capacity of the offgas in **Column AK** of Attachment 1 flowsheets (see Section 5.16 of the calculation).

Attachment 15

Heat Capacity of Primary Air Components

Heat Capacity General Equation: => $Cp = a + b \cdot T + c \cdot T^2 + d \cdot T^3$ (Felder, Table B.2 & CRC, page 6-133 for Argon Only)

Table B-1 - Heat Capacity Coefficient Conversion

	Heat Capacity Coefficient (J/mol-C) [1]				MW [3]	Heat Capacity Coefficient (KJ/kg-C)			
	a	b	c	d	(g/mol)	a	b	c	d
Air	28.94	4.15E-03	3.19E-06	-1.97E-09	29.00	0.998	1.43E-04	1.10E-07	-6.78E-11
N_2	29.00	2.20E-03	5.72E-06	-2.87E-09	28.02	1.035	7.85E-05	2.04E-07	-1.02E-10
O_2	29.10	1.16E-02	-6.08E-06	1.31E-09	32.00	0.909	3.62E-04	-1.90E-07	4.10E-11
Ar [2]	20.8				39.95	0.521			
CO_2	36.11	4.23E-02	-2.89E-05	7.46E-09	44.01	0.8205	9.62E-04	-6.56E-07	1.70E-10
H_2O	33.46	6.88E-03	7.60E-06	-3.59E-09	18.02	1.8573	3.82E-04	4.22E-07	-1.99E-10

[1] Input 2.7 (Ref. 10.2.9, p. 622 & 624)

[2] Input 2.7 (Ref. 10.2.6, p. 6-133)

[3] Input 2.2 (Ref. 10.2.6)

Attachment 16 Deleted

Attachment 17 Not Used

Attachment 18 Not Used

Attachment 19 Not Used

Attachment 20 TCO Temperature Increase and Residual TCO Gas Discharge Mass Flowrate Calculation

Attachment 20 calculates the temperature rise across the Thermal Catalytic Oxidizer (TCO), LVP-SCO-00001, and the TCO discharge mass flowrate for gas components produced or consumed from the oxidation reaction, using MathCAD.

The temperature increase is added to the TCO inlet temperature to determine the TCO outlet temperature in Cell **O-38** of Attachment 1 flowsheets. The mass flow of additional dry air, CO_2 produced, O_2 consumed and steam produced from the oxidation reactions are added to or subtracted from the corresponding flowrates to obtain the mass flows in the TCO discharge (cells **C-38, BI-38, BC-38** and **BU-38** respectively in Attachment 1 flowsheets).

Attachment 20 - TCO Temperature Increase, and Residual TCO Gas Discharge Mass Flowrate Calculation

Unit Definition:

Length

$\mathrm{mm} \equiv \dfrac{\mathrm{m}}{1000}$

$\mathrm{in} \equiv 25.4 \cdot \mathrm{mm}$

$\mathrm{ft} \equiv 12 \cdot \mathrm{in}$

$\mathrm{cm} \equiv \dfrac{\mathrm{m}}{100}$

$\mu\mathrm{m} \equiv \dfrac{\mathrm{mm}}{1000}$

Energy

$\mathrm{J} \equiv \dfrac{\mathrm{kg} \cdot \mathrm{m}^2}{\mathrm{s}^2}$

$\mathrm{KJ} \equiv 1000 \cdot \mathrm{J}$

$\mathrm{Btu} \equiv 1055.1 \cdot \mathrm{J}$

Gravity

$g_n := 9.81 \cdot \dfrac{\mathrm{m}}{\mathrm{s}^2}$

Temperature

$\mathrm{C} \equiv \mathrm{K}$

$\mathrm{F} \equiv \dfrac{5}{9} \cdot \mathrm{C}$

$\mathrm{F} \equiv \mathrm{R}$

Gas Constant

$R_G := 8.314 \cdot \dfrac{\mathrm{J}}{\mathrm{mol} \cdot \mathrm{K}}$

Power

$\mathrm{W} \equiv \dfrac{\mathrm{J}}{\mathrm{s}}$

$\mathrm{mW} \equiv \dfrac{\mathrm{W}}{1000}$

$\mathrm{kW} \equiv 1000 \cdot \mathrm{W}$

$\mathrm{Hp} \equiv 745.71 \cdot \mathrm{W}$

Volume

$\mathrm{L} \equiv \dfrac{\mathrm{m}^3}{1000}$

$\mathrm{gal} \equiv \dfrac{\mathrm{ft}^3}{7.4805}$

$\mathrm{ml} \equiv \dfrac{\mathrm{L}}{1000}$

Pressure

$\mathrm{Pa} \equiv \dfrac{\mathrm{kg}}{\mathrm{m} \cdot \mathrm{s}^2}$

$\mu\mathrm{Pa} \equiv \dfrac{\mathrm{Pa}}{1000000}$

$\mathrm{bar} \equiv 100000 \cdot \mathrm{Pa}$

$\mathrm{mbar} \equiv \dfrac{\mathrm{bar}}{1000}$

$\mathrm{atm} \equiv 1.01325 \cdot \mathrm{bar}$

$\mathrm{psi} \equiv \dfrac{\mathrm{atm}}{14.696}$

$\mathrm{inWC} \equiv \dfrac{\mathrm{psi}}{27.681}$

$\mathrm{mmWC} \equiv \dfrac{\mathrm{inWC}}{25.4}$

Force

$\mathrm{N} \equiv \mathrm{kg} \cdot \dfrac{\mathrm{m}}{\mathrm{s}^2}$

$\mathrm{mN} := \dfrac{\mathrm{N}}{1000}$

Viscosity

$\mathrm{cP} \equiv 1000 \cdot \mu\mathrm{Pa} \cdot \mathrm{s}$

$\mathrm{P} \equiv 100 \cdot \mathrm{cP}$

Mass

$\mathrm{g} \equiv \dfrac{\mathrm{kg}}{1000}$

$\mathrm{lb} \equiv \dfrac{\mathrm{kg}}{2.20462}$

$\mu\mathrm{g} \equiv \dfrac{\mathrm{g}}{1000000}$

Substance

$\mathrm{kmol} \equiv 1000 \cdot \mathrm{mole}$

$\mathrm{lbmole} \equiv \dfrac{\mathrm{kmol}}{2.20462}$

$\mathrm{mmol} \equiv \dfrac{\mathrm{mole}}{1000}$

Time

$\mathrm{min} \equiv 60 \cdot \mathrm{s}$

$\mathrm{hr} \equiv 3600 \cdot \mathrm{s}$

$\mathrm{day} \equiv 24 \cdot \mathrm{hr}$

$\mathrm{year} \equiv 365.25 \cdot \mathrm{day}$

This attachment calculates the temperature rise across the TCO. It also determines what components are added or subtracted from the gas as the gas reacts in the TCO.

A20.1 The molecular weights of different chemical species used in this calculation (VOC, CO, CO_2, H_2O & O_2) are identified per Table 2 in Section 2 (Input 2.2):

$MW_{VOC} := 58.1 \cdot \dfrac{\mathrm{g}}{\mathrm{mol}}$

$MW_{CO2} := 44.01 \cdot \dfrac{\mathrm{g}}{\mathrm{mol}}$

$MW_{O2} := 32 \cdot \dfrac{\mathrm{g}}{\mathrm{mol}}$

$MW_{CO} := 28.01 \cdot \dfrac{\mathrm{g}}{\mathrm{mol}}$

$MW_{H2O} := 18.01 \cdot \dfrac{\mathrm{g}}{\mathrm{mol}}$

A20.2 The heat of reaction (H_r) is the difference between the enthalpy of the products and the enthalpy of the reactants at a given temperature and pressure (Felder, pg. 422).

The TCO unit oxidizes volatile and semi-volatile organic compounds. The standard oxidization reactions in the catalyst skid TCO are defined below.

VOC Reaction (C_3H_6O - Allyl Alcohol): $2\,C_3H_6O + 8\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$

CO Reaction: $2\,CO + O_2 \rightarrow 2\,CO_2$

The associated heats of reaction are determined below using defined component enthalpies per Barin (Ref. 10.2.2) at 700 K (427°C). The temperature in the TCO is expected to be about 399°C based on the skid preheater setting (750 °R per Input 19; see Cell O-37 of Attachment 1 flowsheets). Per Input 40, 41, 43 and 45 in Section 2.1 of the main calculation:

$H_{CO} := -98.518 \cdot \frac{KJ}{mol}$ (Ref. 10.2.2, pg 271)

$H_{H2O} := -227.635 \cdot \frac{KJ}{mol}$ (Ref. 10.2.2, pg 650)

$H_{CO2} := -375.749 \cdot \frac{KJ}{mol}$ (Ref. 10.2.2, pg 272)

$H_{O2} := 12.499 \cdot \frac{KJ}{mol}$ (Ref. 10.2.2, pg 1093)

The enthalpy for VOCs is based on allyl alcohol and is calculated from reference data from Poling (Ref. 10.2.17, pg. A-22 and A-37).

The enthalpy of formation (ΔH_f^0) for the reference state of 298.15K and 1 atm of allyl alcohol is as follows (Ref. 10.2.17, pg A.22):

$H_{VOC0} := -123.6 \cdot \frac{KJ}{mol}$ (Input 39)

The equation to calculate the heat capacity of allyl alcohol, C_{pVOC} (J/mol*K), is shown below (Ref. 10.2.17, pg A.36 & A.37):

$C_{pVOC}/R_G = a_0 + a_1T + a_2T^2 + a_3T^3 + a_4T^4$ (Equation 16c)

$R_G = 8.314 \cdot \frac{J}{mol \cdot K}$

For allyl alcohol, C_3H_6O, the coefficients are: $a_0 = 0.248$, $a_1 = 34.938{*}10^{-3}$, $a_2 = -1.685{*}10^{-5}$, $a_3 = -0.192{*}10^{-8}$, $a_4 = 0.324{*}10^{-11}$ (Ref. 10.2.17, pg A.37).

$$C_{pVOC}(T_G) := R_G \cdot \left[0.248 + \left(34.938 \cdot 10^{-3}\right) \cdot \frac{1}{K} \cdot T_G + \left(-1.685 \cdot 10^{-5}\right) \cdot \frac{1}{K^2} \cdot T_G^{\,2} + \left(-0.192 \cdot 10^{-8}\right) \cdot \frac{1}{K^3} \cdot T_G^{\,3} + \left(0.324 \cdot 10^{-11}\right) \cdot \frac{1}{K^4} \cdot T_G^{\,4}\right]$$

Determining the enthalpy at 700K (Ref. 10.2.17, Equation 3-1.5, pg 3.2):

$$H_{VOC} := H_{VOC0} + \int_{298.15 \cdot K}^{700 \cdot K} C_{pVOC}(T_G)\, dT_G \qquad H_{VOC} = -79.329 \cdot \frac{KJ}{mol}$$

Now that the enthalpies of the products and reactants have been determined, calculate the heat of reaction for the TCO oxidation reactions.

VOC Reaction (C_3H_6O - Allyl Alcohol): $2\ C_3H_6O + 8\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

Based on Equation (22a) & (22b) in Section 5:

$\Delta H_r = \Sigma(\nu^*\Delta H)_{products} - \Sigma(\nu^*\Delta H)_{reactants}$

$\Delta H = \Delta H_r(T)^*n/\nu$ Where $\Delta H_r(T)$ = heat of reaction at temperature T, in this case 700K (kJ/mol)

ΔH = enthalpy change of reactants and products at temperature T (kJ/mol)
n = moles of reactant or product

ν = stoichiometric coefficient

Enthalpy change for VOC reaction:

$$H_{rVOC} := \frac{6 \cdot H_{CO2} + 6 \cdot H_{H2O} - 2 \cdot H_{VOC} - 8H_{O2}}{2}$$

$$H_{rVOC} = -1.781 \times 10^3 \cdot \frac{KJ}{mol}$$ (per mol of VOC reacted)

CO Reaction: $2\ CO + O_2 \rightarrow 2\ CO_2$

Enthalpy change for CO reaction:

$$H_{rCO} := \frac{2 \cdot H_{CO2} - 2 \cdot H_{CO} - H_{O2}}{2}$$

$$H_{rCO} = -283.481 \cdot \frac{KJ}{mol}$$ (per mol of CO reacted)

Calculating the total energy change by introducing mass flowrate.

A20.3 The total mass flowrate at the TCO inlet for the five cases are defined below from cell [*K-37*] in Attachment 1 flowsheets:

$i := 1 .. 4$

$$m_T := \begin{pmatrix} 5510 \\ 5030 \\ 4010 \\ 2060 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A20.4 The mass flowrate of VOC and CO in the melter offgas for the five cases are defined below from cells [*CY-37*] and [*EO-37*] in Attachment 1 flowsheets, respectively:

$$m_{VOC} := \begin{pmatrix} 1.87 \\ 0.488 \\ 3.96 \times 10^{-4} \\ 1.98 \times 10^{-4} \end{pmatrix} \cdot \frac{kg}{hr} \qquad m_{CO} := \begin{pmatrix} 1.67 \\ 0.925 \\ 8.34 \times 10^{-2} \\ 4.17 \times 10^{-2} \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A20.5 Based on the contaminant mass flowrates, molecular weights, and reaction energies, the total energy change for the four cases is calculated as follows:

$$Q_{rTCO_i} := \frac{m_{CO_i}}{MW_{CO}} \cdot H_{rCO} + \frac{m_{VOC_i}}{MW_{VOC}} \cdot H_{rVOC} \qquad -Q_{rTCO} = \begin{pmatrix} 7.422 \times 10^{4} \\ 2.432 \times 10^{4} \\ 856.203 \\ 428.102 \end{pmatrix} \cdot \frac{KJ}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A20.6 The heat capacity of the offgas for the four cases at the TCO discharge is defined per cell [AK-38]:

$$Cp_{offgas} := \begin{pmatrix} 1.159 \\ 1.133 \\ 1.102 \\ 1.102 \end{pmatrix} \cdot \frac{KJ}{kg \cdot C}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A20.7 The temperature increase across the TCO is calculated from Equation (22d) in Section 5:

$$\Delta T_{TCO_i} := \frac{-Q_{rTCO_i}}{m_{T_i} \cdot Cp_{offgas_i}} \qquad \Delta T_{TCO} = \begin{pmatrix} 11.6 \\ 4.3 \\ 0.2 \\ 0.2 \end{pmatrix} \cdot C$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

This temperature increase is added to the TCO inlet temperature to determine the TCO outlet temperature in Cell **O-38** of Attachment 1 flowsheets.

A20.8 The molar flowrate of carbon dioxide (i.e., dry gas component) generated from the oxidization reactions is calculated based on a 95% conversion (Input 13), the calculated VOC and CO molar flowrates, and the stoichiometric ratio between CO/VOC and CO_2 (See Section A20.2 & A20.4):

$$n_{CO2_i} := \left(\frac{m_{CO_i}}{MW_{CO}}\cdot\frac{2}{2} + \frac{m_{VOC_i}}{MW_{VOC}}\cdot\frac{6}{2}\right)\cdot 95\%$$

$$n_{CO2} = \begin{pmatrix} 148.37 \\ 55.311 \\ 2.848 \\ 1.424 \end{pmatrix}\cdot\frac{mol}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A20.9 The molar flowrate of steam resulting from the oxidization reactions is calculated based on a 95% conversion (Input 13), the calculated VOC molar flowrates, and the defined stoichiometric ratio between VOC and H_2O (See Section A20.2 & A20.4):

$$n_{H2O_i} := \left(\frac{m_{VOC_i}}{MW_{VOC}}\cdot\frac{6}{2}\right)\cdot 95\cdot\%$$

$$n_{H2O} = \begin{pmatrix} 91.73 \\ 23.938 \\ 0.019 \\ 9.713\times 10^{-3} \end{pmatrix}\cdot\frac{mol}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A20.10 The standard volumetric flowrate of the additional steam from Section A20.9 is calculated as follows using the molar flowrate above, the ideal gas equation (Equation 1b) and the defined standard temperatures and pressures:

$$T_S := 293.15\cdot K$$

$$P_S := 1\cdot atm$$

$$V_{H2O_i} := \frac{n_{H2O_i}\cdot R_G\cdot T_S}{P_S}$$

$$V_{H2O} = \begin{pmatrix} 1.299 \\ 0.339 \\ 2.75\times 10^{-4} \\ 1.375\times 10^{-4} \end{pmatrix}\cdot\frac{ft^3}{min}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

The steam standard volumetric flowrate formed from the oxidation reaction is then added to the steam standard flow from the previous unit to obtain the steam standard flow in the TCO discharge in cell **E-38** of Attachment 1 flowsheets.

A20.11 The molar flowrate of oxygen gas consumed from the oxidization reactions is calculated based on a 95% conversion (Input 13), the calculated VOC and CO molar flowrates, and the defined stoichiometric ratio between CO/VOC and O_2 (See Section A20.2 & A20.4):

$$n_{O2_i} := \left(\frac{m_{CO_i}}{MW_{CO}}\cdot\frac{1}{2} + \frac{m_{VOC_i}}{MW_{VOC}}\cdot\frac{8}{2}\right)\cdot 95\cdot\% \qquad n_{O2} = \begin{pmatrix}150.627\\47.604\\1.44\\0.72\end{pmatrix}\cdot\frac{\text{mol}}{\text{hr}} \quad \begin{array}{l}\text{Maximum (2 Melters)}\\\text{Nominal (2 Melters)}\\\text{Minimum (2 Melters)}\\\text{Minimum (1 Melter)}\end{array}$$

A20.12 The standard volumetric flowrate of the additional net dry air (from CO_2 produced and O_2 consumed) from Sections A20.8 and A20.11 is calculated as follows using the molar flowrate calculated above, the ideal gas equation (Equation 1b) and the defined standard temperatures and pressures:

$$V_{Air_i} := \frac{\left(n_{CO2_i} - n_{O2_i}\right)\cdot R_G\cdot T_S}{P_S} \qquad V_{Air} = \begin{pmatrix}-0.032\\0.109\\0.02\\9.966\times 10^{-3}\end{pmatrix}\cdot\frac{\text{ft}^3}{\text{min}} \quad \begin{array}{l}\text{Maximum (2 Melters)}\\\text{Nominal (2 Melters)}\\\text{Minimum (2 Melters)}\\\text{Minimum (1 Melter)}\end{array}$$

These flowrates are added to the TCO discharge flow in cell **C-38** of Attachment 1 flowsheets.

A20.13 The mass flowrate of additional CO_2 produced based on the molar flowrate from Section A20.8 is calculated:

$$m_{CO2_i} := n_{CO2_i}\cdot MW_{CO2} \qquad m_{CO2} = \begin{pmatrix}6.53\\2.434\\0.125\\0.063\end{pmatrix}\cdot\frac{\text{kg}}{\text{hr}} \quad \begin{array}{l}\text{Maximum (2 Melters)}\\\text{Nominal (2 Melters)}\\\text{Minimum (2 Melters)}\\\text{Minimum (1 Melter)}\end{array}$$

The mass flow of CO_2 produced is added to the CO_2 mass flow exiting the TCO in cell **BI-38** of Attachment 1 flowsheets.

A20.14 The mass flowrate of consumed O_2 based on the molar flowrate from Section A20.11 is calculated below:

$$m_{O2_i} := n_{O2_i} \cdot MW_{O2} \qquad m_{O2} = \begin{pmatrix} 4.82 \\ 1.523 \\ 0.046 \\ 0.023 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

The mass flowrate of consumed O_2 are subtracted from the O_2 mass inlet flow to give the O_2 mass flowrate exiting the TCO in cell **BC-38** of Attachment 1 flowsheets.

A20.15 The mass flowrate of additional steam (H_2O) produced based on the molar flowrate from Section A20.9 is calculated below:

$$m_{H2O_i} := n_{H2O_i} \cdot MW_{H2O} \qquad m_{H2O} = \begin{pmatrix} 1.652 \\ 0.431 \\ 3.498 \times 10^{-4} \\ 1.749 \times 10^{-4} \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

The mass flow of steam produced is added to the steam mass flow exiting the TCO in cell **BU-38** of Attachment 1 flowsheets.

Attachment 21 Not Used

Attachment 22 Deleted

Attachment 23 Deleted

Attachment 24 Total Hydrocarbon Concentrations in Offgas Exiting Melter

Attachment 24 spreadsheet is used to determine the minimum, average and maximum VOC content of offgas exiting the melter based on VSL testing data (Ref. 9.7, Table 4.4 & 4.5, pg. T-18 through T-20).

Per Assumption 30 in Section 6.1 of the calculation, all of the VOC exiting the melters is assumed to travel through the SBS and WESP with no change in concentration.

Spreadsheet Explanation:

1. References for each data set are defined in Columns A through D.
2. The total hydrocarbon concentrations (ppm_v) from Ref. 9.7, Table 4.4 & 4.5 are manually entered into Column E.
3. The average hydrocarbon concentration is calculated in Cell [E-646] using Excel's AVERAGE function.
4. The standard deviation is calculated in Cell [E-647] using Excel's STDEV function.
5. The minimum hydrocarbon concentration is calculated in Cell [E-649] using Excel's MIN function.
6. The statistical maximum hydrocarbon concentration is calculated in Cell [E-650] by adding the standard deviation to the average value.

The average VOC concentration is used in the nominal case and the minimum concentration is used in the minimum cases. The total VOC concentration is entered in Cell **DC-15** of Attachment 1 flowsheets for stream LMP14 (controlled offgas). The VOC concentration in LOP02 (SBS discharge, Cell DC-17) and LOP08 (WESP discharge, Cell DC-21) are the same as the concentration in LMP14 (Cell DC-15).
For the maximum cases, Input 2.14 provides input data for SVOC/VOC mass flowrates and LMP06 mass flowrates used in the determination of the maximum VOC concentration. See Section 5.22 for the methodology used in maximum cases.

