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FLOWTRAN BENCHMARKING WITH ONSET OF FLOW INSTABILITY DATA FROM 1988 COLUMBIA UNIVERSITY SINGLE-TUBE OFI EXPERIMENT

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SUMMARY

Benchmarking FLOWTRAN, Version 16.2, with an Onset of Significant Voiding (OSV) criterion against measured Onset of Flow Instability (OFI) data from the 1988-89 Columbia University downflow tests has shown that FLOWTRAN with OSV is a conservative OFI predictor. Calculated limiting flow rates based on the SRS OSV criterion were always higher than the measured flow rates at OFI. This work supplements recent FLOWTRAN benchmarking against 1963 downflow tests at Columbia University and 1988 downflow tests at the SRL Heat Transfer Laboratory. These studies provide confidence that using FLOWTRAN with an OSV based criterion for SRS reactor limits analyses will generate operating limits that are conservative with respect to OFI, the criterion selected to prevent fuel damage.

The OSV based limit criterion used for benchmarking against the 1988-89 Columbia data and in SRS limits analyses is a constant Stanton number 0.00455 for all Peclet numbers. This SRS working criterion was derived from the Saha-Zuber correlation. The Stanton number value is a conservative bound on the Saha-Zuber correlation for Peclet numbers greater than 70,000.

In analyzing the 1988-89 Columbia data, FLOWTRAN was used to model the fluid flow pressure drop versus the flow rate for a range of tube diameters and heat fluxes. FLOWTRAN's calculated pressure drops were in good agreement with the measured pressure drops for single-phase flow. Because FLOWTRAN is a single-phase code, it cannot calculate two-phase pressure drop below the OSV flow rate.

1. INTRODUCTION

Reactor power and flow transient mathematical modeling is necessary to determine maximum safe operating limits for SRS reactors. These limits ensure that if a postulated accident were to occur, the reactor would shut down safely without damage to the fuel assemblies. The FLOWTRAN computer code, Version 16.2, [1] models an individual assembly's thermal-hydraulic behavior and can determine the operating power limits for transients in which the assemblies are filled with liquid water coolant. Operating limits are set to prevent Onset of Flow Instability (OFI) in every core assembly for the most restrictive flow or reactivity induced accident. OFI is currently prevented by setting the limit based on a calculated Onset of Significant Void (OSV) criterion which is a precursor to OFI. FLOWTRAN uses the SRS Working Criterion with a constant Stanton number 0.00455 for all Peclet numbers [1,2,3] to determine a conservative OFI operating limit.

The SRS FLOWTRAN Flow Instability benchmark program objective is to demonstrate that FLOWTRAN with the SRS OSV Working Criterion (St=0.00455) is a conservative OFI predictor. Previously, FLOWTRAN's validity in SRS reactor application was demonstrated by benchmarking FLOWTRAN with experimental results [4,5]. Reference 4 presents FLOWTRAN benchmarking with 1963 Columbia University FI test data for multiple channel tests with typical full power operating flows and heat fluxes. This test rig also had a mockup of a bottom endfitting. FLOWTRAN calculated the flow and energy splits among the channels as well as pressure and temperature distributions. FLOWTRAN also conservatively calculated the onset of flow instability through use of the SRS OSV criterion. The tests in Reference 5 were conducted at the Savannah River Heat Transfer Laboratory and focused on downflow for low Peclet numbers (30,000 - 80,000). The FLOWTRAN SRS OSV Working Criterion conservatively calculated OFI for these conditions.

During 1988 and 1989 significant OFI test results were obtained by the Columbia University Heat Transfer Research Facility in an ongoing test program. These OFI test data covered a wide range of parameters: Peclet number (160,000 - 800,000), Heat Flux (0.0 - 1.0 MBtu/hr-ft^2), and L/D ratio (128 - 267). The range of Peclet numbers for SRS fuel assembly flow channels for normal and simulated accident conditions is 200,000 to 800,000. The heat fluxes at the surface of the fuel assembly at the proposed restart power level (~1200 MW) are below 0.5 MBtu/hr-ft^2. The L/D ratios for the SRS fuel assembly flow channels are 300-485 and are higher than those for the test rigs. Stanton numbers at OFI increase with L/D for both the 1988-89 and the earlier 1963 Columbia University tests.

This report benchmarks FLOWTRAN with these new OFI results and provides further confidence that FLOWTRAN with an OSV based limit criterion will calculate conservative SRS reactor power limits with respect to OFI.

2. TEST FACILITY

A brief discussion of the Columbia University single-tube OFI tests follows. The detailed description of these tests is given in the Columbia University test reports [6,7].

2.1 TEST LOOP

Figure 1 presents the test loop schematic. The following components comprise the test loop:

- A 100 gallon hot water heater to supply deionized water to the pump;

- A recirculating pump capable of supplying 260 gpm to the test section;

- A single tube test section;

- Two heat exchangers to remove energy from the water before it returns to the 100 gallon water tank;

- A bypass loop to direct excess flow from the test section.

2.2 TEST SECTION

The test section is 10.5 feet long (Figure 2). The heated test section is an 8 foot length of tubing. Upstream and downstream of the heated section is a 1.5 foot copper section which serves as a connector to the power system. The power input to the test section is a DC electric generator which supplies up to 240 volts and approximately 6000 amps or 1.5 MW to the test section. This energy source can generate a 1.0 MBtu/hr-ft^2 surface heat flux in the various diameter test sections selected for this program. Table 1 presents the single tube geometry.

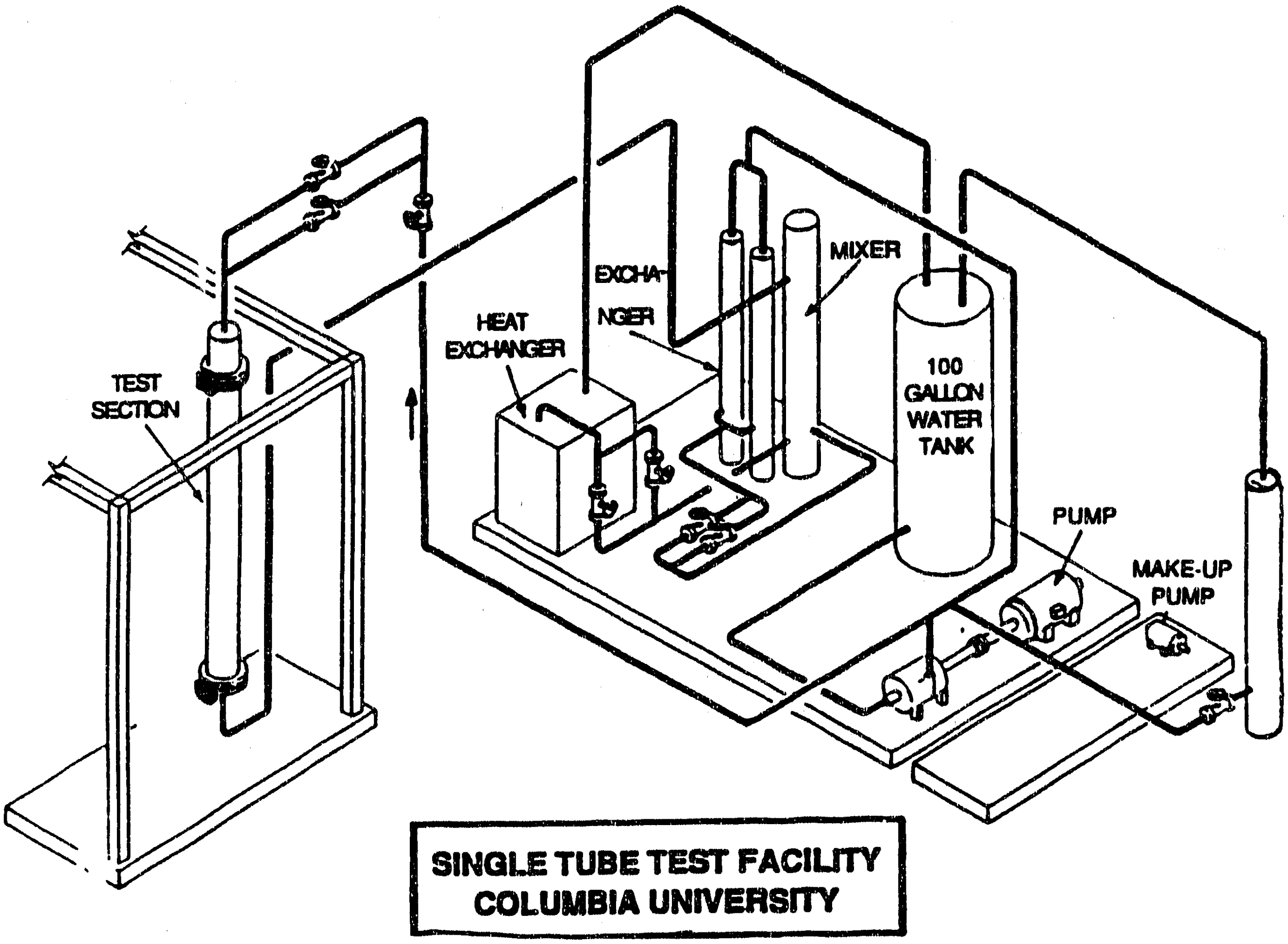


FIGURE 1. TEST LOOP SCHEMATIC

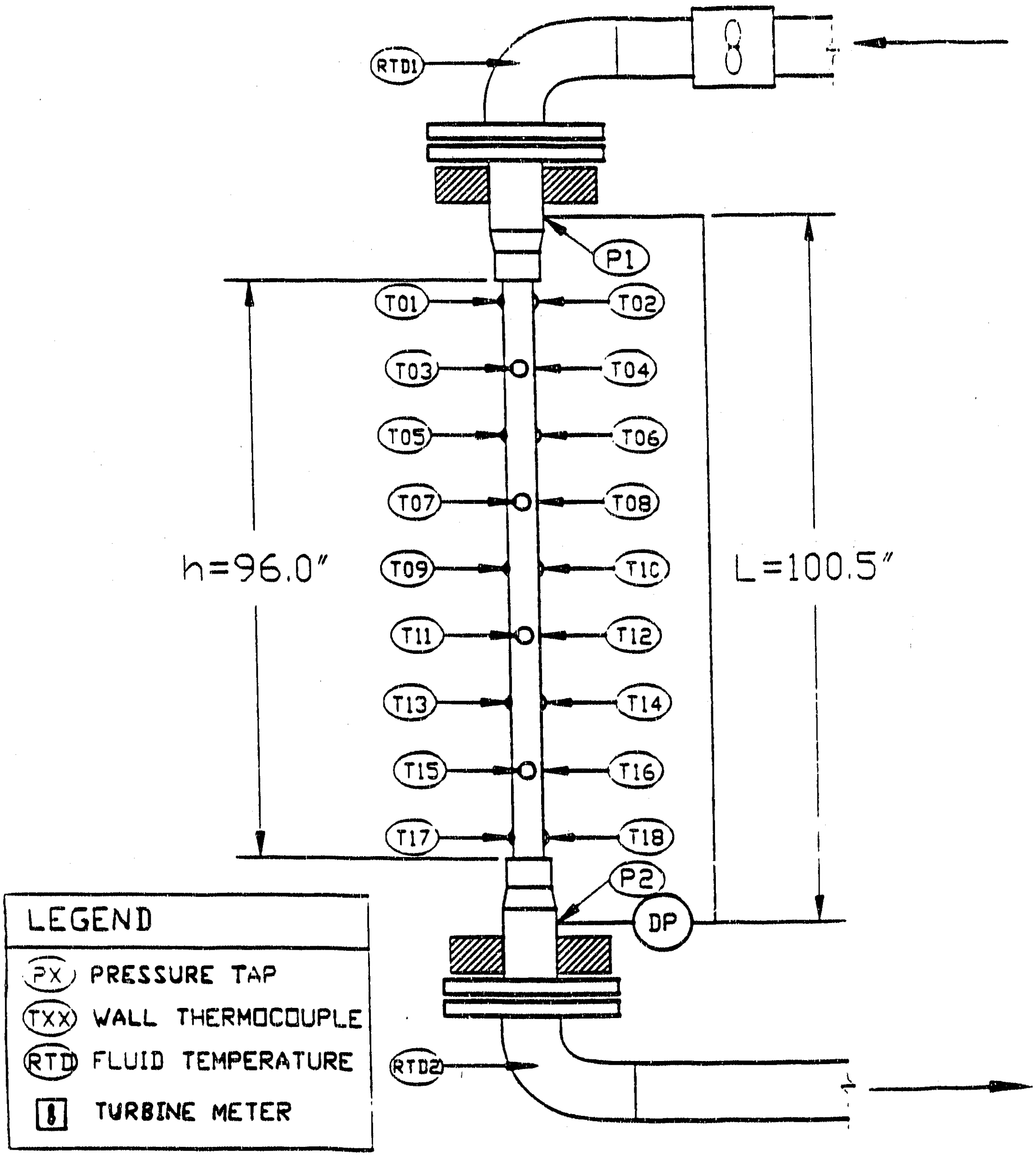


FIGURE 2. TEST SECTION INSTRUMENTATION

Table 1

SINGLE TUBE GEOMETRY

Test	Test Section	Material	OD (in)	ID (in)	Heated Length (in)
2.1	4.745-002S	304 type SS	0.8759	0.7516	96
4	4.620-001I	Inconel 600	0.7482	0.6125	96
7	4.620-001I	304 type SS	0.7485	0.6000	96
9	4.370-003I	Inconel 600	0.4970	0.3590	96

2.3 INSTRUMENTATION

The test instruments are presented in Figure 2. The loop instrumentation is used primarily to operate the loop and establish the test section conditions, The test section instrumentation provides the required test data, namely pressure drop and tube wall temperature. Figure 2 shows the test section thermocouple, pressure tap, and flowmeter locations.

Prior to installation in the test section each instrument was calibrated. Those instruments which provide data necessary for test analysis were calibrated to NIST (National Institute of Standards and Technology) standards. Instruments which were included as backups to primary instruments (e.g. the orifice plate) or were required for loop operation were calibrated but are not traceable to NIST standards.

2.4 TEST PROCEDURE

The test procedure is summarized here. The detailed test procedure description is given in Reference 6.

1. The test engineer conducts instrumentation performance reliability checks and a heat balance check.

2. The test engineer establishes the test loop conditions, i.e. test section power, inlet temperature, exit pressure, and initial flow rate.

3. The measured parameters, including the loop operating and test section conditions, are recorded in the HP-1000 computer when

the loop control parameters are within the deviation limits (Table 3) and the loop is at steady state.

4. The test engineer plots the measured pressure drop versus flow rate on graph paper.

5. The test engineer reduces the inlet flow and repeats Step 4 until the pressure drop increases.

6. The test engineer increases the test section flow rate and repeats Step 4 until the test section is in single-phase liquid flow.

7. The test engineer may rerun the checkpoint condition to ensure the test section integrity. The checkpoint conditions are 64.7 psia exit pressure, 77 F inlet temperature, and 600,000 Btu/hr-ft^2 heat flux.

2.5 DATA REDUCTION

The HP-1000 computer records data at 400 channels per second. During the test the loop parameters are presented on several panels, and the test section data are displayed on a CRT. The data acquisition system records data both in input voltage (raw data) and engineering units. The engineering units are calculated from calibration data for each instrument. Both raw voltage data and engineering unit data are saved.

3. TEST MATRIX

The test matrix parameters (Table 2) were designed to cover SRS reactor normal operating and hypothetical accident conditions, which can range from 68 - 113 F inlet temperature and 200,000 - 800,000 Peclet number. A demand curve is the frictional pressure drop across a heated flow channel plotted versus the flow rate and is obtained by fixing the heat flux, inlet temperature and exit pressure, and then varying the inlet flow rate. The onset of flow instability is determined from the demand curve where the pressure drop is a minimum with respect to the flow rate. The test parameters were controlled within a narrow band (Table 3) to define the demand curve accurately.

Table 2

TEST MATRIX

HEAT FLUX BTU/HR-FT2	EXIT PRESSURE PSIA		INLET TEMPERATURE F	
0	34.7	64.7	77	121
400,000	34.7	64.7	77	121
600,000	34.7	64.7	77	121
800,000	34.7	64.7	77	121
1,000,000	34.7	64.7	77	121

Table 3

MEASUREMENT DEVIATION LIMITS
DURING PRESSURE DROP MEASUREMENT

PARAMETERS	DEVIATION LIMIT
Heat Flux	1%
Exit Pressure	1 psia
Inlet Temperature	1 F

4. DATA ANALYSIS

Data analysis covers the measured pressure drop, FLOWTRAN pressure drop calculations, measured OFI flow rate, and FLOWTRAN OSV flow rate calculations. The analysis has two major parts. The first part establishes that the FLOWTRAN code effectively models thermal-hydraulic flow through the heated tubes. This is achieved by determining two modeling parameters, the surface wall absolute roughness and the heated wall correction correlation exponent. A FLOWTRAN model for the test rig uses these input parameters to calculate pressure drops for comparison with the experimentally measured demand curve for single-phase flow. The second part uses a FLOWTRAN model with SRS Working Criterion (St=0.00455) to calculate an OSV point for comparison with the measured OFI point for a given heat flux, inlet temperature, and exit pressure. An uncertainty analysis is also presented to quantify and establish FLOWTRAN with OSV as a conservative OFI predictor.

FLOWTRAN models the test section between the two pressure tap locations (Figure 3) using 58 total nodes in three sections (Appendix D, Figure D-1). Appendix D presents a sample FLOWTRAN input file.

4.1 MEASURED PRESSURE DROP

Figure 3 diagrams the pressure drop measurement between two pressure tap locations. The pressure drop calculation method is:

$$DP_m = P1' - P2' \qquad (1)$$

$$P1' = P1 + \frac{\rho\, g\, L}{144\ g_c} \qquad (2)$$

$$P2 = P2' \qquad (3)$$

$$DP_m = P1 + \frac{\rho\, g\, L}{144\ g_c} - P2 \qquad (4)$$

Equation 4 is used to calculate the measured pressure drop DP_m(psi) at test conditions. P_1 and P_2 are the static pressures shown in Figure 3 and are calculated in psia by FLOWTRAN. The water density in the pressure transducer line is ρ and is set at 62.248 lbm/ft^3 for an assumed 77 F test room temperature. The room temperature uncertainty is taken as ±10 F. L is the pressure tap separation in feet, and $g/(144g_c)$ is the gravitational conversion factor to psi.

4.2 MODELING FLOWTRAN PRESSURE DROP

FLOWTRAN uses the traditional hydraulic fluid friction factor and velocity power law relationship [1] to calculate single-phase pressure drop. Because the velocity is directly derived from the measured flow rate, benchmarking FLOWTRAN's pressure drop calculations is primarily validating the friction factor determination. FLOWTRAN uses the Moody equation [9] to calculate the friction factor [8]. The Moody equation, like other well-established friction factor equations

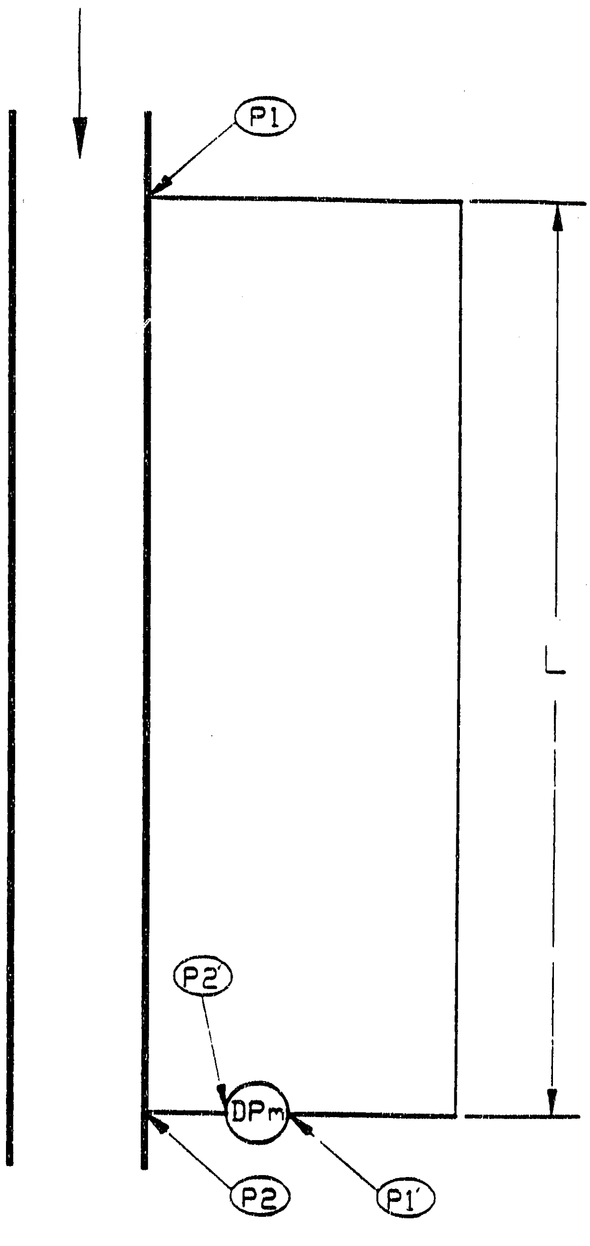


FIGURE 3. PRESSURE DROP MEASUREMENT

[10], is a function of the absolute wall roughness, the tube inner diameter, and the Reynolds number (Re). Other well-established equations [10] tend to calculate values about 3% high for high flow rates (Re > 1,000,000), be slightly low for low flow rates (Re < 100,000), and be in very good agreement for medium flow rates. The Moody equation can be expected to follow this pattern [1]. Based upon this behavior, criteria were established for benchmarking FLOWTRAN calculations versus measured data for unheated and heated tests.

Criteria for the unheated runs in order of importance are:
1. good agreement for medium flows (100,000 < Re <1,000,000),
2. agreement within 3% for high flows (Re > 1,000,000),
3. calculations slightly lower for low flows (Re < 100,000).

Criteria for the heated runs in order of importance are:
1. good agreement for medium flows (100,000 < Re <1,000,000),
2. agreement within 6% for high flows (Re > 1,000,000),
3. calculations slightly lower for low flows (Re < 100,000).

A 3% error band is expected for high flow rates from the friction factor equation. An additional 3% was allowed for calculating FLOWTRAN high flow pressure drops, making an adjusted 6% total error band for Criterion 2. This additional band accounts for the heated wall effect correlation being an approximate correction.

The wall surface roughness and the heated wall correction exponent are input parameters to FLOWTRAN that directly impact the friction factor calculation. The following subsections discuss establishing these parameters for the tubes used by Columbia University.

4.2.1 SURFACE WALL ROUGHNESS

The standard wall surface roughness for a pipe or tube can be obtained within a certain range from hydraulic handbook charts. A more precise value can be determined through direct measurement or calculation from the experimentally determined fluid flow friction factor obtained from unheated test data (no heated wall effect). The unheated pressure drop data were analyzed for each tube to determine the tube wall friction factor for each datum point. The surface roughness was calculated for each friction factor determined from experimental data, using the Moody friction factor formula contained within FLOWTRAN. All values agreed with the handbook value range [11]. The roughnesses for the unheated test runs were also calculated using other established friction factor equations [10] and fell within the same range as the Moody roughnesses.

For each individual tube a surface roughness range was selected from its calculated values. Different values within this range were tried in the Moody equation to find an agreement between calculated and measured friction factors that satisfied the criteria for unheated runs. The final roughness value was verified when the FLOWTRAN calculations agreed with the unheated measured pressure drops per the unheated run criteria. Figure 4 compares the calculated FLOWTRAN pressure drops with the measured pressure drops for all the unheated test runs. Agreement is good for the entire data range for all tubes. The FLOWTRAN calculations for all tubes met all three criteria. This established that the FLOWTRAN pressure drop calculations matched the experimental isothermal hydraulic baseline. Table 4 lists each individual tube's wall surface roughness used to calculate the pressure drops in Figure 4. The FLOWTRAN, or Moody, equation produced better agreement with the measured data friction factors than did the other friction factor equations. All heated test run FLOWTRAN calculations used the roughness factors in Table 4.

Table 4

WALL SURFACE ROUGHNESS
USED IN FLOWTRAN CALCULATION

Test #	Test Section #	Wall Roughness (in)
2.1	4.745-002S	6.0×10^{-5}
4	4.620-001I	2.5×10^{-5}
7	4.620-001S	4.5×10^{-5}
9	4.370-003I	1.2×10^{-4}

4.2.2 HEATED WALL EFFECT

FLOWTRAN uses the following correlation to account for the friction factor change due to the heated wall effect

MEASURED AND FLOWTRAN CALCULATED PRESSURE DROP
INC TUBE ID=0.359" & 0.6125" ; SS TUBE ID=0.600" & 0.7516"
UNIFORM FLUX=0.0 MBTU/HR-FT2

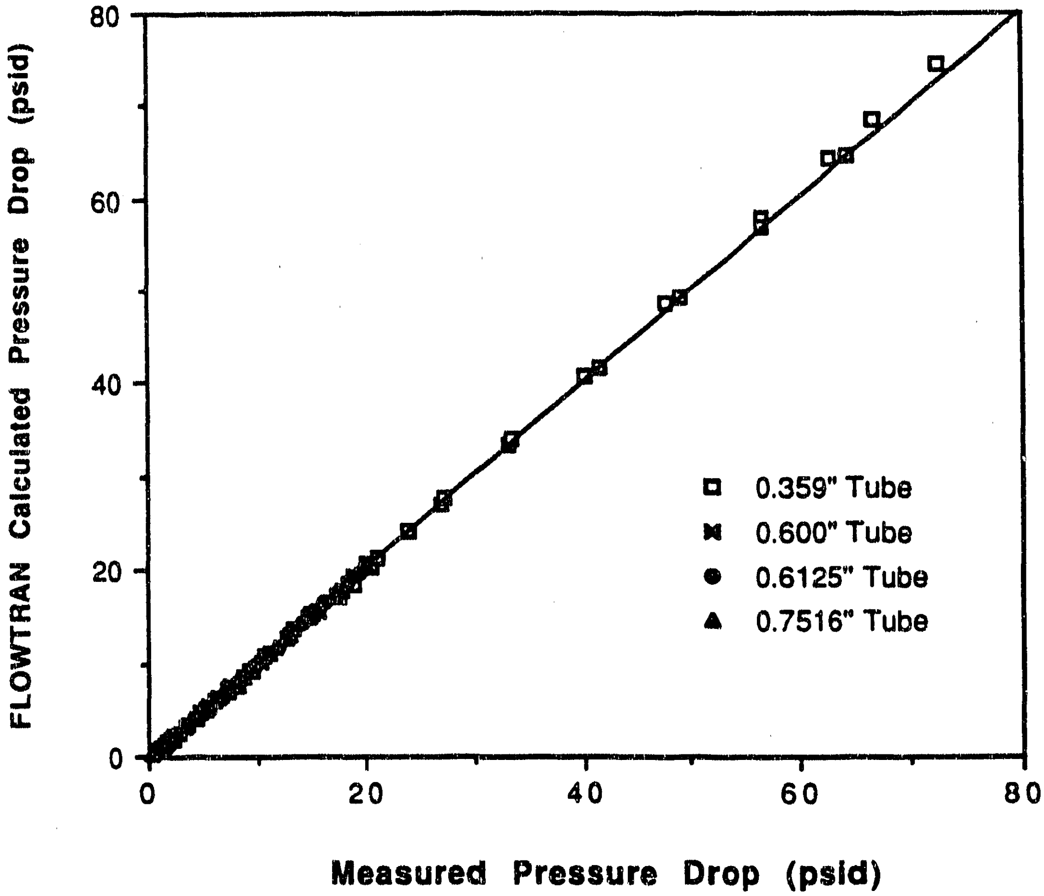


FIGURE 4. UNHEATED PRESSURE DROP COMPARISON

$$\frac{f}{f_b} = 1 + \frac{P_h}{P_w}\left[\left(\frac{\mu_w}{\mu_b}\right)^n - 1\right], \qquad (5)$$

where

f_b = friction factor evaluated at the bulk fluid temperature

P_h = heated perimeter

P_w = wetted perimeter

μ_w = dynamic viscosity evaluated at the wall temperature

μ_b = bulk fluid dynamic viscosity

n = an input that varies with diameter.