	A	B	C	D	E
1	**Attachment 24**				
2	**Total Hydrocarbon Concentrations in Offgas Exiting Melter**				
3	24590-101-TSA-W000-0009-87-12, Rev. B (Ref. 9.7)				
4					
5					
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
8					23.1
9					18.2
10					11.5
11					8.8
12					9.4
13					24.1
14					22.4
15					25.3
16					17.5
17					13.6
18					12.8
19					13.3
20					24.7
21					16.6
22					19.2
23					18.9
24					24.9
25					30.7
26					29.6
27	4.4	T-18 & T-19	B1	Run #1, 28" from cold cap	28.3
28					26.3
29					23.0
30					21.4
31					27.6
32					30.1
33					30.4
34					30.6
35					18.9
36					15.9
37					14.6
38					12.7
39					17.9
40					23.1
41					24.2
42					18.1
43					16.0
44					12.7
45					12.7
46					12.2
47					14.5
48					16.7
49					15.9
50					15.9
51					14.2
52					12.0
53					17.9
54					23.3
55					24.4
56					22.6
57					19.9
58					17.2
59					20.3
60					21.4
61					23.3
62					26.3
63					25.3
64					21.8
65					21.2
66					17.6
67					18.1
68					14.3
69					13.5
70	4.4	T-18 & T-19	B1	Run #1, 28" from cold cap	12.2
71					10.6
72					10.2
73					9.0
74					8.3

	A	B	C	D	E
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
75					7.9
76					8.5
77					14.9
78					34.5
79					31.8
80					23.9
81					21.1
82					17.7
83					14.2
84					29.1
85					39.5
86					29.9
87					23.2
88					17.1
89					16.5
90					14.0
91					21.2
92					38.3
93					43.6
94					33.3
95					22.0
96					17.2
97					14.4
98					26.4
99					21.2
100					19.9
101					15.1
102					11.8
103					10.5
104					9.4
105					8.1
106					8.3
107					9.0
108					8.0
109					8.5
110					8.7
111					8.3
112	4.4	T-18 & T-19	B1	Run #1, 28" from cold cap	7.5
113					8.4
114					8.3
115					9.7
116					8.8
117					9.9
118					10.8
119					11.2
120					15.8
121					13.6
122					9.9
123					8.8
124					8.2
125					8.9
126					15.6
127					33.0
128					87.8
129					68.7
130					53.8
131					35.2
132					112.3
133					282.3
134					153.3
135					91.6
136					60.4
137					47.5
138					43.9
139					43.7
140					49.9
141					38.0
142					36.3
143					34.1
144					42.1
145					52.9
146					89.5

	A	B	C	D	E
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
147					169.2
148					159.2
149					125.0
150					68.6
151					49.0
152					46.1
153					48.3
154	4.4	T-18 & T-19	B1	Run #1, 14" from cold cap	84.3
155					90.7
156					71.0
157					55.8
158					48.9
159					46.0
160					78.9
161					157.4
162					137.8
163					84.6
164					92.1
165					98.5
166					101.5
167					114.3
168					81.0
169					21.5
170					63.8
171					51.9
172					47.1
173					41.3
174					150.2
175					160.7
176					181.7
177					81.6
178					58.7
179					49.0
180					41.7
181					68.4
182					90.2
183					80.1
184					72.8
185					56.7
186					59.4
187					50.2
188					81.9
189					147.3
190					114.3
191					104.1
192					88.7
193					120.3
194					127.9
195					151.7
196	4.4	T-18 & T-19	B1	Run #1, 14" from cold cap	167.0
197					135.2
198					100.3
199					84.0
200					98.5
201					51.6
202					107.2
203					91.4
204					65.5
205					49.2
206					89.1
207					72.8
208					47.5
209					53.1
210					57.3
211					48.6
212					36.4
213					33.3
214					28.8
215					26.8
216					35.1
217					36.2
218					28.7

	A	B	C	D	E
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
219					28.2
220					21.8
221					21.6
222					22.4
223					26.2
224					49.2
225					41.8
226					40.3
227					36.7
228					38.0
229					34.7
230					32.3
231					46.2
232					50.5
233					99.0
234					72.6
235					58.8
236					59.8
237	4.4	T-18 & T-19	B1	Run #1, 14" from cold cap	105.1
238					105.1
239					52.6
240					43.4
241					46.2
242					61.8
243					66.9
244					107.7
245					66.0
246					49.7
247					41.5
248					36.4
249					36.4
250					53.6
251					91.1
252					57.7
253					52.7
254					54.7
255					54.5
256					56.2
257					77.9
258					202.8
259					236.8
260					158.3
261	4.4	T-18 & T-19	B1	Run #1, on cold cap	120.5
262					74.0
263					50.5
264					46.0
265					70.7
266					22.1
267					0.1
268					0.1
269					0.1
270					0.1
271					0.1
272					17.1
273					104.9
274					103.5
275					135.9
276					96.5
277					52.3
278					45.1
279					48.3
280					67.0
281					56.7
282					58.0
283					91.2
284					81.4
285					65.0
286					43.0
287					118.8
288					71.9
289					99.5
290					64.3

	A	B	C	D	E
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
291					89.0
292					66.0
293					40.0
294					77.0
295	4.4	T-18 & T-19	B1	Run #1, on cold cap	52.3
296					61.0
297					56.7
298					67.2
299					64.5
300					41.3
301					37.8
302					43.6
303					57.5
304					57.4
305					20.8
306					76.9
307					37.2
308					35.5
309					35.6
310					58.8
311					97.6
312					57.3
313					57.9
314					37.9
315					35.5
316					17.0
317					29.2
318					56.6
319					78.7
320					53.3
321	4.4	T-18 & T-19	B1	Run #1, on cold cap	14.2
322					32.5
323					31.7
324					81.9
325					20.5
326					76.4
327					75.9
328					36.2
329					31.4
330					48.6
331					103.1
332					85.2
333					54.5
334					83.9
335					35.9
336					28.4
337					39.3
338					40.7
339					61.4
340					78.1
341					60.0
342					33.5
343					32.0
344					27.0
345					24.4
346					28.0
347					92.7
348					55.3
349					37.4
350					27.1
351					28.1
352					10.8
353					58.9
354					85.5
355					83.0
356					32.0
357					22.8
358					26.5
359					24.5
360					38.8
361					84.4
362	4.4	T-18 & T-19	B1	Run #1, on cold cap	59.9

	A	B	C	D	E
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
363					33.4
364					25.3
365					28.5
366					44.2
367					150.8
368					67.7
369					52.6
370					27.3
371					15.8
372					30.7
373					41.8
374					89.1
375					78.3
376					64.4
377					9.4
378					29.3
379					28.5
380					31.1
381					68.0
382					13.3
383					116.7
384					267.0
385					365.9
386					192.7
387					121.1
388					95.5
389					99.2
390					331.0
391					143.5
392					80.4
393					89.1
394					110.4
395					322.0
396	4.5	T-20	B1	Run #2, on cold cap	415.2
397					164.2
398					91.2
399					86.7
400					287.3
401					380.2
402					36.2
403					128.0
404					84.5
405					123.5
406					217.5
407					137.2
408					98.4
409					158.9
410					149.3
411					171.2
412					160.7
413					98.2
414					89.4
415					126.1
416					160.4
417					151.4
418					138.3
419					84.5
420					73.1
421					119.0
422					78.8
423					73.4
424					51.4
425					40.0
426					83.3
427					82.3
428					73.5
429					59.7
430					53.6
431					107.6
432					119.3
433					92.2
434					71.3

	A	B	C	D	E
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
435					51.7
436					43.9
437					96.0
438					75.9
439	4.5	T-20	B1	Run #2, on cold cap	43.2
440					31.5
441					37.0
442					44.8
443					36.6
444					24.1
445					21.2
446					26.3
447					36.0
448					31.6
449					22.4
450					20.3
451					24.1
452					27.2
453					22.2
454					19.8
455					15.8
456					16.7
457					25.9
458					23.2
459					18.7
460					17.1
461					19.0
462					24.8
463					12.2
464					21.2
465					19.2
466					17.2
467					22.0
468					21.6
469					21.2
470					15.7
471					15.8
472					47.7
473					84.8
474					67.0
475					47.8
476					38.7
477					42.9
478					34.6
479					29.4
480					24.5
481					27.8
482					36.6
483					32.1
484					24.4
485	4.5	T-20	B1	Run #2, on cold cap	20.6
486					20.6
487					25.6
488					23.4
489					9.2
490					22.3
491					24.8
492					23.7
493					20.4
494					17.0
495					16.0
496					25.4
497					20.8
498					15.4
499					21.1
500					24.5
501					25.5
502					23.8
503					29.4
504					21.8
505					21.9
506					23.3

	A	B	C	D	E
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
507					25.4
508					24.7
509					19.4
510					20.1
511					23.0
512					24.5
513					9.8
514					26.3
515					57.7
516					58.2
517					52.6
518					55.6
519					38.5
520					33.2
521					39.7
522					47.5
523					40.4
524					30.0
525					27.7
526					33.7
527					30.5
528					31.6
529					29.5
530	4.5	T-20	B1	Run #2, on cold cap	23.6
531					23.6
532					22.7
533					18.9
534					18.5
535					20.3
536					21.0
537					20.8
538					19.2
539					17.5
540					14.3
541					17.6
542					15.0
543					14.4
544					13.5
545					12.5
546					20.6
547					25.4
548					22.2
549					16.5
550					16.3
551					15.5
552					18.0
553					17.1
554					14.9
555					14.6
556					15.2
557					21.7
558					17.9
559					15.6
560					14.5
561					14.7
562					19.4
563					17.2
564					14.4
565					14.0
566					14.9
567					19.1
568					15.8
569					14.4
570					11.7
571					13.2
572					17.9
573					18.7
574					15.9
575					13.6
576					12.4
577	4.5	T-20	B1	Run #2, on cold cap	22.7
578					15.6

	A	B	C	D	E
6	Report Table	Report Page	Feed Vector	Run Number	Total hydrocarbon conc. (Input 2.4)
7					ppmv
579					14.0
580					11.2
581					11.2
582					26.4
583					16.9
584					12.5
585					11.7
586					13.1
587					28.9
588					22.1
589					15.4
590					23.7
591					14.1
592					86.5
593					70.4
594					54.5
595					49.6
596					60.1
597					76.6
598					27.8
599					26.0
600					22.0
601					25.0
602					30.7
603					34.8
604					26.3
605					15.7
606					30.0
607					39.8
608					35.7
609					19.0
610					22.2
611					23.2
612					28.6
613					22.8
614					21.1
615					25.6
616					30.8
617					26.3
618					21.9
619					22.8
620					23.5
621					20.3
622					19.9
623	4.5	T-20	B1	Run #2, on cold cap	24.3
624					23.3
625					28.8
626					25.7
627					29.4
628					22.1
629					21.0
630					28.4
631					25.5
632					28.2
633					22.4
634					23.2
635					20.2
636					20.1
637					21.0
638					18.4
639					22.3
640					18.1
641					15.5
642					30.7
643					20.4
644					15.5
645					
646			VOC conc.	Average	**49.1**
647				Std dev	49.8
648					
649				Minimum	**0.05**
650				Maximum (average + stdev)	**98.9**

Attachment 25 Activated Carbon Bed Adsorber Pressure Drop Equation

Attachment 25 provides the equation to determine the pressure drop across the carbon beds based on vendor submittal data.

Spreadsheet Explanation:

1. Flowrates and pressure drop data for the LAW activated carbon units at two gas flowrates were manually entered into Columns B & C from vendor submittal 24590-QL-POA-MWK0-00001-10-00015 (Ref. 9.33, pg 27, 30, 34 & 38). Data from Modes 2 & 3 in the submittal are used because this reflects the planned flow path.
2. The two pressure drop points are plotted against the actual flowrate data in the provided figure.
3. The Excel trendline feature was used to define a linear equation for the data set as shown on the figure.
4. The equation is used to re-predict the pressure drop data in Column D.
5. The differential percentage between the equation predictions and the actual data is defined in Column E. The comparison shows that the equation is good at reproducing the defined pressure drop data.

The resulting equation is used in Attachment 1 flowsheets, cell **S-33**, to predict the pressure drop across the carbon beds.

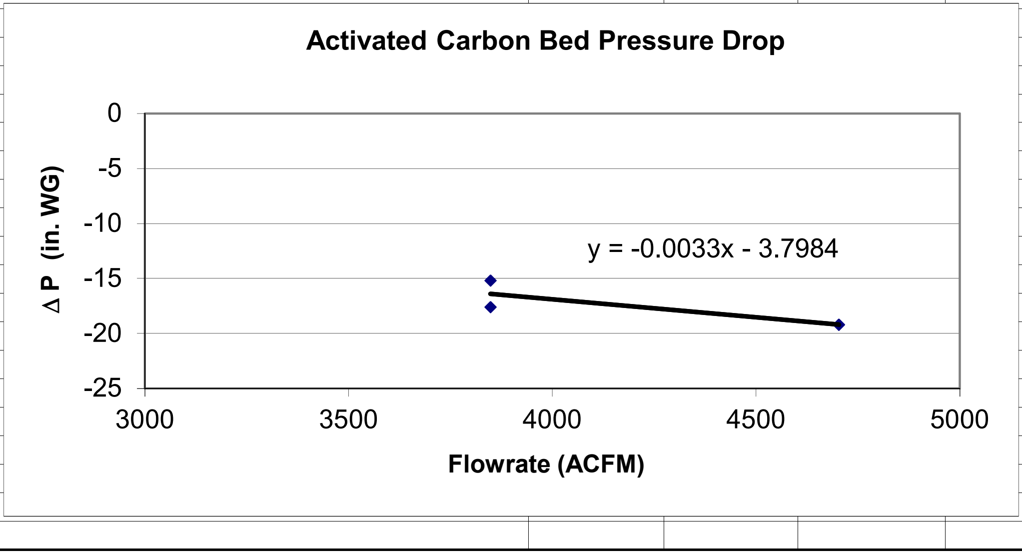
Attachment 25

Activated Carbon Bed Pressure Drop Equation

Pressure Drop Data are obtained from 24590-QL-POA-MWK0-00001-10-00015 (Ref. 9.33, pg 27, 30, 34 & 38) [Input 2.8]

Condition	Flowrate [Input 2.8]	ΔP [Input 2.8]	ΔP predicted from Equation	
	ACFM	in. WG	in. WG	Error
Minimum (Mode 2 - Flow through Unit B then Unit A)	3848	-17.6	-16.5	-6.3%
Minimum (Mode 3 - Flow through Unit A then Unit B)	3848	-15.2	-16.5	8.5%
Maximum (Mode 2 - Flow through Unit B then Unit A)	4703	-19.2	-19.3	0.6%
Maximum (Mode 3 - Flow through Unit A then Unit B)	4703	-19.2	-19.3	0.6%

Overall Error => -0.6%



Attachment 26 Deleted

Attachment 27 Not Used

Attachment 28 DM-1200 Melter, SBS, and WESP Gas Emissions

Attachment 28 spreadsheets are used to determine the gas composition of offgas exiting the melter, SBS, and WESP based on VSL testing data. The results are used in Attachment 1 flowsheets for streams LMP14 (melter offgas, Row 15) for CO_2 and various other gas components, also in LOP02 (SBS discharge, Row 17) and LOP08 (WESP discharge, Row 21) to define the gas composition.

There is one worksheet each for the melter, SBS and WESP.

There are two additional spreadsheets included in Attachment 28. These spreadsheets list the HNO_2 and HNO_3 content of the gas exiting the HEPA filters and carbon beds. The results are included here for the convenience of Mechanical Systems and are not used in the flowsheets.

Spreadsheet Explanation for Melter, SBS, and WESP:

1. DM-1200 melter, SBS, and WESP gaseous emission concentrations for the identified gas compounds are manually entered into Columns G through V for the melter (on the “Att 28 (melter)” worksheet), Columns G through U for the SBS (on the “Att 28 (SBS)” worksheet), and Columns I through X for the WESP (on the “Att 28 (WESP)” worksheet). References for each data set are defined in Columns A through F for the melter and SBS and Columns A through H for the WESP.
2. The maximum, minimum, average, and standard deviation for all entered gas concentrations (both prototypical and non-prototypical) are determined in Rows 24 through 27 for melter emissions, Rows 18 through 21 for SBS emissions, and Rows 26 through 29 for WESP emissions.
3. The average for the entered gas concentrations for the different feed vectors are determined in Rows 28 through 30 for melter emissions, Rows 22 through 24 for SBS emissions, and Rows 30 through 33 for WESP emissions. (NOTE: Only prototypical concentrations are included. Non-prototypical is defined as runs that included organic spikes.)
4. The average of the feed vector averages and the standard deviation are calculated in Rows 31 and 32 for melter emissions, Rows 25 and 26 for SBS emissions, and Rows 34 and 35 for WESP emissions.
5. The statistical maximum gas concentration for each identified gas compound is calculated in Row 33 (Melter), Row 27 (SBS), and Row 36 (WESP) by adding the standard deviation to the average particulate concentration.
6. The statistical minimum gas concentration for each identified gas compound is calculated in Row 34 (Melter), Row 28 (SBS) and Row 37 (WESP) by subtracting the standard deviation from the average particulate concentration.

The maximum gas concentrations (ppm_v) are used in the maximum flowsheet cases (except for CO, NO, NO_2, HCl, HF, and SO_2), the average concentrations are used in the nominal case, and the minimum concentrations are used in the minimum cases. The data is entered in Columns CE, CK, CQ, CW, DU, EA, EM, ES and row 15 for LMP14, row 17 (LOP02) and row 21 for LOP08 in Attachment 1 flowsheets (minimum & nominal cases). Only N_2O and NH_3 concentrations (ppm_v) from the spreadsheets are entered for the maximum cases.

The maximum gas concentrations for CO, NO, NO_2, HCl, HF, and SO_2 come from Input 2.14 for the maximum case.

Spreadsheet Explanation for HEPA filters and carbon beds:

1. HNO_2 and HNO_3 emission concentrations are manually entered into Columns H and I for the HEPA filters and carbon beds (on individual spreadsheets). References for each data set are defined in Columns A through D.
2. The maximum, minimum, average, and standard deviation for all entered gas concentrations are determined in Rows 27 through 30 for the HEPA filters. The average and standard deviation is listed in Rows 13 and 14 for the carbon beds. The average and maximum concentrations for the carbon beds are summarized in Rows 20 – 21.
3. In columns L – P for the HEPAs and L – O for the carbon bed, a mass flow is calculated for HNO_2 and HNO_3. For the HEPAs, the total offgas mass flowrates for the three cases (2 melters) from Cell K-30 of Attachment 1 flowsheets are entered into Row 27, Columns N – P. For the Carbon beds, the total offgas mass flowrates for the nominal and maximum cases (2 melters) from Cell K-33 of Attachment 1 flowsheets are entered into Row 14, Columns N & O. The offgas composite molecular weight from Column AE of Attachment 1 flowsheets is entered into Row 28, Columns N – P ("Att 28 (HEPA)" worksheet) and Row 15, Columns N – O ("Att 28 (Carbon Bed)" worksheet). The total stream molar flow (mol/h) is calculated in Row 29 (HEPA sheet) and in Row 16 (Carbon Bed sheet) by multiplying the mass flow (kg/h) by the stream molecular weight (g/mol) & using conversion factor 1 kg / 1000 g.

   The minimum, average, and maximum volumetric concentrations (ppm_v) for HNO_2 and HNO_3 are entered into Column M in "Att 28 (HEPA)" worksheet. The average and maximum volumetric concentrations (ppm_v) for HNO_2 and HNO_3 determined above are entered into Column M in "Att 28 (Carbon Bed)" worksheet. The HNO_2 and HNO_3 molar flowrate for each case is calculated by multiplying the total stream molar flow (row 29, column N - P for HEPA and row 16, column N & O for Carbon Bed) by the respective volume concentration (ppm_v) and dividing by 1×10^6.

   The molecular weights for HNO_2 and HNO_3 were entered into cells L-41 and L-45 in "Att 28 (HEPA)" worksheet, and cells L-27 & L-30 in "Att 28 (Carbon Bed)" worksheet per Input 2.2. Each molar flowrate is multiplied by the molecular weight to calculate the mass flowrate.

   These mass flowrates are for the convenience of Mechanical Systems and are not used further in this calculation.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	***Attachment 28 - DM-1200 Melter Gas Emissions***																						
2																							
3	Report Number	Report Revision	Report Table	Report Page	Feed Vector	Run Number	Average Concentrations (ppm$_v$) of Selected Offgas Species [Input 2.4]														vol%	vol%	**Notes**
4							NO	N_2O	NO_2	HNO_2	HNO_3	NH_3	Acetonitrile	Acrylonitrile	HCl	HCN	HF	SO_2	THC	CO	CO_2	H_2O	
5	24590-101-TSA-W000-0009-111-01 (VSL-02R8800-1) [Ref. 9.2]	B	6.8	T-56	C1	1	4920	601	1531	8.2	0.05	547	0.5	0.5	0.5	4.5	1.7	0.5		206	2.18%	21.7%	
6																							
7																							
8	24590-101-TSA-W000-0009-143-01 (VSL-03R3851-1) [Ref. 9.4]	B	6.6	T-27	B1	1	2500	230	150	4	2.2	53			0.5	2.2	0.5	9.1		94	1.20%	23.0%	
9																							
10																							
11	24590-101-TSA-W000-0009-105-00006 (VSL-04R4851-1) [Ref. 9.1]	A	7.3	T-58	C1	A	3100	300	320	4.2	0.5	230	0.5	0.5	0.5	1.9	1	2.6		95	1.10%	16.0%	
12						B	1600	190	180	2.1	0.5	290	27	0.5	0.5	0.5	0.5	2.1		35	0.53%	8.5%	
13						C	1800	210	180	2.2	0.5	360	22	0.5	0.5	0.5	0.5	0.5		29	0.57%	10.0%	
14						D	3400	360	490	5.2	0.5	440	0.5	0.5	0.5	0.5	0.5	0.5		86	1.20%	17.0%	
15						E	4500	400	690	6.5	1.5	220	0.5	0.5	0.5	1.8	2.4	3.6		130	1.40%	21.0%	
16	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1) [Ref. 9.5]	B	6.19	T-109	Bounding A2	1 - AA spike	4332	394.0	972.0	6.3	0.5	155	230	0.5	0.5	0.5	0.5	0.5	326.0	236	1.00%	18.8%	
17			6.20	T-110		1 - Naph/MeOH	3836	399.0	847	6.7	0.5	215	0.5	0.5	8.1	0.5	0.5	10.1	269.0	133	0.69%	17.7%	
18			6.21	T-111		1 - No organics	4376	387.0	850.0	8.9	3.5	225	0.5	0.5	0.5	0.5	0.5	0.5	91.5	87.8	0.95%	18.6%	Values may be influenced by data taken immediately after organic spiking was stopped.
19			6.22	T-112		2B	5095	453.0	954.0	9.4	4.2	180	0.5	0.5	0.5	0.5	0.5	1.8		123	1.07%	21.2%	
20			6.23	T-113		2A - Naph/AA spike	3701	371.0	765	3.2	0.5	203	230	0.5	0.5	0.5	0.5	0.5	400.0	126	0.86%	14.3%	
21			6.24	T-114		2A - Naph/MeOH	3704	364.0	602.0	5.5	0.5	255	0.5	0.5	8.6	0.5	0.5	12.1	337.0	89.2	0.58%	15.8%	
22			6.25	T-115		2A - No organics	3622	360.0	583.0	8.7	2.9	168	0.5	0.5	0.5	0.5	0.5	2.9	55.1	64	0.79%	14.3%	Organics present are residual from previous spikes
23																							
24				All Data	Maximum =>		5095	601.0	1531	9.4	4.2	547	230	0.5	8.6	4.5	2.4	12.1	400	236	2.18%	23.0%	
25					Minimum =>		1600.0	190.0	150.0	2.1	0.1	53.0	0.5	0.5	0.5	0.5	0.5	0.5	55.1	29.0	0.53%	8.5%	
26					Average =>		3606	358.5	651.0	5.8	1.3	252.9	39.5	0.5	1.6	1.1	0.8	3.4	246.4	109.6	1.01%	17.0%	
27					STDEV =>		1065	105.2	382.2	2.4	1.3	124.9	85.0	0.0	2.9	1.2	0.6	4.0	140.9	57.3	0.43%	4.3%	
28				Feed Vector Averages	A2 =>		4364	400	796	9	4	191	1	0.5	0.5	0.5	0.5	1.7	73	92	0.9%	18.0%	
29					B1 =>		2500	230	150	4.0	2.2	53			0.5	2.2	0.5	9.1		94	1.20%	23.0%	
30					C1 =>		3220	344	565	4.7	0.6	348	8.5	0.5	0.5	1.6	1.1	1.6		97	1.16%	15.7%	
31			Average of Feed Vector Averages	Only Prototypical Data	Average =>		**3361**	**325**	**504**	5.9	2.1	**197**	4.5	0.5	**0.5**	1.4	**0.7**	**4.2**		**94**	**1.1%**	19%	
32					STDEV =>		940	87	327	2.7	1.5	148			0.0	0.9	0.3	4.3		2.6	0.1%	4%	
33					Max (Avg. + STDEV) =>		**4302**	**411**	**831**	8.6	3.6	**345**			**0.5**	2.3	**1.0**	**8.4**		**97**	**1.2%**	23%	
34					Min (Avg. - STDEV) =>		**2421**	**238**	**176**	3.2	0.6	**50**			**0.5**	0.6	**0.4**	**-0.1**		**92**	**1.0%**	15%	
35																							
36	Note:	1. Gas concentration results reported as a less than value (i.e., less than detection), are entered below as half of the detection limit.																					
37		2. The min, max and average values in bold are manually entered into Attachment 1 flowsheets for corresponding melter emissions in min, max and nominal cases. If the minimum value is less than zero, zero ppm is entered for the minimum concentration.																					

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	***Attachment 28 - DM-1200 SBS Gas Emissions***																					
2																						
3	Report	Report	Report	Report	Feed	Run Number	Average Concentrations (ppm$_v$) of Selected Offgas Species [Input 2.4]													%		**Notes**
4	Number	Revision	Table	Page	Vector		NO	N_2O	NO_2	HNO_2	HNO_3	NH_3	Acetonitrile	Acrylonitrile	HCl	HCN	HF	SO_2	CO	CO_2	H_2O	
5	24590-101-TSA-W000-0009-111-01 (VSL-02R8800-1) [Ref. 9.2]	B	6.8	T-56	C1	1	4771	751	2335	13.77	0.5	14.7	7.9	2.4	0.5	6.9	2.4	0.5	275	2.30%	8.1%	
6																						
7																						
8	24590-101-TSA-W000-0009-111-02 (VSL-02R8800-2) [Ref. 9.3]	B	6.10	T-62	A1	1	4775	624	2674		0.5	0.5	20.4	0.5	0.5	7.7	0.5	1.1	375	1.88%	7.60%	
9						2	5053	908	3560		0.5	7.6	19.7	0.5	0.5	12.2	0.5	1.9	464	3.05%	8.60%	
10	24590-101-TSA-W000-0009-143-01 (VSL-03R3851-1) [Ref. 9.4]	B	6.6	T-27	B1	1	2400	290	530	3.5	2.4	7.6			0.5	3.3	0.5	4.1	100	1.50%	7.1%	
11																						
12																						
13	24590-101-TSA-W000-0009-105-00006 (VSL-04R4851-1) [Ref. 9.1]	A	7.3	T-58	C1	B	1300	190	300	0.5	0.5	110	15	0.5	0.5	0.5	0.5	2.4	33	0.52%	5.0%	
14						C	1800	250	440	1.8	0.5	160	25	0.5	0.5	0.5	0.5	0.5	37	0.68%	5.5%	
15						D	2600	350	930	5.4	1.8	69	0.5	0.5	0.5	0.5	0.5	0.5	90	1.10%	5.8%	
16						E	3100	410	1500	12	6.2	6.6	0.5	0.5	2.4	1.5	2.1	0.5	140	1.40%	5.2%	
17																						
18				All Data	Maximum =>		5053	908	3560	14	6	160.0	25	2	2.4	12	2.4	4.1	464	3.05%	8.6%	
19					Minimum =>		1300.0	190	300	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	33.0	0.52%	5.0%	
20					Average =>		3225	471.6	1533.6	6.2	1.6	47.0	12.7	0.8	0.7	4.1	0.9	1.4	189.3	1.55%	6.6%	
21					STDEV =>		1462	259.6	1203.5	5.5	2.0	60.0	9.9	0.7	0.7	4.4	0.8	1.3	163	0.84%	1.4%	
22				Feed Vector Averages	A1 =>		4914.0	766.0	3117.0		0.5	4.1	20.1	0.5	0.5	10.0	0.5	1.5	419.5	2.5%	8.1%	
23					B1 =>		2400.0	290.0	530.0	3.5	2.4	7.6			0.5	3.3	0.5	4.1	100.0	1.5%	7.1%	
24					C1 =>		2714.2	390.2	1101.0	6.7	1.9	72.1	9.8	0.9	0.9	2.0	1.2	0.9	115.0	1.2%	5.9%	
25				Average of Feed Vector Averages	Average =>		**3343**	**482**	**1583**	**5.1**	**1.6**	**28**	14.9	0.7	**0.6**	5.1	**0.7**	**2.2**	**212**	1.7%	7.0%	
26					STDEV =>		1370	251	1359	2.3	1.0	38	7.3	0.3	0.2	4.3	0.4	1.7	180	0.7%	1.1%	
27					Max (Avg. + STDEV) =>		**4713**	**733**	**2942**	**7.4**	**2.6**	**66**	22.2	1.0	**0.8**	9.3	**1.1**	**3.9**	**392**	2.4%	8.1%	
28					Min (Avg. - STDEV) =>		**1973**	**231**	**224**	**2.8**	**0.6**	**-10.4**	7.7	0.4	**0.4**	0.8	**0.3**	**0.5**	**31**	1.1%	5.9%	
29																						
30	Note:	1. Gas concentration results reported as a less than value (i.e., less than detection), are entered below as half of the detection limit.																				
31		'2. The min, max and average values in bold are manually entered into Attachment 1 flowsheets for corresponding SBS emissions in min, max and nominal cases. If the minimum value is less than zero, zero ppm is entered for the minimum concentration.																				

CALCULATION SHEET

By: N. Wilkins
Date: 11/15/2019

Subject: LAW Melter Offgas System Design Basis Flowsheets

PROJECT: RPP-WTP
Job No: 24590
Calc No: 24590-LAW-M4C-LOP-00001
Sheet Rev: 6
Sheet No.:28- 5

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	***Attachment 28 - DM-1200 WESP Gas Emissions***																								
2																									
3	Report Number	Report Revision	Report Table	Report Page	H_2 Report Table	H_2 Report Page	Feed Vector	Run Number	Average Concentrations (ppmv) of Selected Offgas Species [Input 2.4]														%		**Notes**
4									NO	N_2O	NO_2	HNO_2	HNO_3	NH_3	Acetonitrile	Acrylonitrile	H_2	HCl	HCN	HF	SO_2	CO	CO_2	H_2O	
5	24590-101-TSA-W000-0009-111-01 (VSL-02R8800-1) [Ref. 9.2]	B	6.8	T-56	N/A	N/A	C1	1	3920	743	3380	29.4	0.5	1.6	14.9	4.3		0.5	6.7	2.9	0.5	268	2.75%	7.8%	
6																									
7																									
8	24590-101-TSA-W000-0009-111-02 (VSL-02R8800-2) [Ref. 9.3]	B	6.10	T-62	6.10	T-62	A1	1	3167	689	2882		2.5	1.6	17.1	0.5	136.6	0.5	5.4	0.5	1.3	250	1.61%	8.6%	
9								2	3694	684	5792		9.8	0.5	21.1	0.5	111.3	46.9	8.8	0.5	3	491	2.48%	8.7%	
10								3	3971	851	4686		17.1	5.5	20.8	1.1	180	13.1	9.4	0.5	1.5	429	1.96%	7.1%	
11	24590-101-TSA-W000-0009-143-01 (VSL-03R3851-1) [Ref. 9.4]	B	6.6	T-27	6.7	T-28	B1	1	1800	250	650	6.4	3.4	4.9			84	0.5	2.4	0.5	4.9	79	1.20%	6.4%	The highest measured H_2 conc is used.
12																									
13																									
14	24590-101-TSA-W000-0009-105-00006 (VSL-04R4851-1) [Ref. 9.1]	A	7.3	T-58	7.5	T-60	C1	A									128								
15								B	1100	190	460	3.7	0.5	44	0.5	0.5	55	0.5	0.5	0.5	1.6	30	0.52%	4.7%	
16								C	1400	240	660	5.9	1.1	35	0.5	0.5	92	0.5	0.5	0.5	0.5	43	0.69%	4.9%	
17								D	2200	350	1300	20	6.3	0.5	3	1.3	114	0.5	1.1	0.5	0.5	100	1.10%	5.4%	
18	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1) [Ref. 9.5]	B	N/A	N/A	6.27	T-117	Bounding A2	1 - AA									147								
19								1 - no spike									213								
20								1 - Naph/MeOH									318								
21								2B - no spike									330								
22								2A - Naph/AA									202								
23								2A - no spike									201								
24								2A - Naph/MeOH									223								
25																									
26						All Data	Maximum =>		3971.0	851.0	5792.0	29.4	17.1	44.0	21.1	4.3	330.0	46.9	9.4	2.9	4.9	491.0	2.75%	8.70%	
27							Minimum =>		1100.0	190.0	460.0	3.7	0.5	0.5	0.5	0.5	55.0	0.5	0.5	0.5	0.5	30.0	0.52%	4.70%	
28							Average =>		2656.5	499.6	2476.3	13.1	5.2	11.7	11.1	1.2	169.0	7.9	4.4	0.8	1.7	211.3	1.54%	6.70%	
29							STDEV =>		1171.4	267.4	2033.3	11.2	5.8	17.4	9.4	1.4	80.6	16.4	3.7	0.8	1.5	177.9	0.81%	1.60%	
30						Feed Vector Averages	A1 =>		3611	741	4453		9.8	2.5	19.7	0.7	143	20.2	7.9	0.5	1.9	390	2.0%	8.1%	
31							B1 =>		1800	250	650	6.4	3.4	4.9			84	0.5	2.4	0.5	4.9	79	1.2%	6.4%	
32							C1 =>		2155	381	1450	14.8	2.1	20.3	4.7	1.7	97	0.5	2.2	1.1	0.8	110	1.3%	5.7%	
33							A2 =>										233.4								
34					Average of Feed Vector Averages	Only Prototypical Data	Average =>		**2521.9**	**457.4**	**2184.4**	10.6	5.1	**9.2**	12.2	1.2	**108.0**	**7.1**	4.2	**0.7**	**2.5**	**193.1**	1.49%	6.74%	
35							STDEV =>		959.5	254.5	2005.2	5.9	4.1	9.6	10.6	0.7	30.7	11.4	3.2	0.3	2.1	171.2	0.45%	1.25%	
36							Max (Avg. + STDEV) =>		**3481.4**	**711.8**	**4189.7**	16.5	9.2	**18.9**	22.8	1.8	**138.7**	**18.4**	7.4	**1.0**	**4.7**	**364.3**	1.95%	8.00%	
37							Min (Avg. - STDEV) =>		**1562.4**	**202.9**	**179.2**	4.7	1.0	**-0.4**	1.6	0.5	**77.2**	**-4.3**	0.9	**0.4**	**0.4**	**21.8**	1.04%	5.49%	
38																									
39	Note:	1. Gas concentration results reported as a less than value (i.e., less than detection), are entered below as half of the detection limit.																							
40		'2. The min, max and average values in bold are manually entered into Attachment 1 flowsheets (row 21) for corresponding WESP emissions in min, max and nominal cases. If the minimum value is less than zero, zero ppm is entered for the minimum concentration.																							

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	***Attachment 28 - DM-1200 HEPA Gas Emissions***															
2																
3	Report Number	Report Revision	Report Table	Report Page	Feed Vector	Run Number		Concentration (ppm_v) [Input 2.4]								
4								HNO_2	HNO_3							
5	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1) [Ref. 9.5]	B	6.19	T-109	Bounding A2	1 - AA spike	Average	35.2	0.5							
6							Minimum	13.5	0.5							
7							Maximum	49.9	0.5							
8			6.20	T-110		1 - Naph/MeOH	Average	24.5	0.5							
9							Minimum	10.5	0.5							
10							Maximum	39.2	0.5							
11			6.21	T-111		1 - No organics	Average	26.5	0.5							
12							Minimum	8.8	0.5							
13							Maximum	50.2	0.5							
14			6.22	T-112		2B	Average	37.7	23.8							
15							Minimum	16.1	9.3							
16							Maximum	56.2	42.4							
17			6.23	T-113		2A - Naph/AA spike	Average	24.5	0.5							
18							Minimum	11.1	0.5							
19							Maximum	43.5	0.5							
20			6.24	T-114		2A - Naph/MeOH	Average	25.4	0.5							
21							Minimum	13.2	0.5							
22							Maximum	42.4	0.5							
23			6.25	T-115		2A - No organics	Average	26.4	6.5							
24							Minimum	9.0	0.5					flowsheet conditions		
25							Maximum	53.0	25.9					minimum	nominal	maximum
26													Source of data from mass balance tables in Attachment 1	Row 30	Row 30	Row 30
27				All Data	Maximum =>			56.2	42.4				total flow, kg/h (Cell K30)	3.99E+03	4.99E+03	5.47E+03
28					Minimum =>			8.8	0.5				composite stream MW, g/mol (Cell AE30)	28.5	28.1	27.7
29					Average =>			29.4	5.5				total stream molar flow, g-mole/h	139,827	177,507	197,317
30					STDEV =>			15.8	11.2							
31																
32												HNO_2	Concentration (ppmv)	Molar Flow (g-mol/h)		
33												min	8.8	1.23		
34	Note: Gas concentration results reported as a less than value (i.e., less than detection), are entered below as half of the detection limit.											avg	29.4		5.21	
35												max	56.2			11.1
36												HNO_3	Concentration (ppmv)	Molar Flow (g-mol/h)		
37												min	0.5	0.070		
38												avg	5.5		0.98	
39												max	42.4			8.37
40												MW				
41											HNO_2	47	HNO_2	Mass Flow (kg/h)		
42												g/mol	minimum	0.0578		
43													nominal		0.245	
44													maximum			0.521
45											HNO_3	63	HNO_3	Mass Flow (kg/h)		
46												g/mol	minimum	0.00440		
47													nominal		0.0617	
48													maximum			0.527

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	***Attachment 28 - DM-1200 Carbon Bed Gas Emissions***														
2															
3	Report Number	Report Revision	Report Table	Report Page	Feed Vector	Run Number		Concentration (ppm$_v$) [Input 2.4]							
4								HNO_2	HNO_3						
5	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1) [Ref. 9.5]	B	6.19	T-109	Bounding A2	1 - AA spike	Average	28.0	14.5						
6			6.20	T-110		1 - Naph/MeOH	Average	25.3	0.5						
7			6.21	T-111		1 - No organics	Average	22.5	9.4						
8			6.22	T-112		2B	Average	32.1	22.8						
9			6.23	T-113		2A - Naph/AA spike	Average	15.0	7.3						
10			6.24	T-114		2A - Naph/MeOH	Average	28.2	0.5						
11			6.25	T-115		2A - No organics	Average	26.1	0.5					flowsheet conditions	
12														nominal	maximum
13				All Data	Average =>			25.3	7.9				Source of data from mass balance tables in Attachment 1	Row 33	Row 33
14					STDEV =>			5.4	8.5				total flow, kg/h (Cell K33)	5.01E+03	5.49E+03
15													composite stream MW, g/mol (Cell AE33)	28.1	27.7
16													total stream molar flow, g-mole/h	178,223	198,065
17															
18															
19															
20						Nominal = Average		25.3	7.9			HNO_2	Concentration (ppmv)	Molar Flow (g-mol/h)	
21						Maximum = Max of 7 Runs		32.1	22.8			nom	25.3	4.51	
22												max	32.1		6.36
23												HNO_3	Concentration (ppmv)	Molar Flow (g-mol/h)	
24	Note: Gas concentration results reported as a less than value (i.e., less than detection), are entered below as half of the detection limit.											nom	7.9	1.41	
25												max	22.8		4.52
26												MW			
27											HNO_2	47	HNO_2	Mass Flow (kg/h)	
28												g/mol	nominal	0.212	
29													maximum		0.299
30											HNO_3	63	HNO_3	Mass Flow (kg/h)	
31												g/mol	nominal	0.089	
32													maximum		0.285

Attachment 29 Deleted

Attachment 30 Not Used

Attachment 31 Deleted

Attachment 32 Ammonium Nitrate Formation

Attachment 32 determines the mass flowrate of ammonium nitrate deposited on the HEPA filters. This attachment consists of 2 sets of calculations:

- Excel spreadsheet calculation (sheet 1 of 4): The intent of the spreadsheet is to predict the weight percent of NH_4NO_3 deposited on the HEPA filters. This will be done by superimposing two data sets: one set shows the minimum NH_3 gas concentration necessary for the formation of ammonium nitrate at a particular temperature, the other set shows how much of that ammonium nitrate deposited on the HEPA filters at a particular temperature. An equation is used to trend the data sets and will be used to interpolate the percentage of ammonium nitrate deposited before the HEPA filters at the offgas temperatures from Attachment 1 flowsheets.
- MathCAD calculation (sheets 2 – 4): The MathCAD calculations determine the mass flowrate of ammonium nitrate deposited on the HEPA filters based on the stream temperature, the % NH_4NO_3 deposited (calculated from the Excel spreadsheet) and the ammonium nitrate formation reaction.

Spreadsheet Explanation:

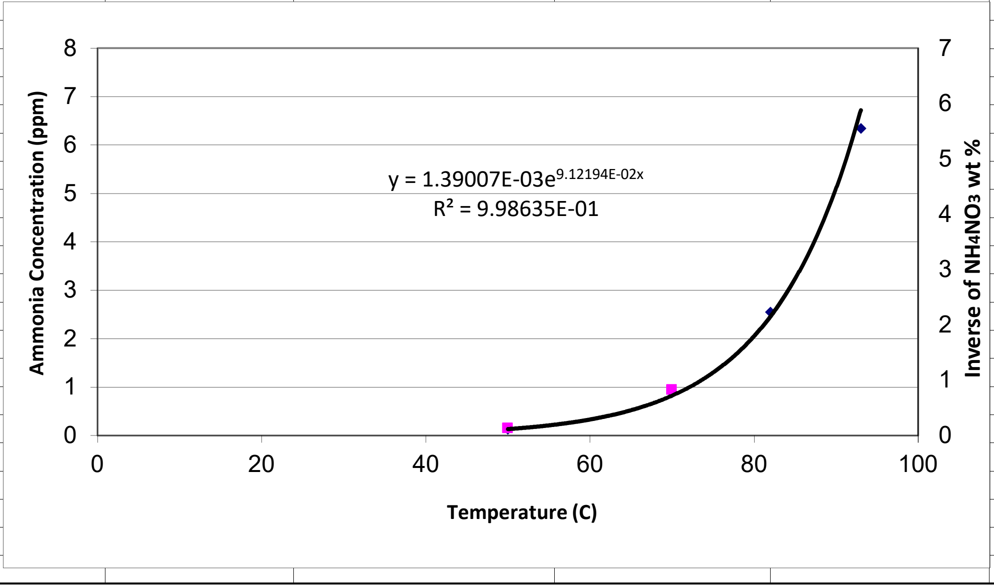
1. The temperature and ammonia concentration at which ammonium nitrate forms is manually entered in Columns A and B based on data from vendor submittal 24590-QL-POA-MWK0-00001-13-00006 (Ref. 9.34, Table 7). Estimated HEPA preheater discharge offgas temperatures from Attachment 1 flowsheets, Cell O-28, are also entered in Column A. The percentage of ammonium nitrate that was shown to be deposited before the HEPA filters (from Ref. 9.34, Table 8) is entered at the associated temperature in Column C.
2. The inverse of the NH_4NO_3 percentage recovered is entered in Column D. This is done so the two curves will trend in the same direction.
3. The Ammonia concentrations (Column B) was plotted versus the offgas temperatures (Column A) on the graph. The Excel trendline function was used to define the exponential fit equation shown in the graph.
4. The inverse of the % NH_4NO_3 and corresponding temperature were plotted on the graph. In Column E, a multiplier (shown in Cell E-7) was manually determined and multiplied with Column D so that this curve overlaps the first curve. The results (Column E for NH_4NO_3 percentage and Column A for temperature) were plotted as a second series on the graph.
5. The trendline equation is used to re-predict the inverse of the % NH_4NO_3 deposited in Column F. In Column G, the predicted inverse of the % NH_4NO_3 results are divided by the multiplier, so the multiplier is cancelled out at this point.
6. The predicted % NH_4NO_3 deposited is determined in Column H and the % error is calculated in Column I. Column H is used to predict the percentage of the total ammonium nitrate deposited on the HEPA filters (including deposits in the tubing prior to HEPA filters) at different temperatures.

The predicted NH_4NO_3 percentages deposited are then entered in the MathCAD calculations to determine the mass of NH_4NO_3 deposited on HEPA filters based on the following ammonium nitrate formation reaction:

$2\cdot NO_2 + 2\cdot NH_3 \leftrightarrow N_2 + H_2O + NH_4NO_3$ (Ref. 9.34, Section 5, pg 31)

The mass of NH_4NO_3 deposited are added to the particulate flowrate entering the HEPA filters in Attachment 1 flowsheets (cell **EU-28**).

	A	B	C	D	E	F	G	H	I	J
1	**Attachment 32 - Ammonium Nitrate Formation**									
2	Sheet 1 of 4 (sheets 2 through 4 are from Mathcad calculations)									
3										
4	Temperature (°C)	NH_3 conc (ppm)	% NH_4NO_3 recovered from tubing prior to HEPA filters and from HEPA Filter 1	Inverse of NH_4NO_3 percentage recovered	Column D multiplied by cell E-6 so resulting curves overlap	Use trendline equation to repredict inverse of NH_4NO_3 percentage recovered	Divide Column F by multiplier (E-6) to cancel out multiplier	Predicted % NH_4NO_3 recovery	Error	
5	(Ref. 9.34, Table 7) [Input 2.9]	(Ref. 9.34, Table 7) [Input 2.9]	(Ref. 9.34, Table 8)* [Input 2.9]	(Inverse of Column C)						
6					0.1237					
7	50	0.127	95%	1.0526	0.130210526	0.1330	1.0752	93%	-2.095%	
8	60					0.3311	2.6769	37%		
9	70	0.884	15%	6.6667	0.82467	0.8244	6.6649	15%	0.027%	
10	71					0.9032	7.3014	14%		
11	77					1.5613	12.6213	8%		
12	82	2.55				2.4635	19.9152	5%		
13	83					2.6988	21.8173	5%		
14	93	6.34				6.7194	54.3204	2%		
15	* sum of % NH_4NO_3 recovered from tubing prior to HEPA filters and from HEPA Filter 1 (50.64% + 44.16% ≈ 95% at 50°C and 0.03% + 14.52% ≈ 15% at 70°C per Ref. 9.34, Table 8)									



Attachment 32 (continued) - Ammonium Nitrate Formation

Unit Definition

The following units are defined for this calculations:

Length

$mm \equiv \frac{m}{1000}$

$in \equiv 25.4 \cdot mm$

$ft \equiv 12 \cdot in$

$cm \equiv \frac{m}{100}$

$\mu m \equiv \frac{mm}{1000}$

Energy

$J \equiv \frac{kg \cdot m^2}{s^2}$

$KJ \equiv 1000 \cdot J$

$Btu \equiv 1055.1 \cdot J$

$cal \equiv 4.184 \cdot J$

$kcal \equiv 1000 \cdot cal$

Temperature

$C \equiv K$

$F \equiv \frac{5}{9} \cdot C$

$F \equiv R$

Power

$W \equiv \frac{J}{s}$

$mW \equiv \frac{W}{1000}$

$kW \equiv 1000 \cdot W$

$Hp \equiv 745.71 \cdot W$

Volume

$L \equiv \frac{m^3}{1000}$

$gal \equiv \frac{ft^3}{7.4805}$

$ml \equiv \frac{L}{1000}$

Pressure

$Pa \equiv \frac{kg}{m \cdot s^2}$

$\mu Pa \equiv \frac{Pa}{1000000}$

$bar \equiv 100000 \cdot Pa$

$mbar \equiv \frac{bar}{1000}$

$atm \equiv 1.01325 \cdot bar$

$psi \equiv \frac{atm}{14.696}$

$inWC \equiv \frac{psi}{27.681}$

$mmWC \equiv \frac{inWC}{25.4}$

$inWG \equiv inWC$

Mass

$g \equiv \frac{kg}{1000}$

$lb \equiv \frac{kg}{2.20462}$

$\mu g \equiv \frac{g}{1000000}$

$pg \equiv \frac{g}{1 \cdot 10^{12}}$

$ng \equiv \frac{g}{1 \cdot 10^{9}}$

$Mt \equiv 1000 \cdot kg$

$mg \equiv \frac{g}{1000}$

Force

$N \equiv kg \cdot \frac{m}{s^2}$

$mN := \frac{N}{1000}$

Gas Constant

$R_G := 8.314 \cdot \frac{J}{mol \cdot K}$

Gravity

$g_n := 9.81 \cdot \frac{m}{s^2}$

Time

$min \equiv 60 \cdot s$

$hr \equiv 3600 \cdot s$

$day \equiv 24 \cdot hr$

$year \equiv 365.25 \cdot day$

$month \equiv \frac{year}{12}$

Substance

$kmol \equiv 1000 \cdot mole$

$lbmole \equiv \frac{kmol}{2.20462}$

$mmol \equiv \frac{mole}{1000}$

Radiation

$Gy \equiv \frac{J}{kg}$

$rad \equiv 0.01 Gy$

$rem \equiv rad$

$mrem \equiv 0.001 \cdot rem$

Viscosity

$cP \equiv 1000 \cdot \mu Pa \cdot s$

$P \equiv 100 \cdot cP$

Rad Decay

$Ci \equiv 3.7 \cdot 10^{10} \cdot Bq$

Temperature from HEPA Preheater Discharge from Attachment 1 flowsheets, Cell O-28:

$$T_{HEPA} := \begin{pmatrix} 77 \\ 71 \\ 60 \\ 60 \end{pmatrix} \cdot C$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melters)

Ammonia Flowrate from Attachment 1 flowsheets, Cell CS-28:

$$m_{NH3} := \begin{pmatrix} 0.0598 \\ 0.0269 \\ 0 \\ 0 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melters)

Percent Ammonium Nitrate deposited (from Excel spreadsheet, Column H, of this attachment at corresponding HEPA preheater discharge temperature):

$$Conversion := \begin{pmatrix} 8 \\ 14 \\ 37 \\ 37 \end{pmatrix} \cdot \%$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melters)

Molecular weight:

$$MW_{NH3} := 17 \cdot \frac{g}{mol}$$ [Input 2.2]

$$MW_{NH4NO3} := 80.03 \cdot \frac{g}{mol}$$ [Input 2.2]

The formation of ammonium nitrate aerosol particulates is based on reaction (1) from 24590-QL-POA-MWK0-00001-13-00006 (Ref. 9.34, pg 31).

$$2\,NO_2 + 2\,NH_3 \leftrightarrow N_2 + H_2O + NH_4NO_3$$

Calculating molar flowrate of ammonia:

$$i := 1 .. 4$$

$$n_{NH3_i} := \frac{m_{NH3_i}}{MW_{NH3}}$$

$$n_{NH3} = \begin{pmatrix} 3.518 \\ 1.582 \\ 0 \\ 0 \end{pmatrix} \cdot \frac{mol}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melters)

Calculating molar flowrate of ammonium nitrate deposited from stoichiometric equation and % deposited:

$$n_{NH4NO3_i} := 0.5 \cdot n_{NH3_i} \cdot Conversion_i \qquad n_{NH4NO3} = \begin{pmatrix} 0.141 \\ 0.111 \\ 0 \\ 0 \end{pmatrix} \cdot \frac{mol}{hr} \quad \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melters)} \end{array}$$

Calculating mass flowrate of ammonium nitrate deposited:

$$m_{NH4NO3_i} := n_{NH4NO3_i} \cdot MW_{NH4NO3} \qquad m_{NH4NO3} = \begin{pmatrix} 0.011 \\ 8.864 \times 10^{-3} \\ 0 \\ 0 \end{pmatrix} \cdot \frac{kg}{hr} \quad \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melters)} \end{array}$$

These values are added to the particulate flowrate entering the HEPA filters in Attachment 1 flowsheets (cell **EU-28**).