Exponent values between 0.14 and 0.35 were tried to optimize the agreement between calculated and measured pressure drop. It was found that the optimum "n" value increases as the diameter increases. Shown below are the optimum "n" values for the tubes and maximum difference between calculated and measured pressure drops for high flow rates:

ID(in)	0.359	0.600	0.6125	0.7516
n	0.12	0.20	0.21	0.22
Max. Diff.	5%	5%	5%	5%

The optimum values produced excellent agreement for low to medium flow rates (1.5 to 2 times the OFI flow) and agreement within 5% for high flow rates for all heat fluxes. Criteria 1 and 2 were met for all heat fluxes. Criterion 3 was not applicable above 0.4 MBtu/hr-ft^2 because the Reynolds number condition occurred below the OSV flow rates. While all three criteria are important in matching isothermal data, only Criteria 1 and 2 are important for heated runs because the OSV flows occur in the low flow range. These exponents satisfied the criteria for heated runs and were used for pressure drop calculations in Appendix B and FLOWTRAN OSV flow rate calculations in Table 5.

The hydraulic diameters for the annular SRS fuel assembly channels range from 0.3" to 0.5". Therefore, the 0.36" and 0.60" ID single tubes are appropriate for modeling SRS reactor channels under the assumption that the thermal hydraulic behavior scales as the hydraulic diameter. Based on these "n" values determined

Table 5

MEASURED OFI CONDITIONS

TEST RUN #	TEST POINTS	POWER KW	HEAT FLUX MBtu/h-ft2	EXIT PRES PSIA	INLET TEMP F	OUTLET TEMP F	MEAS OFI FLOW GPM	PECLET NUMBER	STANTON NUMBER	FLOWTRAN OSV FLOW St=.00455	RATIO
9 - 01	1822-1836	87.63	0.400	34.769	76.898	237.857	3.55 ±0.089	192765 ±4897	0.007390 ±0.000666	3.96	1.12
9 - 02	1803-1811	175.10	0.799	34.859	76.757	241.591	7.25 ±0.181	393709 ±10003	0.008703 ±0.000927	7.87	1.09
9 - 03	1837-1850	87.74	0.400	34.768	121.979	245.972	4.75 ±0.119	255323 ±6487	0.009069 ±0.001292	5.32	1.12
9 - 04	1812-1821	174.82	0.798	34.665	121.810	245.000	9.80 ±0.245	526765 ±13383	0.008252 ±0.001107	10.49	1.07
9 - 05	1695-1714	87.44	0.399	64.774	76.877	272.341	2.95 ±0.074	160896 ±4088	0.007291 ±0.000558	3.26	1.11
9 - 06	1729-1744	131.43	0.600	64.811	76.830	272.433	4.50 ±0.113	245442 ±6236	0.007200 ±0.000552	4.90	1.09
9 - 07	1747-1761	174.84	0.798	64.786	76.702	277.137	5.90 ±0.148	322223 ±8186	0.008964 ±0.000822	6.51	1.10
9 - 07	1798-1802										
9 - 08	1762-1782	218.10	0.995	64.873	76.679	276.810	7.40 ±0.185	404108 ±10267	0.008741 ±0.000789	8.10	1.09
9 - 09	1715-1728	87.43	0.399	64.694	121.819	278.772	3.70 ±0.093	200081 ±5083	0.007886 ±0.000787	4.14	1.12
9 - 09	1745-1746										
9 - 09	1851-1852										
9 - 10	1783-1797	175.72	0.802	64.692	121.500	282.700	7.45 ±0.186	403397 ±10249	0.009913 ±0.001222	8.27	1.11
7 - 01	1541-1557	146.33	0.400	64.889	77.141	255.058	5.70 ±0.143	185389 ±4896	0.006297 ±0.000324	6.09	1.07
7 - 02	1558-1570	292.45	0.799	64.759	76.998	256.784	11.30 ±0.283	367620 ±9709	0.006633 ±0.000347	12.17	1.08
7 - 02	1572-1573										
7 - 03	1521-1540	146.54	0.400	64.851	121.040	264.991	7.05 ±0.176	227361 ±6004	0.006695 ±0.000416	7.69	1.09
7 - 04	1574-1590	292.34	0.799	64.908	121.017	263.799	14.20 ±0.355	457843 ±12091	0.006390 ±0.000391	15.33	1.08
4 - 01	1020-1037	149.49	0.398	34.760	77.357	225.041	6.96 ±0.174	221617 ±5841	0.006845 ±0.000415	7.35	1.06
4 - 02	1038-1053	224.53	0.597	34.730	76.989	224.521	10.46 ±0.262	333103 ±8779	0.006748 ±0.000399	11.40	1.09
4 - 03	1054-1068	298.16	0.793	34.811	76.991	222.790	14.10 ±0.353	449099 ±11836	0.006306 ±0.000359	15.12	1.07
4 - 04	1069-1084	373.62	0.994	34.751	76.975	222.890	17.50 ±0.438	557388 ±14691	0.006403 ±0.000365	18.94	1.08
4 - 05	971-990	149.18	0.397	34.841	121.072	232.910	9.25 ±0.231	291440 ±7681	0.006716 ±0.000502	10.09	1.09
4 - 06	991-1005	223.36	0.594	34.765	121.058	232.165	13.95 ±0.349	439537 ±11584	0.006515 ±0.000474	15.11	1.08
4 - 07	1006-1019	299.93	0.798	34.792	120.939	231.401	18.80 ±0.470	592387 ±15613	0.006302 ±0.000446	20.23	1.08
4 - 08	1085-1099	374.52	0.996	34.851	121.173	231.610	23.50 ±0.588	740433 ±19515	0.006320 ±0.000448	25.26	1.07
4 - 09	954-971	148.68	0.396	64.767	77.142	251.698	5.72 ±0.143	182172 ±4801	0.006056 ±0.000296	6.22	1.09
4 - 10	846-862	224.09	0.596	64.723	76.913	255.117	8.60 ±0.215	274015 ±7222	0.006559 ±0.000330	9.37	1.09
4 - 11	890-906	299.64	0.798	64.737	77.365	255.074	11.50 ±0.288	366381 ±9656	0.006555 ±0.000331	12.56	1.09
4 - 12	907-920	373.81	0.994	64.783	77.333	252.235	14.60 ±0.365	464992 ±12255	0.006033 ±0.000292	15.65	1.07
4 - 13	936-953	149.22	0.397	64.659	120.946	262.371	7.20 ±0.180	227352 ±5992	0.006351 ±0.000377	7.88	1.09
4 - 14	863-876	224.76	0.598	64.786	121.100	263.059	10.87 ±0.272	343268 ±9047	0.006437 ±0.000377	11.87	1.09
4 - 15	877-889	299.07	0.796	64.792	121.289	262.303	14.53 ±0.363	458762 ±12091	0.006272 ±0.000363	15.80	1.09
4 - 16	921-935	373.92	0.995	64.794	120.776	263.070	18.00 ±0.450	568478 ±14983	0.006467 ±0.000379	19.69	1.09
2.1-01	775-789	363.90	0.800	34.729	76.989	210.462	18.73 ±0.468	487156 ±12631	0.005331 ±0.000248	19.56	1.04
2.1-02	790-804	453.95	0.998	34.826	76.816	211.182	23.29 ±0.582	605572 ±15701	0.005410 ±0.000252	24.35	1.05
2.1-03	729-745	181.80	0.400	34.799	121.034	228.860	11.61 ±0.290	298190 ±7731	0.006950 ±0.000462	13.03	1.12

MEASURED OFI CONDITIONS (CONTINUED)

TEST RUN #	TEST POINTS	POWER KW	HEAT FLUX MBtu/h-ft2	EXIT PRES PSIA	INLET TEMP F	OUTLET TEMP F	MEAS OFI FLOW GPM	PECLET NUMBER	STANTON NUMBER	FLOWTRAN OSV FLOW St=.00455	RATIO **
2.1-04	746-761	272.38	0.599	34.733	121.116	224.037	18.27 ±0.457	469395 ±12170	0.005728 ±0.000337	19.53	1.07
2.1-05	762-774	363.03	0.798	34.872	121.065	223.000	24.68 ±0.617	634019 ±16439	0.005455 ±0.000312	25.96	1.05
2.1-06	805-820	453.07	0.996	34.797	121.131	223.000	31.25 ±0.781	803045 ±20821	0.005394 ±0.000306	32.42	1.04
2.1-07	612-625	271.93	0.598	64.686	77.030	246.690	11.12 ±0.278	288595 ±7483	0.006322 ±0.000285	12.05	1.08
2.1-08	677-681	361.55	0.795	64.692	76.980	246.460	14.85 ±0.371	385155 ±9986	0.006269 ±0.000278	16.02	1.08
2.1-09	713-728	455.03	1.001	64.723	76.769	242.662	18.71 ±0.468	485326 ±12583	0.005830 ±0.000248	20.13	1.08
2.1-10	626-644	181.62	0.399	64.721	121.038	256.130	9.22 ±0.231	237100 ±6148	0.006327 ±0.000327	10.14	1.10
2.1-11	645-660	272.18	0.598	64.793	120.976	256.520	13.90 ±0.347	357220 ±9262	0.006306 ±0.000327	15.21	1.09
2.1-12	661-666]	363.70	0.800	64.709	120.980	256.090	18.52 ±0.463	476204 ±12347	0.006270 ±0.000324	20.33	1.10
2.1-12	682-691]										
2.1-13	692-712	453.80	0.998	64.732	120.930	253.920	23.59 ±0.590	606219 ±15718	0.005839 ±0.000288	25.34	1.07

** RATIO - This column is the quotient of FLOWTRAN calculated OSV flow rate at St=0.00455 and measured OFI flow rate.

experimentally, "0.14" would be a reasonable exponent value for an SRS fuel assembly.

4.3 CALCULATED AND MEASURED PRESSURE DROPS

The agreement between FLOWTRAN calculated and measured pressure drops depends upon the heat flux and tube diameter. FLOWTRAN, Version 16.2, is a single-phase code. Beyond the onset of nucleate boiling (ONB) there are two-phase effects due to the bubbles at the heated surfaces and in the bulk fluid. FLOWTRAN, Version 16.2, is applicable for a heated channel up to OSV if the additional resistance due to the bubbles is not a significant contributor to the total pressure drop. FLOWTRAN, Version 16.2, is benchmarked up to OSV conditions, since SRS limit calculations are based upon OSV criterion. Figure 5 shows FLOWTRAN calculated pressure drops versus measured pressure drops for all heated runs. Appendix A contains all the test run demand curves with corresponding FLOWTRAN pressure drops and OSV points. Appendix B lists test run data and the calculated and measured pressure drops.

For the smallest tube diameter, 0.359", the agreement is excellent for all flow rates above the OSV flow rate for all heat fluxes. For the larger tube diameters, 0.600", 0.6125", and 0.7516", the agreement is good for low to medium flow rates (1.5 to 2 times OFI flow rate). For these larger tubes the pressure drops across the channel around the OSV flow range are low (2 to 5 psi), and the agreement between measured and FLOWTRAN calculated pressure drops is not good for high heat flux cases (0.8 and 1.0 MBtu/hr-ft^2). For flow rates higher than two times the OFI flow rate, the FLOWTRAN calculated pressure drops are higher than the measured values, but the difference is less than 5% for all heat fluxes.

Stanton and Peclet number calculations require the saturation temperature at the exit pressure. The exit pressure was kept constant during each experimental run. Since FLOWTRAN calculates absolute pressure from the bottom node to the top node, FLOWTRAN's exit pressure will always be the correct experimental pressure. Therefore, Stanton and Peclet number calculations are not affected by any pressure drop disagreement.

The difference between the FLOWTRAN calculated and measured pressure drops around OSV is attributed to two-phase effects due to

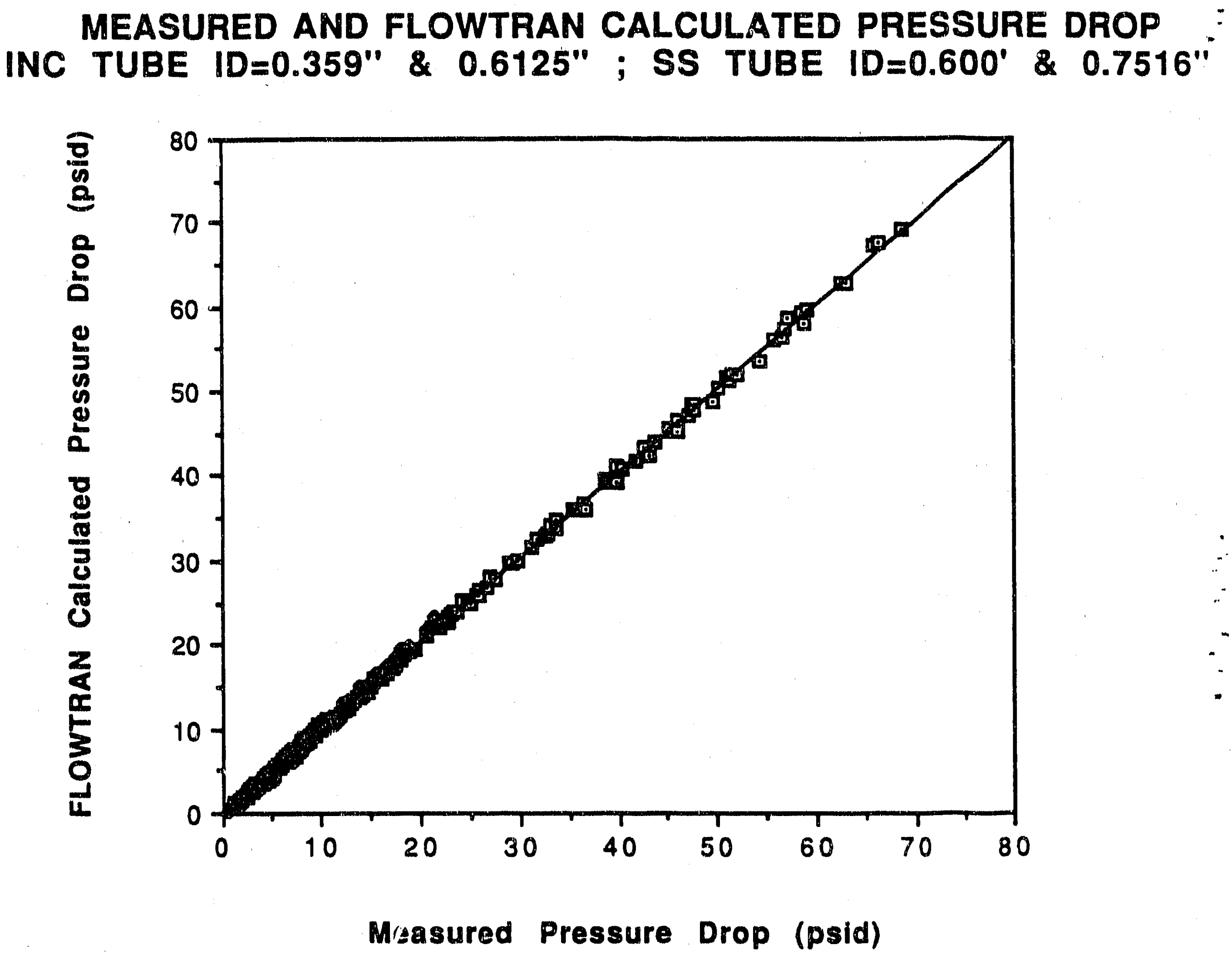


FIGURE 5. HEATED PRESSURE DROP COMPARISON

bubbles along the heated surface and in the bulk fluid for points beyond ONB. The standard FLOWTRAN code, Version 16.2, does not model the acceleration pressure drop and the two-phase multiplier effect. To improve agreement between measurement and calculation, a modified FLOWTRAN code called UNCERT, Version 16-1A, [14,15] which includes models for these effects, was used to calculate selected cases as outlined in Appendix C.

The models in UNCERT had very little impact on the pressure drop calculations up to OSV for large tubes at high heat fluxes and thus did not give the anticipated improvement between measured and calculated pressure drops. The conclusion drawn from these comparisons is that the VOID model in UNCERT, which incorporates the acceleration pressure drop and the two-phase multiplier, needs to be improved. However, it is important to put this observed difference between test data and FLOWTRAN calculations in context for application to SRS assembly limit calculations. Where there were obvious differences between the measured and calculated pressure drops, those tests had low total pressure drops (2 to 5 psi) across the tube's heated length and high heat fluxes (0.8 and 1.0 MBtu/hr-ft^2). In the SRS reactors the channel pressure drops will be larger and the heat fluxes at the restart power levels will be less than 0.5 MBtu/hr-ft^2. For these conditions the void effect contribution up to OSV, the limit calculations end point, is small. This is substantiated by the test data for the smallest diameter tube, 0.359". For all the 0.359" tube OSV conditions FLOWTRAN accurately calculated the pressure drop. For this tube the two-phase contribution was relatively small compared to the total pressure drops, as in a reactor assembly.

The overall assessment is that FLOWTRAN accurately calculates single-phase pressure drop given the proper roughness and "n" value and can be used to model a reactor assembly pressure drop for OSV conditions.

4.4 OSV CRITERION

FLOWTRAN uses the SRS OSV Working Criterion, St=0.00455, for all Peclet numbers to calculate a limiting flow. The logic is that if the flow calculated by FLOWTRAN with the OSV based limit criterion is greater than the observed flow at the point of OFI, then FLOWTRAN with an OSV based limit criterion is a conservative predictor of OFI.

The SRS OSV Working Criterion is expressed in terms of the Peclet (Pe), and Stanton (St) numbers as

$$Pe = \frac{G\, D_e\, c_p}{k_b}, \qquad (6)$$

$$St = \frac{q}{G\, c_p\, (T_s - T_b)} = 0.00455, \qquad (7)$$

where

- q = heat flux
- D_e = equivalent hydraulic diameter
- k_b = liquid thermal conductivity
- T_s = saturated temperature for exit pressure
- T_b = bulk fluid temperature
- c_p = liquid heat capacity
- G = mass flux.

4.5 MEASURED OFI CONDITIONS DETERMINATION

The OFI condition is determined from a demand curve (pressure drop vs. flow rate) which is obtained from tests by measuring the pressure drop versus flow rate at constant power, inlet temperature and exit pressure. For convenience, a demand curve is named a test run and each individual point (pressure drop vs. flow rate) within a demand curve is called a test point. The variations of the test parameters (i.e. power, inlet temperature and exit pressure) within a test run were very small as shown in Table 3. The measured OFI conditions were determined by averaging all data points for each test parameter within a test run. The test data variations within a test run are included in the uncertainty analysis. Table 5 shows the measured OFI conditions.

4.6 MEASURED OFI FLOW DETERMINATION

The flow rate at the onset of flow instability (OFI) is derived from the test data. The measured OFI flow rate is the minimum point on the pressure drop versus flow rate demand curve. The approach used to determine the minimum point (OFI flow rate) was to curve fit sufficient data points around the minimum pressure drop area to establish a demand curve minimum. For some runs engineering judgment was used to omit spurious points to improve the curve fit. Thus, the curve fitting technique complemented with engineering judgment determined the measured OFI flow rate from the demand curve. The actual OFI point may differ from the minimum in the curve derived from the data. This difference is due to error in the test data flow measurements and error in the curve fitting. This uncertainty was estimated for each set of test data based on the spacing of data points and the slope of the curve in the vicinity of the OFI point. A ±2.5% OFI flow rate uncertainty was selected to account for all inherent curve fit uncertainties for all four test diameters. Table 5 shows the measured OFI flow rates.

4.7 PECLET AND STANTON NUMBER CALCULATION

For each heated test run the Peclet and Stanton numbers at OFI conditions were calculated by an external FORTRAN computer program. The source listing for this computer program, ENBALSTPE.FOR, is given in Appendix E. For each test run the average power, inlet temperature, and exit pressure were calculated from all the data points. These averages, the OFI determined outlet temperature, and the corresponding OFI flow rate were inputs to the program. The measured outlet temperature at the OFI flow rate was determined by plotting the measured outlet temperatures versus the flow rate to OFI flow rate ratio. Figure 6 shows one such measured OFI temperature determination. The OFI outlet temperature was taken where the flow rate ratio equaled one. The program calculated the saturation temperature for the exit pressure using FLOWTRAN's correlation for T_s as a function of pressure. The physical property correlations required to calculate Stanton and Peclet numbers were obtained from the FLOWTRAN manual [1]. The Peclet and Stanton numbers for the exit node were calculated using these temperatures and the OFI flow rates. The OFI flow rates, measured outlet temperatures, Peclet and Stanton numbers are shown in Table 5. The graphical presentation of Stanton numbers versus Peclet numbers at OFI along with their uncertainties are shown in Figure 7.

The L/D ratios for the SRS reactor heated channels are 300-485. Figure 8 presents Stanton numbers at OFI for different test conditions (inlet temperatures, exit pressures, and heat fluxes) from

$y = -456.22 + 3690.4x - 6379.1x^2 + 5094.0x^3 - 1961.5x^4 + 295.12x^5 \quad R^2 = 1.000$

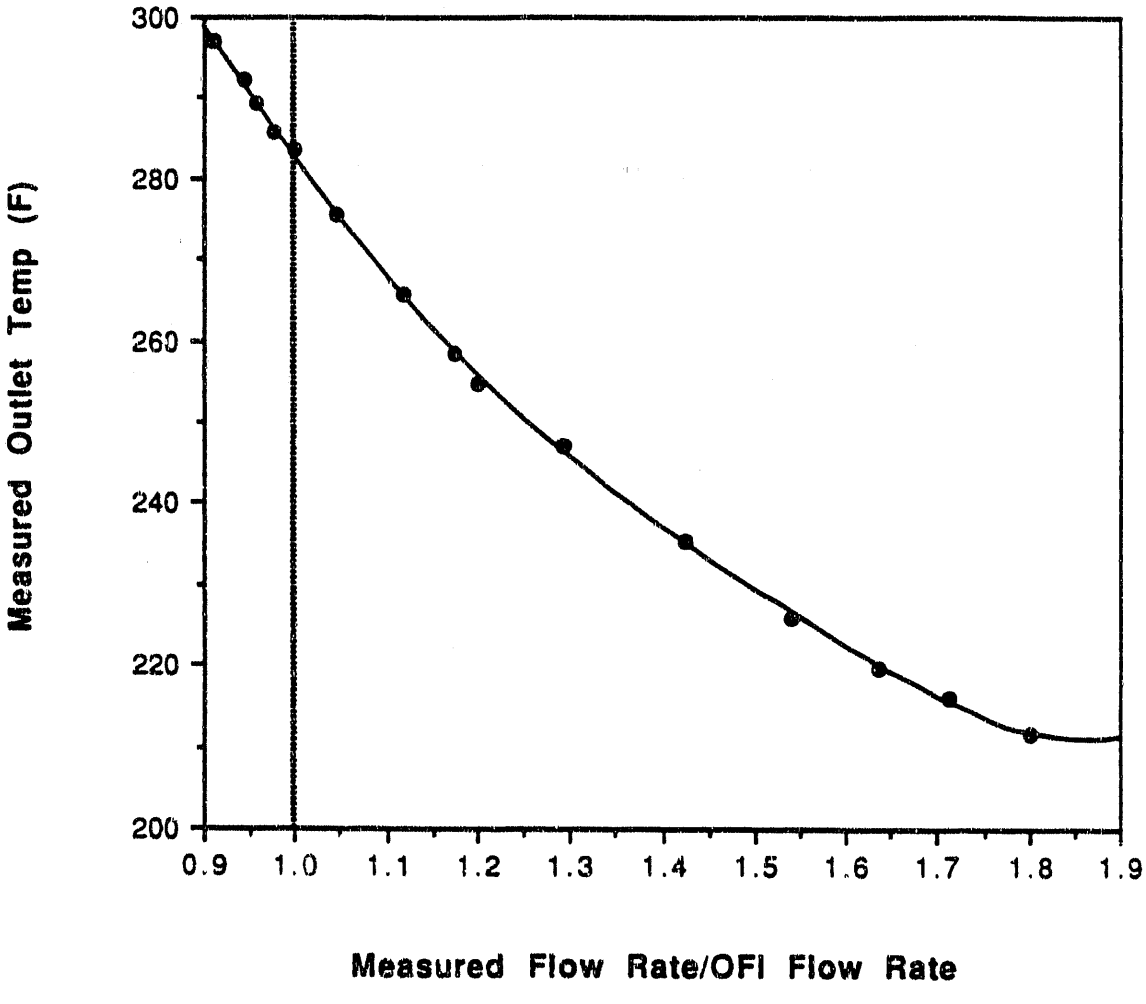


FIGURE 6. MEASURED OFI OUTLET TEMPERATURE DETERMINATION

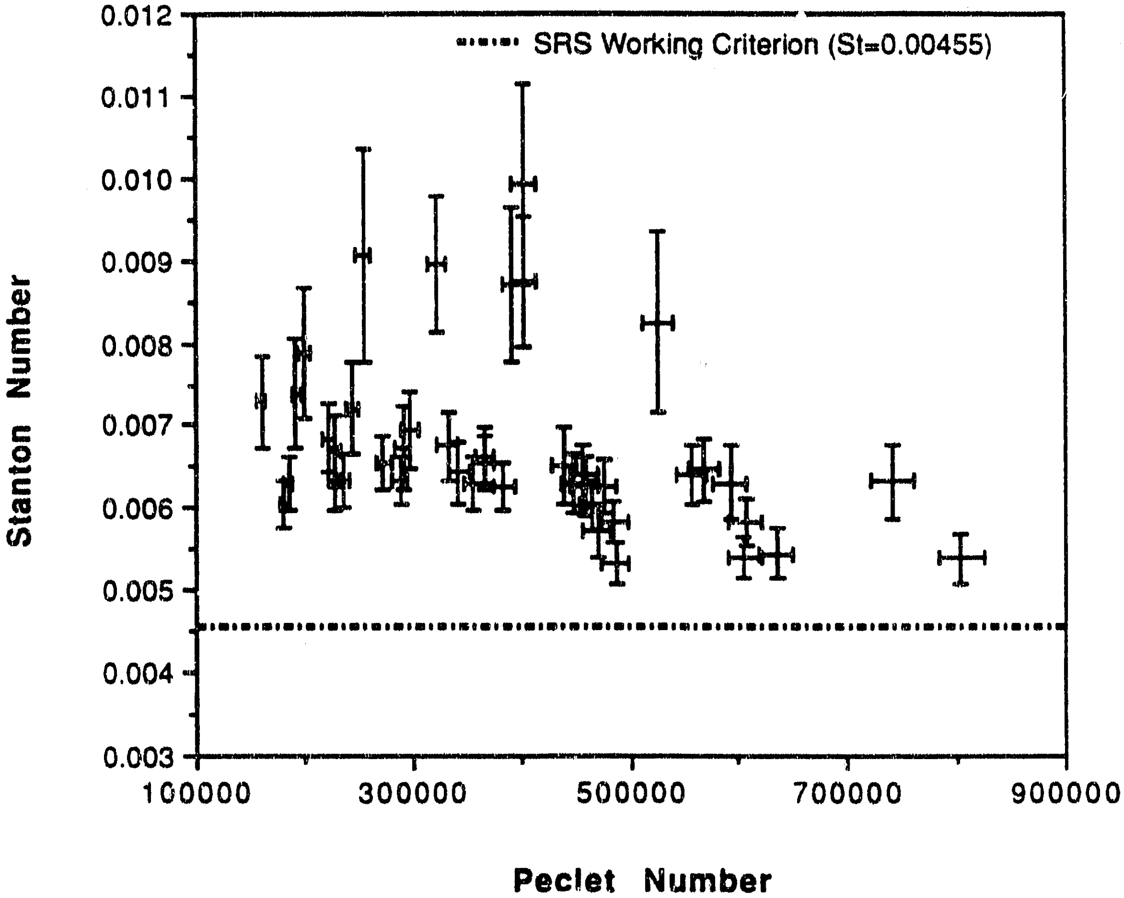
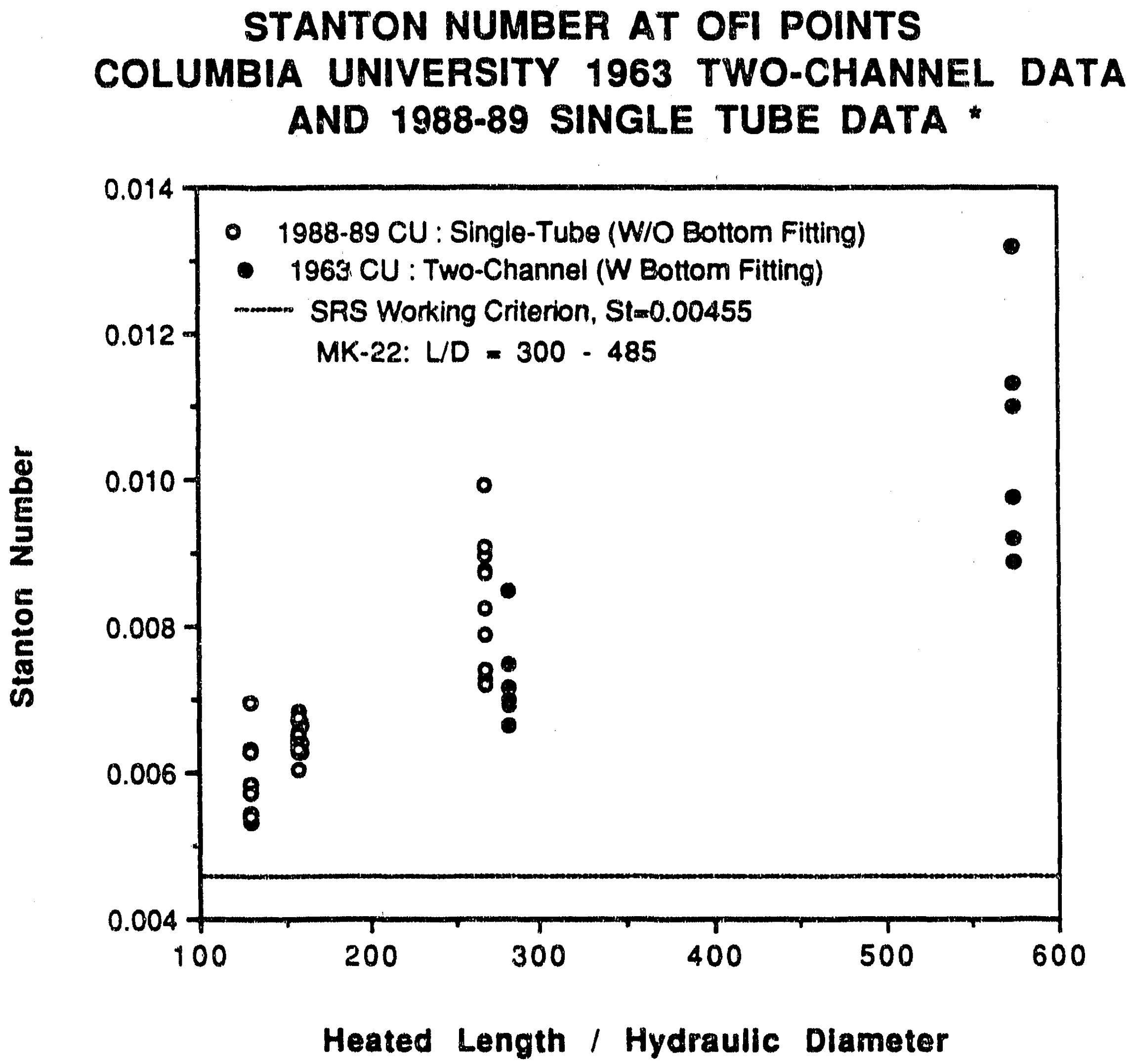