Attachment 33 DM-1200 Melter Particulate Emission Concentrations

This attachment calculates the minimum, average, and maximum melter particulate emission concentrations based on VSL data (Ref. 9.1 - 9.5).

Spreadsheet Explanation:

1. For feed vectors A1, B1 & C1, the DM-1200 melter particulate emission concentrations for the largest particle range are manually entered into Column G along with the associated weight percentage in Column H, respectively. References for each data set are defined in Columns A through F.
2. The overall melter particulate emission concentrations for the first four feed data sets are calculated in Column I by dividing Column G by Column H. (NOTE: This method is a short-cut approach to determine the overall particulate emission concentration as opposed to having to enter all of the particulate mass information for all of the size ranges listed in the VSL data report, and then divide the total mass by the sample volume to obtain the overall particulate concentration). The particulate concentrations for feed vector Bounding A2 (cell I-19 to I-24) are obtained directly from the VSL report.
3. The overall maximum, minimum, average, and standard deviation of particulate concentrations in all feed cases are determined in Cells I-26 through I-29 respectively, using Excel's AVERAGE, MAX, and STDEV functions.
4. The overall maximum, minimum, average, and standard deviation for the particulate concentrations by feed vector are determined similarly in Rows 30 through 33, respectively.
5. The average and standard deviation of the average particulate concentrations by feed vector is calculated in Cells I-35 and I-37.
   Note that the particulate concentrations by feed vector "Bounding A2" are not included in calculating the average value and the standard deviation. The Bounding A2 tests were intended for regulatory purposes and included spiking of different chemicals. They are not baseline tests and are not included in the feed vector averages used in Attachment 1 flowsheets.
6. The statistical maximum overall particulate emission concentration is calculated in Cell I-38 by adding the standard deviation to the average particulate concentration.
7. The statistical minimum overall particulate emission concentration is calculated in Cell I-39 by subtracting the standard deviation from the average particulate concentration.

The average particulate emission concentration from all data, 26.8 mg/ft^3 (cell I-28), is used in **Attachment 4**, Section A4.7.4 to calculate the mass flow of particulates emitted from the melter.
The average, minimum & maximum particulate concentration prototypical data values (Cell I-35, I-38 & I-39) are then used in cell **EU-15** of Attachment 1 flowsheets to determine the particulate mass flow in the melter offgas stream to SBS (stream LMP14). The minimum particulate emission concentration is used in the minimum flowsheet case, the average is used in the nominal case, and the maximum is used in the maximum case.

	A	B	C	D	E	F	G	H	I
1	**Attachment 33**								[Input 2.4]
2	**DM-1200 Melter Particulate Emission Concentrations**								
3									
4	Report Number	Report Revision	Report Table	Report Page	Feed Vector	Sample Number	Large Particles (Input 2.4)		Overall particulate concentration
5							Concentration (mg/dscf)	wt%	mg/dscf
6	24590-101-TSA-W000-0009-111-01 (VSL-02R8800-1) [Ref. 9.2]	B	6.7	T-55	C1	1	4.154	42.0%	9.89
7						2	8.575	51.0%	16.81
8						3	1.813	27.0%	6.71
9	24590-101-TSA-W000-0009-111-02 (VSL-02R8800-2) [Ref. 9.3]	B	6.9	T-60	A1	1	3.76	24.0%	15.67
10						2	47.80	47.0%	101.70
11						3	23.80	43.0%	55.35
12	24590-101-TSA-W000-0009-143-01 (VSL-03R3851-1) [Ref. 9.4]	B	6.5	T-26	B1	1	2.169	40.7%	5.33
13						2	5.520	64.9%	8.51
14						3	7.305	76.7%	9.52
15	24590-101-TSA-W000-0009-105-00006 (VSL-04R4851-1) [Ref. 9.1]	A	7.2	T-57	C1	B	0.70	32.0%	2.19
16						C	6.22	33.5%	18.57
17						D	2.14	27.4%	7.81
18						E	16.57	33.1%	50.06
19	24590-101-TSA-W000-0009-166-00001 (VSL-05R5830-1) [Ref. 9.5]	B	6.3	T-93	Bounding A2	1 - 0144 - 0244			11.35
20						1 - 0351 - 0451			13.62
21						1 - 0547 - 0647			12.61
22						2B - 1430 - 1530			57.30
23						2B - 1647 - 1747			54.20
24						2B - 1908 - 2008			51.50
25									
26						All Data	Maximum =>		101.7
27							Minimum =>		2.2
28							Average =>		**26.8**
29							STDEV =>		26.8
30						Feed Vector Averages	A1 =>		57.6
31							B1 =>		7.8
32							C1 =>		16.0
33							Bounding A2 =>		33.4
34									
35						Average of Feed Vector Averages (Prototypical Data Only)	Average =>		**27.1**
36									
37							STDEV =>		26.7
38							Max (Avg. + STDEV) =>		**53.8**
39							Min (Avg. - STDEV) =>		**0.4**
40									
41	The average melter particulate emission from all data, **26.8 mg/ft^3**, is used in Attachment 4, Section A4.7.4.								
42	The average, minimum and maximum particulate concentration prototypical values are used in Cell **EU-15** of Attachment 1 flowsheets.								

Attachment 34 DM-1200 SBS and WESP Solids DFs

Attachment 34 determines the minimum, average and maximum decontamination factors (DF) for solids through the SBS and WESP.

The WESP decontamination factors (DF) range from 9.5 to 198.7 based on pilot test data as reported in 24590-101-TSA-W000-0009-111-01, 24590-101-TSA-W000-0009-111-02, and 24590-101-TSA-W000-0009-143-01 (Ref. 9.2, 9.3 & 9.4). DF values vary due to differing operating conditions of both the WESP and the overall vitrification system being tested. This overall range is reasonable because it is based on three feed vectors, and each feed vector had two test runs.

The development of the DF values is further explained as follows. The fundamental data collected in the laboratory to determine DF is the mass flow of particulates. This parameter is linearly associated with the capture efficiency (for a relatively fixed inlet mass flow). The capture efficiency was determined from associated DFs for the 3 feed envelopes A, B, and C. For envelope B, the efficiency is reported during deluge operation wherein the power to the electrodes is stopped and deluge water turned on. The DF is a result of particulate collision with the walls of the WESP and with water droplets due to the deluge. A reduced efficiency is shown for this test (89.5% vs 99.5% and 99% per spreadsheet calculations). Because deluge operation is an expected condition to occur daily, the mass balance uses this reduced efficiency to develop an average efficiency for the WESP over its life cycle. The resultant efficiency will be conservative because it tends to skew the answer (deluge only occurs a small percentage of the time). Because efficiency is linear with the actual laboratory measurements (e.g. weight of collected sample), it is appropriate to manipulate efficiency for statistical purposes. This is done with the average and standard deviation as shown. The minimum efficiency is one standard deviation below the average and the maximum is simply the highest efficiency measured. (The maximum efficiency for WESP is defined based on the highest capture efficiency data because adding a standard deviation to the average would result in >100% efficiency which is a precluded outcome). To generate average, minimum & maximum DF values, the efficiency values are converted to DF as shown below.

Spreadsheet Explanation:

1. SBS and WESP decontamination factors measured on the DM-1200 melter system were manually entered into Columns B and D and are based on the references provided. A decontamination factor is a measure of how well a treatment unit is performing at removing unwanted constituents. It is the quotient of the mass entering the treatment unit divided by the mass leaving the treatment unit.

2. Each decontamination factor is converted to capture efficiency in Columns C and E, respectively. The decontamination factor is related to the capture efficiency as follows:

$$DF = \frac{mass\ in}{mass\ out} \qquad \text{(Equation 3a)}$$

$$Capture\ Efficiency = \frac{mass\ in - mass\ out}{mass\ in} = \frac{mass\ in}{mass\ in} - \frac{mass\ out}{mass\ in} = 1 - \frac{1}{DF} \qquad \text{(Equation 3b)}$$

$$\Rightarrow \frac{1}{DF} = 1 - Capture\ Efficiency$$

$$\Rightarrow DF = \frac{1}{1 - Capture\ Efficiency}$$

3. The average and standard deviation for the defined capture efficiencies are calculated in Rows 13 and 14.

4. Minimum and maximum capture efficiencies are defined in Rows 15 and 16 based on the average value and either adding or subtracting the defined standard deviation as appropriate. For WESP, the maximum efficiency is defined based on the highest capture efficiency data because adding a standard deviation to the average would result in >100% efficiency, which is not appropriate.

5. The defined minimum, average, and maximum capture efficiencies for each unit are converted back to a decontamination factors in Columns B and D in Rows 13, 15, and 16. The maximum WESP DF will be based on the maximum data point, 198.7.

The average solids capture efficiency for the SBS and WESP (cell C13 & E13) are used in **Attachment 4**, **Section A4.7.4** to calculate the mass flow of particulates captured in the SBS & WESP.
The minimum, average, and maximum DFs for SBS are used in **Cell EU17** and the minimum, average, and maximum DFs for WESP are used in **Cell EU21** of Attachment 1 flowsheets to calculate the particulate mass flowrates. See Note 14 in Attachment 1, “Notes” worksheet for more explanation of how these values are used.

	A	B	C	D	E	F
1	**Attachment 34**					
2	**DM-1200 SBS and WESP Solids DFs**					
3						
4		SBS		WESP		
5	Vector	DF (Input 2.4)	Capture Efficiency (%) (Equation 3b)	DF (Input 2.4)	Capture Efficiency (%) (Equation 3b)	Reference
6	A1	8.3	88.0%	198.7	99.5%	24590-101-TSA-W000-0009-111-02 (Ref. 9.3, Tables 6.3 & 6.4, Pages T-55 & T-56)
7	B1	10.6	90.6%	9.5	89.5%	24590-101-TSA-W000-0009-143-01, (Ref. 9.4, Tables 6.3 & 6.4, Pages T-24 & T-25)
8	C1	5.7	82.5%	105	99.0%	24590-101-TSA-W000-0009-111-01 (Ref. 9.2, Tables 6.3 & 6.4, Pages T-51 & T-52)
9						
10						
11						
12						
13	Average* =>	**7.7**	**87.0%**	**25.0**	**96.0%**	
14	STDEV =>		4.14%		5.66%	
15	Min* =>	**5.8**	82.9%	**10.4**	90.3%	
16	Max* =>	**11**	91.1%	**198.7**	99.5%	
17						
18	* The minimum, average, and maximum DFs are calculated from the associated capture efficiencies and are used in **Cell EU17** (for SBS)					
19	and **EU21** (for WESP) **of Attachment 1** flowsheets.					
20	The average solids capture efficiencies for the SBS and WESP are used in **Attachment 4, Section A4.7.4**.					
21						

Attachment 35 Mercury Discharge from Activated Carbon Beds

In Attachment 35, the mercury emission limit for the LAW vitrification system (Input 31) is used to calculate the maximum amount of mercury allowed in the offgas after the carbon beds. The calculations are performed in MathCAD.

The mass flowrates of Hg at the carbon bed discharge outlet in the minimum, nominal and maximum cases are then entered into Cell **DK-33** of Attachment 1 flowsheets.

Attachment 35 - Mercury Discharge from Activated Carbon Beds

Unit Definition:

Length

$$mm \equiv \frac{m}{1000}$$
$$in \equiv 25.4\cdot mm$$
$$ft \equiv 12\cdot in$$
$$cm \equiv \frac{m}{100}$$
$$\mu m \equiv \frac{mm}{1000}$$

Energy

$$J \equiv \frac{kg\cdot m^2}{s^2}$$
$$KJ \equiv 1000\cdot J$$
$$Btu \equiv 1055.1\cdot J$$

Temperature

$$C \equiv K$$
$$F \equiv \frac{5}{9}\cdot C$$
$$F \equiv R$$

Power

$$W \equiv \frac{J}{s}$$
$$mW \equiv \frac{W}{1000}$$
$$kW \equiv 1000\cdot W$$
$$Hp \equiv 745.71\cdot W$$

Volume

$$L \equiv \frac{m^3}{1000}$$
$$gal \equiv \frac{ft^3}{7.4805}$$
$$ml \equiv \frac{L}{1000}$$

Pressure

$$Pa \equiv \frac{kg}{m\cdot s^2}$$
$$\mu Pa \equiv \frac{Pa}{1000000}$$
$$bar \equiv 100000\cdot Pa$$
$$mbar \equiv \frac{bar}{1000}$$
$$5\cdot bar$$
$$psi \equiv \frac{atm}{14.696}$$
$$inWC \equiv \frac{psi}{27.681}$$
$$mmWC \equiv \frac{inWC}{25.4}$$

Force

$$N \equiv kg\cdot\frac{m}{s^2}$$
$$mN := \frac{N}{1000}$$

Viscosity

$$cP \equiv 1000\cdot\mu Pa\cdot s$$
$$P \equiv 100\cdot cP$$

Mass

$$g \equiv \frac{kg}{1000}$$
$$lb \equiv \frac{kg}{2.20462}$$
$$\mu g \equiv \frac{g}{1000000}$$
$$MT \equiv 1000\cdot kg$$

Substance

$$kmol \equiv 1000\cdot mole$$
$$lbmole \equiv \frac{kmol}{2.20462}$$
$$mmol \equiv \frac{mole}{1000}$$

Time

$$min \equiv 60\cdot s$$
$$hr \equiv 3600\cdot s$$
$$day \equiv 24\cdot hr$$
$$year \equiv 365.25\cdot day$$

Gravity

$$g_n := 9.81\cdot\frac{m}{s^2}$$

Gas Constant

$$R_G := 8.314\cdot\frac{J}{mol\cdot K}$$

In this calculation, the allowable limit for mercury exiting the carbon beds is used to calculate the maximum amount of mercury in the offgas after the carbon beds. The volume of dry air leaving the carbon beds is multiplied by the permit limit to obtain the result.

A35.1 The outlet dry air for the Activated Carbon Beds are defined below from cell [C-33] in Attachment 1 flowsheets:

$$Air_{in} := \begin{pmatrix} 2415 \\ 2266 \\ 1879 \\ 961 \end{pmatrix}\cdot\frac{ft^3}{min}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A35.2 The permit requires the mercury leaving the Activated Carbon Beds to be less than 45 micrograms per dry standard cubic meter:

$$Hg_{permit} := \frac{45\mu g}{m^3}$$

(Section 2, Table 1, Input 31)

A35.3 Therefore, the maximum amount of mercury leaving the Activated Carbon Beds will be:

$$Hg_{out} := Air_{in} \cdot Hg_{permit}$$

$$Hg_{out} = \begin{pmatrix} 1.85 \times 10^{-4} \\ 1.73 \times 10^{-4} \\ 1.44 \times 10^{-4} \\ 7.35 \times 10^{-5} \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

These values are entered into Cell **DK-33** of Attachment 1 flowsheets to account for mercury after the carbon beds.

Attachment 36 LAW Melter Iodine-129 Emission Determination

The maximum LAW Melter Iodine-129 Emission to the offgas is determined in this attachment using MathCAD.

1. Determine the total waste oxide feed rate to the LAW melter based on the LAW glass throughput and maximum waste oxide loading.
2. Determine the specific activity of I-129 using Equation (13) defined in Section 5.
3. Calculate the maximum LAW Melter I-129 emission rate to the offgas based on the maximum I-129 activity per 100 g waste oxides in the LAW feed (Assumption 15), the total waste oxide feed rate, and I-129 specific activity, taking into account the DF at the melter.

The maximum LAW Melter I-129 emission mass flowrate into the offgas is entered into Cell **EC-15** in Attachment 1 flowsheets. The same I-129 mass flowrate is used in all cases (minimum, nominal and maximum) to maximize iodine emissions.

Attachment 36 - LAW Melter Iodine-129 Emission Determination

Unit Definition:

Length

$mm \equiv \frac{m}{1000}$

$in \equiv 25.4 \cdot mm$

$ft \equiv 12 \cdot in$

$cm \equiv \frac{m}{100}$

$\mu m \equiv \frac{mm}{1000}$

Energy

$J \equiv \frac{kg \cdot m^2}{s^2}$

$KJ \equiv 1000 \cdot J$

$Btu \equiv 1055.1 \cdot J$

$cal \equiv 4.184 \cdot J$

$kcal \equiv 1000 \cdot cal$

Temperature

$C \equiv K$

$F \equiv \frac{5}{9} \cdot C$

$F \equiv R$

Power

$W \equiv \frac{J}{s}$

$mW \equiv \frac{W}{1000}$

$kW \equiv 1000 \cdot W$

$Hp \equiv 745.71 \cdot W$

Volume

$L \equiv \frac{m^3}{1000}$

$gal \equiv \frac{ft^3}{7.4805}$

$ml \equiv \frac{L}{1000}$

Pressure

$Pa \equiv \frac{kg}{m \cdot s^2}$

$\mu Pa \equiv \frac{Pa}{1000000}$

$bar \equiv 100000 \cdot Pa$

$mbar \equiv \frac{bar}{1000}$

$atm \equiv 1.01325 \cdot bar$

$psi \equiv \frac{atm}{14.696}$

$inWC \equiv \frac{psi}{27.681}$

$mmWC \equiv \frac{inWC}{25.4}$

$inWG \equiv inWC$

Force

$N \equiv kg \cdot \frac{m}{s^2}$

$mN := \frac{N}{1000}$

Radiation

$Gy \equiv \frac{J}{kg}$

$rad \equiv 0.01 Gy$

$rem \equiv rad$

$mrem \equiv 0.001 \cdot rem$

Substance

$kmol \equiv 1000 \cdot mole$

$lbmole \equiv \frac{kmol}{2.20462}$

$mmol \equiv \frac{mole}{1000}$

Time

$min \equiv 60 \cdot s$

$hr \equiv 3600 \cdot s$

$day \equiv 24 \cdot hr$

$year \equiv 365.25 \cdot day$

$month \equiv \frac{year}{12}$

Mass

$g \equiv \frac{kg}{1000}$

$lb \equiv \frac{kg}{2.20462}$

$\mu g \equiv \frac{g}{1000000}$

$pg \equiv \frac{g}{1 \cdot 10^{12}}$

$ng \equiv \frac{g}{1 \cdot 10^{9}}$

$Mt \equiv 1000 \cdot kg$

$mg \equiv \frac{g}{1000}$

Gravity

$g_n := 9.81 \cdot \frac{m}{s^2}$

Gas Constant

$R_G := 8.314 \cdot \frac{J}{mol \cdot K}$

Rad Decay

$Ci \equiv 3.7 \cdot 10^{10} \cdot Bq$

Viscosity

$cP \equiv 1000 \cdot \mu Pa \cdot s$

$P \equiv 100 \cdot cP$

A36.1 Maximum Iodine-129 Activity Limit per 100 grams Waste Oxide in the LAW Feed:

$A_{I129} := \frac{2.9 \cdot 10^{-7} \cdot Ci}{100 \cdot g}$ (Assumption 15)

A36.2 Pertinent Physical Properties of Iodine-129:

Molecular Weight:	$MW_{I129} := 128.904988 \cdot \frac{g}{mol}$	(Input 20)
Half Life:	$HalfLife_{I129} := 1.7 \cdot 10^{7} \cdot year$	(Input 21)
Avogadro's Number:	$N_{AG} := 6.02 \cdot 10^{23} \cdot \frac{1}{mol}$	(Ref. 10.2.9, Page 49)

A36.3 Waste Oxide Feed Rate to the LAW Melter

Per Melter:

LAW glass throughput: $Glass_{LAW} := 15.0 \cdot \frac{Mt}{day}$ (30 MTG/day for 2 melters per Input 8)

Maximum Waste Oxide Loading in LAW glass: $WO_{Loading} := 25\%$ (Assumption 5)

Mass of Waste Oxide : $m_{WO} := Glass_{LAW} \cdot WO_{Loading}$ $m_{WO} = 156.25 \cdot \frac{kg}{hr}$

A36.4 Specific Activity for Iodine-129:

The specific activity for I-129 is determined from Equation 13 defined in Section 5:

$$AM_{I129} := \frac{\ln(2) \cdot N_{AG}}{MW_{I129} \cdot HalfLife_{I129}}$$ (Equation 13)

$AM_{I129} = 6.034 \times 10^{6} \cdot \frac{Bq}{g}$ $AM_{I129} = 1.631 \times 10^{-4} \cdot \frac{Ci}{g}$

A36.5 LAW Melter Iodine-129 Emission Rate into LAW Offgas:

The DF for the iodine ion is 2.5 (Input 54). This means that 60% of the iodine is captured in the glass product (using Equation 3b); 40% escapes to the offgas.

$$m_{I129} := \frac{m_{WO} \cdot A_{I129}}{AM_{I129} \cdot 2.5}$$ $m_{I129} = 1.111 \times 10^{-3} \cdot \frac{kg}{hr}$

To maximize the release of Iodine-129 from the LAW melter, it is assumed that no iodine is lost in Pretreatment (Assumption 5). The presence of methyl iodide is neglected due to the low probability that it is present in the offgas (Assumption 56).

The maximum LAW Melter I-129 emission mass flowrate into the offgas is entered into Cell **EC-15** in Attachment 1 flowsheets.

Attachment 37 Catalyst Skid Pressure Drop Equations

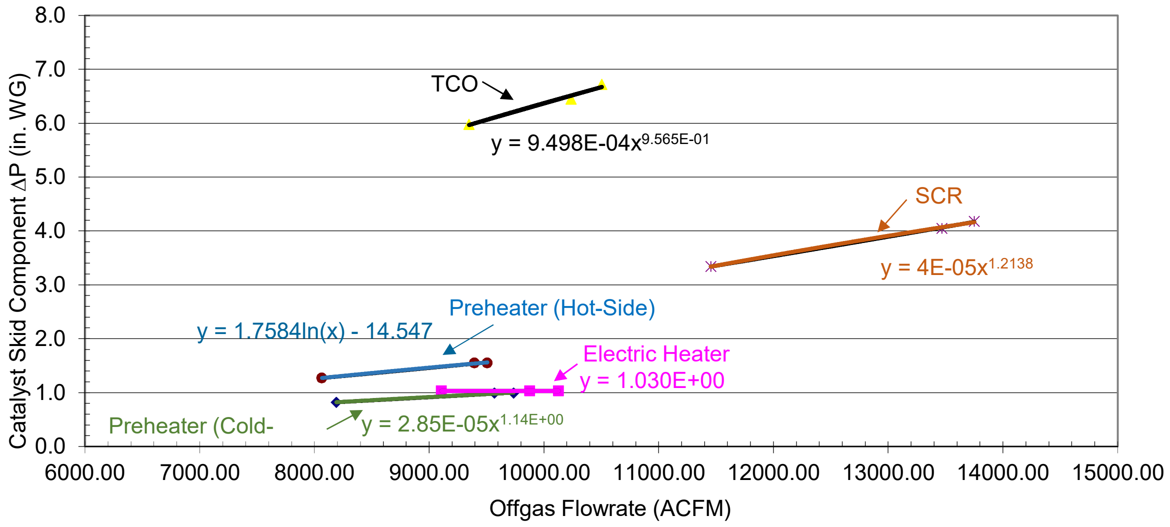
The spreadsheet in Attachment 37 is used to develop equations to estimate the pressure drops over the different units within the catalyst skid based on vendor submittal data (Ref. 9.11).

Spreadsheet Explanation:

1. The catalyst skid subcomponents inlet/outlet pressures and outlet flowrates (ACFM) from vendor submittal 24590-CD-POC-MBT0-00007-02-00001 (Ref. 9.11) were manually entered into Columns D, E, and F, respectively.
2. Subtracting Column D from Column E calculates the subcomponent pressure drops in Column G.
3. The subcomponent pressure drops are plotted against the actual gas volumetric flowrates in the provided figure.
4. The Excel trendline feature was used to define power equations for each data set as shown on the figure.
5. The established equations are used to re-predict the pressure drop data in Column H. The differential percentage between the equation predictions and the actual data is defined in Column I. The comparison shows that the equations are very accurate at reproducing the defined pressure drop data.

The equations developed are used in cells **S36 - S38** and **S44 - S45** in Attachment 1 flowsheets to estimate the pressure drops through various units within the catalyst skid.

	A	B	C	D	E	F	G	H	I	J
1	***Attachment 37 - Catalyst Skid Pressure Drop Equations***									
2	Inlet and outlet pressures are obtained from 24590-CD-POC-MBT0-00007-02-00001 (Ref. 9.11).									
3										
4				Pressure [Input 2.4]		Actual Flow				
5				in	out	Out [Input 2.4]	ΔP	Equation ΔP		
6	Condition	Skid Component	Reference	(in. WG)	(in. WG)	(ACFM)	in. WG	in. WG	Error	
7	Nominal	Preheater Cold-Side (Node 1 to 2)	(Ref. 9.11, Sect. 9.1.1 & 9.1.2)	-100.00	-100.82	8191.00	0.82	0.82	0.52%	
8	Maximum (Min Temp)			-122.00	-122.99	9568.00	0.99	0.98	-0.61%	
9	Maximum (Max Temp)			-122.00	-122.99	9734.00	0.99	1.00	1.36%	
10	Nominal	Electric Heater (Node 2 to 3)	(Ref. 9.11, Sect. 9.1.2 & 9.1.3)	-100.82	-101.85	9107.00	1.03	1.03	0.00%	
11	Maximum (Min Temp)			-122.99	-124.02	9878.00	1.03	1.03	0.00%	
12	Maximum (Max Temp)			-122.99	-124.02	10129.00	1.03	1.03	0.00%	
13	Nominal	TCO (Node 3 to 4)	(Ref. 9.11, Sect. 9.1.3 & 9.1.4)	-101.85	-107.83	9348.00	5.98	5.97	-0.25%	
14	Maximum (Min Temp)			-124.02	-130.47	10237.00	6.45	6.51	0.88%	
15	Maximum (Max Temp)			-124.02	-130.74	10504.00	6.72	6.67	-0.76%	
16				Pressure		Actual				
17				in	out	Flow Out	ΔP	Equation ΔP		
18	Condition	Skid Component		(in. WG)	(in. WG)	(ACFM)	in. WG	in. WG	Error	
19	Nominal	SCR (Node 4 to 6)	(Ref. 9.11, Sect. 9.1.5 & 9.1.6)	-107.83	-111.17	11455.00	3.34	3.38	1.19%	
20	Maximum (Min Temp)			-130.47	-134.52	13469.00	4.05	4.11	1.58%	
21	Maximum (Max Temp)			-130.74	-134.92	13750.00	4.18	4.22	0.91%	
22	Nominal	Preheater Hot-Side (Node 6 to 7)	(Ref. 9.11, Sect. 9.1.6 & 9.1.7)	-111.17	-112.44	8065.00	1.27	1.27	0.02%	
23	Maximum (Min Temp)			-134.52	-136.07	9395.00	1.55	1.54	-0.73%	
24	Maximum (Max Temp)			-134.92	-136.47	9507.00	1.55	1.56	0.62%	
25										



Attachment 38 Not Used

Attachment 39 Caustic Scrubber Outlet Temperature Calculation

Attachment 39 determines the temperature of the offgas and the amount of steam exiting the caustic scrubber based on the mass and energy balance described in Section 5.18. The calculations are done using MathCAD.

The caustic scrubber outlet temperature calculated in this attachment is entered into cell **O-48** in Attachment 1 flowsheets. The mass flowrate of water vapor in the offgas discharge from the scrubber is entered into cell **BU-48** in Attachment 1 flowsheets.

Attachment 39 - Caustic Scrubber Outlet Temperature Calculation

Unit Definition:

Length

$mm \equiv \frac{m}{1000}$

$in \equiv 25.4 \cdot mm$

$ft \equiv 12 \cdot in$

$cm \equiv \frac{m}{100}$

$\mu m \equiv \frac{mm}{1000}$

Energy

$J \equiv \frac{kg \cdot m^2}{s^2}$

$KJ \equiv 1000 \cdot J$

$Btu \equiv 1055.1 \cdot J$

$cal \equiv 4.184 \cdot J$

$kcal \equiv 1000 \cdot cal$

Temperature

$C \equiv K$

$F \equiv \frac{5}{9} \cdot C$

$F \equiv R$

Power

$W \equiv \frac{J}{s}$

$mW \equiv \frac{W}{1000}$

$kW \equiv 1000 \cdot W$

$Hp \equiv 745.71 \cdot W$

Volume

$L \equiv \frac{m^3}{1000}$

$gal \equiv \frac{ft^3}{7.4805}$

$ml \equiv \frac{L}{1000}$

Pressure

$Pa \equiv \frac{kg}{m \cdot s^2}$

$\mu Pa \equiv \frac{Pa}{1000000}$

$bar \equiv 100000 \cdot Pa$

$mbar \equiv \frac{bar}{1000}$

$atm \equiv 1.01325 \cdot bar$

$psi \equiv \frac{atm}{14.696}$

$inWC \equiv \frac{psi}{27.681}$

$mmWC \equiv \frac{inWC}{25.4}$

$inWG \equiv inWC$

Force

$N \equiv kg \cdot \frac{m}{s^2}$

$mN := \frac{N}{1000}$

Viscosity

$cP \equiv 1000 \cdot \mu Pa \cdot s$

$P \equiv 100 \cdot cP$

Substance

$kmol \equiv 1000 \cdot mole$

$lbmole \equiv \frac{kmol}{2.20462}$

$mmol \equiv \frac{mole}{1000}$

Time

$min \equiv 60 \cdot s$

$hr \equiv 3600 \cdot s$

$day \equiv 24 \cdot hr$

$year \equiv 365.25 \cdot day$

$month \equiv \frac{year}{12}$

Mass

$g \equiv \frac{kg}{1000}$

$lb \equiv \frac{kg}{2.20462}$

$\mu g \equiv \frac{g}{1000000}$

$Mt \equiv 1000 \cdot kg$

$mg \equiv \frac{g}{1000}$

Gravity

$g_n := 9.81 \cdot \frac{m}{s^2}$

Gas Constant

$R_G := 8.314 \cdot \frac{J}{mol \cdot K}$

In this attachment, the temperature of the offgas and the amount of steam that exits the caustic scrubber are determined based on the mass and energy balance described in Section 5.18.

A39.1 Scrubber Spray Nozzle Inlet Dry Air SCFM:

To determine the total volumetric flowrate of dry air traveling through the scrubber, the volumetric flow of air from the spray nozzles must be determined. From the caustic scrubber operating instructions 24590-QL-POA-MKAS-00003-08-00003 (Input 4 in Section 2.1 of the main calculation), the SCFM of air through each spray nozzle is 36 ft^3/min per nozzle. Multiply by four to obtain the total spray air flowrate since there are four spray nozzles (nozzles N07A- D per Ref. 9.45, Table 1).

$$Spray_{Air\_in} := 4 \cdot \begin{pmatrix} 36 \\ 36 \\ 36 \\ 36 \end{pmatrix} \frac{ft^3}{min} \qquad Spray_{Air\_in} = \begin{array}{ll} \begin{pmatrix} 144 \\ 144 \\ 144 \\ 144 \end{pmatrix} \cdot \frac{ft^3}{min} & \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array} \end{array}$$

These spray air volumetric flow are added to the caustic scrubber discharge in cell **C-48** of Attachment 1 flowsheets.

A39.2 Scrubber Offgas Inlet Temperature is obtained from Cell O-45 of Attachment 1 flowsheets (temperature determined in Attachment 40):

$$T_{in} := \begin{pmatrix} 208 \\ 183 \\ 148 \\ 143 \end{pmatrix} \cdot C$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A39.3 Mass flowrates of offgas, steam and dry air entering the caustic scrubber:

Offgas and steam mass flowrates entering the caustic scrubber are taken from Attachment 1 flowsheets.

Total Offgas In	Total Steam In
(From cell K-47)	(From cell BU-47)

$$m_{GasIn} := \begin{pmatrix} 7170 \\ 6700 \\ 5660 \\ 3700 \end{pmatrix} \cdot \frac{kg}{hr} \qquad m_{H2Oin} := \begin{pmatrix} 580 \\ 360 \\ 150 \\ 77 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

Mass flowrates of dry air entering the caustic scrubber is calculated as follows:

$$m_{Air} := m_{GasIn} - m_{H2Oin} \qquad m_{Air} = \begin{pmatrix} 6590 \\ 6340 \\ 5510 \\ 3623 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A39.4 Heat capacity of air and water vapor at the caustic scrubber inlet temperature:

The heat capacity equations for air and water vapor are taken from Attachment 15:

$$Cp_{Air} := 0.998\cdot\frac{KJ}{kg\cdot C} + 1.43\cdot10^{-4}\cdot\frac{KJ}{kg\cdot C^2}\cdot T_{in} + 1.10\cdot10^{-7}\cdot\frac{KJ}{kg\cdot C^3}\cdot {T_{in}}^2 - 6.78\cdot10^{-11}\cdot\frac{KJ}{kg\cdot C^4}\cdot {T_{in}}^3$$

$$Cp_{H2O} := 1.8573\cdot\frac{KJ}{kg\cdot C} + 3.82\cdot10^{-4}\cdot\frac{KJ}{kg\cdot C^2}\cdot T_{in} + 4.22\cdot10^{-7}\cdot\frac{KJ}{kg\cdot C^3}\cdot {T_{in}}^2 - 1.99\cdot10^{-10}\cdot\frac{KJ}{kg\cdot C^4}\cdot {T_{in}}^3$$

$$Cp_{Air} = \begin{pmatrix} 1.032 \\ 1.027 \\ 1.021 \\ 1.021 \end{pmatrix}\cdot\frac{KJ}{kg\cdot C} \qquad Cp_{H2O} = \begin{pmatrix} 1.953 \\ 1.94 \\ 1.922 \\ 1.92 \end{pmatrix}\cdot\frac{KJ}{kg\cdot C}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A39.5 Determine the caustic scrubber outlet temperature (T_s) and the mass flow of steam in the caustic scrubber discharge (mH2Oout):

Per Assumption 19, the offgas exiting the LVP caustic scrubber is assumed to be saturated. The caustic scrubber outlet offgas temperature (T_s) is initially guessed. Adjust the saturation temperature T_s until the energy balance below sums to zero.

Caustic scrubber outlet offgas temperature (initial guess)	Scrubber discharge pressure (Cell W-48 of Attachment 1 flowsheets)	Saturation humidity from Attachment 44 at corresponding temperature (T_s) and pressure:

$$T_s := \begin{pmatrix} 50.64 \\ 47.79 \\ 41.0 \\ 39.54 \end{pmatrix}\cdot C \qquad Pressure := \begin{pmatrix} 600 \\ 677 \\ 722 \\ 743 \end{pmatrix}\cdot mbar \qquad H_s := \begin{pmatrix} 0.1675 \\ 0.1214 \\ 0.0755 \\ 0.0672 \end{pmatrix}\cdot\frac{kg}{kg}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

The final T_s is entered into cell **O-48** in Attachment 1 flowsheets.

Latent heat of vaporization: $\lambda_s := 2382.9 \cdot \frac{KJ}{kg}$

From Felder Table B.4 (Ref. 10.2.9, pg 628)
Heat of vaporization for water at 50 deg C
(Input 49)

$i := 1 .. 4$

The mass flow of steam in the caustic scrubber offgas discharge (LVP18), mH2Oout, is calculated below.

Per Equation (20) in Section 5
:

$$mH2Oout_i := \frac{m_{Air_i} \cdot Cp_{Air} \cdot \left(T_{in_i} - T_{s_i}\right) + Cp_{H2O} \cdot m_{H2Oin_i} \cdot \left(T_{in_i} - T_{s_i}\right) + m_{H2Oin_i} \cdot \lambda_s}{\lambda_s}$$

Per saturation humidity definition:

$$mH2Oout_i := m_{Air_i} \cdot H_{s_i}$$

$$mH2Oout = \begin{pmatrix} 1104 \\ 770 \\ 416 \\ 243 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

The mass flowrate of water vapor in the offgas discharge from the scrubber is entered into cell **BU-48** in Attachment 1 flowsheets.

Verify the energy balance:

$$SUM_i := mH2Oout_i - \frac{m_{Air_i} \cdot Cp_{Air_i} \cdot \left(T_{in_i} - T_{s_i}\right) + Cp_{H2O_i} \cdot m_{H2Oin_i} \cdot \left(T_{in_i} - T_{s_i}\right) + m_{H2Oin_i} \cdot \lambda_s}{\lambda_s}$$

$$SUM = \begin{pmatrix} -0 \\ 0 \\ 0 \\ -0 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

Attachment 40 Catalyst Skid Recuperative Heat Exchanger Discharge Temperature Determination

Attachment 40 uses an iterative calculation process to determine the outlet temperatures of the heat exchanger LVP-HX-00001. The calculations are done using MathCAD.

Equations (23b), (23d) & (23e) were developed in Section 5.21 and will be used in Attachment 40 calculations.

$$\Delta T_L = \frac{(T_{CatHotIn} - T_{CatColdOut}) - (T_{CatHotOut} - T_{CatColdIn})}{\ln\left(\frac{T_{CatHotIn} - T_{CatColdOut}}{T_{CatHotOut} - T_{CatColdIn}}\right)} \qquad Equation\ (23b)$$

$$T_{CatColdOut} = T_{CatColdIn} + \frac{U_{Cat} * A_{Cat} * \Delta T_L}{m_{CatCold} * Cp_{CatCold}} \qquad Equation\ (23d)$$

$$T_{CatHotOut} = T_{CatHotIn} - \frac{U_{Cat} * A_{Cat} * \Delta T_L}{m_{CatHot} * Cp_{CatHot}} \qquad Equation\ (23e)$$

Where,

ΔT_L = log mean temperature difference for the catalytic skid heat exchanger (°C)
$T_{CatHotIn}$ = hot side fluid inlet temperature (°C)
$T_{CatHotOut}$ = hot side fluid outlet temperature (°C)
$T_{CatColdIn}$ = cold side fluid inlet temperature (°C)
$T_{CatColdOut}$ = cold side fluid outlet temperature (°C)
$m_{CatCold}$ = cold side mass flow rate (kg/hr)
$Cp_{CatCold}$ = cold side fluid heat capacity (kJ/(kg·°C)
m_{CatHot} = hot side mass flow rate (kg/hr)
Cp_{CatHot} = hot side fluid heat capacity (kJ/(kg·°C)

Calculation Method:

An initial guess is made for the heat exchanger cold side and hot side discharge temperatures ($T_{CatColdOut}$ and $T_{CatHotOut}$). These temperatures are entered into Cells O-36 (cold side discharge) and O-45 (hot side discharge) of Attachment 1 main flowsheets.

The heat exchanger cold side and hot side inlet temperatures, $T_{CatColdIn}$ and $T_{CatHotIn}$, are taken from cells O-33 and O-44 of Attachment 1 main flowsheets.

The log mean temperature difference between the hot and cold sides of the heat exchanger is calculated using Equation (23b) in Section 5.

The mass flowrates on the cold and hot sides are taken from cells K-36 and K-44 of Attachment 1 main flowsheets.

The heat capacity of the cold side fluid is taken from cells AK-36 (outlet) and AK-33 (inlet) of Attachment 1 main flowsheets. The average cold side heat capacity is calculated.

The heat capacity of the hot side fluid is taken from cells AK-44 (inlet) and AK-45 (outlet) of Attachment 1 main flowsheets. The average hot side heat capacity is calculated.

The heat exchanger cold side and hot side discharge temperatures, $T_{CatColdOutC}$ and $T_{CatHotOutC}$, are calculated from Equation (23d) & (23e) (the “C” in the subscript is to differentiate these outlet temperatures from the initial outlet temperature guess).

An iteration is done to select the new cold side and hot side outlet temperatures:

$$T_{CatColdOutA} = \frac{\frac{T_{CatColdOut} + T_{CatColdOutC}}{2} + T_{CatColdOut}}{2}$$

$$T_{CatHotOutA} = \frac{\frac{T_{CatHotOut} + T_{CatHotOutC}}{2} + T_{CatHotOut}}{2}$$

$T_{CatColdOutA}$ and $T_{CatHotOutA}$ are now the new cold side and hot side discharge temperatures $T_{CatColdOut}$ and $T_{CatHotOut}$. These temperatures are entered into Cells **O-36** (cold side) and **O-45** (hot side) of Attachment 1 main flowsheets.

The method above is repeated until the calculated $T_{CatColdOutA}$ and $T_{CatHotOutA}$ match the initial discharge temperature guess, $T_{CatColdOut}$ and $T_{CatHotOut}$.

Attachment 40 - Catalyst Skid Recuperative Heat Exchanger Discharge Temperature Determination

Unit Definition:

Length

$mm \equiv \frac{m}{1000}$

$in \equiv 25.4 \cdot mm$

$ft \equiv 12 \cdot in$

$cm \equiv \frac{m}{100}$

$\mu m \equiv \frac{mm}{1000}$

Energy

$J \equiv \frac{kg \cdot m^2}{s^2}$

$KJ \equiv 1000 \cdot J$

$Btu \equiv 1055.1 \cdot J$

$cal \equiv 4.184 \cdot J$

$kcal \equiv 1000 \cdot cal$

Temperature

$C \equiv K$

$F \equiv \frac{5}{9} \cdot C$

$F \equiv R$

Power

$W \equiv \frac{J}{s}$

$mW \equiv \frac{W}{1000}$

$kW \equiv 1000 \cdot W$

$Hp \equiv 745.71 \cdot W$

Volume

$L \equiv \frac{m^3}{1000}$

$gal \equiv \frac{ft^3}{7.4805}$

$ml \equiv \frac{L}{1000}$

Pressure

$Pa \equiv \frac{kg}{m \cdot s^2}$

$\mu Pa \equiv \frac{Pa}{1000000}$

$bar \equiv 100000 \cdot Pa$

$mbar \equiv \frac{bar}{1000}$

$atm \equiv 1.01325 \cdot bar$

$psi \equiv \frac{atm}{14.696}$

$inWC \equiv \frac{psi}{27.681}$

$mmWC \equiv \frac{inWC}{25.4}$

$inWG \equiv inWC$

Force

$N \equiv kg \cdot \frac{m}{s^2}$

$mN := \frac{N}{1000}$

Viscosity

$cP \equiv 1000 \cdot \mu Pa \cdot s$

$P \equiv 100 \cdot cP$

Substance

$kmol \equiv 1000 \cdot mole$

$lbmole \equiv \frac{kmol}{2.20462}$

$mmol \equiv \frac{mole}{1000}$

Time

$min \equiv 60 \cdot s$

$hr \equiv 3600 \cdot s$

$day \equiv 24 \cdot hr$

$year \equiv 365.25 \cdot day$

$month \equiv \frac{year}{12}$

Mass

$g \equiv \frac{kg}{1000}$

$lb \equiv \frac{kg}{2.20462}$

$\mu g \equiv \frac{g}{1000000}$

$Mt \equiv 1000 \cdot kg$

$mg \equiv \frac{g}{1000}$

Gravity

$g_n := 9.81 \cdot \frac{m}{s^2}$

Gas Constant

$R_G := 8.314 \cdot \frac{J}{mol \cdot K}$

A40.1 Vendor Supplied Overall Heat Transfer Coefficient:

$U_{Cat} := 2.74 \cdot \frac{Btu}{hr \cdot ft^2 \cdot F}$ $U_{Cat} = 15.559 \cdot \frac{W}{m^2 \cdot C}$ (Input 2.12)

A40.2 Vendor Supplied Heat Transfer Area:

$A_{Cat} := 4056 \cdot ft^2$ $A_{Cat} = 376.815\ m^2$ (Input 2.12)

A40.3 Heat Exchanger Cold side and Hot side Outlet Temperatures (Initial guess, solved Iteratively from Section A40.11):

$$\boxed{T_{CatColdOut} := \begin{pmatrix} 357 \\ 337 \\ 298.2 \\ 256.6 \end{pmatrix} \cdot C} \qquad \boxed{T_{CatHotOut} := \begin{pmatrix} 208 \\ 183 \\ 148 \\ 142.9 \end{pmatrix} \cdot C}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

These temperatures are entered into Cells **O-36** (cold side) and **O-45** (hot side) in Attachment 1 flowsheets.

A40.4 Heat Exchanger Inlet Temperatures are taken from Attachment 1 flowsheets:

From cell O-33
(cold side inlet)

From cell O-44
(hot side inlet)

$$T_{CatColdIn} := \begin{pmatrix} 97 \\ 76 \\ 55 \\ 55 \end{pmatrix} \cdot C \qquad T_{CatHotIn} := \begin{pmatrix} 406 \\ 377 \\ 320 \\ 258 \end{pmatrix} \cdot C$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A40.5 Logarithmic mean temperature between the hot and cold sides of the heat exchanger is determined using Equation (23b) in Section 5.

$i := 1 .. 4$

$$\Delta T_{L_i} := \frac{\left(T_{CatHotIn_i} - T_{CatColdOut_i}\right) - \left(T_{CatHotOut_i} - T_{CatColdIn_i}\right)}{\ln\left(\dfrac{T_{CatHotIn_i} - T_{CatColdOut_i}}{T_{CatHotOut_i} - T_{CatColdIn_i}}\right)}$$

$$\Delta T_L = \begin{pmatrix} 75.822 \\ 68.093 \\ 49.08 \\ 20.895 \end{pmatrix} \cdot C$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A40.6 Heat Exchanger Cold side and Hot side Mass Flowrates are taken from Attachment 1 flowsheets:

From cell K-36 (cold side)

From cell K-44 (hot side)

$$m_{CatCold} := \begin{pmatrix} 5510 \\ 5030 \\ 4010 \\ 2060 \end{pmatrix} \cdot \frac{kg}{hr} \qquad m_{CatHot} := \begin{pmatrix} 7150 \\ 6680 \\ 5650 \\ 3690 \end{pmatrix} \cdot \frac{kg}{hr}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A40.7 Heat Exchanger Outlet Heat Capacity are taken from Attachment 1 flowsheets:

From cell AK-36 (cold side outlet)

From cell AK-45 (hot side outlet)

$$Cp_{CatColdOut} := \begin{pmatrix} 1.146 \\ 1.118 \\ 1.081 \\ 1.071 \end{pmatrix} \cdot \frac{KJ}{kg \cdot C} \qquad Cp_{CatHotOut} := \begin{pmatrix} 1.107 \\ 1.078 \\ 1.045 \\ 1.040 \end{pmatrix} \cdot \frac{KJ}{kg \cdot C}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A40.8 Heat Exchanger Inlet Heat Capacity are taken from Attachment 1 flowsheets:

From cell AK-33 (cold side inlet)

From cell AK-44 (hot side inlet)

$$Cp_{CatColdIn} := \begin{pmatrix} 1.089 \\ 1.064 \\ 1.034 \\ 1.033 \end{pmatrix} \cdot \frac{KJ}{kg \cdot C} \qquad Cp_{CatHotIn} := \begin{pmatrix} 1.153 \\ 1.119 \\ 1.080 \\ 1.062 \end{pmatrix} \cdot \frac{KJ}{kg \cdot C}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

A40.9 Average Cold Side and Hot Side Heat Capacity Calculation:

$$Cp_{CatCold_i} := \frac{Cp_{CatColdIn_i} + Cp_{CatColdOut_i}}{2} \qquad Cp_{CatCold} = \begin{array}{ll} \begin{pmatrix} 1.117 \\ 1.091 \\ 1.058 \\ 1.052 \end{pmatrix} \cdot \frac{KJ}{kg \cdot C} & \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array} \end{array}$$

$$Cp_{CatHot_i} := \frac{Cp_{CatHotIn_i} + Cp_{CatHotOut_i}}{2} \qquad Cp_{CatHot} = \begin{array}{ll} \begin{pmatrix} 1.13 \\ 1.099 \\ 1.063 \\ 1.051 \end{pmatrix} \cdot \frac{KJ}{kg \cdot C} & \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array} \end{array}$$

A40.10 Heat Exchanger Cold Side and Hot Side Outlet Temperature Calculation:

Solving for Cold Side Outlet temperature per Equation (23d) in Section 5:

$$T_{CatColdOutC_i} := T_{CatColdIn_i} + \frac{U_{Cat} \cdot A_{Cat} \cdot \Delta T_{L_i}}{m_{CatCold_i} \cdot Cp_{CatCold_i}} \qquad T_{CatColdOutC} = \begin{array}{ll} \begin{pmatrix} 356.901 \\ 337.893 \\ 299.284 \\ 258.505 \end{pmatrix} \cdot C & \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array} \end{array}$$

Solving for Hot Side Outlet temperature per Equation (23e) in Section 5:

$$T_{CatHotOutC_i} := T_{CatHotIn_i} - \frac{U_{Cat} \cdot A_{Cat} \cdot \Delta T_{L_i}}{m_{CatHot_i} \cdot Cp_{CatHot_i}} \qquad T_{CatHotOutC} = \begin{array}{ll} \begin{pmatrix} 207.928 \\ 181.143 \\ 147.439 \\ 144.282 \end{pmatrix} \cdot C & \begin{array}{l} \text{Maximum (2 Melters)} \\ \text{Nominal (2 Melters)} \\ \text{Minimum (2 Melters)} \\ \text{Minimum (1 Melter)} \end{array} \end{array}$$

A40.11 Heat Exchanger Cold side and Hot Side Outlet Temperature Averaging to get new cold side and hot side outlet temperatures for the iterative calculations.

$$T_{CatColdOutA_i} := \frac{\frac{T_{CatColdOut_i} + T_{CatColdOutC_i}}{2} + T_{CatColdOut_i}}{2}$$

$$\boxed{T_{CatColdOutA} = \begin{pmatrix} 357 \\ 337 \\ 298 \\ 257 \end{pmatrix} \cdot C}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

$$T_{CatHotOutA_i} := \frac{\frac{T_{CatHotOut_i} + T_{CatHotOutC_i}}{2} + T_{CatHotOut_i}}{2}$$

$$\boxed{T_{CatHotOutA} = \begin{pmatrix} 208 \\ 183 \\ 148 \\ 143 \end{pmatrix} \cdot C}$$

Maximum (2 Melters)
Nominal (2 Melters)
Minimum (2 Melters)
Minimum (1 Melter)

The new calculated Heat Exchanger Cold side and Hot Side Outlet Temperatures match the initial outlet temperature guesses in section A40.3.