FIGURE 7. TEST DATA STANTON VERSUS PECLET NUMBERS AT OFI



* For tests with different inlet temp., exit pres., and heat flux at a given L/D

FIGURE 8. STANTON NUMBER AT OFI VERSUS L/D

the 1988-89 tests and 1963 Columbia tests [4] plotted against L/D and shows the trend that Stanton number increases with L/D. The OFI data from 1988-89 and 1963 Columbia University tests and SRS HTL test [5] are shown in Figure 9. This figure shows that the Stanton numbers are greater than 0.00455 for all Peclet numbers (20,000 to 800,000). The range of Peclet numbers for the SRS reactor channels for normal and simulated accident conditions is 200,000 to 800,000. The SRS reactor channel heat fluxes at the proposed restart power level (~1200 MW) are below 0.5 MBtu/hr-ft^2. Figures 7 and 8 show that the SRS Working Criterion, St=0.00455, is a conservative OFI predictor for the SRS reactor fuel assemblies at the reactor restart power level.

4.8 FLOWTRAN OSV FLOW CALCULATIONS

OSV flow rates were calculated by FLOWTRAN for the SRS Working Criterion (St = 0.00455) using average powers, inlet temperatures, and exit pressures. Table 5 shows the FLOWTRAN input data used to calculate the OSV flow rates as well as the calculated OSV flow rates. Figures A-9 to A-51 present the FLOWTRAN calculated OSV flow rates. The column RATIO in Table 5 represents the calculated OSV flow rate for St = 0.00455 divided by the measured OFI flow rate. Table 5 shows that the FLOWTRAN onset of significant voiding (OSV) calculations for St = 0.00455 are conservative OFI predictors because RATIO > 1.0 for all test cases.

4.9 UNCERTAINTY ANALYSIS

The uncertainties in the Peclet and Stanton numbers at the measured OFI conditions and the pressure drops were calculated from the uncertainties for both experimentally measured quantities and physical properties. Table 6 presents a measurement uncertainties example; all experimental uncertainties are presented in Columbia University's report, Section 4.2 [7]. Table 7 shows the test section geometry and water physical properties uncertainties. Uncertainties in all other experimental parameters are calculated from these uncertainties using a root sum of squares formula. Equations 8 - 13 were used in an external FORTRAN program to calculate the Peclet and Stanton number uncertainties at OFI. The program source listing, UNCERSTPE.FOR, is given in Appendix E.

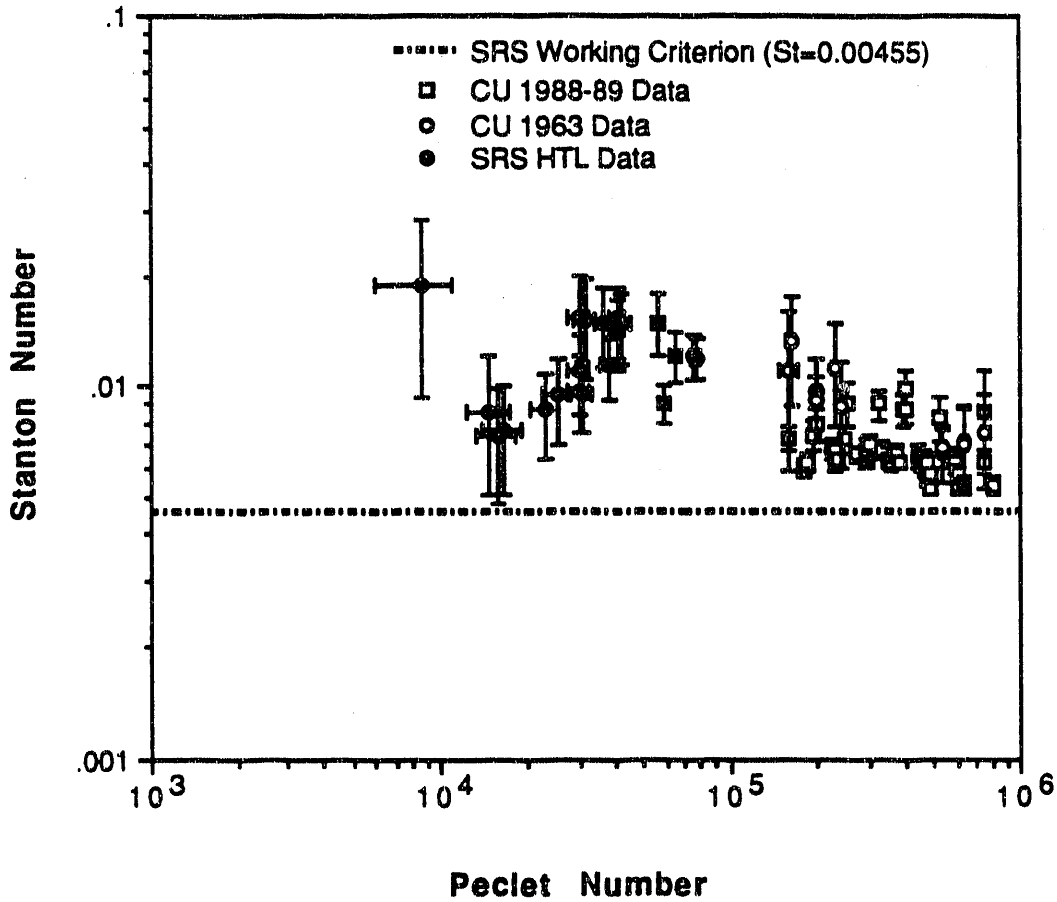


FIGURE 9. ACCUMULATED DATA STANTON VERSUS PECLET NUMBERS AT OFI

Table 6

MEASUREMENT UNCERTAINTIES

Uncertainty Analysis Sample:
Test #4, 0.6125" ID tube

Measurement	Range of Measurement	Accuracy of Instrument	DAS (End to End) (% of reading)	Digitizing Error*
P Inlet (PTI1)	200 psi	0.112% of F.S.	0.304%	0.200psi
P Outlet (PTO1)	200 psi	0.112% of F.S.	0.304%	0.200 psi
DP (DT1)	15 psid	0.112% of F.S.	0.304%	0.015 psid
T Inlet (TRTI1)	360 F	0.25 F	0.005%	0.500 F
T Outlet (TRTO1)	360 F	0.25 F	0.005%	0.500 F
Flow Rate (FTI2)	60 gpm	0.5106% of F.S.	0.200%	0.060 gpm
Current	10000 amp	0.10% of reading	0.304%	10 amp
Voltage	200 volt	0.050% of reading	0.304%	0.200 volt

* Error in multiplexer digitizer is 0.005 volts for signal voltage range of 5.00 volts, which corresponds to the full range of measurement.

Total Uncertainty:

Total Uncertainty is calculated based on Kline & McClintock procedure [13]

Example: If the DT1 reading is 1 psid,
Overall accuracy of the DP (DT1)
=SQRT((15 psid*0.112%)**2+(1 psid*0.304%)**2+(0.015 psid)**2)
=0.0227 psid

Table 7

TEST SECTION GEOMETRY AND WATER PROPERTIES UNCERTAINTIES

Inner Diameter[1]	±0.005 in.[5]	±0.0015 in.[6]
Heated Length[1]	±0.038 in.	
Pressure Tap Separation[1]	±0.058 in.	
Water Physical Properties[2]	$\Delta c_p/c_p$, $\Delta k/k$, $\Delta \rho/\rho = \pm 0.1\%$ $\Delta \rho/\rho_p = \pm 0.14\%$[4]	
Saturation Temperature[2]	$\Delta T_s = \pm 0.024$ C	
Exit Temperature[3]	$\Delta T_o = \pm 1.8$ F	

---

[1] Columbia University measurement uncertainty

[2] Correlation uncertainties per FLOWTRAN manual

[3] Measured outlet temperature uncertainty

[4] Used in the pressure drop uncertainty estimation. Water temperature inside pressure transducer line assumed as 77±10 F.

[5] Tests 2.1, 4, 7 ; [6] Test 9

The measured outlet temperature, T_o, and its uncertainty are required for Equations 11 and 12. Since the temperature at the OFI flow rate is not directly measured, its uncertainty value must cover temperature measurement uncertainties in the demand curve and curve fitting regression error. The data regression error is insignificant (see Figure 6). Columbia University [7] reported the maximum measured outlet temperature uncertainty as ±0.6 F. Thus, a lower uncertainty bound would be ±0.6 F. This uncertainty was judged to be too low, because the outlet temperature was measured below the end of the heater tube. Below the heated section vapor bubbles should collapse. The collapse of the bubbles should raise the bulk fluid temperature about 0.5 F. Therefore, the bulk temperature at the measurement location should be slightly higher than the temperature at the OFI location. Considering all these factors, ±1.8 F was selected for the measured outlet temperature uncertainty at OFI and was judged to be conservative.

The experimental uncertainties formulae are:

Pressure Drop:

From Equation 4 the pressure drop uncertainty can be expressed as

$$\Delta(DP_{12}) = \pm\sqrt{[\Delta(DP_m)]^2 + \left[\frac{\rho\, g\, L}{144\, g_c}\right]^2 \left\{\left[\frac{\Delta\rho}{\rho}\right]^2 + \left[\frac{\Delta L}{L}\right]^2\right\}}, \qquad (8)$$

where

$\Delta(DP_{12})$ = uncertainty in pressure drop between the pressure taps

$\Delta(DP_m)$ = uncertainty in measurement pressure drop between the taps.

Peclet Number:

Equation 8 for the Peclet number can be expressed in terms of the measured parameter Q, the volumetric flow rate, as

$$Pe = \frac{4\, c_p\, \rho\, Q}{\pi\, k_b\, D_e}. \qquad (9)$$

Using Equation 10, the Peclet number uncertainty can be expressed as

$$\Delta Pe = \pm\, Pe \sqrt{\left(\frac{\Delta D_e}{D_e}\right)^2 + \left(\frac{\Delta \rho}{\rho}\right)^2 + \left(\frac{\Delta c_p}{c_p}\right)^2 + \left(\frac{\Delta k_b}{k_b}\right)^2 + \left(\frac{\Delta Q}{Q}\right)^2} \quad (10)$$

Stanton Number:

Equation 11 for the Stanton number is derived from Equation 6 in terms of the measured parameters volumetric flow rate and power in the following form

$$St = \frac{\dfrac{w\, D_e}{4\, h}}{Q\, \rho\, c_p\, (T_s - T_o)}\,, \quad (11)$$

where

h = heated length
w = power
Q = volumetric flow rate.

Using Equation 11, the Stanton number uncertainty can be expressed as

$$\Delta St = \pm\, St \sqrt{\left[\left(\frac{\Delta w}{w}\right)^2 + \left(\frac{\Delta c_p}{c_p}\right)^2 + \left(\frac{\Delta \rho}{\rho}\right)^2 + \left(\frac{\Delta Q}{Q}\right)^2\right] + \frac{\Delta T_s^2 + \Delta T_o^2}{(T_s - T_o)^2} + \left(\frac{\Delta D_e}{D_e}\right)^2 + \left(\frac{\Delta h}{h}\right)^2}\,. \quad (12)$$

The parameter Δw in Equation 12 is given by

$$\Delta w = \pm \sqrt{\Delta w_m^2 + \Delta w_v^2}\,, \quad (13)$$

where

Δw_m = measurement power uncertainty

Δw_v = standard deviation of the power within a test run.

5. CONCLUSIONS

1. FLOWTRAN accurately modeled the pressure drop for single-phase flow in both heated and unheated tubes with the proper input values for the wall absolute roughness and the heated wall effect correlation exponent. For a tube with a hydraulic diameter similar to that of an SRS reactor channel, pressure drops calculated by FLOWTRAN agree closely with the measured pressure drops up to OSV, since the two-phase contribution is relatively small compared to the total channel pressure drop. For larger tubes at high heat fluxes the total pressure drop is low, and the two-phase contributions are much more significant. Consequently, the agreement between measured and FLOWTRAN calculated pressure drops near OSV is not good.

2. For all the current Columbia University OFI tests, the FLOWTRAN calculated flows at OSV, based on the SRS working criterion, St=0.00455, were lower than the flows at which the test rigs went into flow instability. This substantiated St=0.00455 as a conservative predictor of OFI in FLOWTRAN for the range of test conditions: Peclet numbers between 100,000 and 300,000 and surface heat fluxes up to 1 MBtu/hr-ft^2.

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APPENDIX - A

PRESSURE DROP COMPARISON GRAPHS

This appendix contains 51 figures which present graphical representation of pressure drop versus flow rate for the test cases. Figures A-1 through A-8 are the comparisons of measured and FLOWTRAN calculated pressure drops for cold test cases. Figures A-9 through A-51 show measured and FLOWTRAN calculated pressure drops, the measured OFI flow range, and the FLOWTRAN calculated OSV flow rates for St=0.00455. The figures show the measured pressure drop points with their associated flow and pressure drop uncertainties. In this appendix, the figure caption "INC" denotes inconel 600 and "SS" denotes 304 type stainless steel. The following are the figure numbers associated with the test conditions.

Figure	Test Run	Heat Flux MBtu/hr-ft^2	Inlet Temp F	Exit Pres Psia
FIGURE A-1	.359" tube base run 1	0.0	77	64.7
FIGURE A-2	.359" tube base run 2	0.0	122	64.7
FIGURE A-3	.600" tube base run 1	0.0	77	64.7
FIGURE A-4	.600" tube base run 2	0.0	121	64.7
FIGURE A-5	.6125" tube base run 1	0.0	77	64.7
FIGURE A-6	.6125" tube base run 2	0.0	121	64.7
FIGURE A-7	.7516" tube base run 1	0.001	77	64.7
FIGURE A-8	.7516" tube base run 2	0.0	121	64.7
FIGURE A-9	9 - 01	0.4	77	34.7
FIGURE A-10	9 - 02	0.8	77	34.7
FIGURE A-11	9 - 03	0.4	122	34.7
FIGURE A-12	9 - 04	0.8	122	34.7
FIGURE A-13	9 - 05	0.4	77	64.7
FIGURE A-14	9 - 06	0.6	77	64.7
FIGURE A-15	9 - 07	0.8	77	64.7
FIGURE A-16	9 - 08	1.0	77	64.7
FIGURE A-17	9 - 09	0.4	122	64.7
FIGURE A-18	9 - 10	0.8	122	64.7
FIGURE A-19	7 - 01	0.4	77	64.7
FIGURE A-20	7 - 02	0.8	77	64.7
FIGURE A-21	7 - 03	0.4	121	64.7
FIGURE A-22	7 - 04	0.8	121	64.7
FIGURE A-23	4 - 01	0.4	77	34.7

Figure	Test Run	Heat Flux MBtu/hr-ft^2	Inlet Temp F	Exit Pres Psia
FIGURE A-24	4 - 02	0.6	77	34.7
FIGURE A-25	4 - 03	0.8	77	34.7
FIGURE A-26	4 - 04	1.0	77	34.7
FIGURE A-27	4 - 05	0.4	121	34.7
FIGURE A-28	4 - 06	0.6	121	34.7
FIGURE A-29	4 - 07	0.8	121	34.7
FIGURE A-30	4 - 08	1.0	121	34.7
FIGURE A-31	4 - 09	0.4	77	64.7
FIGURE A-32	4 - 10	0.6	77	64.7
FIGURE A-33	4 - 11	0.8	77	64.7
FIGURE A-34	4 - 12	1.0	77	64.7
FIGURE A-35	4 - 13	0.4	121	64.7
FIGURE A-36	4 - 14	0.6	121	64.7
FIGURE A-37	4 - 15	0.8	121	64.7
FIGURE A-38	4 - 16	1.0	121	64.7
FIGURE A-39	2.1-01	0.8	77	34.7
FIGURE A-40	2.1-02	1.0	77	34.7
FIGURE A-41	2.1-03	0.4	121	34.7
FIGURE A-42	2.1-04	0.6	121	34.7
FIGURE A-43	2.1-05	0.8	121	34.7
FIGURE A-44	2.1-06	1.0	121	34.7
FIGURE A-45	2.1-07	0.6	77	64.7
FIGURE A-46	2.1-08	0.8	77	64.7
FIGURE A-47	2.1-09	1.0	77	64.7
FIGURE A-48	2.1-10	0.4	121	64.7
FIGURE A-49	2.1-11	0.6	121	64.7
FIGURE A-50	2.1-12	0.8	121	64.7
FIGURE A-51	2.1-13	1.0	121	64.7

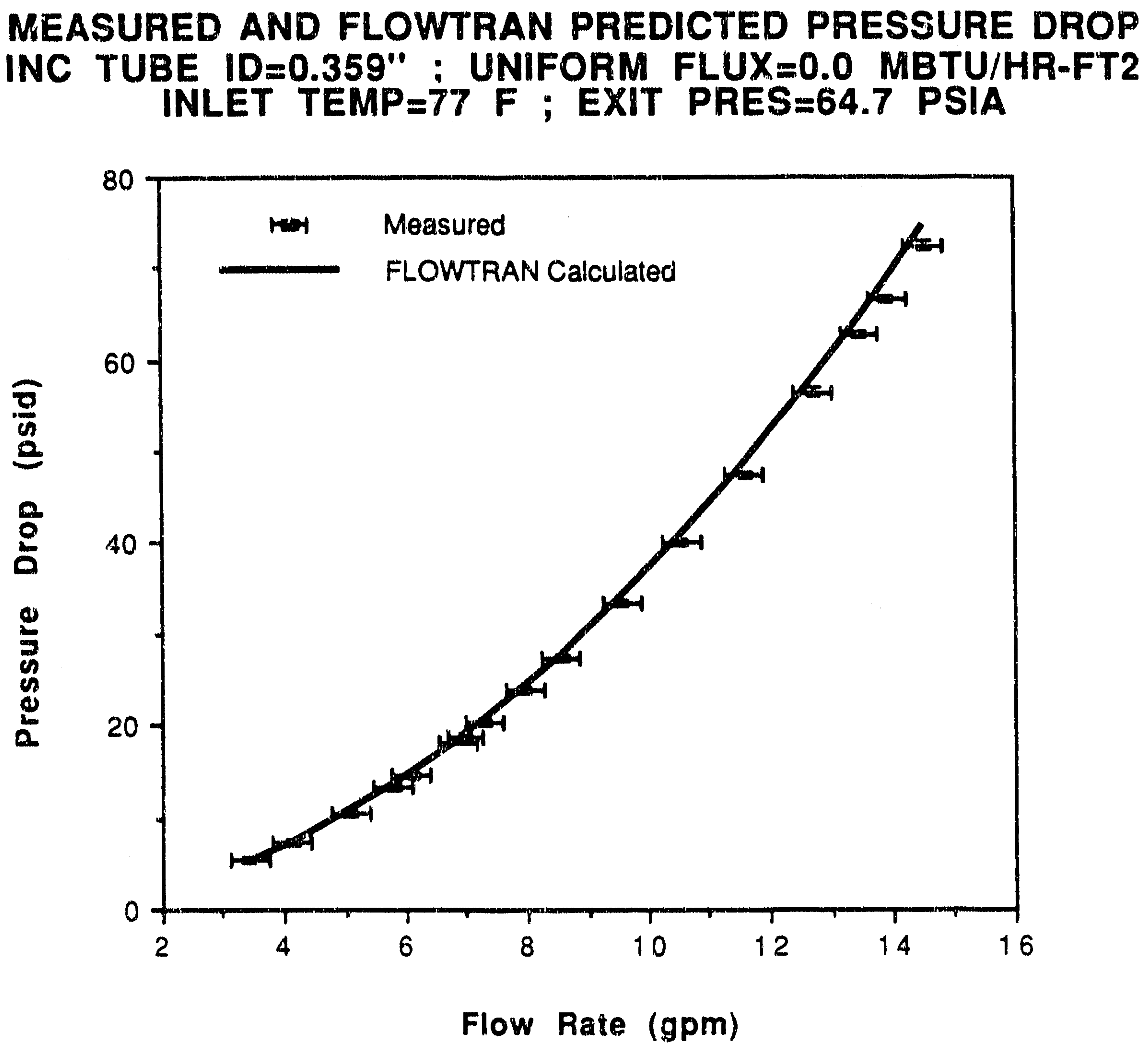

FIGURE A-1. 0.359" TUBE BASE RUN 1

MEASURED AND FLOWTRAN PREDICTED PRESSURE DROP
INC TUBE ID=0.359" ; UNIFORM FLUX=0.0 MBTU/HR-FT2
INLET TEMP=122 F ; EXIT PRES=64.7 PSIA

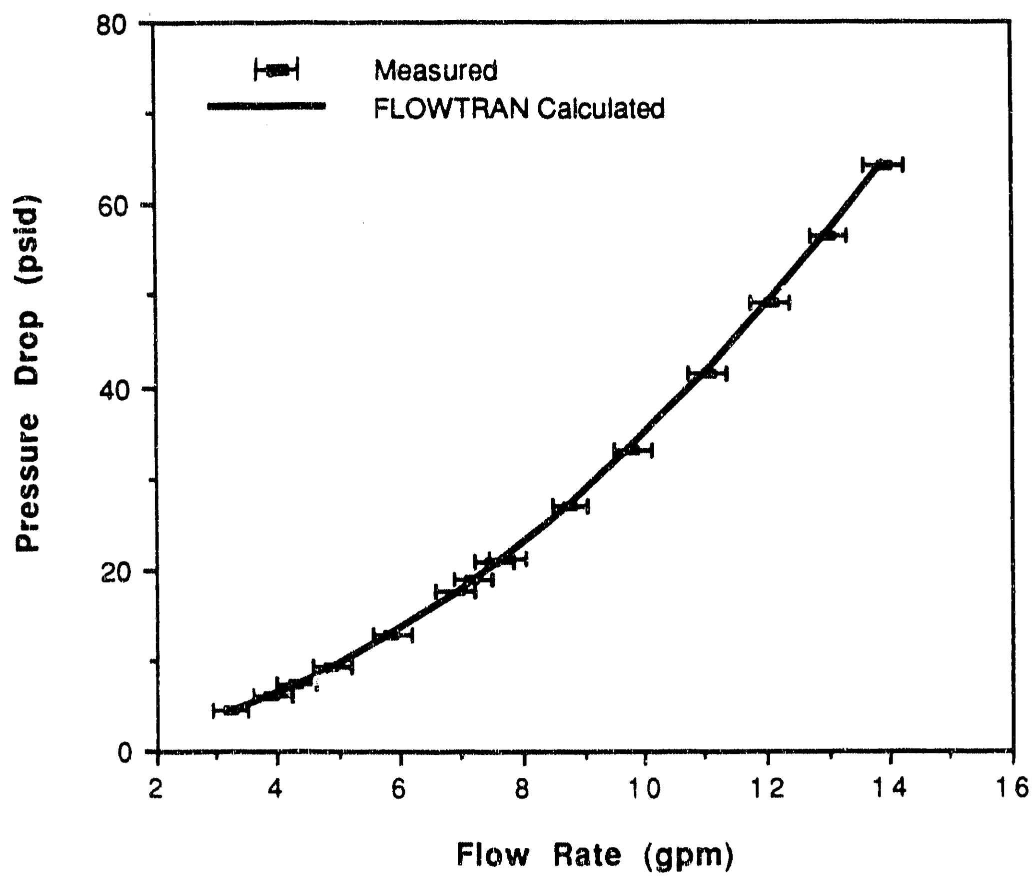

FIGURE A-2. 0.359" TUBE BASE RUN 2

MEASURED AND FLOWTRAN PREDICTED PRESSURE DROP
SS TUBE ID=0.600" ; UNIFORM FLUX=0.0 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=64.7 PSIA