Attachment 41 Pressure Drop Across Control Valve

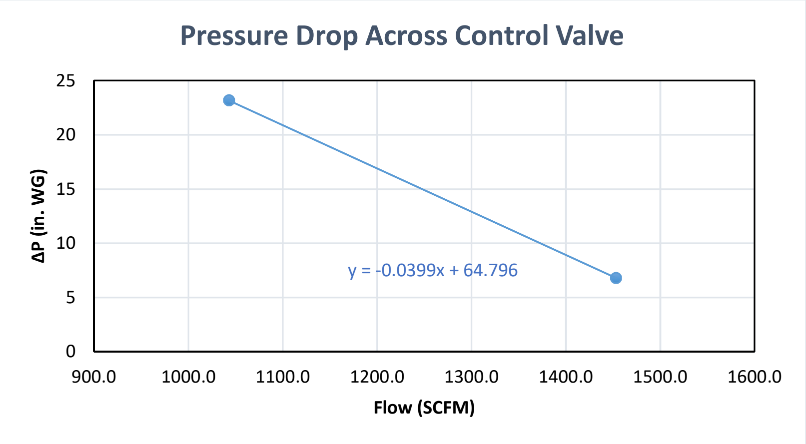
Attachment 41 determines the pressure drop across the 10” control valve on the WESP offgas discharge line for the minimum, nominal and maximum cases based on the control valve datasheets (Ref. 9.36 and 9.58).

Spreadsheet Explanation:

1. The standard temperature and pressure for this flowsheet calculation are listed in row 5. These values are converted to °F and in. WG in row 8.
2. Flowrates (ACFM), inlet temperature, and inlet pressure and pressure drop across the 10” control valve was manually entered from the valve datasheets (Input 2.13) in Columns B, C, D, and F (rows 12 and 13).
3. The flow in SCFM is calculated using Equation (6b) (see Section 5.6).
4. Column E and Column F (rows 12 &13) are plotted and the trendline is shown. This trendline is used to calculate the pressure drop in the Attachment 1 flowsheets (cell S-24).

The trendline is used to calculate the pressure drop in the Attachment 1 flowsheets (cell **S-24**).

	A	B	C	D	E	F	G	H	I
2	**Attachment 41 - Pressure Drop Across Control Valve LOP-FV-1140/2140**								
3	Data from Datasheets 24590-LAW-JVD-LOP-11400/21400 (Ref. 9.36 & 9.58)								
4									
5	Standard Temperature and Pressure are 20 deg C, 1 atm (Attachment 1, Note 1 in "Notes" worksheet)								
6									
7	Converted:		Std Temperature (° F)		Std Pressure (in. WC)				
8			68		406.8				
9	Pressure Drop Across Control Valve (Input 2.13)								
10		Flow (ACFM)	Inlet Temperature (° F)	Pressure (in. WC absolute)	Flow (SCFM)	ΔP (in. WG)			
11									
12		1216	105	373.4	1043.0	23.16			
13		1997	126	328.6	1453.4	6.78			
14									
15									
16									



Attachment 42 TCO Carbon Monoxide (CO) Decontamination Factors

Attachment 42 determines the decontamination factor (DF) for CO in the TCO unit based on VSL testing data (Ref. 9.1 - 9.4).

Spreadsheet Explanation:

1. The carbon monoxide concentration from the outlets of the WESP and the catalyst skid were manually entered in Columns G & H. The data is taken from the references listed in Column A. Additional information on report revision, report table, page numbers, feed vector, etc. is listed in Columns B through F.
2. The decontamination factor (DF) is calculated in Column I by dividing Column G by Column H (DF = mass in / mass out) per Equation (3a).
3. Each decontamination factor is converted to capture efficiency in Column J. Capture efficiency = (DF-1)/DF, per Equation (3b).
4. The average and standard deviation for the capture efficiencies are calculated in Cell J-19 and J-20 using Excel AVERAGE and STDEV functions.
5. Minimum and maximum capture efficiencies are determined in Cell J-21 and J-22 based on the average value and either adding or subtracting the defined standard deviation as appropriate.
6. The defined minimum, average, and maximum capture efficiencies for each unit are converted back to decontamination factors in Cell I-19, I-21 & I-22. Rearranging Equation (3b) gives:

$$\frac{1}{DF} = 1 - \text{Capture Efficiency} \quad \Leftrightarrow \quad DF = \frac{1}{1 - \text{Capture Efficiency}}$$

The decontamination factors are used in cell **ES-38** of Attachment 1 flowsheets to determine the CO concentration (ppm_v) in the TCO discharge stream. The minimum decontamination factor is used in the maximum flowsheet cases to maximize the CO concentration for conservatism. The nominal is used in the nominal case. The maximum decontamination factor is used in the minimum cases.

Attachment 42
TCO Carbon Monoxide (CO) Decontamination Factors

Report Number	Report Revision	Report Table	Report Page	Feed Vector	Run Number	CO Concentration (ppmv) - Input 2.4		DF	Capture Efficiency (%)
						WESP Outlet	Catalyst Outlet	(Equation 3a)	(Equation 3b)
24590-101-TSA-W000-0009-111-01 (VSL-02R8800-1) [Ref. 9.2]	B	6.8	T-56	C1	1	268	47.5	5.6	82.3%
24590-101-TSA-W000-0009-111-02 (VSL-02R8800-2) [Ref. 9.3]	B	6.10	T-62	A1	1	250	5.4	46.3	97.8%
					2	491	184	2.7	62.5%
					3	429	6.7	64.0	98.4%
24590-101-TSA-W000-0009-143-01 (VSL-03R3851-1) [Ref. 9.4]	B	6.6	T-27	B1	1	79	10	7.9	87.3%
24590-101-TSA-W000-0009-105-00006 (VSL-04R4851-1) [Ref. 9.1]	A	7.3	T-58	C1	B	30	3.9	7.7	87.0%
					C	43	7.5	5.7	82.6%
					D	100	17	5.9	83.0%

The min, average, and max DFs are calculated from the associated capture efficiencies.
The values in Bold are used in cell **ES-37** as the DF for CO.

Average =>	**6.7**	85.1%
STDEV =>		11.20%
Min =>	**3.8**	73.9%
Max =>	**27**	96.3%

Attachment 43 Deleted

Attachment 44 Water Vapor Pressure at Different System Pressures, Varied with Temperature

Attachment 44 determines the absolute humidity at different caustic scrubber outlet temperatures for the 4 melter cases in Attachment 1 flowsheets. Each worksheet applies to a different melter case. Each case has a different system pressure.

Spreadsheet explanation

1. Temperatures in °C are entered in column B.

2. The total pressure (mbar) of the caustic scrubber offgas discharge (LVP18) for each case (cell W-48 in Attachment 1 flowsheets) is entered in cell D-4, and converted to atm in cell F-4. The molecular weights of air and water are entered into cells D-5 and D-6 per Input 2.2.

2. Corresponding water vapor pressure data for the temperature range in column B is determined in column C (mbar) & column D (atm). The water vapor pressure in mbar is calculated using the temperature dependent equation determined in Attachment 14. The vapor pressure is then converted from mbar to atm in Column D using the conversion factor of 1000 mbar/bar and 1.01325 bar/atm.

3. The corresponding absolute humidity is calculated in Column E by using Equation 18 in Section 5.

The absolute humidity values calculated are used in **Attachment 39, Section A39.5**.

	A	B	C	D	E	F	G
1	**Attachment 44**						
2							
3	Caustic scrubber offgas discharge pressure						
4	***(Attachment 1 - minimum 1 melter case)***			743.0	mbar	0.73	atm
5			MW,air	29	g/mol	(Input 2.2)	
6			MW,water	18.01	g/mol	(Input 2.2)	
7							
8		Temperature	Water vapor pressure (mbar)	Water vapor pressure (atm)	Absolute humidity (kg H_2O/kg Dry Air)		
9		(^oC)	(Equation from Attachment 14)	(converted from mbar to atm)	calculated from vapor pressure data (Equation 18)		
10							
11		34	53.76	0.05	0.0484		
12		35	56.80	0.06	0.0514		
13		36	59.98	0.06	0.0545		
14		37	63.32	0.06	0.0579		
15		38	66.81	0.07	0.0614		
16		39	70.46	0.07	0.0651		
17		39.54	72.50	0.07	0.0672		
18		40	74.28	0.07	0.0690		
19		41	78.28	0.08	0.0731		
20		42	82.46	0.08	0.0775		
21		43	86.83	0.09	0.0822		
22		44	91.41	0.09	0.0871		
23		45	96.19	0.09	0.0924		
24		46	101.18	0.10	0.0979		
25		47	106.40	0.11	0.1038		
26		48	111.86	0.11	0.1101		
27		49	117.56	0.12	0.1167		
28		50	123.50	0.12	0.1238		
29		51	129.71	0.13	0.1314		
30		52	136.19	0.13	0.1394		
31		53	142.95	0.14	0.1480		
32		54	150.00	0.15	0.1571		

	A	B	C	D	E	F	G
1	**Attachment 44**						
2							
3	Caustic scrubber offgas discharge pressure						
4	***(Attachment 1 - minimum 2 melter case)***			722.0	mbar	0.71	atm
5			MW,air	29	g/mol	(Input 2.2)	
6			MW,water	18.01	g/mol	(Input 2.2)	
7							
8		Temperature	Water vapor pressure (mbar)	Water vapor pressure (atm)	Absolute humidity (kg H_2O/kg Dry Air)		
9		(^{o}C)	(Equation from Attachment 14)	(converted from mbar to atm)	calculated from vapor pressure data (Equation 18)		
10							
11		35	56.80	0.06	0.0530		
12		36	59.98	0.06	0.0563		
13		37	63.32	0.06	0.0597		
14		38	66.81	0.07	0.0633		
15		39	70.46	0.07	0.0672		
16		40	74.28	0.07	0.0712		
17		41	78.28	0.08	0.0755		
18		42	82.46	0.08	0.0801		
19		43	86.83	0.09	0.0849		
20		44	91.41	0.09	0.0900		
21		45	96.19	0.09	0.0955		
22		46	101.18	0.10	0.1012		
23		47	106.40	0.11	0.1073		
24		48	111.86	0.11	0.1139		
25		49	117.56	0.12	0.1208		
26		50	123.50	0.12	0.1282		
27		51	129.71	0.13	0.1360		
28		52	136.19	0.13	0.1444		
29		53	142.95	0.14	0.1533		
30		54	150.00	0.15	0.1629		

	A	B	C	D	E	F	G
1	**Attachment 44**						
2							
3	Caustic scrubber offgas discharge pressure						
4	***(Attachment 1 - nominal 2 melter case)***			677.0	mbar	0.67	atm
5			MW,air	29	g/mol	(Input 2.2)	
6			MW,water	18.01	g/mol	(Input 2.2)	
7							
8		Temperature	Water vapor pressure (mbar)	Water vapor pressure (atm)	Absolute humidity (kg H_2O/kg Dry Air)		
9		(°C)	(Equation from Attachment 14)	(converted from mbar to atm)	calculated from vapor pressure data (Equation 18)		
10							
11		35	56.80	0.06	0.0569		
12		36	59.98	0.06	0.0604		
13		37	63.32	0.06	0.0641		
14		38	66.81	0.07	0.0680		
15		39	70.46	0.07	0.0721		
16		40	74.28	0.07	0.0765		
17		41	78.28	0.08	0.0812		
18		42	82.46	0.08	0.0861		
19		43	86.83	0.09	0.0914		
20		44	91.41	0.09	0.0969		
21		45	96.19	0.09	0.1028		
22		46	101.18	0.10	0.1091		
23		47	106.40	0.11	0.1158		
24		47.79	110.69	0.11	0.1214		
25		48	111.86	0.11	0.1229		
26		49	117.56	0.12	0.1305		
27		50	123.50	0.12	0.1386		
28		51	129.71	0.13	0.1472		
29		52	136.19	0.13	0.1564		
30		53	142.95	0.14	0.1662		

	A	B	C	D	E	F	G
1	**Attachment 44**						
2							
3	Caustic scrubber offgas discharge pressure						
4	***(Attachment 1 - maximum 2 melter case)***			600.0	mbar	0.59	atm
5			MW,air	29	g/mol	(Input 2.2)	
6			MW,water	18.01	g/mol	(Input 2.2)	
7							
8		Temperature	Water vapor pressure (mbar)	Water vapor pressure (atm)	Absolute humidity (kg H_2O/kg Dry Air)		
9		(^oC)	(Equation from Attachment 14)	(converted from mbar to atm)	calculated from vapor pressure data (Equation 18)		
10							
11		35	56.80	0.06	0.0649		
12		36	59.98	0.06	0.0690		
13		37	63.32	0.06	0.0733		
14		38	66.81	0.07	0.0778		
15		39	70.46	0.07	0.0826		
16		40	74.28	0.07	0.0877		
17		41	78.28	0.08	0.0932		
18		42	82.46	0.08	0.0989		
19		43	86.83	0.09	0.1051		
20		44	91.41	0.09	0.1116		
21		45	96.19	0.09	0.1186		
22		46	101.18	0.10	0.1260		
23		47	106.40	0.11	0.1339		
24		48	111.86	0.11	0.1423		
25		49	117.56	0.12	0.1513		
26		50.64	127.45	0.13	0.1675		
27		50	123.50	0.12	0.1610		
28		51	129.71	0.13	0.1713		
29		52	136.19	0.13	0.1824		
30		53	142.95	0.14	0.1942		
31		54	150.00	0.15	0.2070		
32		55	157.36	0.16	0.2208		

Attachment 45 Hydrogen Fluoride Concentration at HEPA Filters

A concern exists that the melter offgas may have a higher hydrogen fluoride (HF) concentration at times that the HEPA filters may not be able to tolerate. In this attachment, 4 ppm will be assessed as a tolerance limit.

This attachment develops a correlation to predict the HF concentration in LVP04 (stream to the HEPA filters) based on the waste composition fed to Pretreatment and to LAW. This attachment is separate from the flowsheet calculations and is not used in the main body of this calculation; it exists to provide a reference about how HF in the melter offgas may correlate with the amount of fluoride entering WTP in the feed.

During operations, a sample will be taken from the FRP system (feed received from Tank Farms) and at the LCP system (treated LAW from Pretreatment). Sodium and fluoride ions are measured in these samples. Operations may be able to predict which batches could be problematic for the HEPA filters and make adjustments before the feed enters the plant.

Spreadsheet Explanation

Excel spreadsheet "*Att 45_HEPA HF correlation ppm.xlsx*" consists of 3 worksheets:

1. "*Waste Composition Correlation*" worksheet

This worksheet determines the F/Na molar ratio and HF concentration in LVP04 (stream to the HEPA filters) to develop a correlation between the waste feed to PT and the HF concentration in the incoming stream to the HEPA filters.

The correlations are based on the waste fluoride to sodium molar ratio and the HF concentration values at LVP04 from Runs 1 - 23 of calculation 24590-LAW-M4C-V11T-00001 Rev 0 (Ref. 9.65(a), (b) & (c)). Mass data (F, Na, LVP04 stream mass, HF mass) are entered in columns E, F, H & I per Inputs 2.16(c) & (a). Note that the LAW PIBOD calculation (Ref. 9.65, Section 5) identifies 31 different operating scenarios to mimic WTP operation under normal and expected conditions. However, of these 31 scenarios, runs 24 - 31 are permutations of select runs out of runs 1 - 23 in order to demonstrate a specific desired result. Therefore, only runs 1 - 23 will be considered in this assessment. The fluoride to sodium molar ratio (kgmol of F^-/ kgmol of Na^+) of the waste fed into pretreatment was determined in Column G using Equation 45.1, and the HF concentration in LVP04 was determined in column J using Equation 45.2.

Equation 45.1:

$$\frac{n_{F^-(aq)}}{n_{Na^+(aq)}} = \frac{m_{F^-(aq)}/\ MW_{F^-}}{m_{Na^+(aq)}/\ MW_{Na^+}}$$

where: $n_{F^-(aq)}$ = Moles of aqueous fluoride in batch (kgmol)
$n_{Na^+(aq)}$

= Moles of aqueous sodium in batch (kgmol)
$m_{F^-(aq)}$ = Mass of aqueous fluoride in batch (kg)
$m_{Na^+(aq)}$ = Mass of aqueous sodium in batch (kg)
MW_{F^-} = Atomic Wt of F^- = 19.0 kg/kgmol per periodic table
MW_{Na^+} = Atomic Wt of Na^+ = 22.99 kg/kgmol per periodic table

Equation 45.2:

$$Conc_{HF} = \frac{\dot{m}_{HF}}{\dot{m}_{total}} * 10^6$$

where:
$Conc_{HF}$ = Concentration of HF in LVP04 (ppm)
$\dot{m}_{HF}$ = HF mass flowrate in LVP04 (lb/hr)
$\dot{m}_{total}$ = Total mass flowrate of stream LVP04 (lb/hr)

The type of leaching performed in the Pretreatment Facility impacted the concentration of HF in the offgas; therefore, the 23 runs were grouped according to leach case (Oxidative and Caustic Leaching, Caustic Leaching only, and No Leaching). EXCEL 2016 was used to plot the HF concentration in LVP04 versus the F/Na molar ratio and generate a correlation using the Excel Trendline function for each leach case. Note that because only one run (Run 5) was performed with oxidative leaching only, a correlation for all 23 runs was generated.

The LVP04 stream relative humidity from Input 2.16(a) is listed in Column E for information.

2. "*TFCOUP6 Batches*" worksheet

This worksheet identifies the TFCOUP6 batches that may result in a HF concentration in LVP04 that exceeding 4 ppm limit.

- The correlations developed in the "*Waste Composition Correlation*" worksheet and the EXCEL SOLVER tool were used to calculate the waste fluoride/sodium molar ratio (Cells D-6 to D-9) that would produce 4 ppm of HF in LVP04 for each leaching scenario.
- The fluoride/sodium molar ratio (kgmol of F^-/ kgmol of Na^+) for each batch (Column B) was extracted from calculation 24590-WTP-M4C-V11T-00037 Rev B, 24590-RMVD-03212 (Ref. 9.64(a), "*TFCOUP6 Batch Evaluation.xlsx"* spreadsheet) [Assumption 65 in Section 6.1], and in conjunction with each batch's leach scenario (Column C) per 24590-WTP-RPT-PE-07-001 (Ref. 9.67, pg 176-180) [Assumption 59], was evaluated to determine if it would produce HF values above or below 4 ppm in LVP04 (Column D).

3. "*LCP01 Composition Correlation*" worksheet

This worksheet develops a correlation between the weight percent of F^- in the LAW concentrate LCP01 (wt%) and the HF concentration in the incoming stream to the HEPA filters (ppm).

- The mass of F- (aq) in LCP01 and the LCP01 total mass flow for the 23 APPS runs are manually entered in Column B & C per data extracted from 24590-RMVD-03242-02 & -03 ((Ref. 9.65(a) & (b), Run xx\"*APPS Main USER INTERFACE v(3)(0)LAW_PIBOD_RUN_XX.xlsm*"\ worksheet "*APPS_VIT_Streams_1*", Column FV) [Input 2.16(d)].

CALCULATION SHEET

BY: Nancy Wilkins
DATE: 11/15/2019

SUBJECT: LAW Melter Offgas System Design Basis Flowsheets

- The wt% fluoride in LCP01 (wt%) was calculated in Column D using Equation 45.3 below:

Equation 45.3: $$wt\%_{F-} = \frac{\dot{m}_{F^-}}{\dot{m}_{total}} * 100\%$$

Where $wt\%_{F^-}$ = wt% of F^- in LCP01 (wt%)
$\dot{m}_{F^-}$ = Mass of F^- in LCP01 (aq) (kg/hr)
$\dot{m}_{total}$ = Total mass flow rate of LCP01 (kg/hr)

- The HF concentrations in LVP04 (ppm) for the 23 APPS runs determined in the "*Waste Composition Correlation*" worksheet (Column J) are copied into Column E of the spreadsheet.
- EXCEL 2016 was used to plot and generate a correlation for the wt% fluoride in LCP01 and HF concentrations in LVP04.

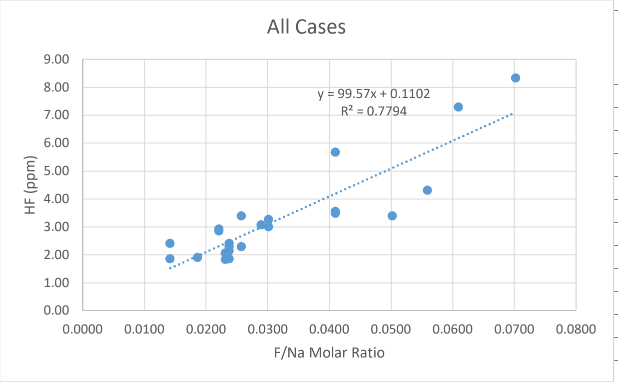
Conclusions:

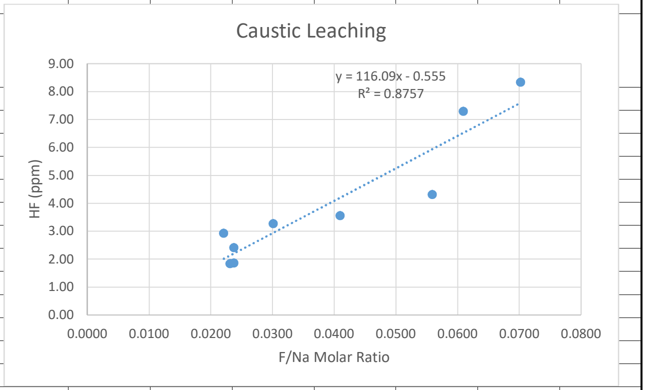
It may be possible to correlate the incoming wt% fluoride in the feed with the concentration of HF in the offgas traveling to the HEPA filters. This would need to be tested and verified.