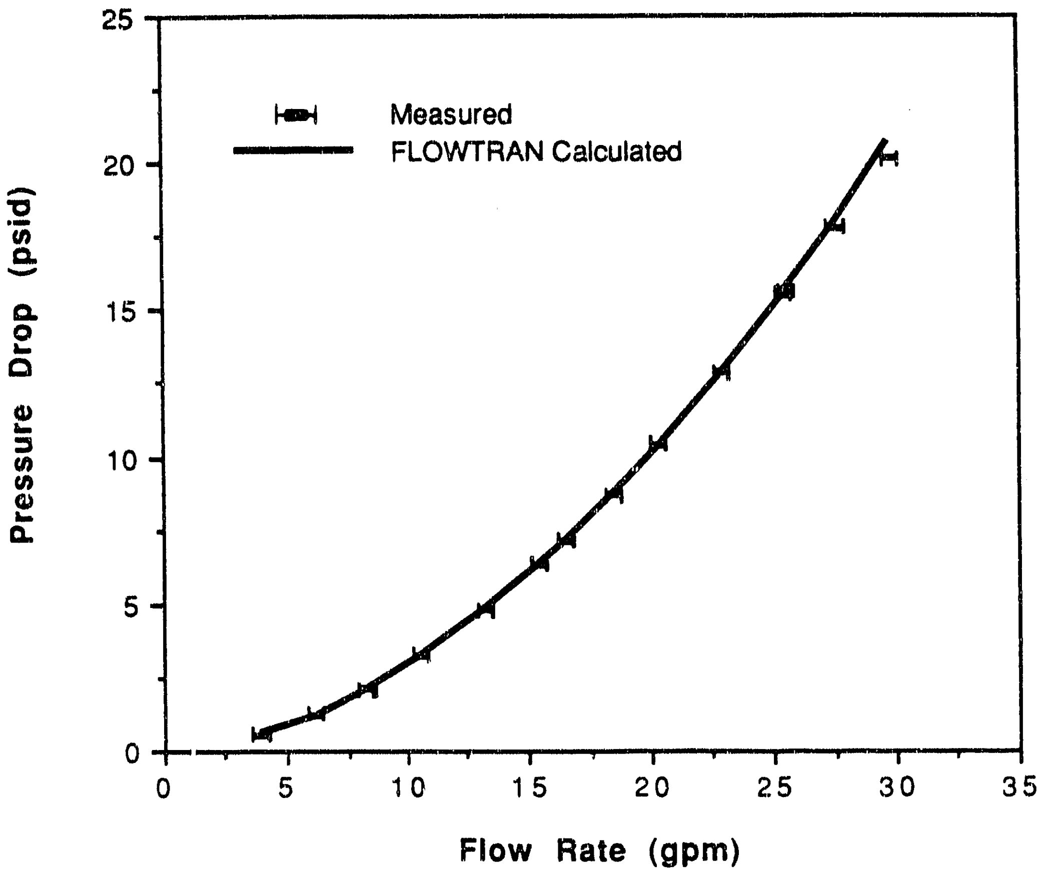

FIGURE A-3. 0.600" TUBE BASE RUN 1

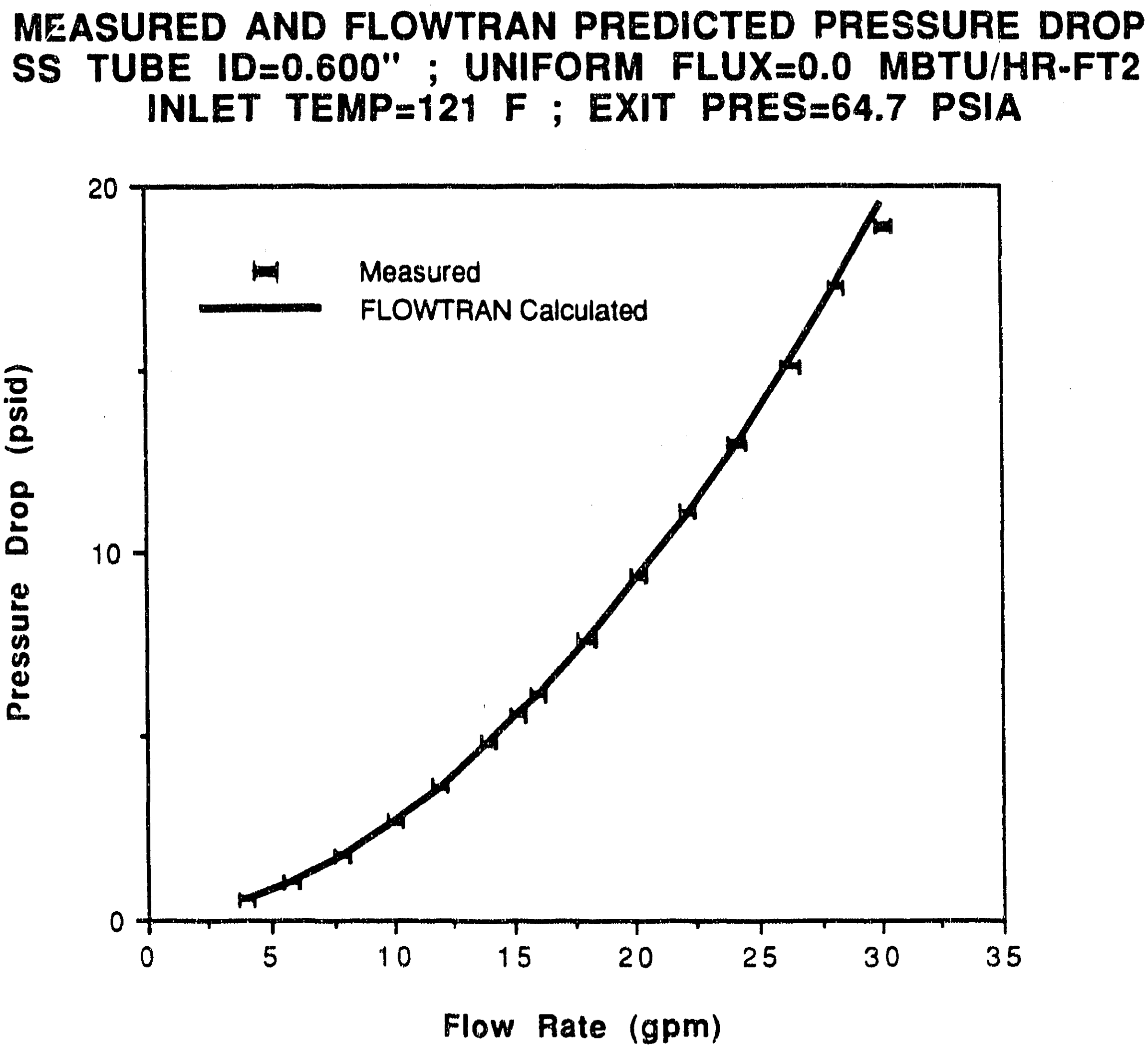

FIGURE A-4. 0.600" TUBE BASE RUN 2

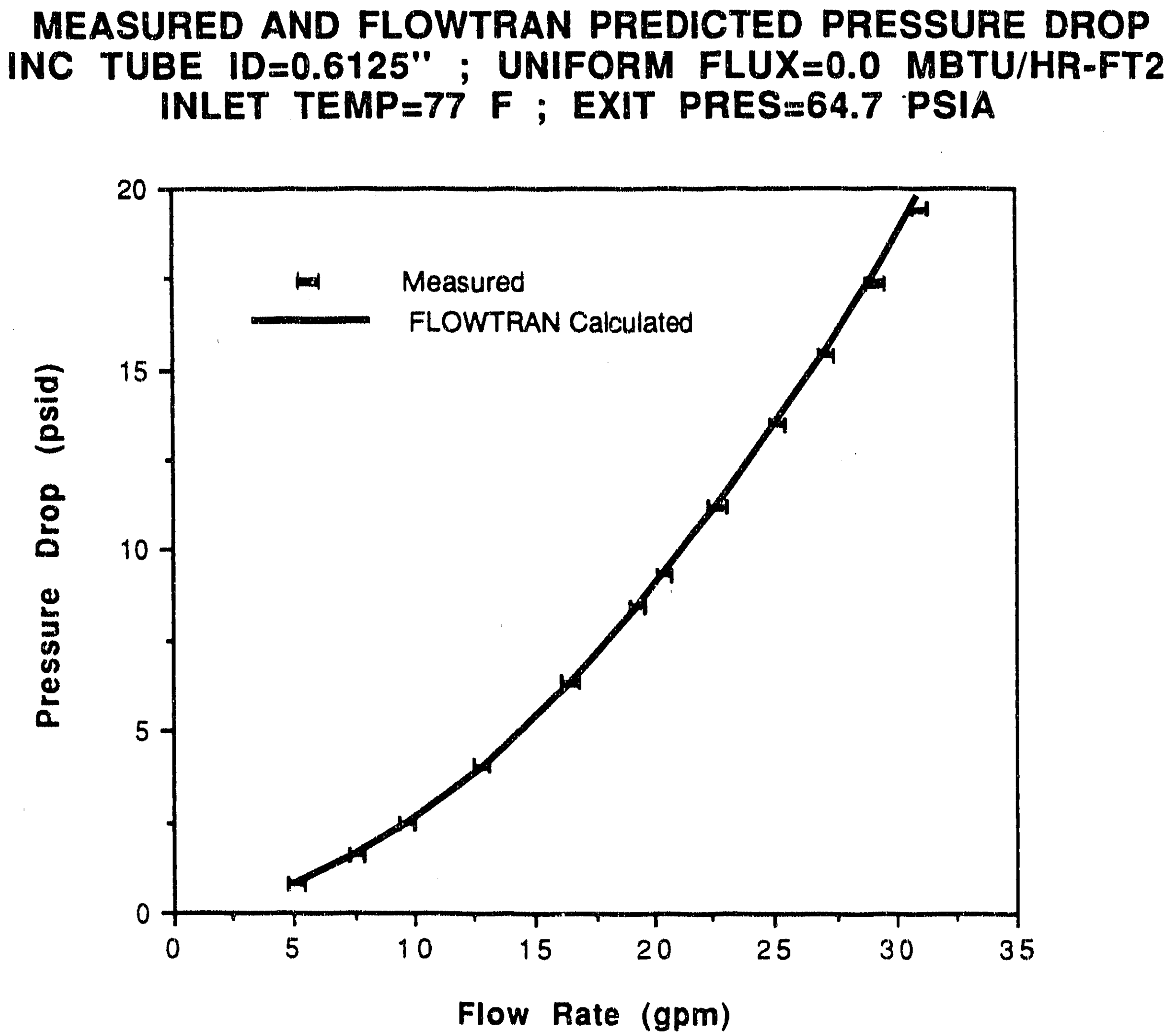

FIGURE A-5. 0.6125" TUBE BASE RUN 1

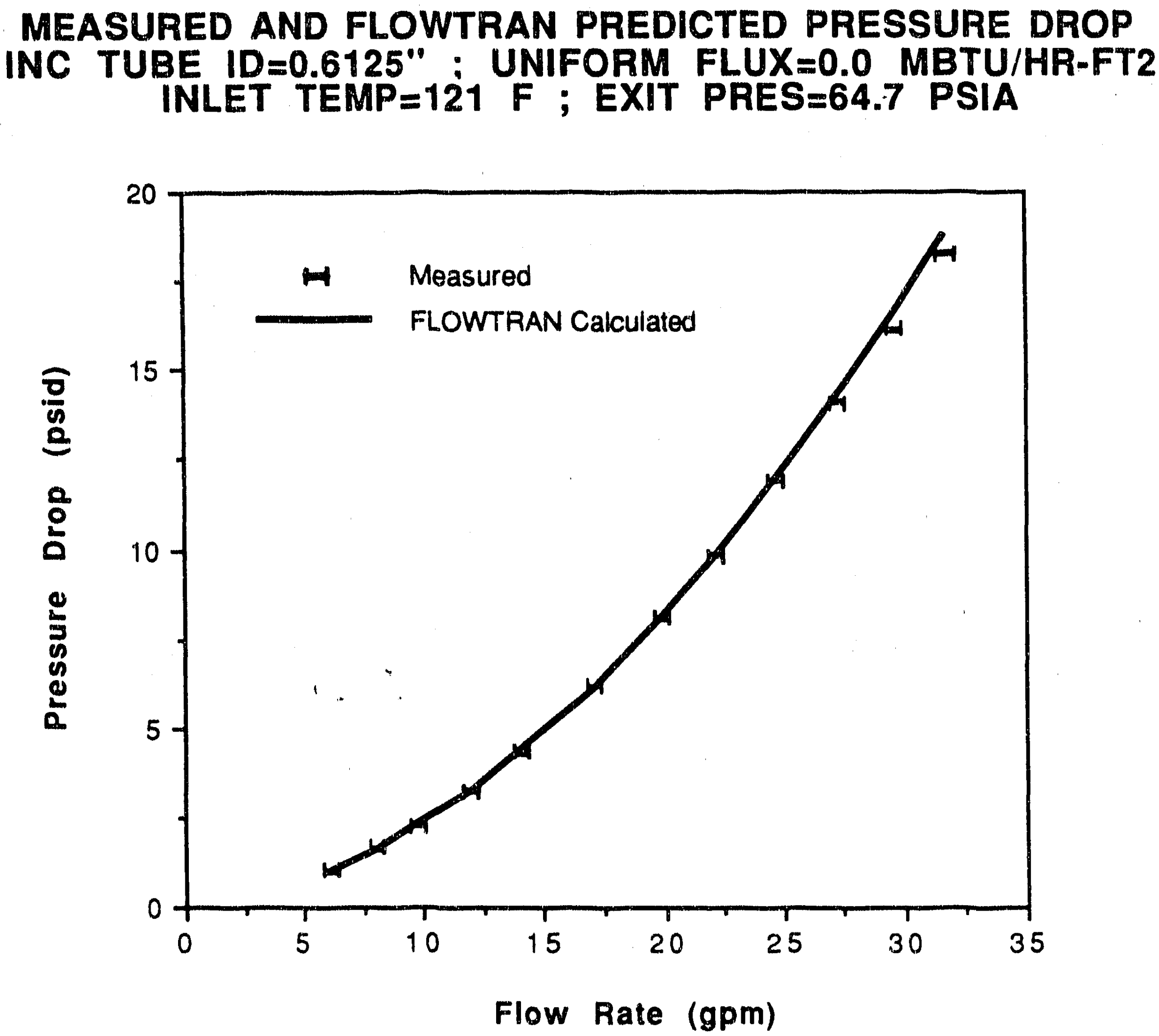

FIGURE A-6. 0.6125" TUBE BASE RUN 2

MEASURED AND FLOWTRAN PREDICTED PRESSURE DROP
SS TUBE ID=0.7516" ; UNIFORM FLUX=0.001 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=64.7 PSIA

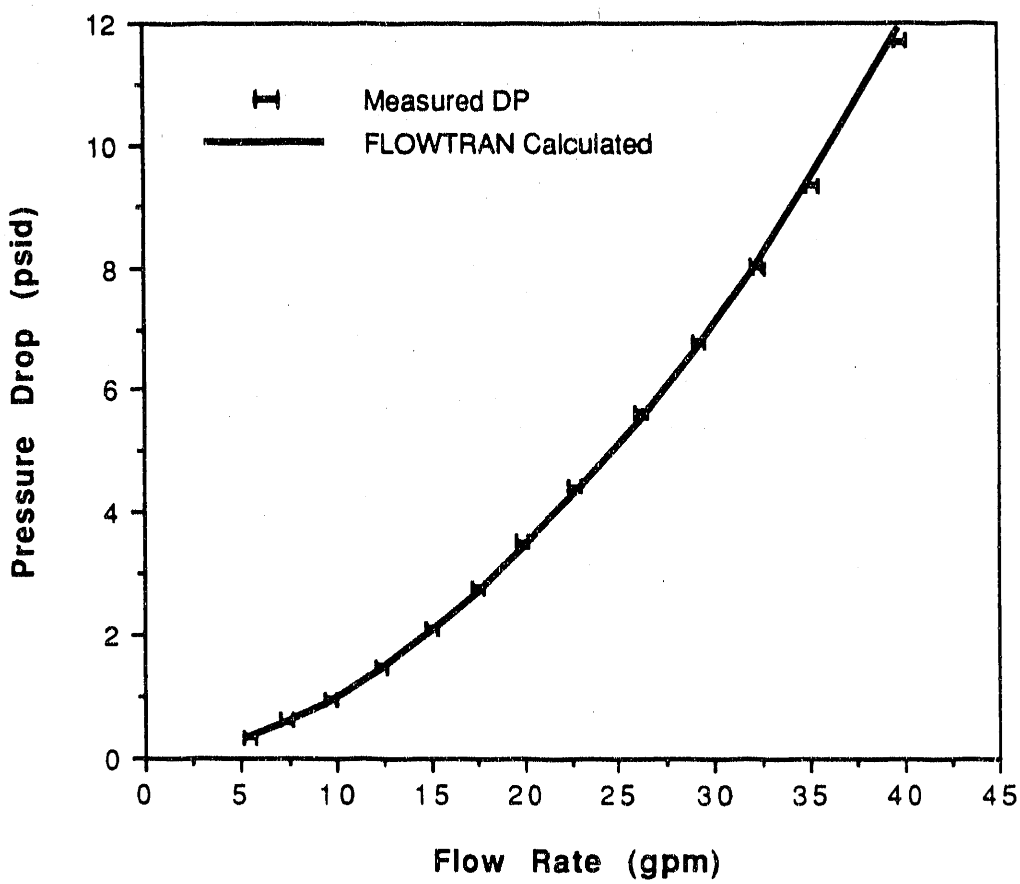

FIGURE A-7. 0.7516" TUBE BASE RUN 1

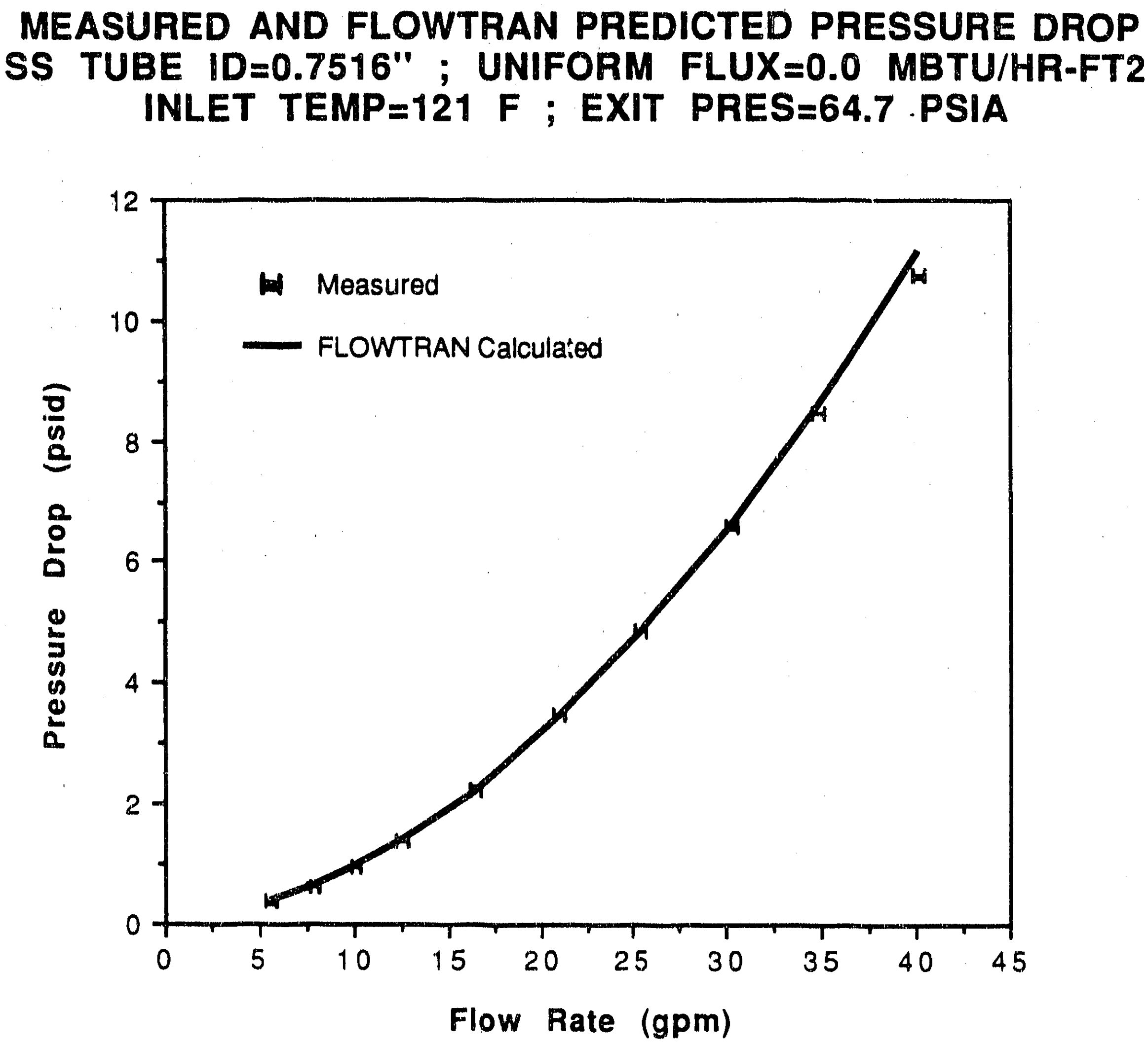

FIGURE A-8. 0.7516" TUBE BASE RUN 2

INC TUBE ID=0.359" ; UNIFORM FLUX=0.4 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=34.7 PSIA

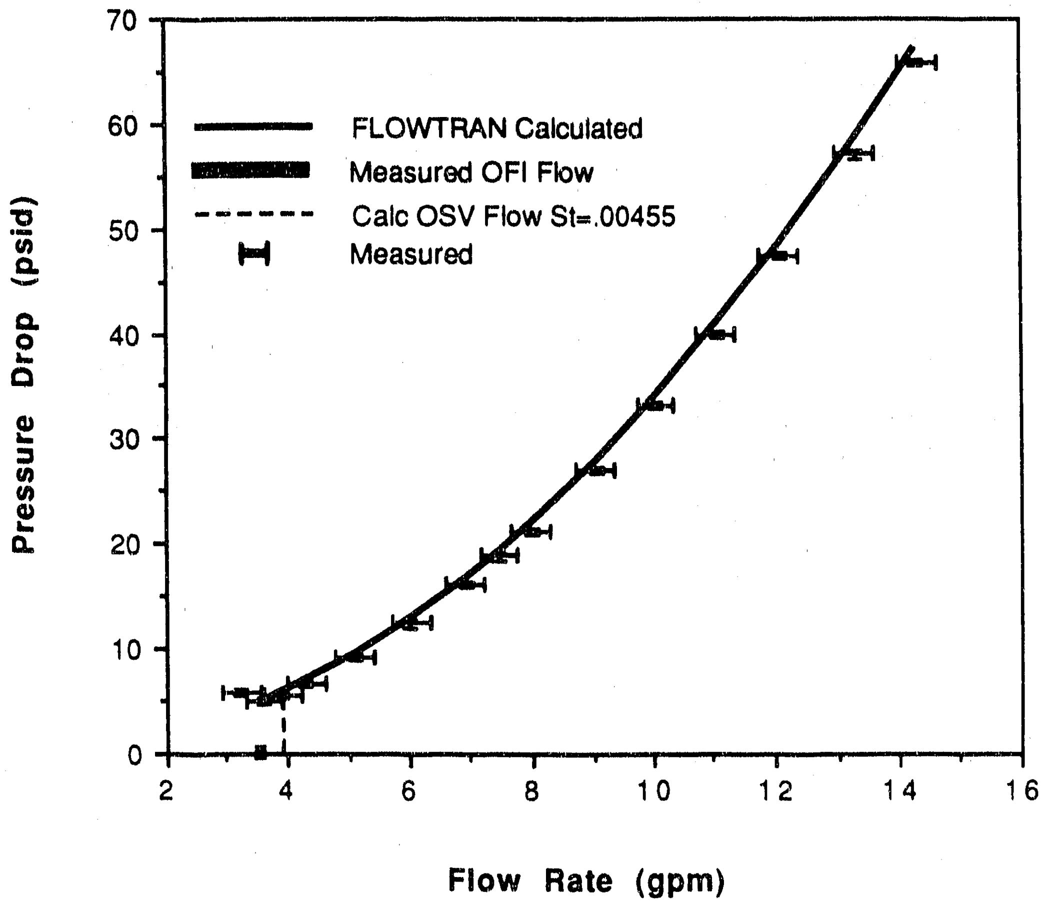

FIGURE A-9. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 9 - 01

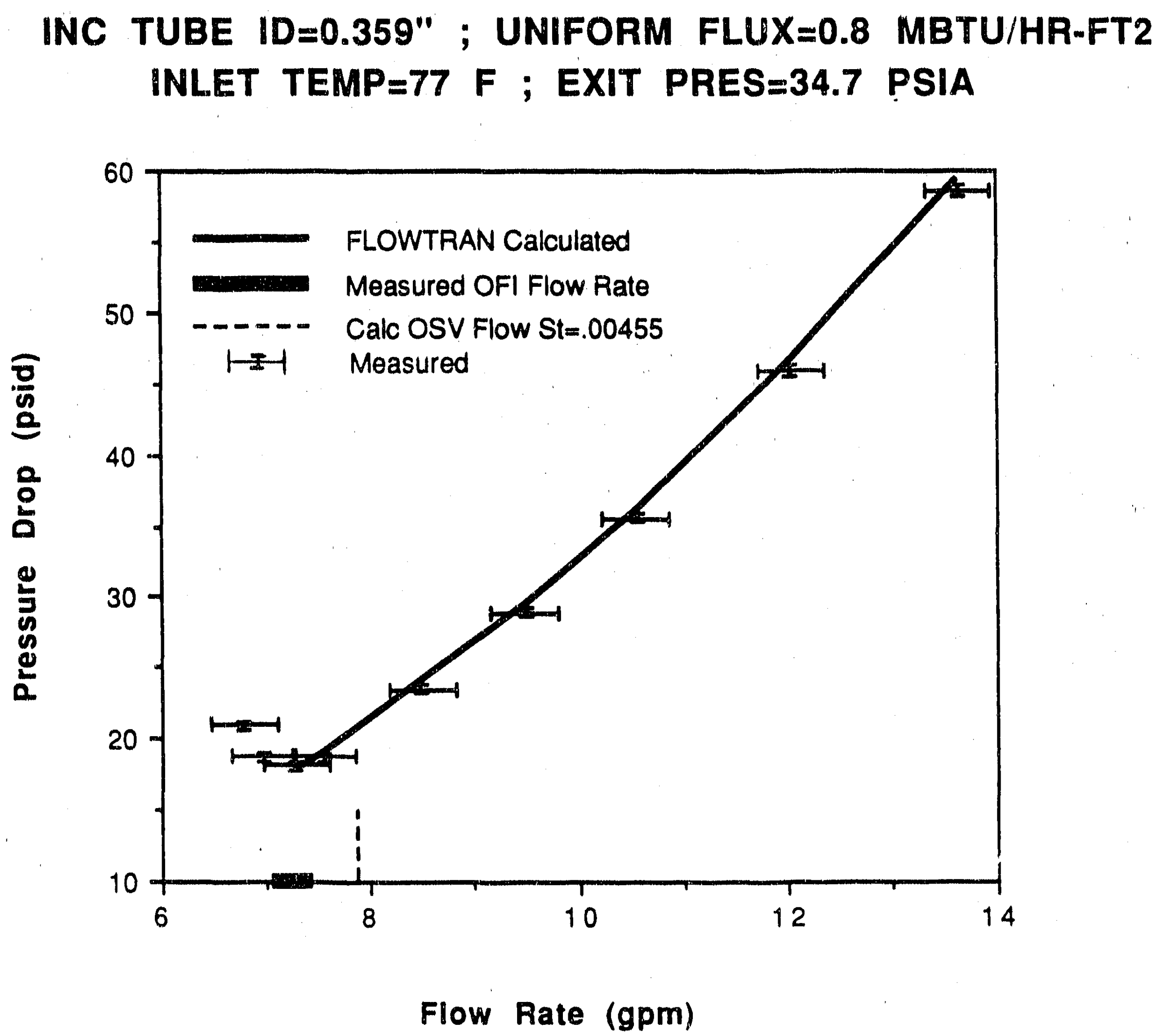

FIGURE A-10. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 9 - 02

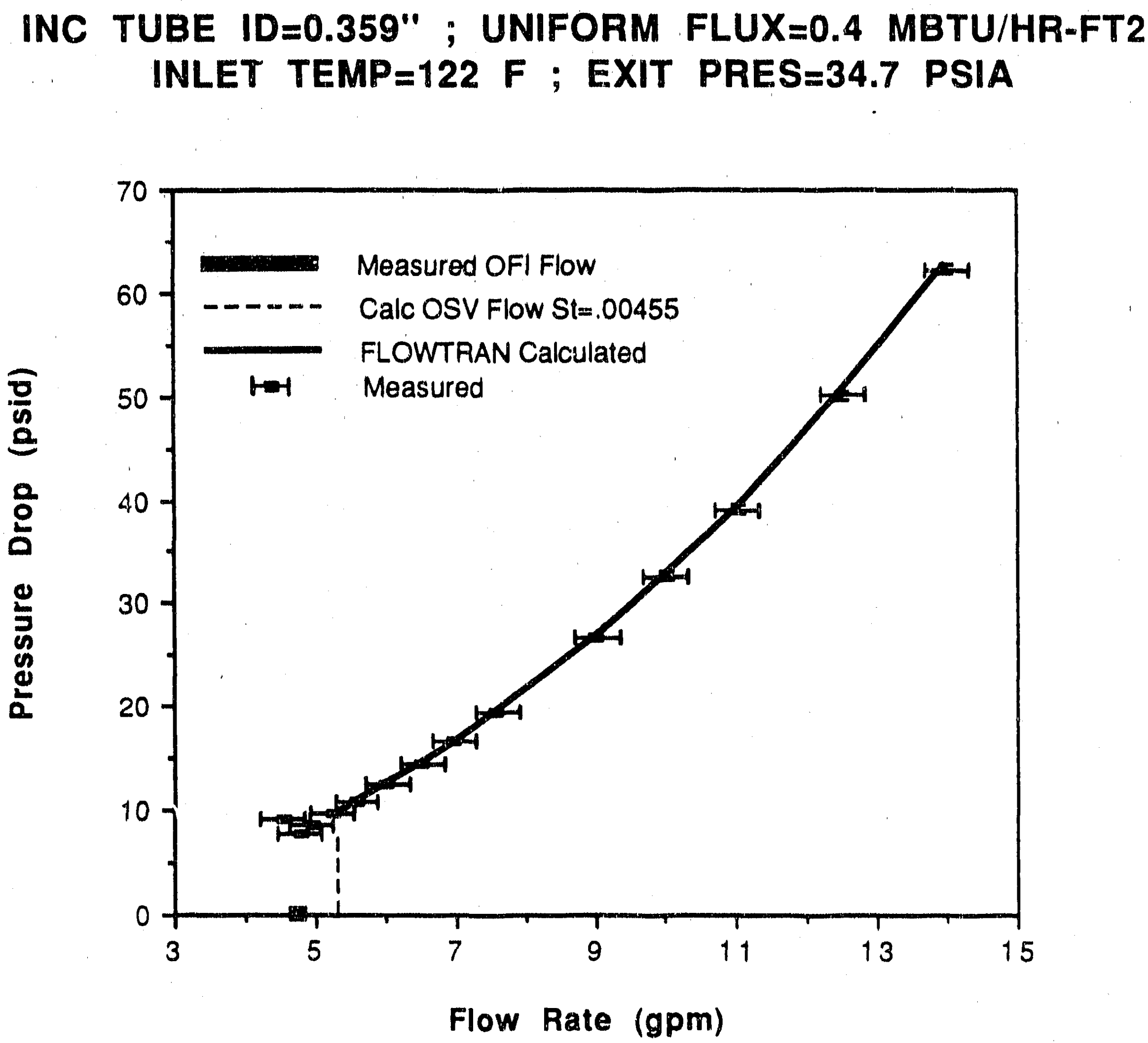

FIGURE A-11. MEASURED DATA AND FLOWTRAN PREDICTIONS
FOR TEST RUN 9 - 03

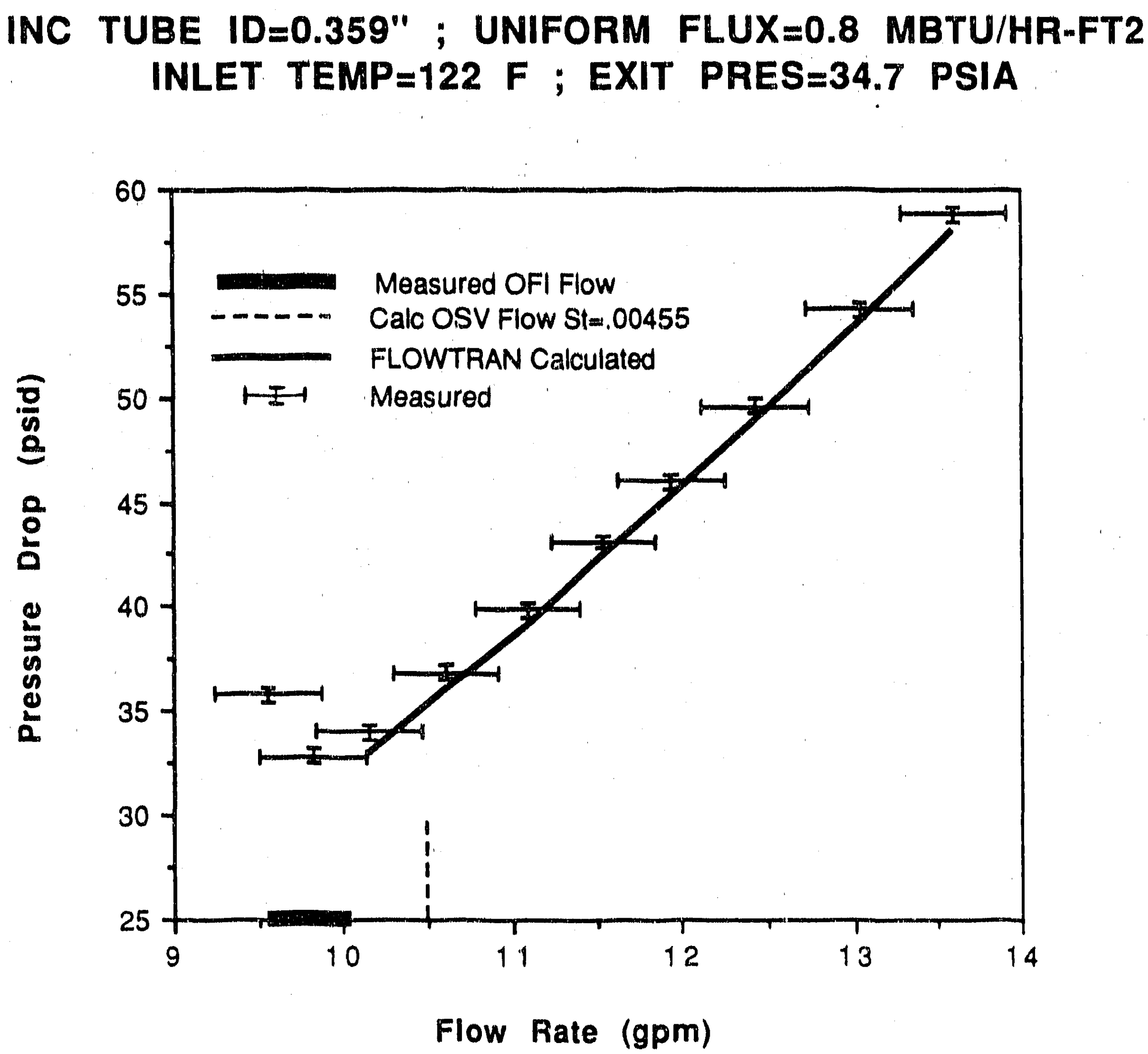

FIGURE A-12. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 9 - 04

INC TUBE ID=0.359" ; UNIFORM FLUX=0.4 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=64.7 PSIA

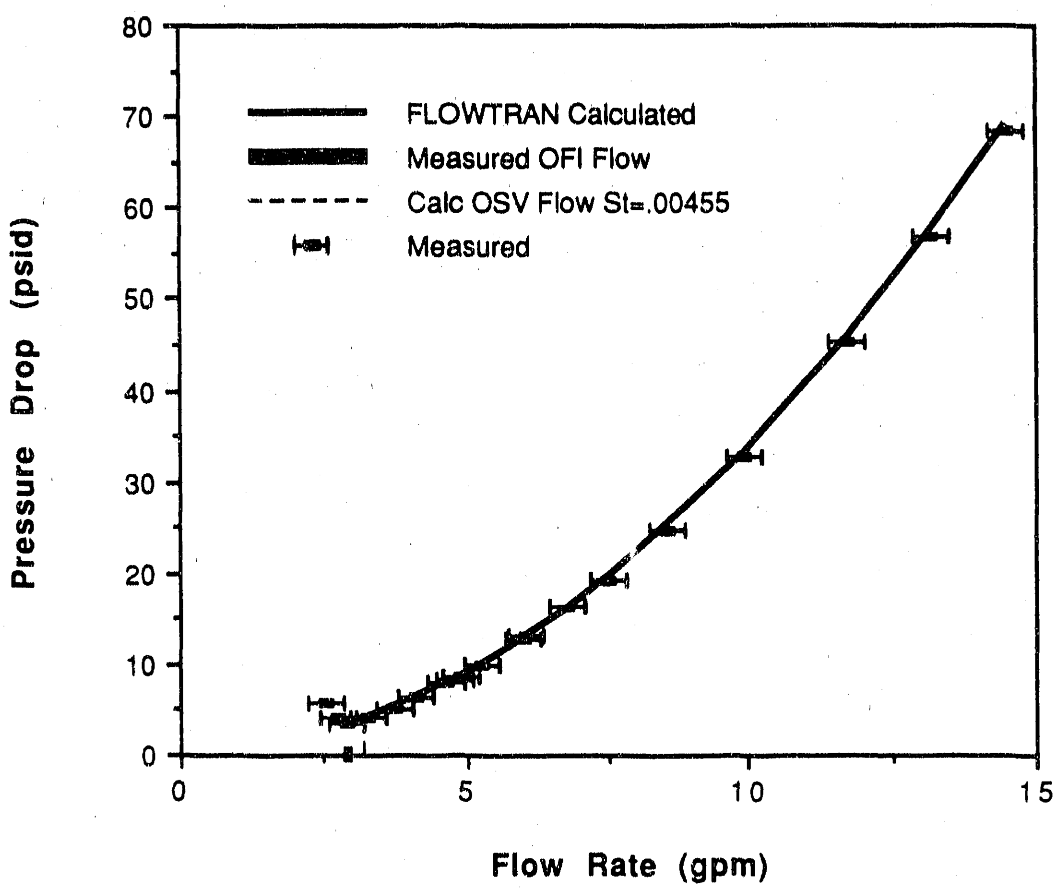

FIGURE A-13. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 9 - 05

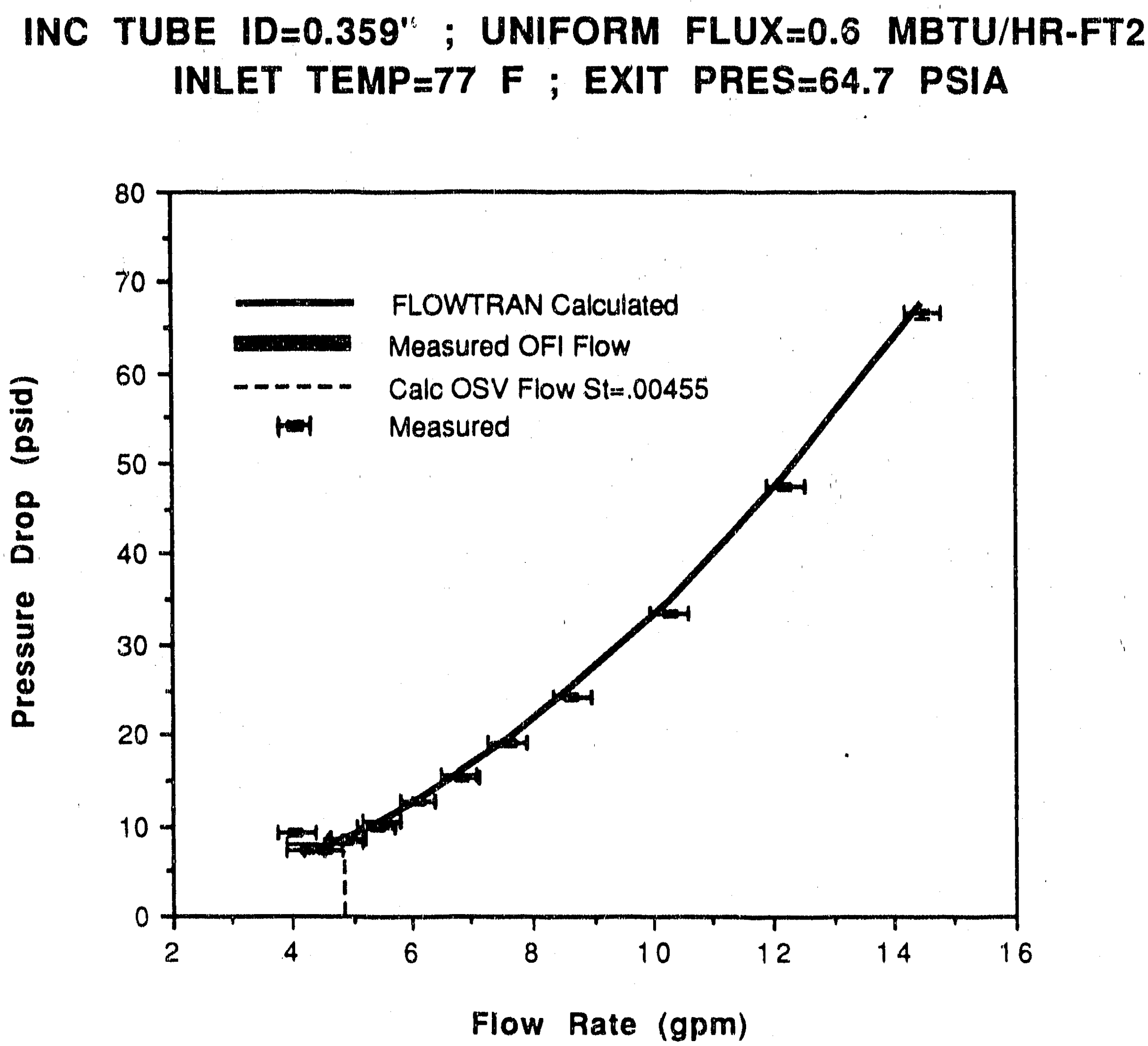

FIGURE A-14. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 9 - 06

INC TUBE ID=0.359" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=64.7 PSIA