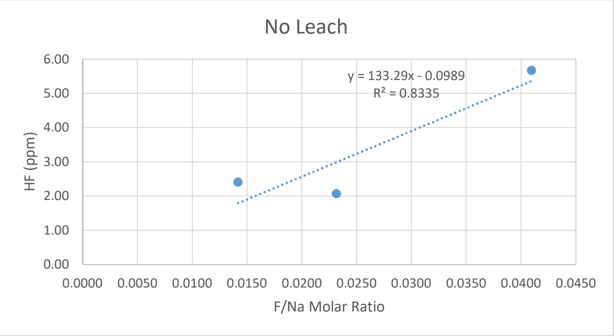
This evaluation shows that 106 of 518 batches (20%) may exceed 4 ppm HF in the offgas stream to the HEPA filters.

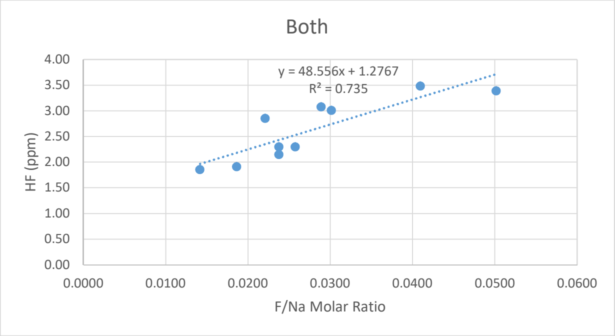
	B	C	D	E	F	G	H	I	J	K	L
1		**Attachment 45 - Correlation of HF Concentration vs F/Na Molar Ratio for Runs 1 - 23**									
2											
3	Run	Feed	Leach Case	Na (kg)	F (kg)	F/Na Molar Ratio	Total Mass of LVP04 (lbs/hr)	Mass of HF in LVP04 (lbs/hr)	HF Concentration in LVP04 (ppm)	LVP04 Relative Humidity (%)	
4	Ref. 9.65(b) & (a)	Ref. 9.65(c).1 Input 2.16(c)	Ref. 9.65(c).1 Input 2.16(c)	Ref. 9.65(c).2 Input 2.16(c)	Ref. 9.65(c).2 Input 2.16(c)	Equation 45.1	Ref. 9.65(b) & (a), Cell HI-31 Input 2.16(a)	Ref. 9.65(b) & (a), cell HI-185	Equation 45.2	Ref. 9.65(b) & (a), Cell HI-17	
5	1	Al-LL	Caustic	696854.6063	13699.41176	0.0238	9887.98	0.0237	2.40	26.05	
6	2	Al-LL	Both	696854.6063	13699.41176	0.0238	10075.64	0.0231	2.30	24.90	
7	3	Al-HL	Caustic	3878793.057	96681.22147	0.0302	9842.61	0.0322	3.27	26.05	
8	4	Al-HL	Both	3878793.057	96681.22147	0.0302	9754.01	0.0293	3.00	33.02	
9	5	Cr	Oxidative	3763435.453	80102.667	0.0258	10119.12	0.0343	3.39	34.84	
10	6	Cr	Both	3763435.453	80102.667	0.0258	10018.14	0.0230	2.29	34.83	
11	7	Bi	No Leaching	2348165.779	79501.46286	0.0410	9935.17	0.0563	5.67	26.05	
12	8	Bi	Caustic	2348165.779	79501.46286	0.0410	9834.87	0.0349	3.55	26.05	
13	9	Bi	Both	2348165.779	79501.46286	0.0410	10013.60	0.0348	3.48	34.84	
14	10	F	Both	1775284.669	73643.71257	0.0502	9990.87	0.0339	3.39	34.83	
15	11	FeAl	Caustic	1058533.367	48914.60903	0.0559	9784.17	0.0421	4.31	26.05	
16	12	PO4	Caustic	497271.8346	25041.50536	0.0609	9784.69	0.0713	7.29	26.04	
17	13	Fe	No Leaching	1307218.457	25026.80628	0.0232	9879.46	0.0204	2.07	26.05	
18	14	Fe	Caustic	1307218.457	25026.80628	0.0232	9818.72	0.0180	1.83	26.05	
19	15	ZrAl	Caustic	345054.959	20025.742	0.0702	9767.08	0.0814	8.33	26.04	
20	16	Ca	No Leaching	1772306.632	20769.86132	0.0142	9996.82	0.0240	2.40	26.05	
21	17	Ca	Both	1772306.632	20769.86132	0.0142	10203.16	0.0189	1.85	40.02	
22	18	U	Both	146939.5058	3512.484169	0.0289	9977.37	0.0307	3.08	34.83	
23	19	SO4	Caustic	2159518.024	39476.46832	0.0221	9847.90	0.0287	2.92	26.04	
24	20	SO4	Both	2159518.024	39476.46832	0.0221	10058.70	0.0287	2.85	35.41	
25	21	Na	Both	1206912.311	18591.05488	0.0186	10042.53	0.0192	1.91	34.83	
26	22	Al-LL min	Caustic	69685.46063	1369.941176	0.0238	9616.04	0.0179	1.86	26.05	
27	23	Al-LL max	Both	6968546.063	136994.1176	0.0238	10081.98	0.0216	2.15	34.83	
28											
29	Input										
30	Calculated Value										
31											
32		Equation 45.1	$\frac{n_{F^-(aq)}}{n_{Na^+(aq)}} = \frac{m_{F^-(aq)}/\ MW_{F^-}}{m_{Na^+(aq)}/\ MW_{Na^+}}$								
33			where:	$n_{F^-(aq)}$	Moles of aqueous fluoride in batch (kgmol)						
34				$n_{Na^+(aq)}$	Moles of aqueous sodium in batch (kgmol)						
35				$m_{F^-(aq)}$	Mass of aqueous fluoride in batch (kg)						
36				$m_{Na^+(aq)}$	Mass of aqueous sodium in batch (kg)						
37				MW_{F^-}	Atomic Weight of fluoride (kg/kgmol)						
38				MW_{Na^+}	Atomic Weight of sodium (kg/kgmol)						
39		Equation 45.2	$Conc_i = \frac{\dot{m}_{HF}}{\dot{m}_{total}} * 10^6$								
40			Where:	$Conc_{HF}$	Concentration of HF (ppm)						
41				$\dot{m}_{HF}$	HF mass flowrate (lb/hr)						
42				$\dot{m}_{total}$	Total mass flowrate (lb/hr)						
43											
44											
45	Ref. 9.65	(c).1	24590-LAW-M4C-V11T-00001, Rev 1, 24590-RMVD-03242-01, "LAW PIBOD Run Setup.xlsx"								
46		(c).2	24590-LAW-M4C-V11T-00001, Rev 1, 24590-RMVD-03242-01, "LAW PIBOD Feed Compositions.xlsm" (use adjusted value)								
47		(b) & (a)	24590-LAW-M4C-V11T-00001, Rev 1, 24590-RMVD-03242-02 & -03, "APPS Main USER INTERFACE v(3)(0)LAW_PIBOD_RUN_XX.xlsx" \APPS_VIT_Streams_1E								
48											
49	24590-LAW-M4C-V11T-00001 is Reference 9.65 in Section 9.										

Attachment 45 - Charts of HF Concentrations versus F/Na Molar Ratios









Attachment 45 - F/Na Threshold for TFCOUP6 Batches

Determine F/Na Molar Threshold that corresponds to a HF concentration of 4 ppm in LVP04

Leach Case	F/Na Molar Ratio Threshold	HF Concentration (PPM)
All	0.0391	4.00
No Leach	0.0308	4.00
Caustic	0.0392	4.00
Both	0.0561	4.00

Calculated Value
Excel Solver

Determine TFCOUP6 Feed Batches that will result in HF concentration in LVP04 exceeding 4 ppm

Reference: 24590-WTP-WTP-RPT-PE-07-001 Rev 1 (Ref. 9.67)
24590-RMVD-03212, "TFCOUP6 Batch Evaluation.xlsx" (Ref. 9.64(a))

Number of batches that exeed 4 ppm: 106

Batch #	F/Na Molar Ratio (Ref. 9.64(a)) Assumption 65	Leach Case Assumption 59	F/Na Molar Ratio Threshold	Exceeds 4 PPM?
1	0.0165	No leach	0.0308	No
2	0.0165	No leach	0.0308	No
3	0.0054	Caustic	0.0392	No
4	0.0165	No leach	0.0308	No
5	0.0165	No leach	0.0308	No
6	0.0165	No leach	0.0308	No
7	0.0165	No leach	0.0308	No
8	0.0233	Caustic	0.0392	No
9	0.0233	Caustic	0.0392	No
10	0.0233	Caustic	0.0392	No
11	0.0233	Caustic	0.0392	No
12	0.0233	Caustic	0.0392	No
13	0.0233	Caustic	0.0392	No
14	0.0137	Caustic	0.0392	No
15	0.0137	Caustic	0.0392	No
16	0.0137	Caustic	0.0392	No
17	0.0137	Caustic	0.0392	No
18	0.0137	Caustic	0.0392	No
19	0.0137	Caustic	0.0392	No
20	0.0479	Both	0.0561	No
21	0.0479	Both	0.0561	No
22	0.0479	Both	0.0561	No
23	0.0479	Both	0.0561	No
24	0.0479	Both	0.0561	No
25	0.0479	Both	0.0561	No
26	0.0603	Caustic	0.0392	Exceeds
27	0.0603	Caustic	0.0392	Exceeds
28	0.0716	Caustic	0.0392	Exceeds
29	0.0603	Caustic	0.0392	Exceeds
30	0.0716	Caustic	0.0392	Exceeds
31	0.0603	Caustic	0.0392	Exceeds
32	0.0716	Caustic	0.0392	Exceeds
33	0.0603	Caustic	0.0392	Exceeds
34	0.0716	Caustic	0.0392	Exceeds
35	0.0008	No leach	0.0308	No
36	0.0603	Caustic	0.0392	Exceeds
37	0.0716	Caustic	0.0392	Exceeds
38	0.0603	Caustic	0.0392	Exceeds
39	0.0714	Caustic	0.0392	Exceeds
40	0.0603	Caustic	0.0392	Exceeds
41	0.0702	Caustic	0.0392	Exceeds
42	0.0702	Caustic	0.0392	Exceeds
43	0.0702	Caustic	0.0392	Exceeds
44	0.0702	Caustic	0.0392	Exceeds
45	0.0702	Caustic	0.0392	Exceeds
46	0.0702	Caustic	0.0392	Exceeds
47	0.0702	Caustic	0.0392	Exceeds
48	0.0211	No leach	0.0308	No
49	0.0211	No leach	0.0308	No
50	0.0211	No leach	0.0308	No
51	0.0211	No leach	0.0308	No
52	0.0211	No leach	0.0308	No
53	0.0211	No leach	0.0308	No
54	0.0211	No leach	0.0308	No
55	0.0856	Caustic	0.0392	Exceeds
56	0.0856	Caustic	0.0392	Exceeds
57	0.0856	Caustic	0.0392	Exceeds
58	0.0856	Caustic	0.0392	Exceeds
59	0.0002	No leach	0.0308	No
60	0.0855	Caustic	0.0392	Exceeds
61	0.0855	Caustic	0.0392	Exceeds
62	0.0838	Caustic	0.0392	Exceeds
63	0.0838	Caustic	0.0392	Exceeds
64	0.0838	Caustic	0.0392	Exceeds
65	0.0838	Caustic	0.0392	Exceeds
66	0.0837	Caustic	0.0392	Exceeds
67	0.0015	No leach	0.0308	No
68	0.0837	Caustic	0.0392	Exceeds
69	0.0156	Both	0.0561	No
70	0.0156	Both	0.0561	No
71	0.0156	Both	0.0561	No
72	0.0156	Both	0.0561	No
73	0.0156	Both	0.0561	No
74	0.0156	Both	0.0561	No
75	0.0156	Both	0.0561	No
76	0.0052	Both	0.0561	No
77	0.0156	Both	0.0561	No
78	0.0648	Both	0.0561	Exceeds
79	0.0648	Both	0.0561	Exceeds
80	0.0648	Both	0.0561	Exceeds
81	0.0648	Both	0.0561	Exceeds
82	0.0648	Both	0.0561	Exceeds
83	0.0648	Both	0.0561	Exceeds
84	0.1183	Both	0.0561	Exceeds
85	0.1183	Both	0.0561	Exceeds
86	0.1182	Both	0.0561	Exceeds
87	0.1182	Both	0.0561	Exceeds
88	0.1182	Both	0.0561	Exceeds
89	0.1181	Both	0.0561	Exceeds
90	0.0672	Both	0.0561	Exceeds
91	0.0672	Both	0.0561	Exceeds
92	0.0672	Both	0.0561	Exceeds
93	0.0672	Both	0.0561	Exceeds
94	0.0672	Both	0.0561	Exceeds
95	0.0672	Both	0.0561	Exceeds
96	0.1008	Both	0.0561	Exceeds

	A	B	C	D	E	F	G
20	Batch #	F/Na Molar Ratio (Ref. 9.64(a)) Assumption 65	Leach Case Assumption 59	F/Na Molar Ratio Threshold	Exceeds 4 PPM?		
117	97	0.1008	Both	0.0561	Exceeds		
118	98	0.0053	No leach	0.0308	No		
119	99	0.1007	Both	0.0561	Exceeds		
120	100	0.1007	Both	0.0561	Exceeds		
121	101	0.1007	Both	0.0561	Exceeds		
122	102	0.1006	Both	0.0561	Exceeds		
123	103	0.0686	Caustic	0.0392	Exceeds		
124	104	0.0686	Caustic	0.0392	Exceeds		
125	105	0.0686	Caustic	0.0392	Exceeds		
126	106	0.0686	Caustic	0.0392	Exceeds		
127	107	0.0686	Caustic	0.0392	Exceeds		
128	108	0.0685	Caustic	0.0392	Exceeds		
129	109	0.0421	Both	0.0561	No		
130	110	0.0421	Both	0.0561	No		
131	111	0.0421	Both	0.0561	No		
132	112	0.0421	Both	0.0561	No		
133	113	0.0421	Both	0.0561	No		
134	114	0.0421	Both	0.0561	No		
135	115	0.0261	Both	0.0561	No		
136	116	0.0261	Both	0.0561	No		
137	117	0.0261	Both	0.0561	No		
138	118	0.0261	Both	0.0561	No		
139	119	0.0261	Both	0.0561	No		
140	120	0.0261	Both	0.0561	No		
141	121	0.0254	Caustic	0.0392	No		
142	122	0.0254	Caustic	0.0392	No		
143	123	0.0254	Caustic	0.0392	No		
144	124	0.0254	Caustic	0.0392	No		
145	125	0.0254	Caustic	0.0392	No		
146	126	0.0148	Both	0.0561	No		
147	127	0.0254	Caustic	0.0392	No		
148	128	0.0418	Both	0.0561	No		
149	129	0.0418	Both	0.0561	No		
150	130	0.0418	Both	0.0561	No		
151	131	0.0418	Both	0.0561	No		
152	132	0.0418	Both	0.0561	No		
153	133	0.0418	Both	0.0561	No		
154	134	0.0171	Caustic	0.0392	No		
155	135	0.0171	Caustic	0.0392	No		
156	136	0.0171	Caustic	0.0392	No		
157	137	0.0171	Caustic	0.0392	No		
158	138	0.0171	Caustic	0.0392	No		
159	139	0.0171	Caustic	0.0392	No		
160	140	0.0201	Both	0.0561	No		
161	141	0.0201	Both	0.0561	No		
162	142	0.0201	Both	0.0561	No		
163	143	0.0030	No leach	0.0308	No		
164	144	0.0201	Both	0.0561	No		
165	145	0.0200	Both	0.0561	No		
166	146	0.0200	Both	0.0561	No		
167	147	0.0167	Caustic	0.0392	No		
168	148	0.0167	Caustic	0.0392	No		
169	149	0.0167	Caustic	0.0392	No		
170	150	0.0167	Caustic	0.0392	No		
171	151	0.0167	Caustic	0.0392	No		
172	152	0.0166	Caustic	0.0392	No		
173	153	0.0166	Caustic	0.0392	No		
174	154	0.0081	Caustic	0.0392	No		
175	155	0.0036	No leach	0.0308	No		
176	156	0.0081	Caustic	0.0392	No		
177	157	0.0081	Caustic	0.0392	No		
178	158	0.0081	Caustic	0.0392	No		
179	159	0.0081	Caustic	0.0392	No		
180	160	0.0081	Caustic	0.0392	No		
181	161	0.0143	Caustic	0.0392	No		
182	162	0.0354	Both	0.0561	No		
183	163	0.0354	Both	0.0561	No		
184	164	0.0354	Both	0.0561	No		
185	165	0.0354	Both	0.0561	No		
186	166	0.0354	Both	0.0561	No		
187	167	0.0354	Both	0.0561	No		
188	168	0.0365	Oxidative	0.0391	No		
189	169	0.0365	Oxidative	0.0391	No		
190	170	0.0365	Oxidative	0.0391	No		
191	171	0.0365	Oxidative	0.0391	No		
192	172	0.0365	Oxidative	0.0391	No		
193	173	0.0364	Oxidative	0.0391	No		
194	174	0.0069	Caustic	0.0392	No		
195	175	0.0069	Caustic	0.0392	No		
196	176	0.0069	Caustic	0.0392	No		
197	177	0.0069	Caustic	0.0392	No		
198	178	0.0069	Caustic	0.0392	No		
199	179	0.0034	No leach	0.0308	No		
200	180	0.0069	Caustic	0.0392	No		
201	181	0.0718	Both	0.0561	Exceeds		
202	182	0.0718	Both	0.0561	Exceeds		
203	183	0.0718	Both	0.0561	Exceeds		
204	184	0.0718	Both	0.0561	Exceeds		
205	185	0.0718	Both	0.0561	Exceeds		
206	186	0.0718	Both	0.0561	Exceeds		
207	187	0.0717	Both	0.0561	Exceeds		
208	188	0.0488	Both	0.0561	No		
209	189	0.0488	Both	0.0561	No		
210	190	0.0488	Both	0.0561	No		
211	191	0.0488	Both	0.0561	No		
212	192	0.0488	Both	0.0561	No		
213	193	0.0488	Both	0.0561	No		
214	194	0.0397	Both	0.0561	No		
215	195	0.0397	Both	0.0561	No		
216	196	0.0397	Both	0.0561	No		
217	197	0.0397	Both	0.0561	No		
218	198	0.0397	Both	0.0561	No		
219	199	0.0397	Both	0.0561	No		
220	200	0.0218	Both	0.0561	No		
221	201	0.0218	Both	0.0561	No		
222	202	0.0218	Both	0.0561	No		
223	203	0.0218	Both	0.0561	No		
224	204	0.0046	Both	0.0561	No		
225	205	0.0218	Both	0.0561	No		
226	206	0.0218	Both	0.0561	No		
227	207	0.0296	Both	0.0561	No		
228	208	0.0296	Both	0.0561	No		
229	209	0.0296	Both	0.0561	No		
230	210	0.0296	Both	0.0561	No		
231	211	0.0296	Both	0.0561	No		
232	212	0.0296	Both	0.0561	No		
233	213	0.0218	Both	0.0561	No		

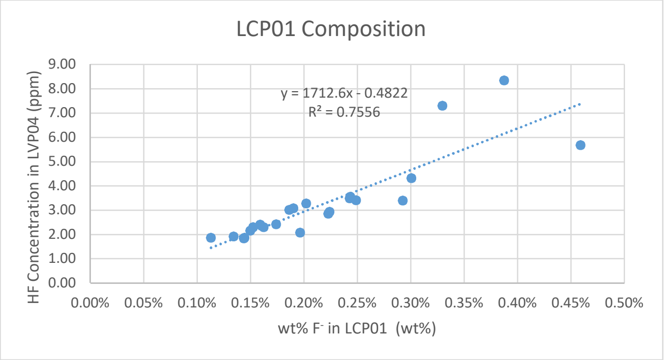
	A	B	C	D	E	F	G
20	Batch #	F/Na Molar Ratio (Ref. 9.64(a)) Assumption 65	Leach Case Assumption 59	F/Na Molar Ratio Threshold	Exceeds 4 PPM?		
234	214	0.0218	Both	0.0561	No		
235	215	0.0218	Both	0.0561	No		
236	216	0.0218	Both	0.0561	No		
237	217	0.0218	Both	0.0561	No		
238	218	0.0218	Both	0.0561	No		
239	219	0.0218	Both	0.0561	No		
240	220	0.0199	Both	0.0561	No		
241	221	0.0199	Both	0.0561	No		
242	222	0.0199	Both	0.0561	No		
243	223	0.0226	Both	0.0561	No		
244	224	0.0199	Both	0.0561	No		
245	225	0.0199	Both	0.0561	No		
246	226	0.0199	Both	0.0561	No		
247	227	0.0172	Both	0.0561	No		
248	228	0.0172	Both	0.0561	No		
249	229	0.0172	Both	0.0561	No		
250	230	0.0172	Both	0.0561	No		
251	231	0.0172	Both	0.0561	No		
252	232	0.0172	Both	0.0561	No		
253	233	0.0157	Both	0.0561	No		
254	234	0.0157	Both	0.0561	No		
255	235	0.0157	Both	0.0561	No		
256	236	0.0157	Both	0.0561	No		
257	237	0.0157	Both	0.0561	No		
258	238	0.0157	Both	0.0561	No		
259	239	0.0207	Both	0.0561	No		
260	240	0.0207	Both	0.0561	No		
261	241	0.0207	Both	0.0561	No		
262	242	0.0207	Both	0.0561	No		
263	243	0.0207	Both	0.0561	No		
264	244	0.0043	No leach	0.0308	No		
265	245	0.0207	Both	0.0561	No		
266	246	0.0204	Both	0.0561	No		
267	247	0.0204	Both	0.0561	No		
268	248	0.0204	Both	0.0561	No		
269	249	0.0204	Both	0.0561	No		
270	250	0.0204	Both	0.0561	No		
271	251	0.0204	Both	0.0561	No		
272	252	0.0204	Both	0.0561	No		
273	253	0.0198	Both	0.0561	No		
274	254	0.0198	Both	0.0561	No		
275	255	0.0198	Both	0.0561	No		
276	256	0.0198	Both	0.0561	No		
277	257	0.0198	Both	0.0561	No		
278	258	0.0198	Both	0.0561	No		
279	259	0.0215	Both	0.0561	No		
280	260	0.0215	Both	0.0561	No		
281	261	0.0215	Both	0.0561	No		
282	262	0.0215	Both	0.0561	No		
283	263	0.0182	No leach	0.0308	No		
284	264	0.0215	Both	0.0561	No		
285	265	0.0215	Both	0.0561	No		
286	266	0.0220	Both	0.0561	No		
287	267	0.0220	Both	0.0561	No		
288	268	0.0220	Both	0.0561	No		
289	269	0.0220	Both	0.0561	No		
290	270	0.0220	Both	0.0561	No		
291	271	0.0220	Both	0.0561	No		
292	272	0.0197	Caustic	0.0392	No		
293	273	0.0197	Caustic	0.0392	No		
294	274	0.0197	Caustic	0.0392	No		
295	275	0.0197	Caustic	0.0392	No		
296	276	0.0197	Caustic	0.0392	No		
297	277	0.0197	Caustic	0.0392	No		
298	278	0.0226	Both	0.0561	No		
299	279	0.0226	Both	0.0561	No		
300	280	0.0226	Both	0.0561	No		
301	281	0.0226	Both	0.0561	No		
302	282	0.0226	Both	0.0561	No		
303	283	0.0226	Both	0.0561	No		
304	284	0.0226	Both	0.0561	No		
305	285	0.0191	Caustic	0.0392	No		
306	286	0.0191	Caustic	0.0392	No		
307	287	0.0191	Caustic	0.0392	No		
308	288	0.0191	Caustic	0.0392	No		
309	289	0.0191	Caustic	0.0392	No		
310	290	0.0191	Caustic	0.0392	No		
311	291	0.0205	Caustic	0.0392	No		
312	292	0.0205	Caustic	0.0392	No		
313	293	0.0205	Caustic	0.0392	No		
314	294	0.0205	Caustic	0.0392	No		
315	295	0.0205	Caustic	0.0392	No		
316	296	0.0205	Caustic	0.0392	No		
317	297	0.0333	Both	0.0561	No		
318	298	0.0333	Both	0.0561	No		
319	299	0.0333	Both	0.0561	No		
320	300	0.0333	Both	0.0561	No		
321	301	0.0332	Both	0.0561	No		
322	302	0.0332	Both	0.0561	No		
323	303	0.0446	No leach	0.0308	Exceeds		
324	304	0.0446	No leach	0.0308	Exceeds		
325	305	0.0446	No leach	0.0308	Exceeds		
326	306	0.0446	No leach	0.0308	Exceeds		
327	307	0.0446	No leach	0.0308	Exceeds		
328	308	0.0446	No leach	0.0308	Exceeds		
329	309	0.0193	Caustic	0.0392	No		
330	310	0.0193	Caustic	0.0392	No		
331	311	0.0193	Caustic	0.0392	No		
332	312	0.0193	Caustic	0.0392	No		
333	313	0.0193	Caustic	0.0392	No		
334	314	0.0193	Caustic	0.0392	No		
335	315	0.0193	Caustic	0.0392	No		
336	316	0.0425	Both	0.0561	No		
337	317	0.0425	Both	0.0561	No		
338	318	0.0425	Both	0.0561	No		
339	319	0.0425	Both	0.0561	No		
340	320	0.0425	Both	0.0561	No		
341	321	0.0038	No leach	0.0308	No		
342	322	0.0425	Both	0.0561	No		
343	323	0.0144	Caustic	0.0392	No		
344	324	0.0144	Caustic	0.0392	No		
345	325	0.0144	Caustic	0.0392	No		
346	326	0.0144	Caustic	0.0392	No		
347	327	0.0144	Caustic	0.0392	No		
348	328	0.0144	Caustic	0.0392	No		
349	329	0.0213	Caustic	0.0392	No		
350	330	0.0213	Caustic	0.0392	No		