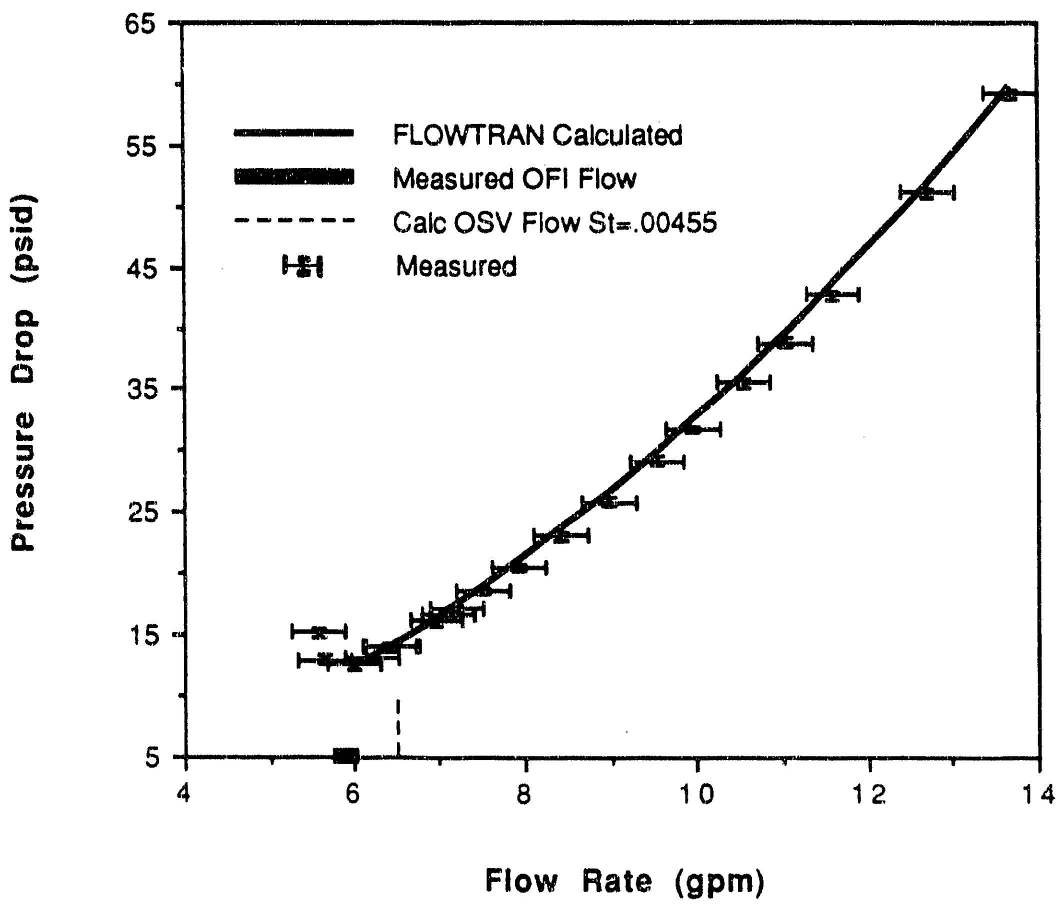

FIGURE A-15. MEASURED DATA AND FLOWTRAN PREDICTIONS
FOR TEST RUN 9 - 07

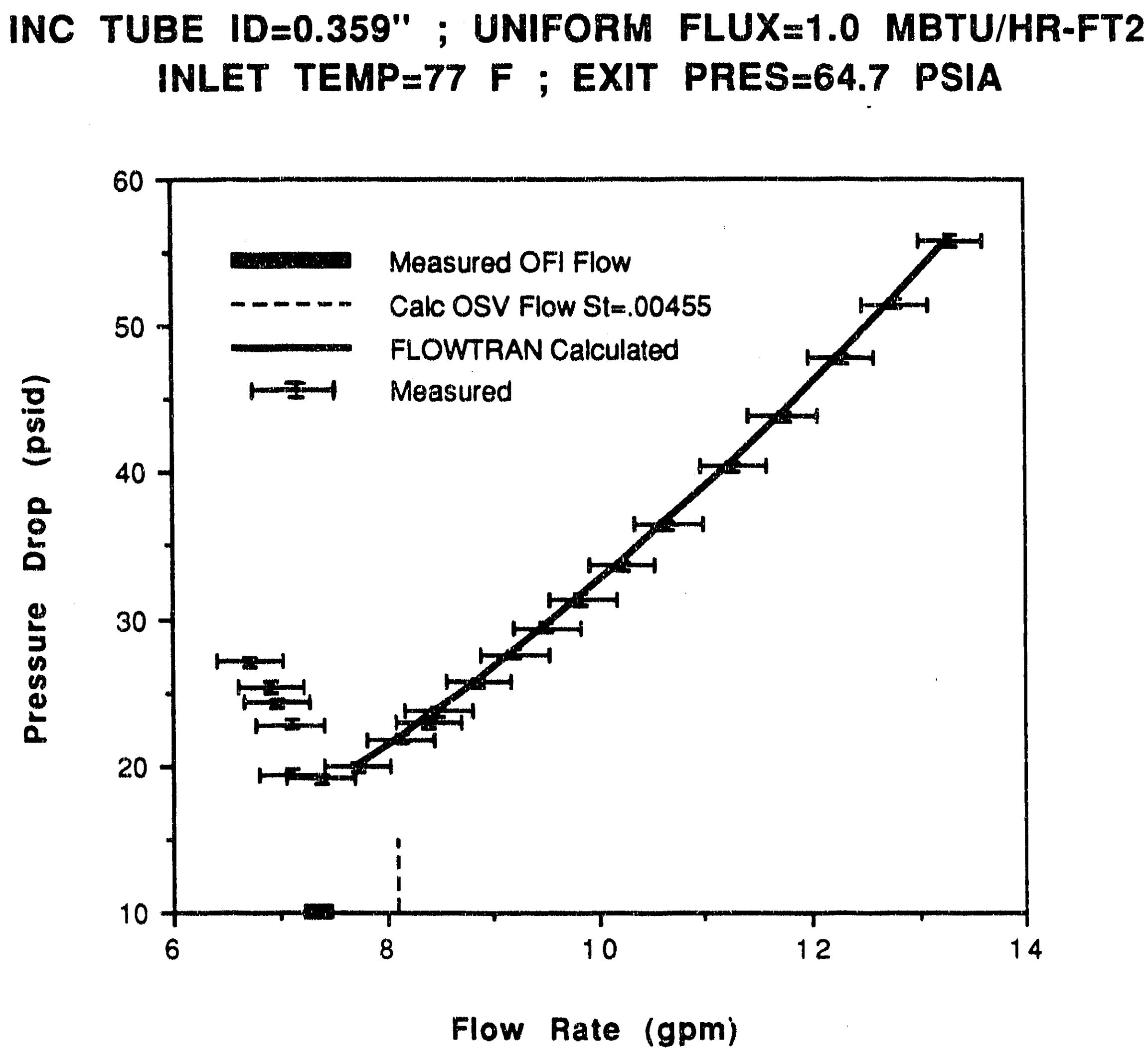

FIGURE A-16. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 9 - 08

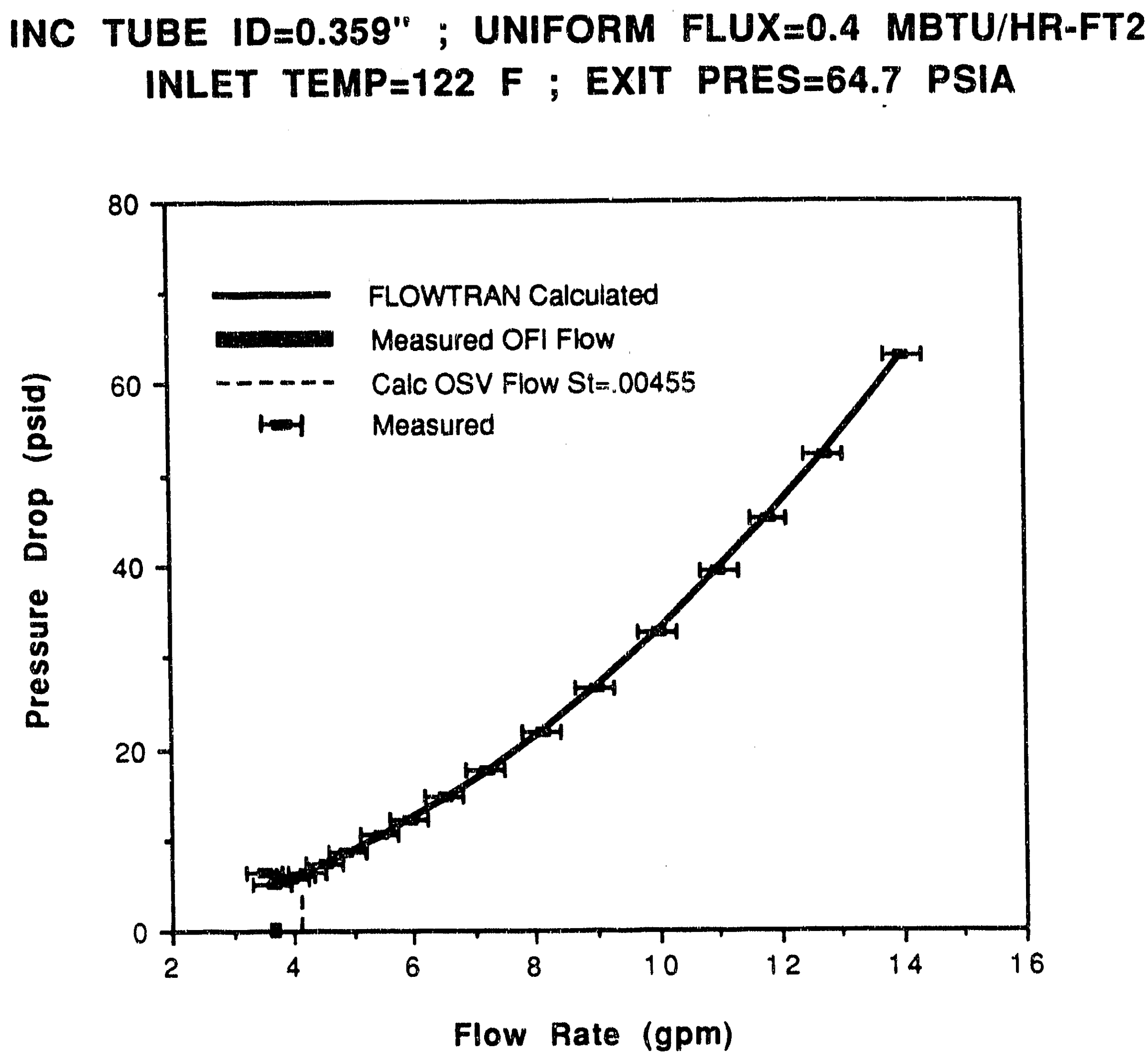

FIGURE A-17. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 9 - 09

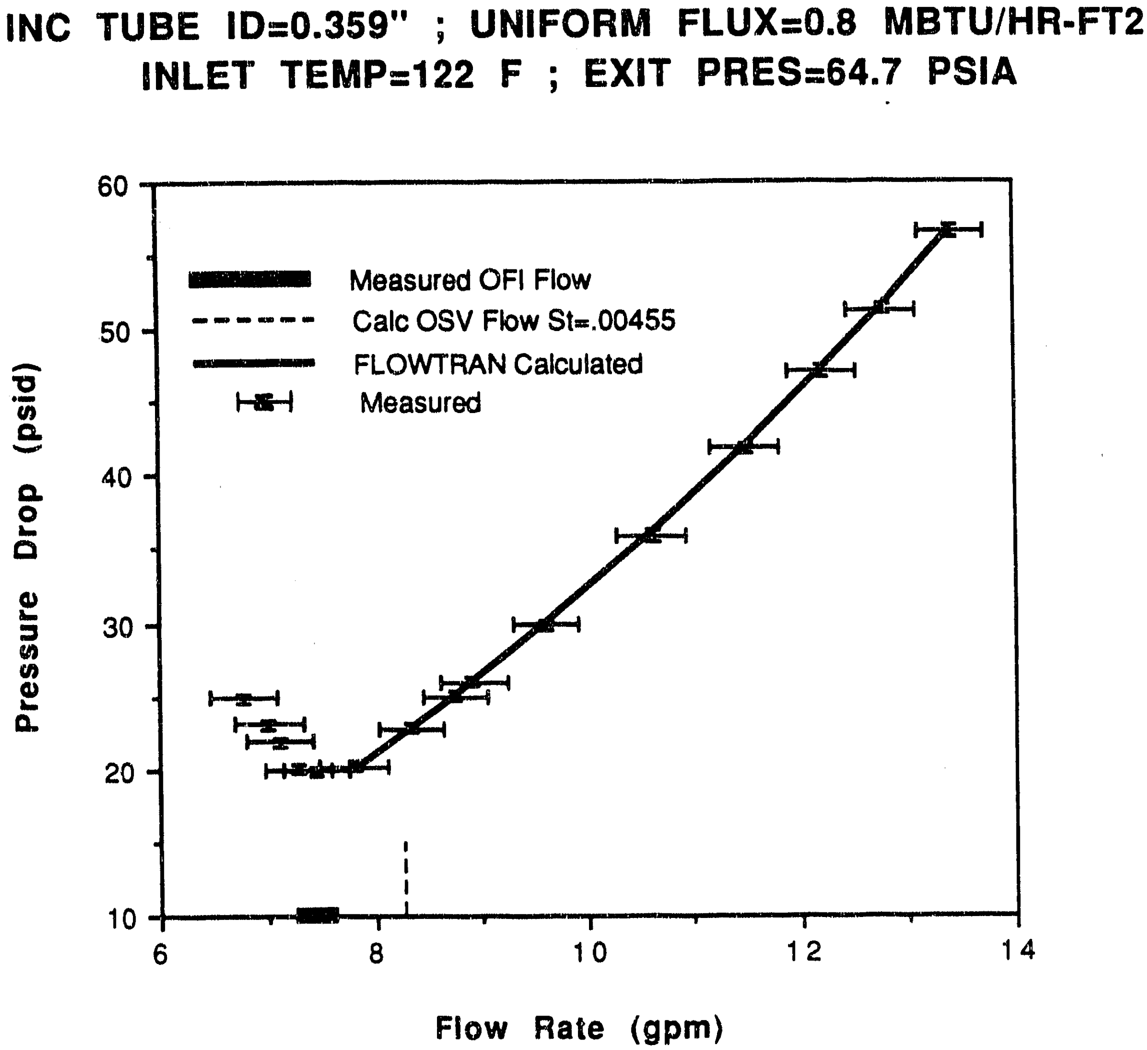

FIGURE A-18. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 9 - 10

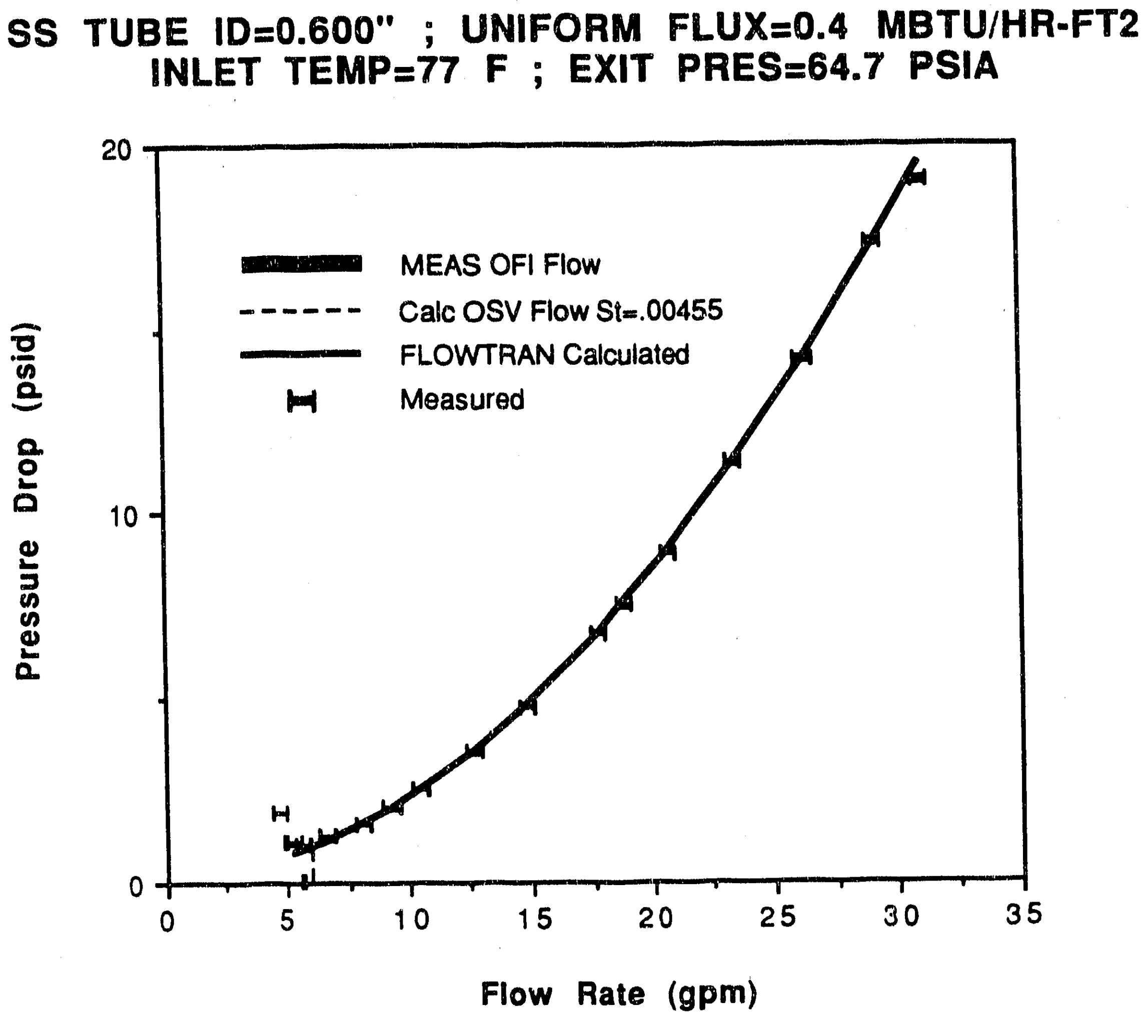

FIGURE A-19. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 7 - 01

SS TUBE ID=0.600" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=64.7 PSIA

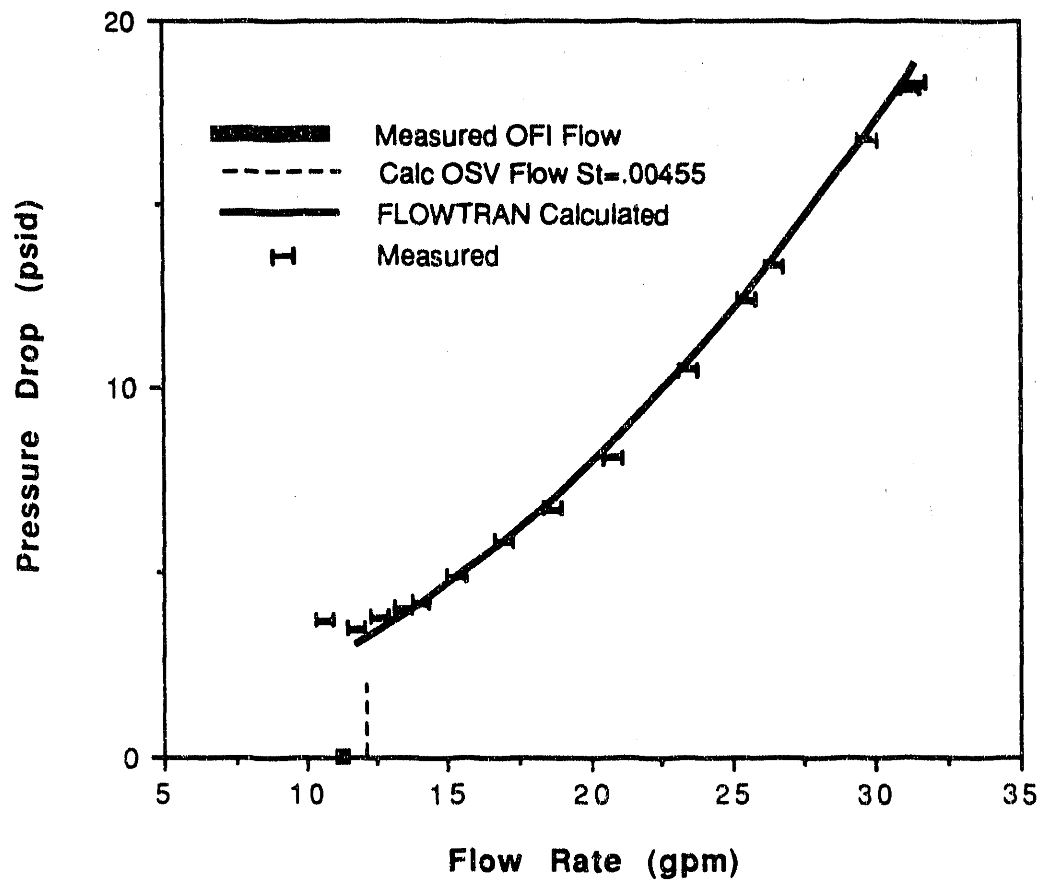

FIGURE A-20. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 7 - 02

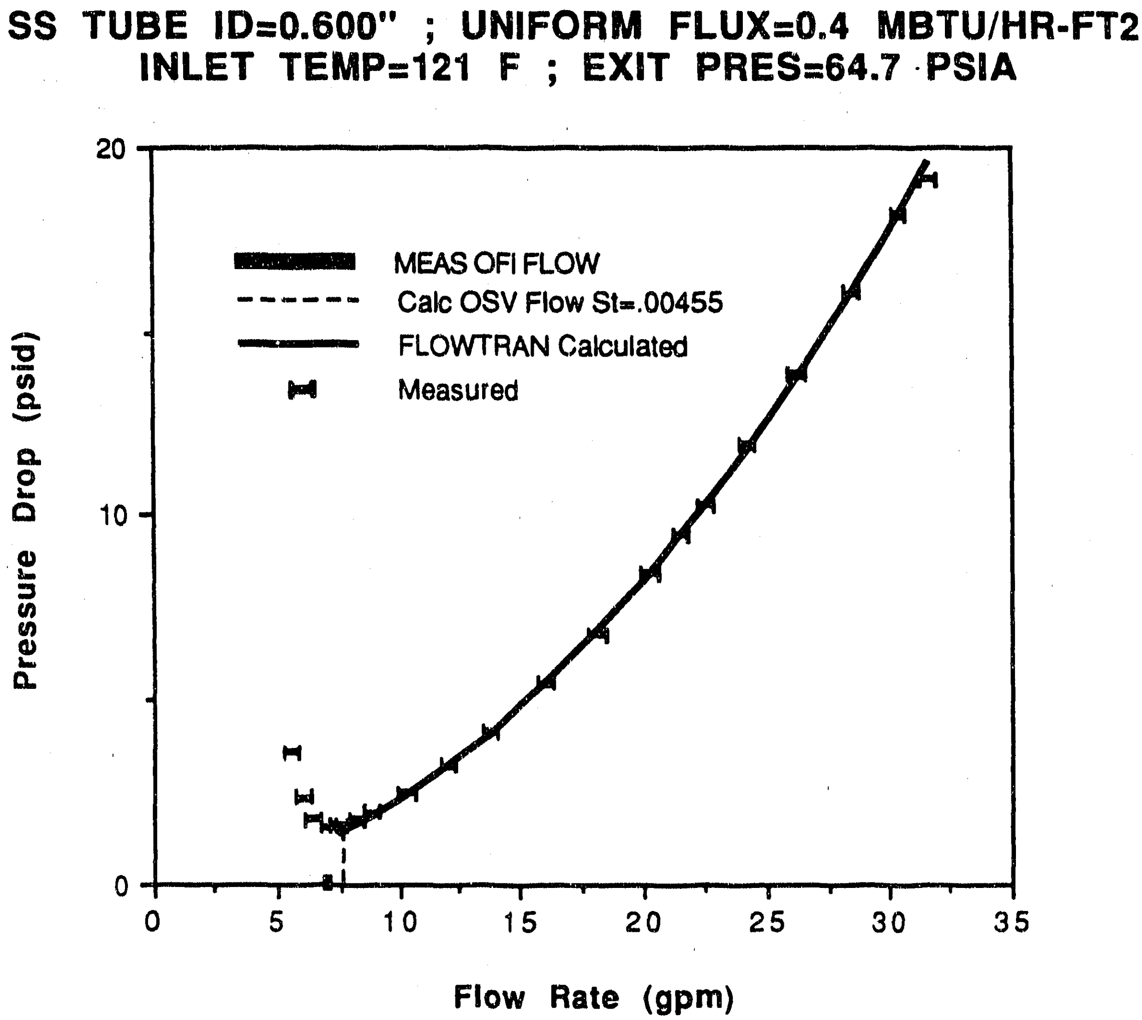

FIGURE A-21. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 7 - 03

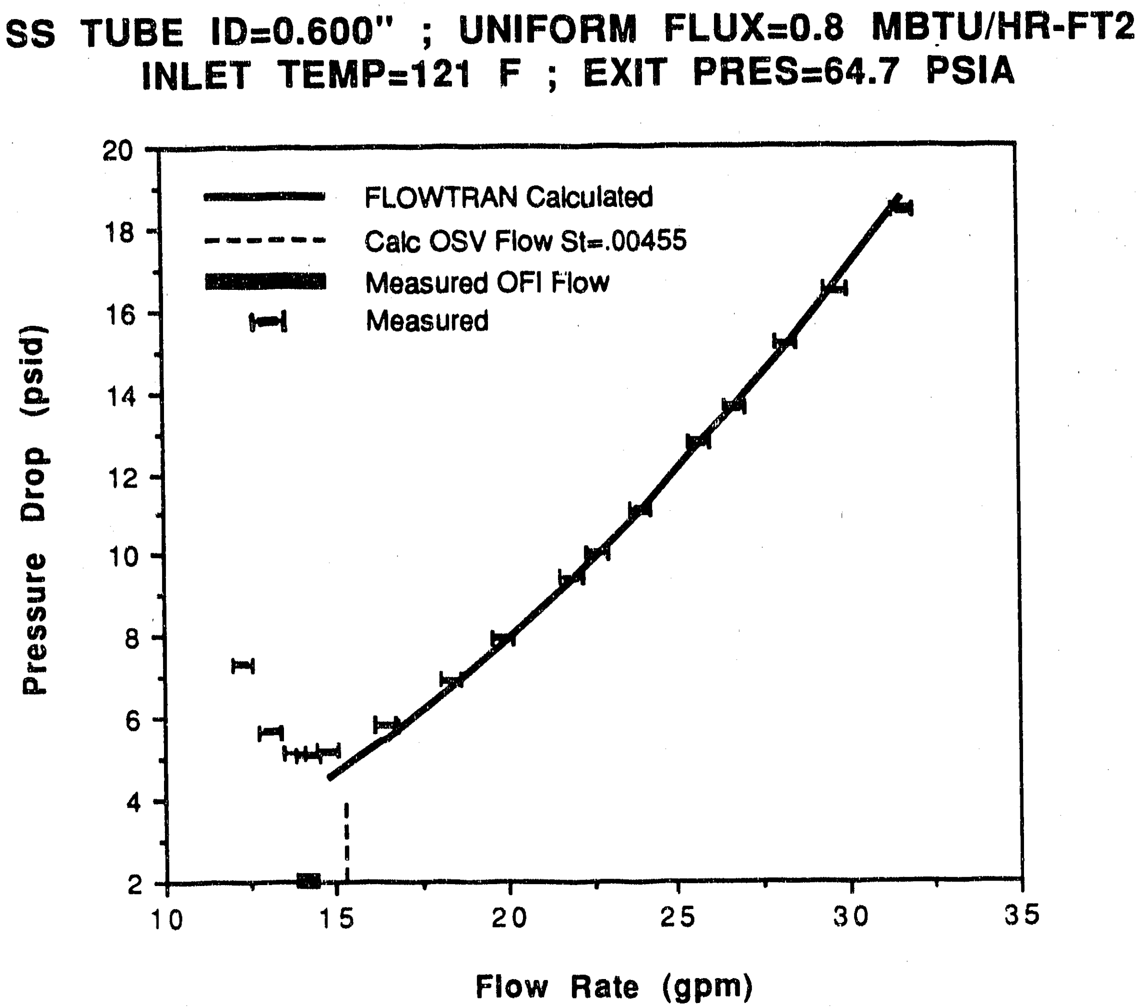

FIGURE A-22. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 7 - 04

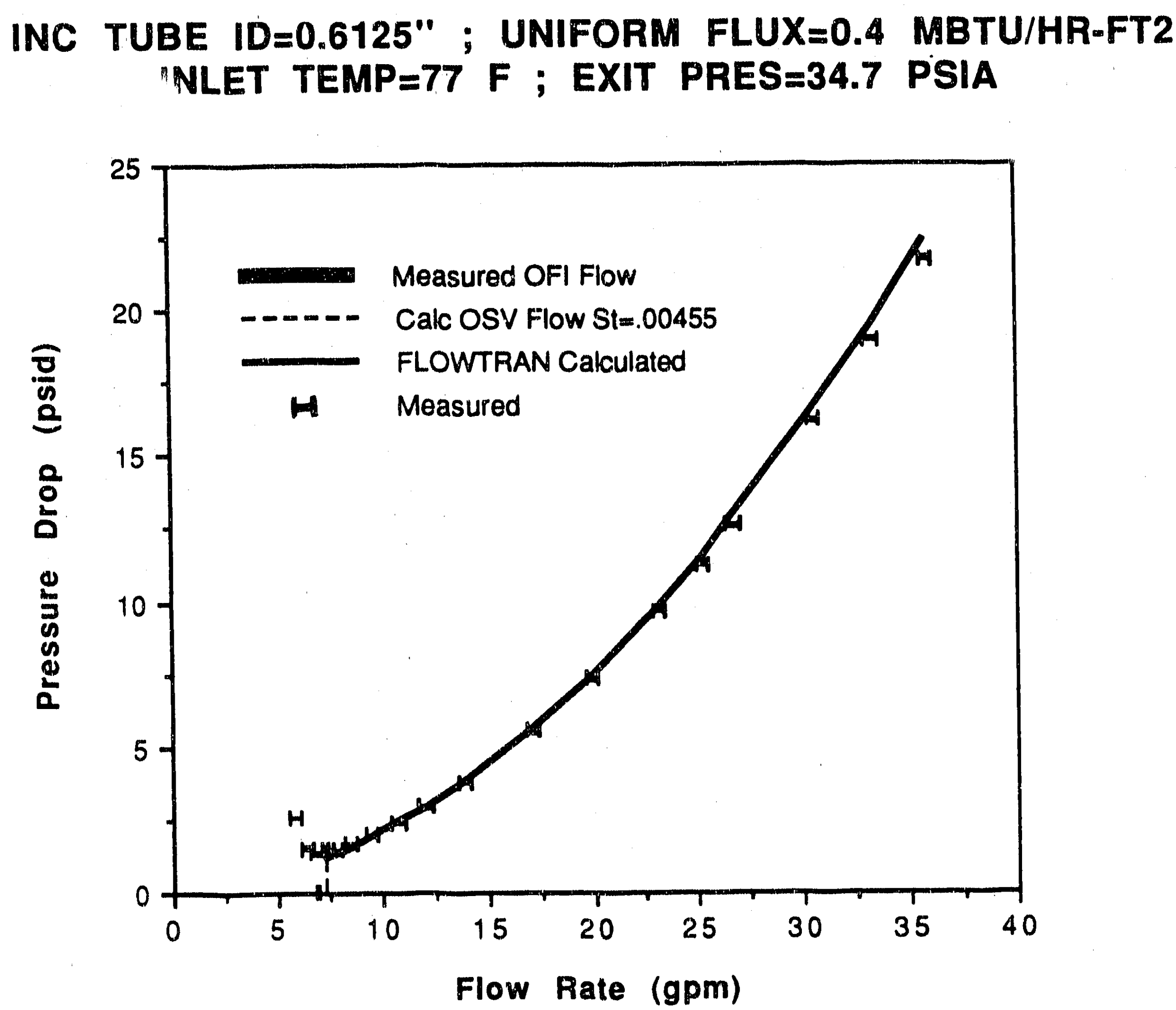

FIGURE A-23. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 01

INC TUBE ID=0.6125" ; UNIFORM FLUX=0.6 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=34.7 PSIA