	A	B	C	D	E	F	G
20	Batch #	F/Na Molar Ratio (Ref. 9.64(a)) Assumption 65	Leach Case Assumption 59	F/Na Molar Ratio Threshold	Exceeds 4 PPM?		
351	331	0.0213	Caustic	0.0392	No		
352	332	0.0213	Caustic	0.0392	No		
353	333	0.0213	Caustic	0.0392	No		
354	334	0.0213	Caustic	0.0392	No		
355	335	0.0373	Both	0.0561	No		
356	336	0.0373	Both	0.0561	No		
357	337	0.0373	Both	0.0561	No		
358	338	0.0373	Both	0.0561	No		
359	339	0.0373	Both	0.0561	No		
360	340	0.0373	Both	0.0561	No		
361	341	0.0147	Caustic	0.0392	No		
362	342	0.0147	Caustic	0.0392	No		
363	343	0.0147	Caustic	0.0392	No		
364	344	0.0147	Caustic	0.0392	No		
365	345	0.0147	Caustic	0.0392	No		
366	346	0.0147	Caustic	0.0392	No		
367	347	0.0147	Caustic	0.0392	No		
368	348	0.0462	Caustic	0.0392	Exceeds		
369	349	0.0462	Caustic	0.0392	Exceeds		
370	350	0.0462	Caustic	0.0392	Exceeds		
371	351	0.0462	Caustic	0.0392	Exceeds		
372	352	0.0462	Caustic	0.0392	Exceeds		
373	353	0.0462	Caustic	0.0392	Exceeds		
374	354	0.0117	Caustic	0.0392	No		
375	355	0.0117	Caustic	0.0392	No		
376	356	0.0117	Caustic	0.0392	No		
377	357	0.0117	Caustic	0.0392	No		
378	358	0.0117	Caustic	0.0392	No		
379	359	0.0117	Caustic	0.0392	No		
380	360	0.0262	Both	0.0561	No		
381	361	0.0262	Both	0.0561	No		
382	362	0.0262	Both	0.0561	No		
383	363	0.0262	Both	0.0561	No		
384	364	0.0262	Both	0.0561	No		
385	365	0.0079	No leach	0.0308	No		
386	366	0.0262	Both	0.0561	No		
387	367	0.0216	Caustic	0.0392	No		
388	368	0.0216	Caustic	0.0392	No		
389	369	0.0216	Caustic	0.0392	No		
390	370	0.0216	Caustic	0.0392	No		
391	371	0.0216	Caustic	0.0392	No		
392	372	0.0216	Caustic	0.0392	No		
393	373	0.0435	Caustic	0.0392	Exceeds		
394	374	0.0435	Caustic	0.0392	Exceeds		
395	375	0.0435	Caustic	0.0392	Exceeds		
396	376	0.0435	Caustic	0.0392	Exceeds		
397	377	0.0435	Caustic	0.0392	Exceeds		
398	378	0.0435	Caustic	0.0392	Exceeds		
399	379	0.0435	Caustic	0.0392	Exceeds		
400	380	0.0268	Both	0.0561	No		
401	381	0.0268	Both	0.0561	No		
402	382	0.0268	Both	0.0561	No		
403	383	0.0268	Both	0.0561	No		
404	384	0.0268	Both	0.0561	No		
405	385	0.0268	Both	0.0561	No		
406	386	0.0564	Caustic	0.0392	Exceeds		
407	387	0.0564	Caustic	0.0392	Exceeds		
408	388	0.0564	Caustic	0.0392	Exceeds		
409	389	0.0564	Caustic	0.0392	Exceeds		
410	390	0.0564	Caustic	0.0392	Exceeds		
411	391	0.0564	Caustic	0.0392	Exceeds		
412	392	0.0563	Caustic	0.0392	Exceeds		
413	393	0.0306	Both	0.0561	No		
414	394	0.0214	Both	0.0561	No		
415	395	0.0214	Both	0.0561	No		
416	396	0.0214	Both	0.0561	No		
417	397	0.0214	Both	0.0561	No		
418	398	0.0214	Both	0.0561	No		
419	399	0.0214	Both	0.0561	No		
420	400	0.0214	Both	0.0561	No		
421	401	0.0215	Caustic	0.0392	No		
422	402	0.0215	Caustic	0.0392	No		
423	403	0.0215	Caustic	0.0392	No		
424	404	0.0214	Caustic	0.0392	No		
425	405	0.0214	Caustic	0.0392	No		
426	406	0.0214	Caustic	0.0392	No		
427	407	0.0214	Caustic	0.0392	No		
428	408	0.0306	Both	0.0561	No		
429	409	0.0306	Both	0.0561	No		
430	410	0.0306	Both	0.0561	No		
431	411	0.0306	Both	0.0561	No		
432	412	0.0306	Both	0.0561	No		
433	413	0.0306	Both	0.0561	No		
434	414	0.0057	Both	0.0561	No		
435	415	0.0057	Both	0.0561	No		
436	416	0.1057	Caustic	0.0392	Exceeds		
437	417	0.0057	Both	0.0561	No		
438	418	0.0057	Both	0.0561	No		
439	419	0.0057	Both	0.0561	No		
440	420	0.0057	Both	0.0561	No		
441	421	0.0057	Both	0.0561	No		
442	422	0.0057	Both	0.0561	No		
443	423	0.0277	Both	0.0561	No		
444	424	0.0277	Both	0.0561	No		
445	425	0.0277	Both	0.0561	No		
446	426	0.0277	Both	0.0561	No		
447	427	0.0277	Both	0.0561	No		
448	428	0.0277	Both	0.0561	No		
449	429	0.0305	Both	0.0561	No		
450	430	0.0305	Both	0.0561	No		
451	431	0.0305	Both	0.0561	No		
452	432	0.0167	Both	0.0561	No		
453	433	0.0167	Both	0.0561	No		
454	434	0.0167	Both	0.0561	No		
455	435	0.0167	Both	0.0561	No		
456	436	0.0167	Both	0.0561	No		
457	437	0.0167	Both	0.0561	No		
458	438	0.0167	Both	0.0561	No		
459	439	0.0167	Both	0.0561	No		
460	440	0.0655	Caustic	0.0392	Exceeds		
461	441	0.0844	No leach	0.0308	Exceeds		
462	442	0.0655	Caustic	0.0392	Exceeds		
463	443	0.0655	Caustic	0.0392	Exceeds		
464	444	0.0655	Caustic	0.0392	Exceeds		
465	445	0.0655	Caustic	0.0392	Exceeds		
466	446	0.0655	Caustic	0.0392	Exceeds		
467	447	0.0655	Caustic	0.0392	Exceeds		

	A	B	C	D	E	F	G
20	Batch #	F/Na Molar Ratio (Ref. 9.64(a)) Assumption 65	Leach Case Assumption 59	F/Na Molar Ratio Threshold	Exceeds 4 PPM?		
468	448	0.0655	Caustic	0.0392	Exceeds		
469	449	0.0094	Both	0.0561	No		
470	450	0.0094	Both	0.0561	No		
471	451	0.0094	Both	0.0561	No		
472	452	0.0094	Both	0.0561	No		
473	453	0.0094	Both	0.0561	No		
474	454	0.0094	Both	0.0561	No		
475	455	0.0094	Both	0.0561	No		
476	456	0.0094	Both	0.0561	No		
477	457	0.0198	Both	0.0561	No		
478	458	0.0198	Both	0.0561	No		
479	459	0.0198	Both	0.0561	No		
480	460	0.0198	Both	0.0561	No		
481	461	0.0198	Both	0.0561	No		
482	462	0.0198	Both	0.0561	No		
483	463	0.0198	Both	0.0561	No		
484	464	0.0198	Both	0.0561	No		
485	465	0.0092	Both	0.0561	No		
486	466	0.0092	Both	0.0561	No		
487	467	0.0092	Both	0.0561	No		
488	468	0.0092	Both	0.0561	No		
489	469	0.0092	Both	0.0561	No		
490	470	0.0092	Both	0.0561	No		
491	471	0.0092	Both	0.0561	No		
492	472	0.0091	Both	0.0561	No		
493	473	0.0134	Caustic	0.0392	No		
494	474	0.0134	Caustic	0.0392	No		
495	475	0.0134	Caustic	0.0392	No		
496	476	0.0134	Caustic	0.0392	No		
497	477	0.0134	Caustic	0.0392	No		
498	478	0.0134	Caustic	0.0392	No		
499	479	0.0134	Caustic	0.0392	No		
500	480	0.0134	Caustic	0.0392	No		
501	481	0.0466	Both	0.0561	No		
502	482	0.0466	Both	0.0561	No		
503	483	0.0466	Both	0.0561	No		
504	484	0.0260	Both	0.0561	No		
505	485	0.0260	Both	0.0561	No		
506	486	0.0260	Both	0.0561	No		
507	487	0.0259	Both	0.0561	No		
508	488	0.0103	Both	0.0561	No		
509	489	0.0103	Both	0.0561	No		
510	490	0.0103	Both	0.0561	No		
511	491	0.0103	Both	0.0561	No		
512	492	0.0103	Both	0.0561	No		
513	493	0.0103	Both	0.0561	No		
514	494	0.0103	Both	0.0561	No		
515	495	0.0103	Both	0.0561	No		
516	496	0.0283	Both	0.0561	No		
517	497	0.0283	Both	0.0561	No		
518	498	0.0283	Both	0.0561	No		
519	499	0.0283	Both	0.0561	No		
520	500	0.0283	Both	0.0561	No		
521	501	0.0283	Both	0.0561	No		
522	502	0.0241	Both	0.0561	No		
523	503	0.0241	Both	0.0561	No		
524	504	0.0240	Both	0.0561	No		
525	505	0.0240	Both	0.0561	No		
526	506	0.0240	Both	0.0561	No		
527	507	0.0239	Both	0.0561	No		
528	508	0.0239	Both	0.0561	No		
529	509	0.0239	Both	0.0561	No		
530	510	0.0239	Both	0.0561	No		
531	511	0.0239	Both	0.0561	No		
532	512	0.0239	Both	0.0561	No		
533	513	0.0082	Both	0.0561	No		
534	514	0.0082	Both	0.0561	No		
535	515	0.0082	Both	0.0561	No		
536	516	0.0082	Both	0.0561	No		
537	517	0.0082	Both	0.0561	No		
538	518	0.0082	Both	0.0561	No		

Attachment 45 - wt% of F⁻ in LCP01 vs HF Concentration in LVP04

Run No.	Mass of F- (aq) in LCP01 (kg/hr) (Ref. 9.65(a) & (b)) Input 2.16 (d)	LCP01 Total Mass Flowrate (kg/hr) (Ref. 9.65(a) & (b)) Input 2.16(d)	wt% F⁻ in LCP04 (wt%) Equation 45.3	HF Concentration in LVP04 (ppm) "Waste Composition Correlation" worksheet, Column J
1	1.31	824.57	0.16%	2.40
2	1.28	838.32	0.15%	2.30
3	1.78	879.93	0.20%	3.27
4	1.62	869.21	0.19%	3.00
5	1.90	763.18	0.25%	3.39
6	1.27	783.01	0.16%	2.29
7	3.12	678.50	0.46%	5.67
8	1.93	791.87	0.24%	3.55
9	1.93	793.68	0.24%	3.48
10	1.87	640.05	0.29%	3.39
11	2.33	774.49	0.30%	4.31
12	3.75	1136.33	0.33%	7.29
13	1.13	575.02	0.20%	2.07
14	0.99	691.69	0.14%	1.83
15	4.38	1130.92	0.39%	8.33
16	1.33	763.58	0.17%	2.40
17	1.04	924.98	0.11%	1.85
18	1.70	892.48	0.19%	3.08
19	1.59	709.84	0.22%	2.92
20	1.58	710.79	0.22%	2.85
21	1.06	788.32	0.13%	1.91
22	0.99	685.36	0.14%	1.86
23	1.20	799.28	0.15%	2.15



Equation 45.3
$$wt\%_{F-} = \frac{\dot{m}_{F-}}{\dot{m}_{total}} * 100\%$$

Where
$wt\%_{F-}$ wt% of F⁻ in LCP01 (wt%)
$\dot{m}_{F-}$ Mass of F- (aq) in LCP01 (kg/hr)
$\dot{m}_{total}$ Total mass flow rate of LCP01 (kg/hr)

Ref. 9.65 (b) & (a) - 24590-LAW-M4C-V11T-00001, Rev 0, 24590-RMVD-03242-02 & -03, "*APPS Main USER INTERFACE v(3)(0)LAW_PIBOD_RUN_XX* .xlsm"\"APPS_VIT_Streams_1" worksheet, Column FV (Cells FV-31 & FV-102)

CALCULATION SHEET

PROJECT: RPP-WTP
JOB NO.: 24590
BY: Nancy Wilkins
CALC NO.: 24590-LAW-M4C-LOP-00001
DATE: 11/15/2019
SHEET REV: 6
SHEET NO.: 46-1

SUBJECT: LAW Melter Offgas System Design Basis Flowsheets

Attachment 46 Chromalox Technical Data

The pressure drop data for Chromalox Air Heaters are included in this attachment per Ref. 10.2.21, sheets I-20 & I-21.

Technical Information

Determining Energy Requirements - Air & Gas Heating

Air & Gas Heating — Cryogenics

Industrial gases are usually stored in a liquid state with heat being added to vaporize and boil off the gas as usage requires. General heat equations apply except that pipes, tubes and vessels containing the cryogenic fluid or gas frequently represent a heat source rather than a heat loss. If the size and materials of the tanks or vessels are known, then heat calculations for the temperature rise can be performed as in standard vessel heating or boiler problems. The following example is typical of a cryogenic heating application.

Problem — Vaporize and preheat 30,000 SCFH of liquid Nitrogen (N_2) from -345°F to 70°F at atmospheric conditions. The properties of N_2 from Cryogenic Gas Tables are: Boiling point, -320°F Specific heat Btu/lb/°F = 0.474 (liq.), 0.248 (gas) Latent heat of vaporization = 85.7 Btu/lb Atm. density of N_2 at 32°F = 0.0784 lb/ft³.

Solution — Amount of liquid N_2 to be vaporized 30,000 SCFH x 0.0784 lb/ft³ = 2,352 lbs/hr

1. **Raise** liquid from -345°F to -320°F (boiling point) ΔT = 25°F.

$$kW = \frac{Wt \times C_p \times \Delta T}{3412\ \text{Btu/kW}} \times SF$$

Where:
Wt = Weight of material in lbs
C_p = Specific heat of the liquid N_2
ΔT = Temperature rise in °F
SF = Suggested safety factor of 20%

$$kW = \frac{2{,}352\ \text{lbs} \times 0.474 \times 25}{3412\ \text{Btu/kW}} \times 1.2 = 9.8\ kW$$

2. **Vaporize** the liquid N_2

$$kW = \frac{2{,}352\ \text{lbs} \times 85.7}{3412\ \text{Btu/kW}} \times 1.2 = 70.9\ kW$$

3. **Raise** the temperature of the N_2 from boiling point -320°F to 70°F — ΔT = 390°F.

$$kW = \frac{2{,}352\ \text{lbs} \times 0.248 \times 390}{3412\ \text{Btu/kW}} \times 1.2 = 80\ kW$$

Total kW/hr required = 9.8 + 70.9 + 80 = 169.7

Equipment Recommendations — Generally, cryogenic applications utilize both a vaporizer unit and a gas preheater. High watt density heaters immersed in the cryogenic fluid can be used for the vaporizer. Standard circulation heaters and watt densities are recommended for gas preheating. Protect the heater terminals from frost and moisture with element seals and liquid tight terminal covers.

Material Recommendations — Ordinary carbon steel is subject to brittle fracture at temperatures below -20°F and is generally not recommended. Stainless steel, high nickel bearing alloys or aluminum alloys may be used. Use Teflon® for gaskets asTeflon® remains pliable at low temperatures.

Air & Gas Heating — Batch Ovens

Most oven applications consist of heating work product inside an insulated enclosure. Heat loss calculations involve the determination of the heat requirements to heat the enclosure and work product using heated air circulated by natural or forced convection. Any make up or ventilation air must also be considered. The following example outlines the calculation of the heat required for a typical oven heating application.

Problem — An oven with inside dimensions of 2 ft H x 3 ft W x 4 ft D is maintained at 350°F. The oven has sheet steel walls with 2 inches of insulation and is ventilated with 400 cfh (ft³/hr) of 70°F air which exhausts to the outside to remove fumes. The oven is charged with 250 lbs of coated steel parts on a steel tray weighing 40 lbs. The process requires the parts to be heated from 70°F to 350°F in 3/4 hour.

Weight of steel = 290 lbs
Specific heat of steel — 0.12 Btu/lb/°F
Weight of air = 0.080 lbs/ft³ at 70°F
Specific heat of air = 0.24 Btu/lb/°F
Temperature rise = 280°F
Surface losses with 2 inch insulation = 18 W/ft²/hr at 280°F temperature difference (Graph G-126S)
Surface area of oven = 52 ft²
Time = 3/4 hr (0.75)
Airflow rate = 400 ft³/hr

Solution —

1. **Calculate** kWh required to heat metal.

$$kW = \frac{290\ \text{lbs} \times 0.12\ \text{Btu/lb/°F} \times 280\text{°F}}{3412\ \text{Btu/kW}} = 2.86\ kW$$

2. **Calculate** kWh required to heat ventilated air

$$kW = \frac{400\ \text{cfh} \times 0.080\ \text{Lbs} \times 0.24\ C_p \times 280\ \Delta T \times 0.75\ t}{3412\ \text{Btu/kW}} = 0.47 kW$$

Where:
cfh = Air flow rate (400)
Lbs/ft³ = Density of air (0.080)
C_p = Specific heat of air (0.24)
ΔT = Temperature rise (280)
= Time in hours (0.75)

3. **Calculate** surface losses. Since the oven is already at temperature, losses are at full value.

$$kW = \frac{18\ \text{W/ft}^2\text{/hr} \times 52\ \text{ft}^2\ \text{area} \times 0.75\ \text{hr}}{1{,}000\ \text{W/kW}} = 0.70\ kW$$

4. **Total** kW = 2.86 + 0.47 + 0.70 = 4.03 kW

5. **For Oven Applications**, add 30% to cover door losses and other contingencies. kWh required (including safety factor) is

$$kWh = \frac{kW}{t} = \frac{4.03\ kW}{0.75\ \text{hrs}} = 5.37\ kW \times 1.3 = 6.98\ kW$$

Equipment Recommendations — Several process air heaters, including strip heaters, finstrips, bare tubulars or type OV oven heaters, are suitable for oven heating applications.

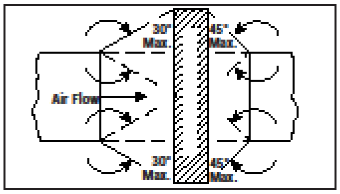
Pressure Drop for Process Air Heaters

The pressure drop through TDH and ADH process air heaters with bare tubular or finned tubular elements, CAB heaters with finstrip elements, and ADH and DH air heaters with finned tubular elements will vary considerably depending on product design and construction. Chromalox sales engineering can provide pressure drop calculations for virtually any duct heater (or circulation heater) application. Graphs G-112S3, G-189S1, G-227-2, and G-227ADH on the following page provide guidance for estimating the pressure drop for many Chromalox process air heaters[1]. Graph G-189S1 can be used for most finned tubular applications providing the elements are mounted in a three or six row configuration.

Transitions in Ducts — In some air distribution systems, the duct heater may be considerably larger or smaller than the associated ductwork. The duct heater can be adapted to different size ductwork by installing a sheet metal transition. The transition must be designed so that the slope on the upstream side of the equipment is limited to 30° (see below). On the leaving side, the slope should not be more than 45°.

Note 1 — Contact the factory for pressure drop calculations for duct heaters mounted lengthwise or in series and for GCH gas circulation heaters. These applications require special calculations for proper application and air handler sizing.

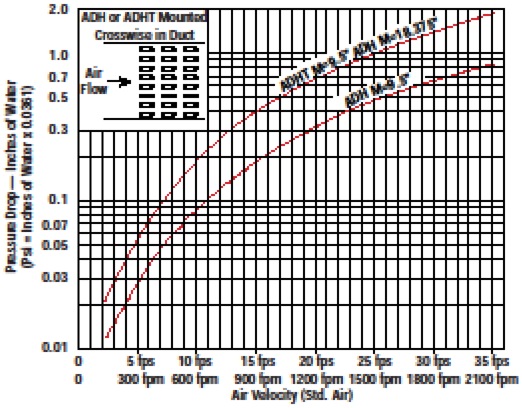
Recommended Dimensions for Duct Transitions



Technical Information

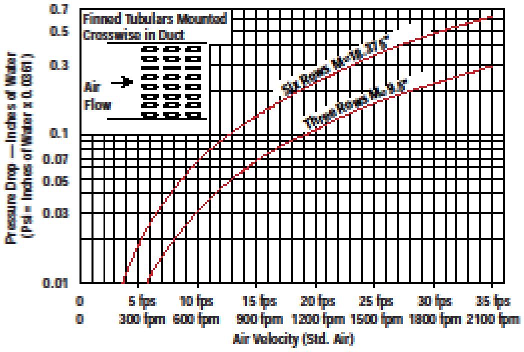
Determining Pressure Drop - Air and Gas Heating

Graph G-227ADH — Pressure Drop Vs. Velocity ADH and ADHT Tubular Element Air Heaters



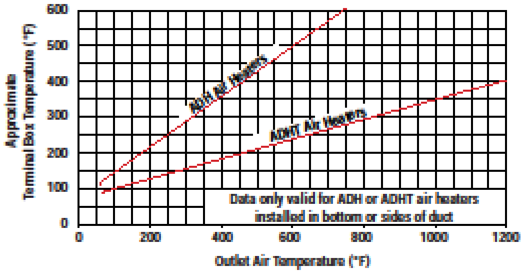
Note — Contact factory for pressure drop calculations for ADH/ADHT air heaters mounted lengthwise in duct and ADHT heaters where M is greater than 9.5"

Graph G-189S1 — Pressure Drop Vs. Velocity Fintube® Elements and Air Heaters

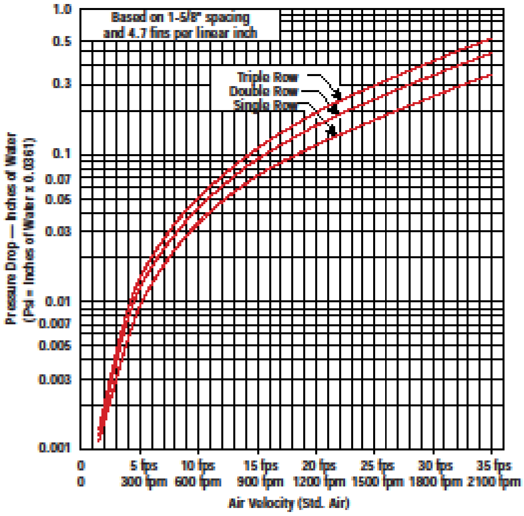


Note — Contact factory for pressure drop calculations for finned tubular element air heaters mounted lengthwise in duct.

Graph ADHTB — ADH/ADHT Terminal Box Temperatures Field Wiring Selection Guide



Graph G-112S3 — Pressure Drop Vs. Velocity Finstrip® and CAB Air Heaters



Graph G-227-2 — Pressure Drop Vs. Velocity TDH Tubular Element Air Heaters