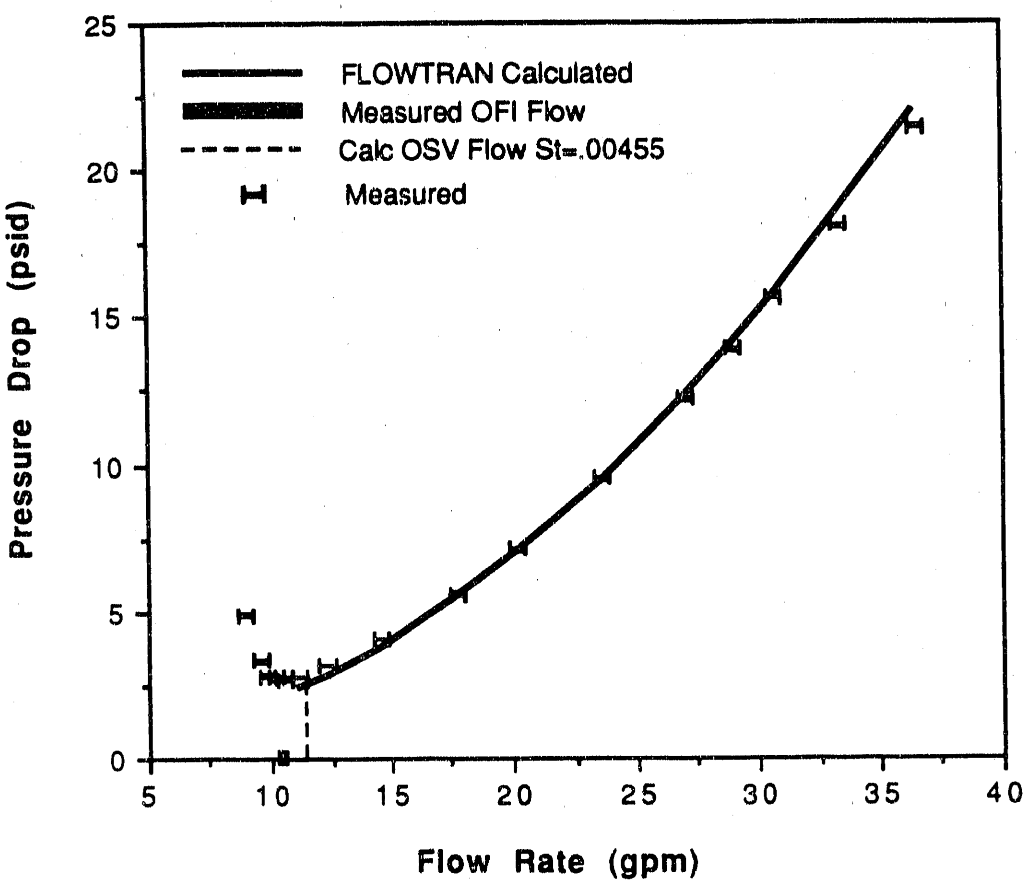

FIGURE A-24. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 02

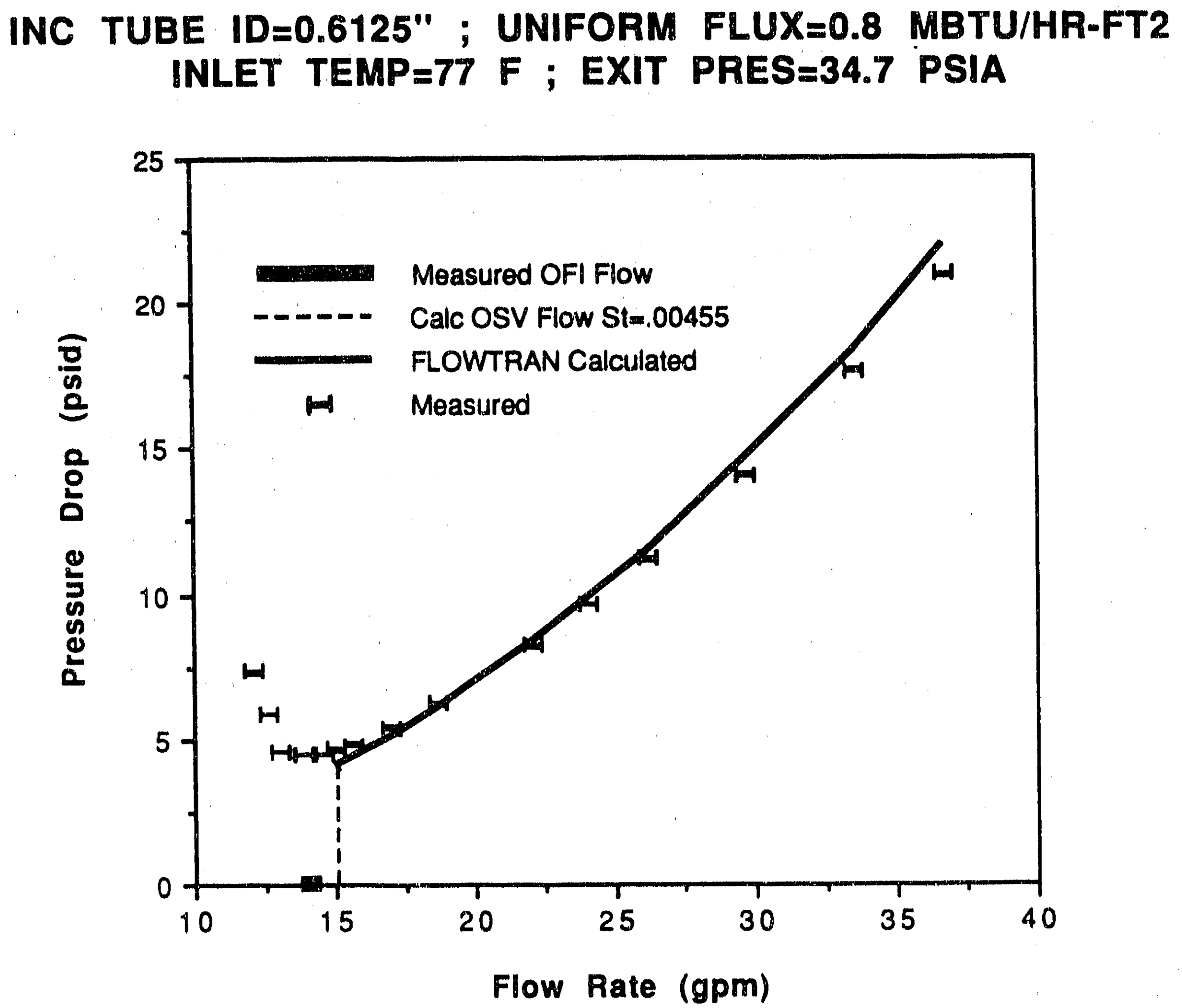

FIGURE A-25. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 03

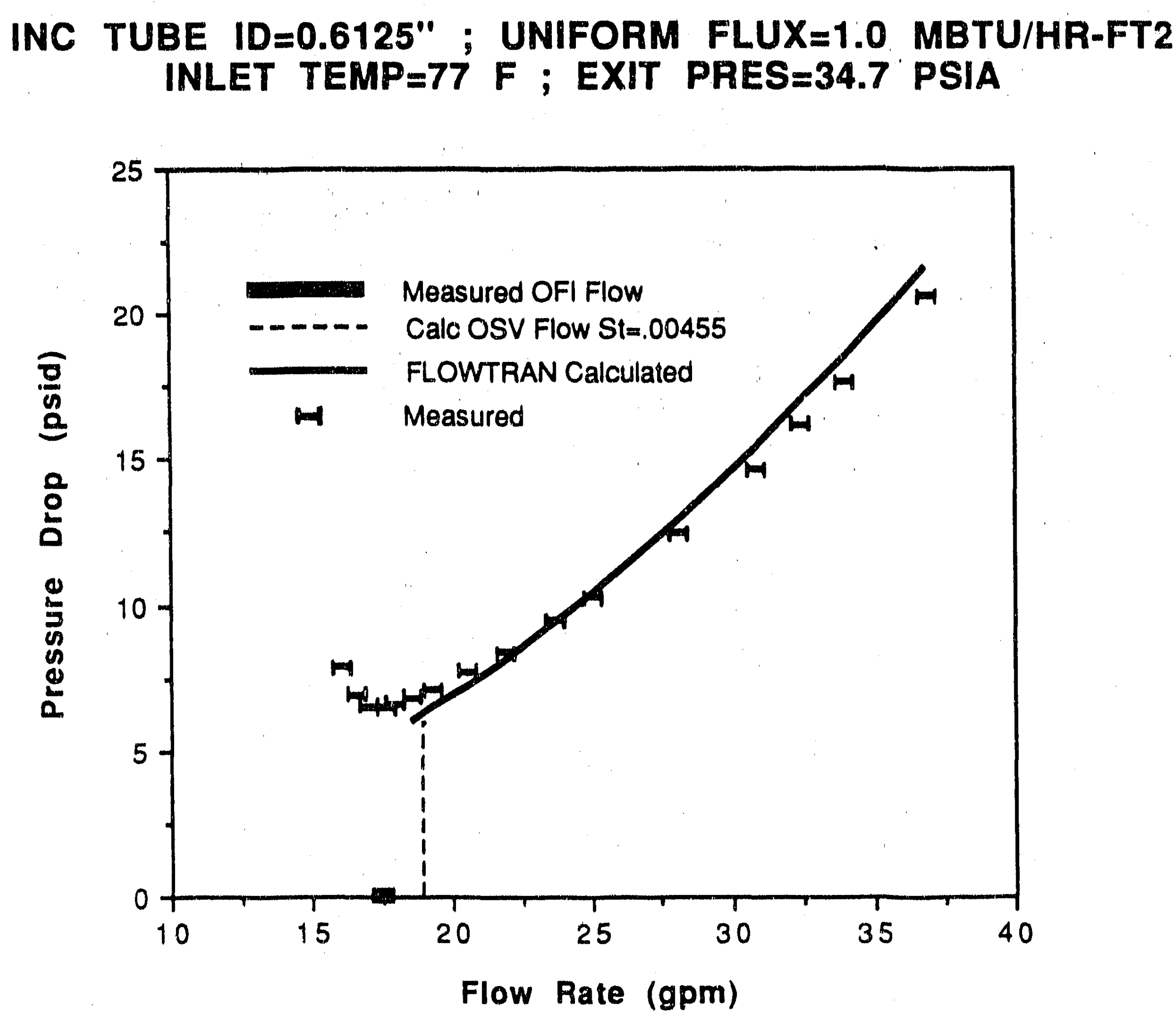

FIGURE A-26. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 04

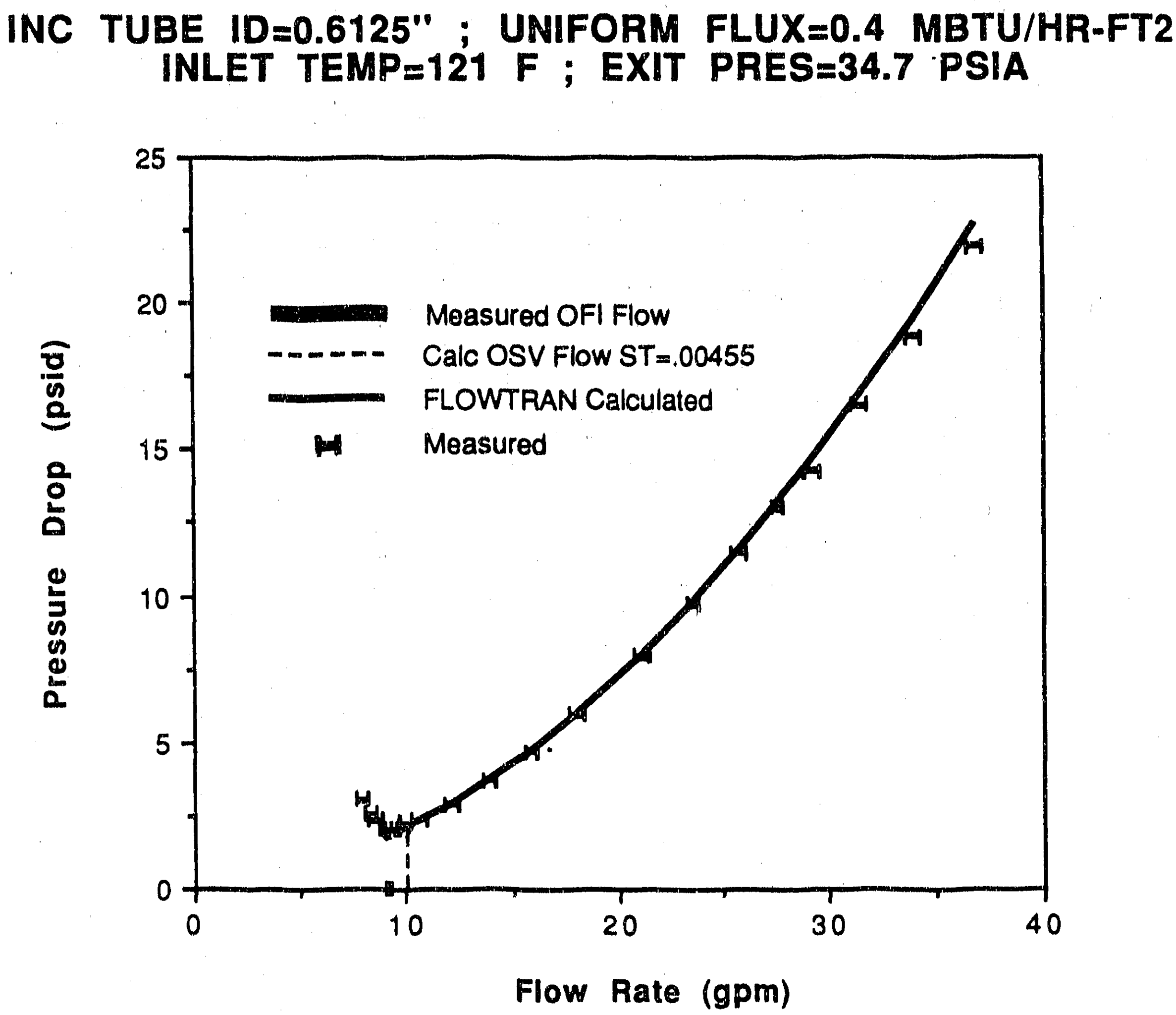

FIGURE A-27. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 05

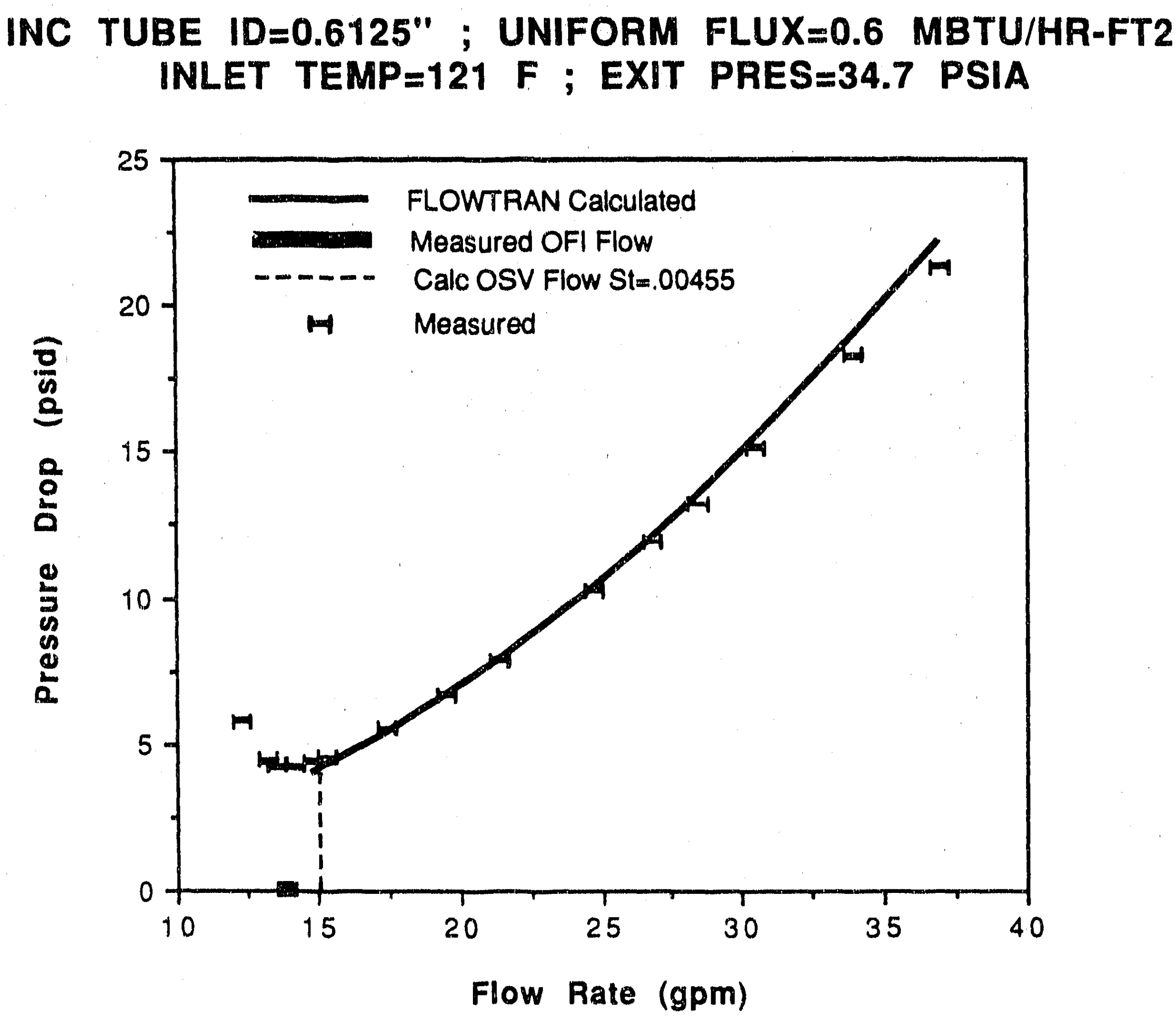

FIGURE A-28. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 06

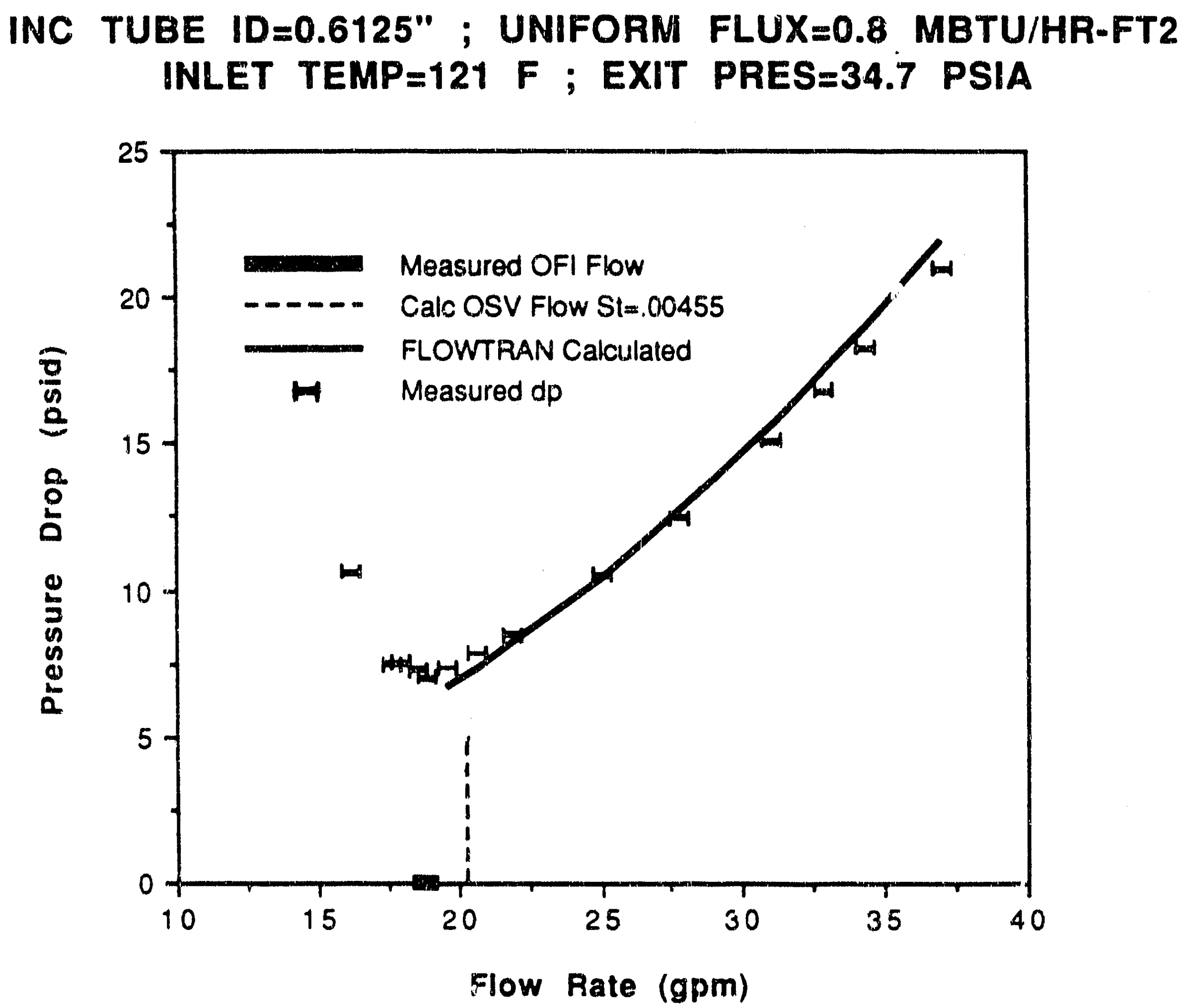

FIGURE A-29. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 07

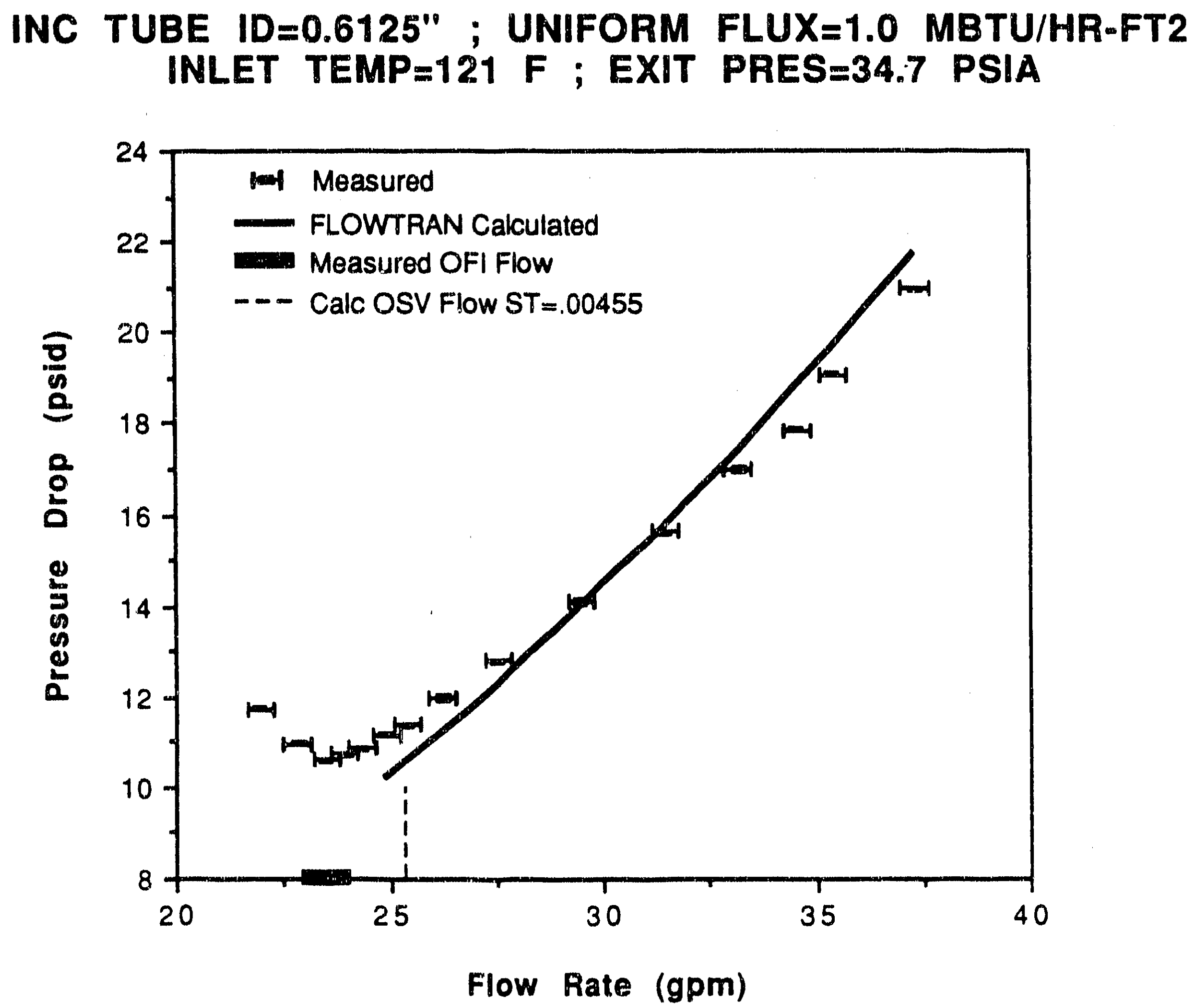

FIGURE A-30. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 08

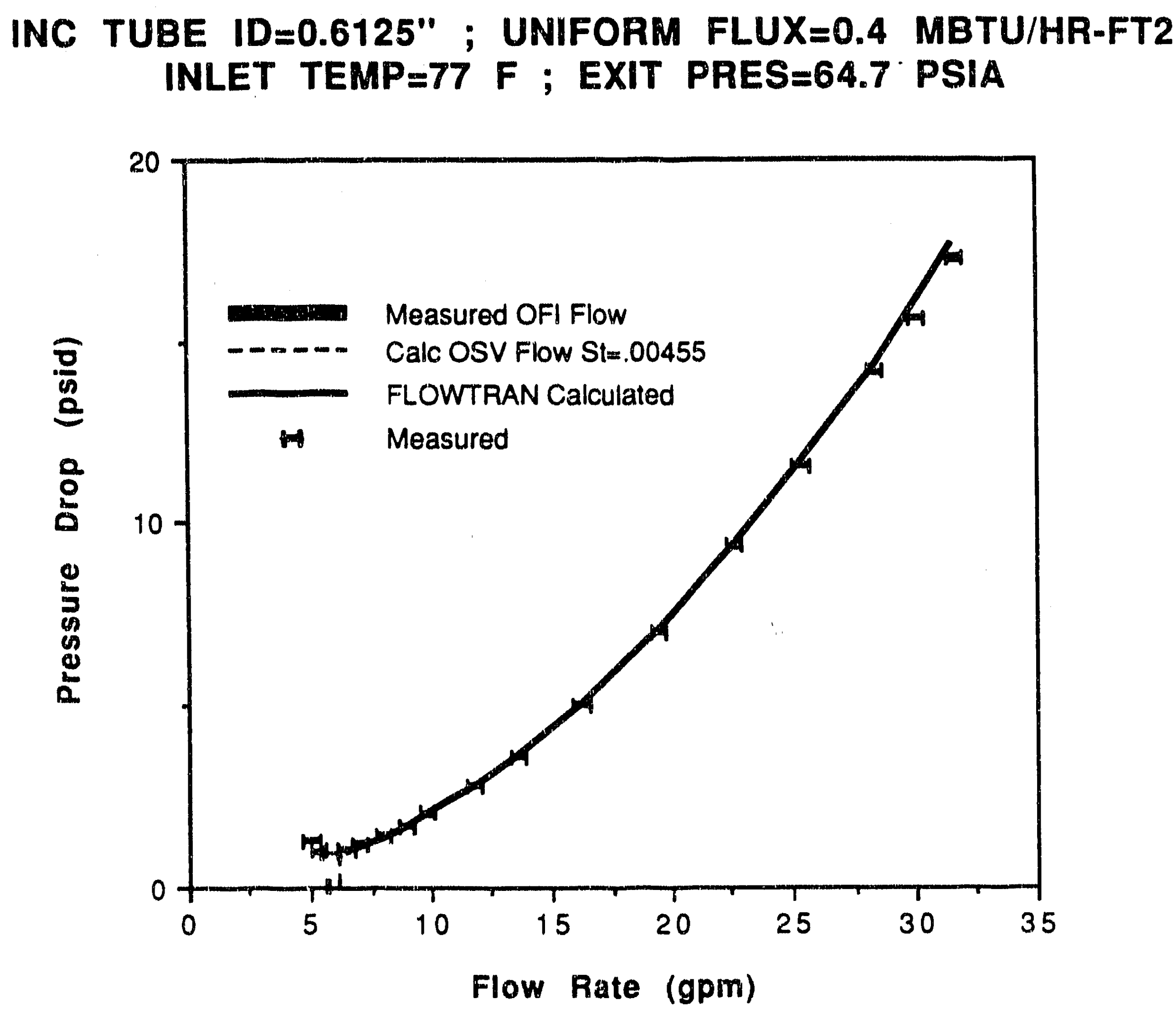

FIGURE A-31. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 09

INC TUBE ID=0.6125" ; UNIFORM FLUX=0.6 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=64.7 PSIA

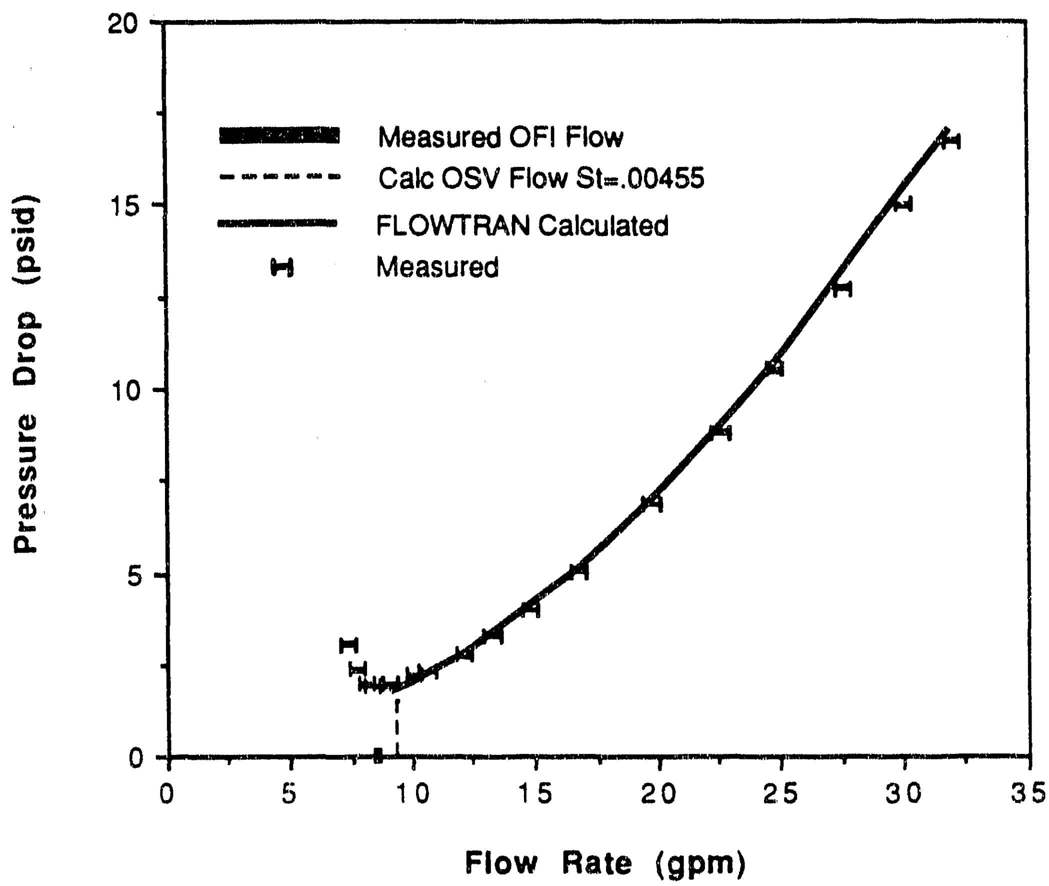

FIGURE A-32. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 10

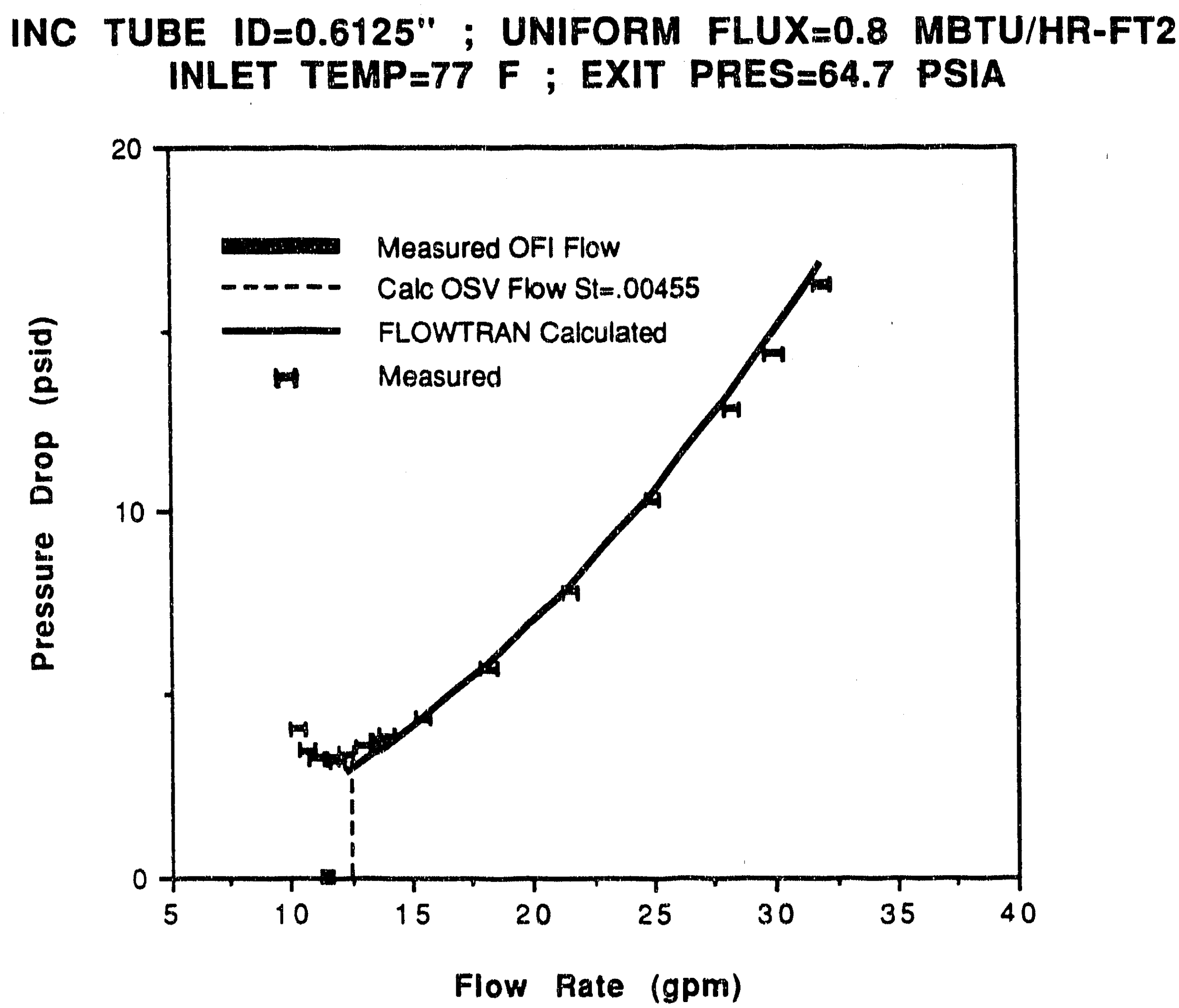

FIGURE A-33. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 11

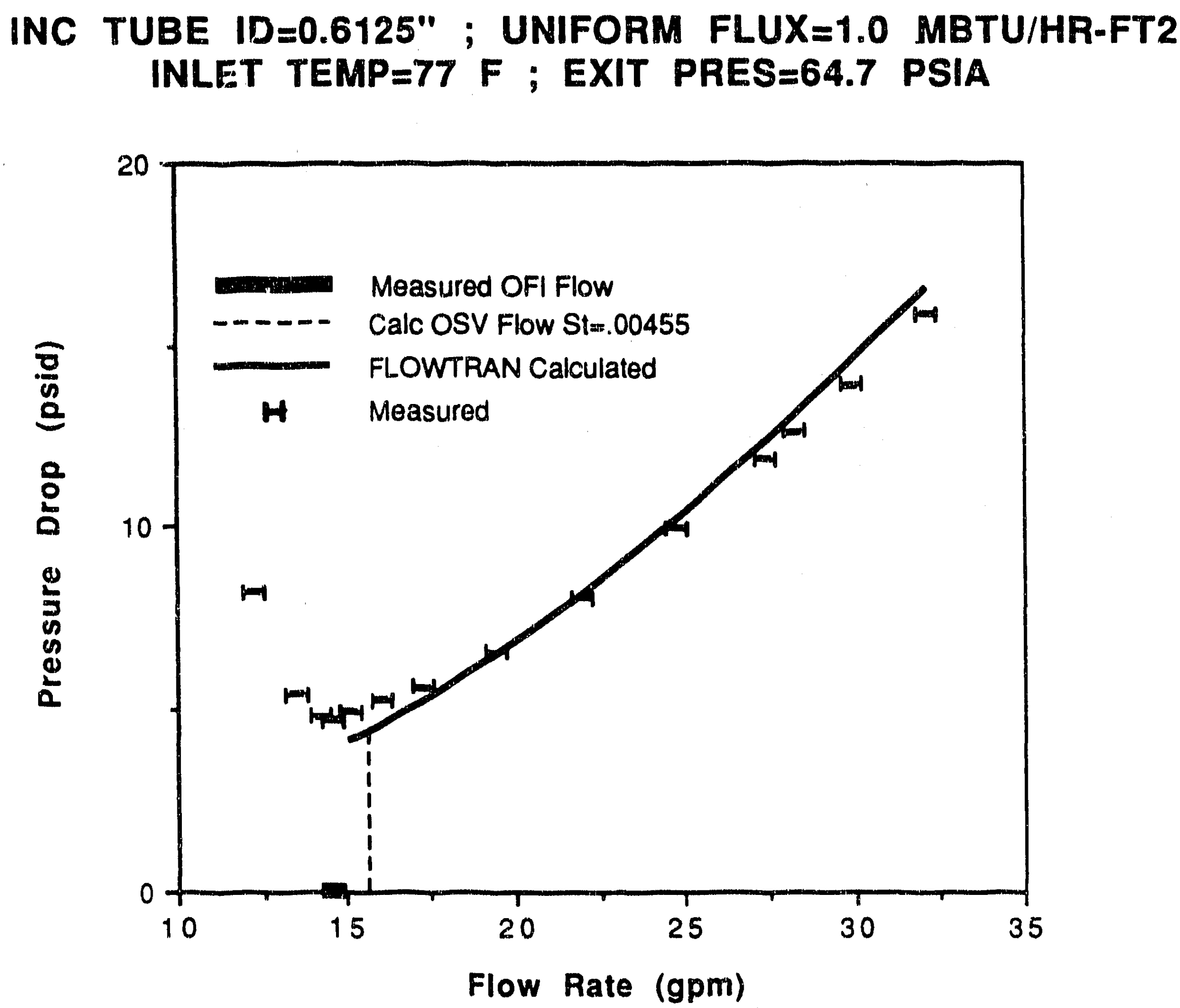

FIGURE A-34. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 12

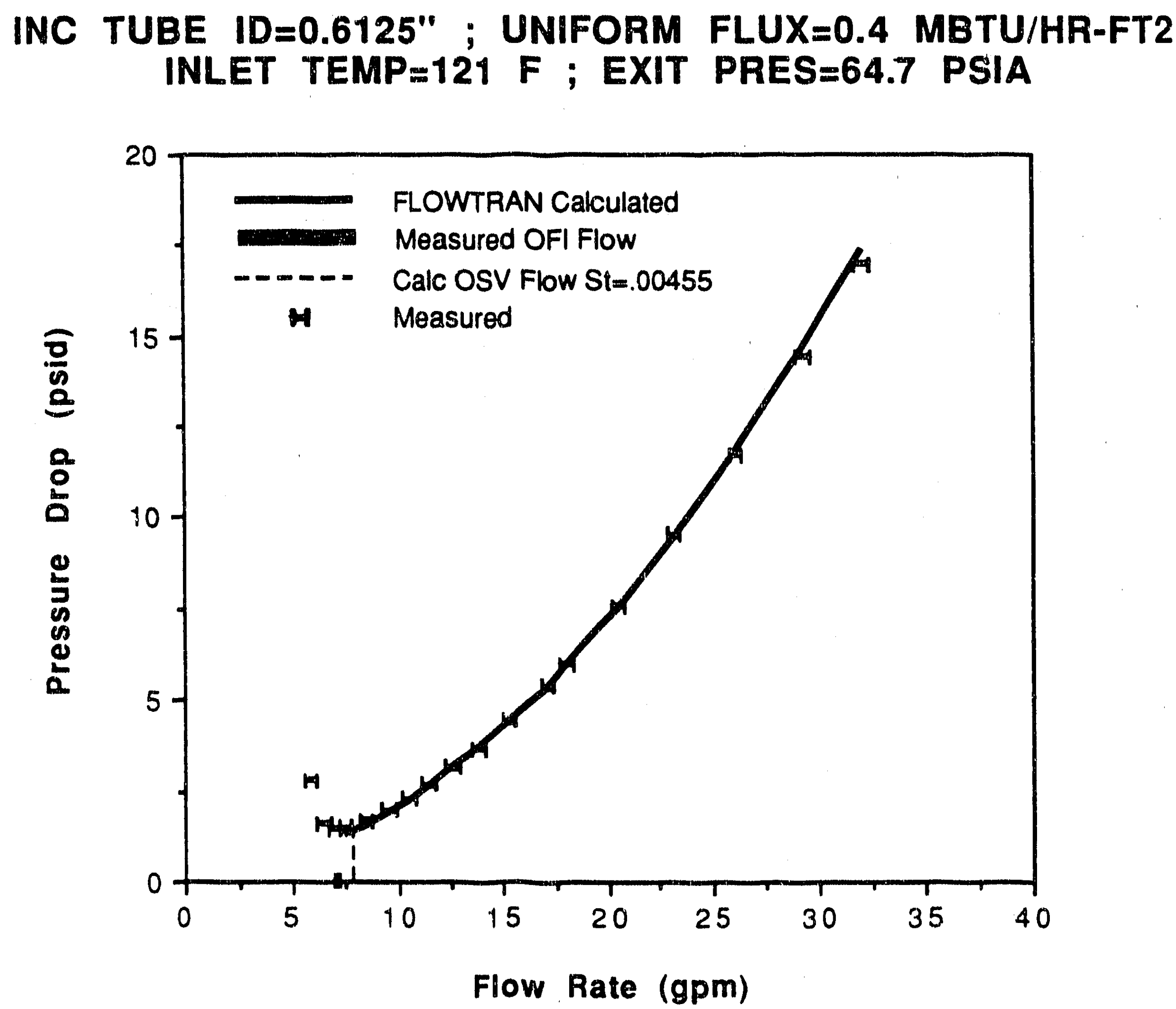

FIGURE A-35. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 13

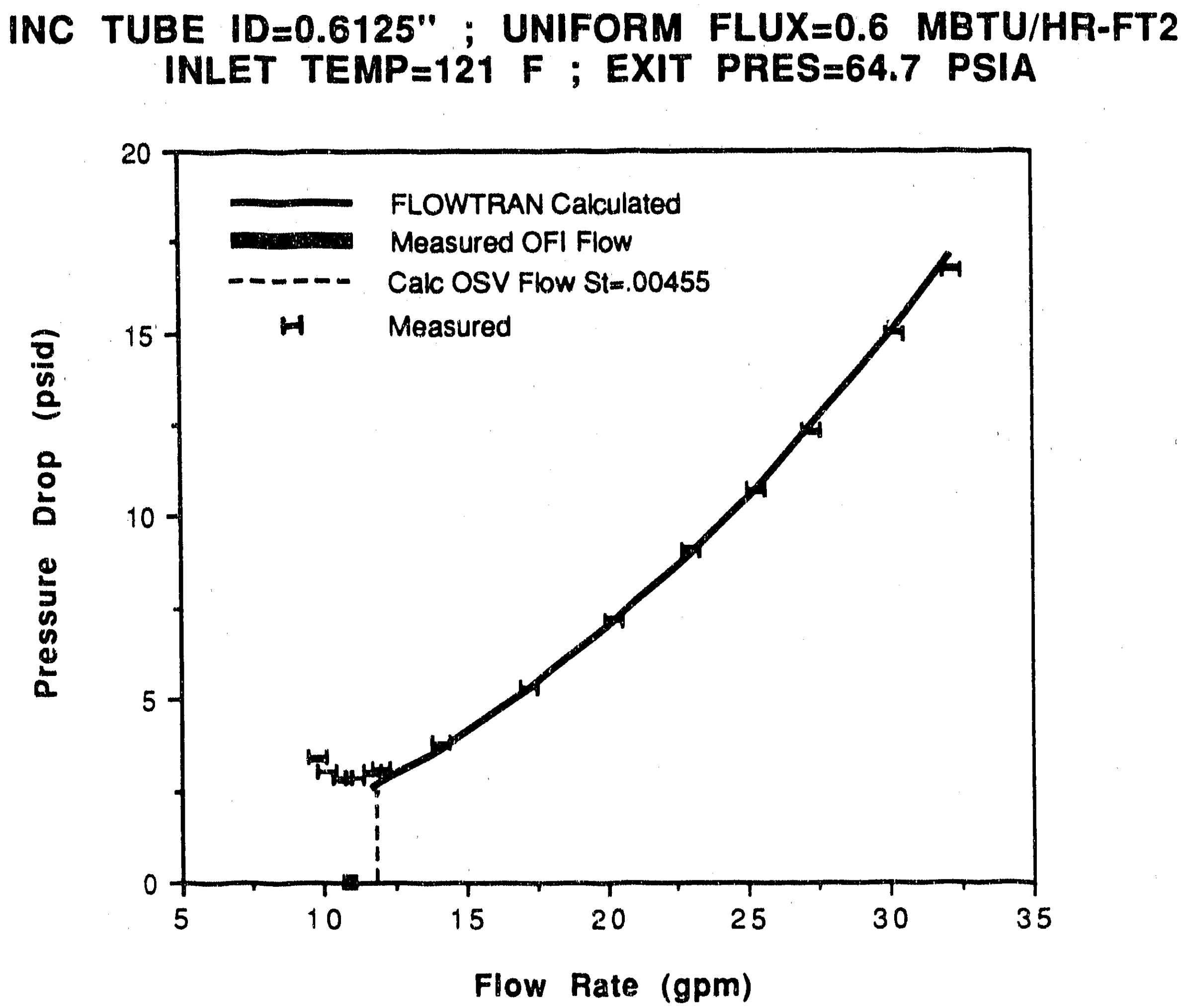

FIGURE A-36. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 14

INC TUBE ID=0.6125" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=121 F ; EXIT PRES=64.7 PSIA

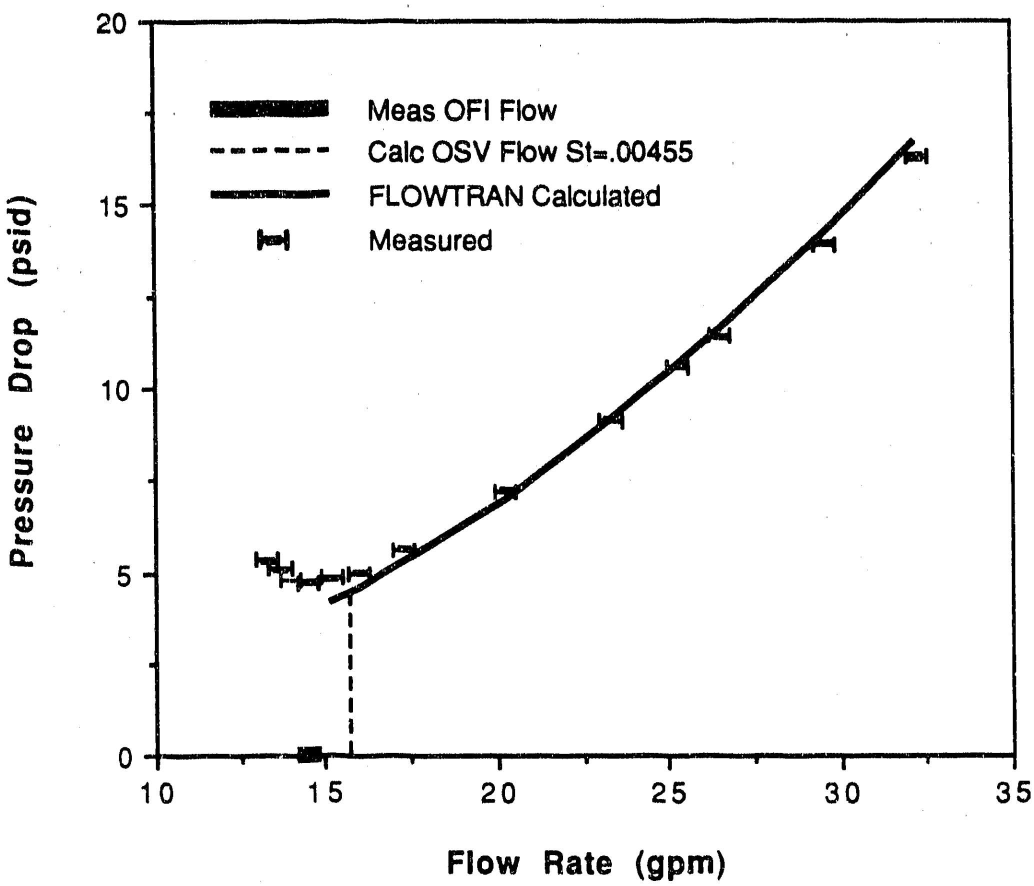

FIGURE A-37. MEASURED DATA AND FLOWTRAN PREDICTIONS
FOR TEST RUN 4 - 15

INC TUBE ID=0.6125" ; UNIFORM FLUX=1.0 MBTU.HR-FT2
INLET TEMP=121 F ; EXIT PRES=64.7 PSIA

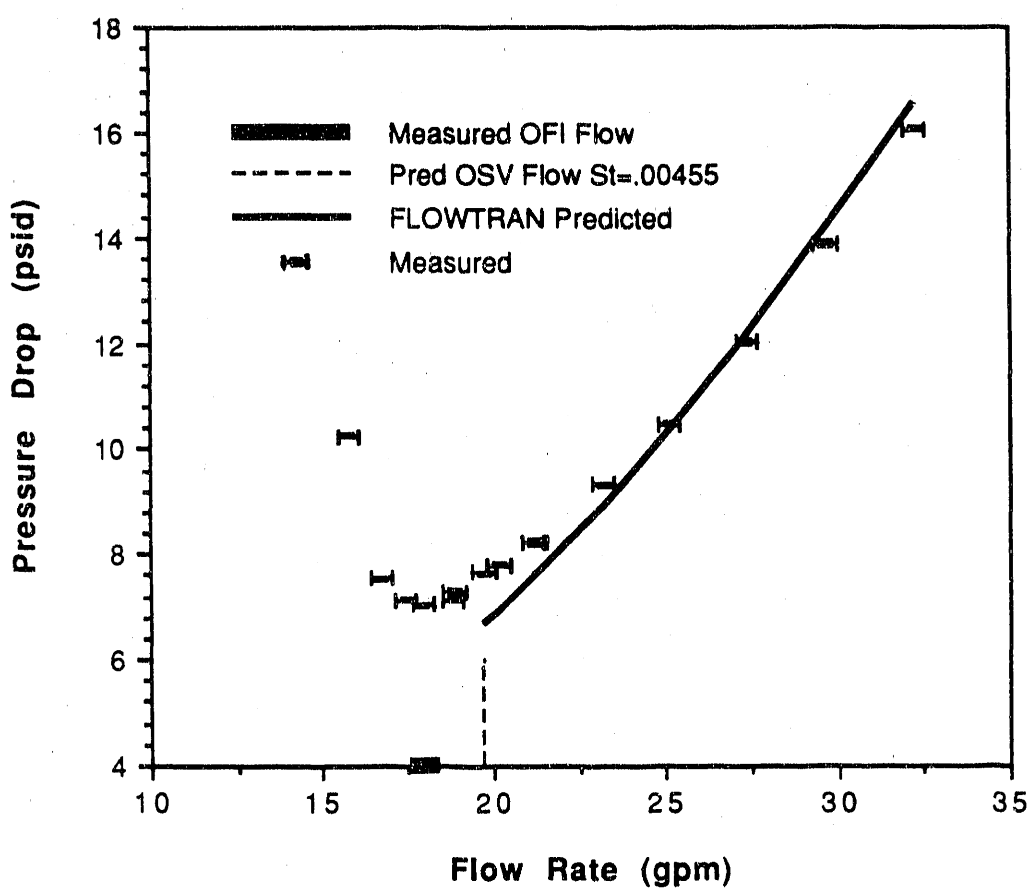

FIGURE A-38. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 4 - 16

SS TUBE ID=0.7516" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=34.7 PSIA

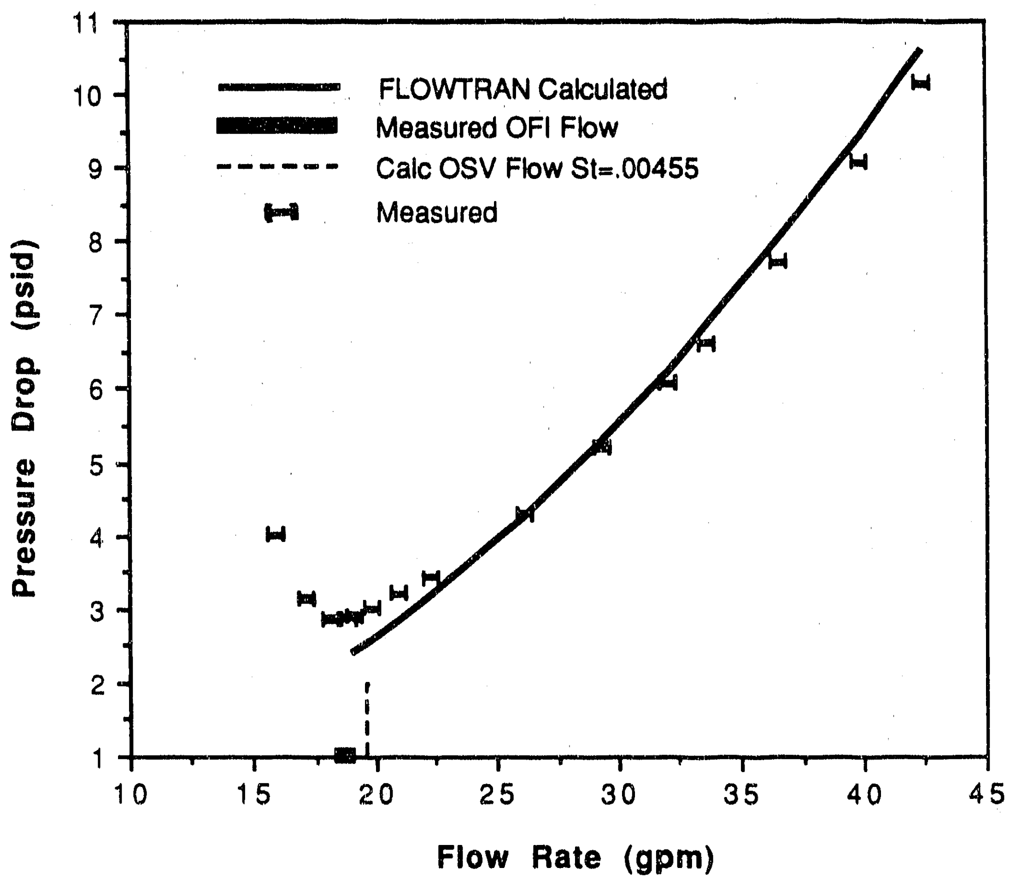

FIGURE A-39. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 01

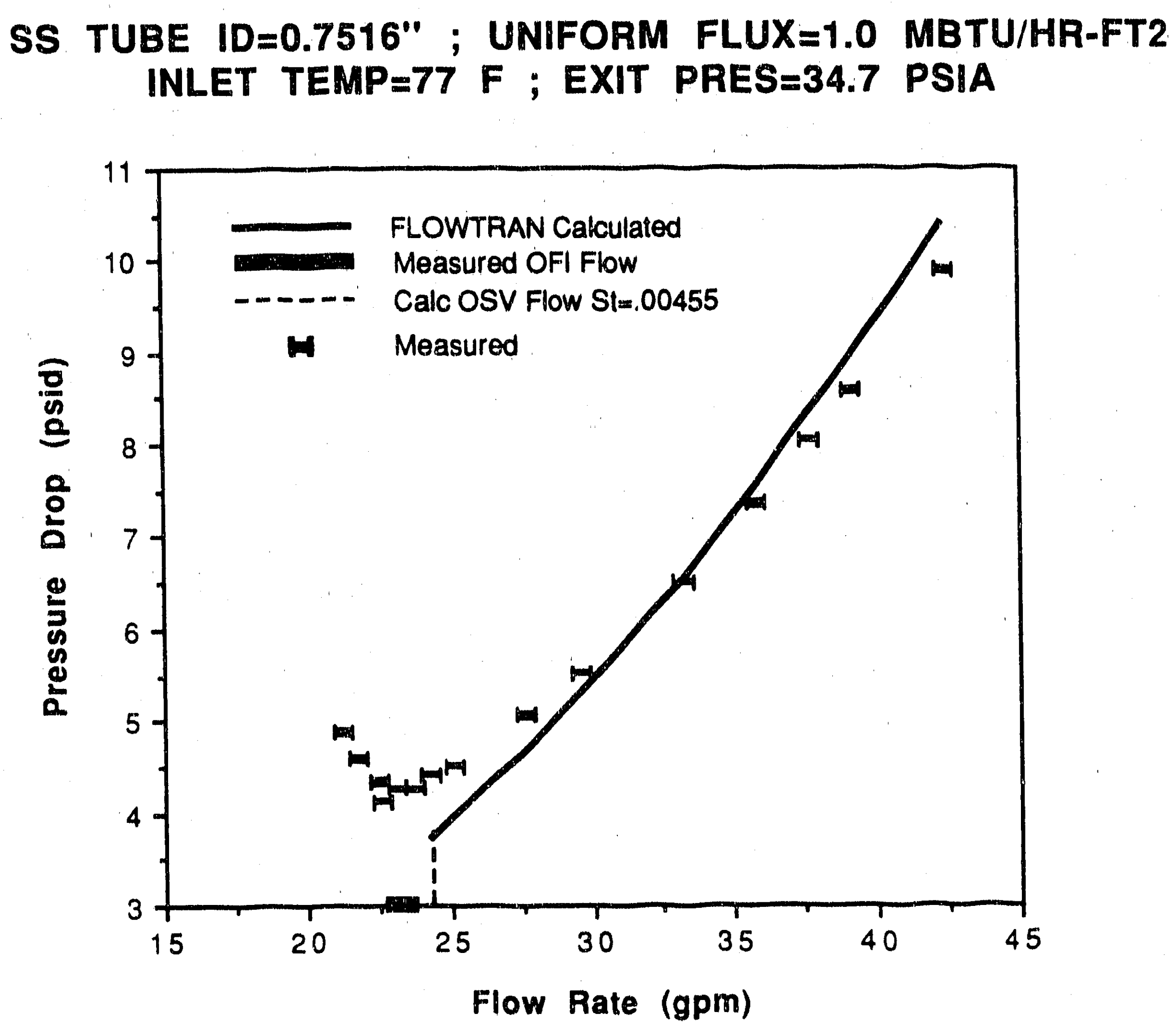

FIGURE A-40. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 02

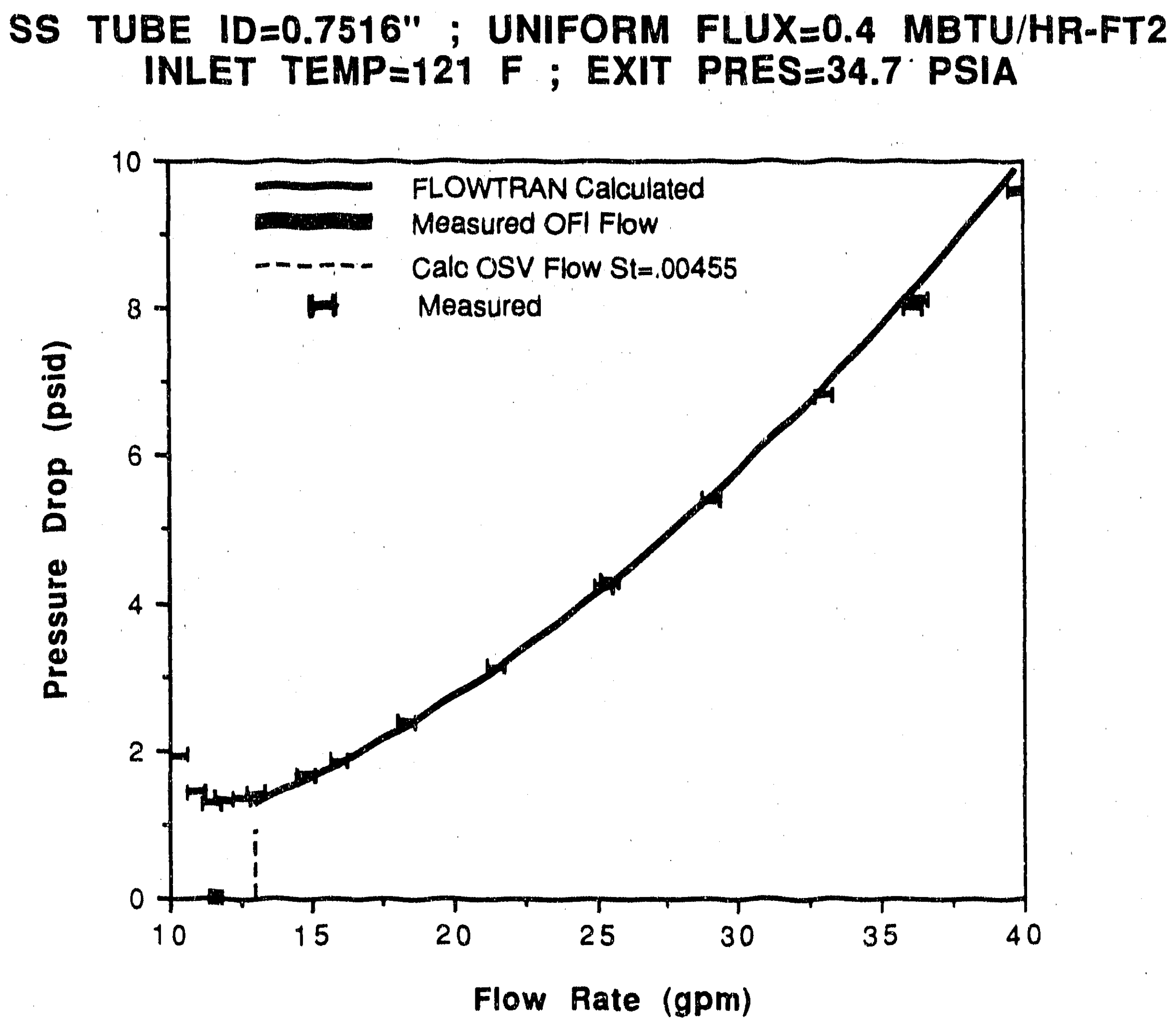

FIGURE A-41. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 03

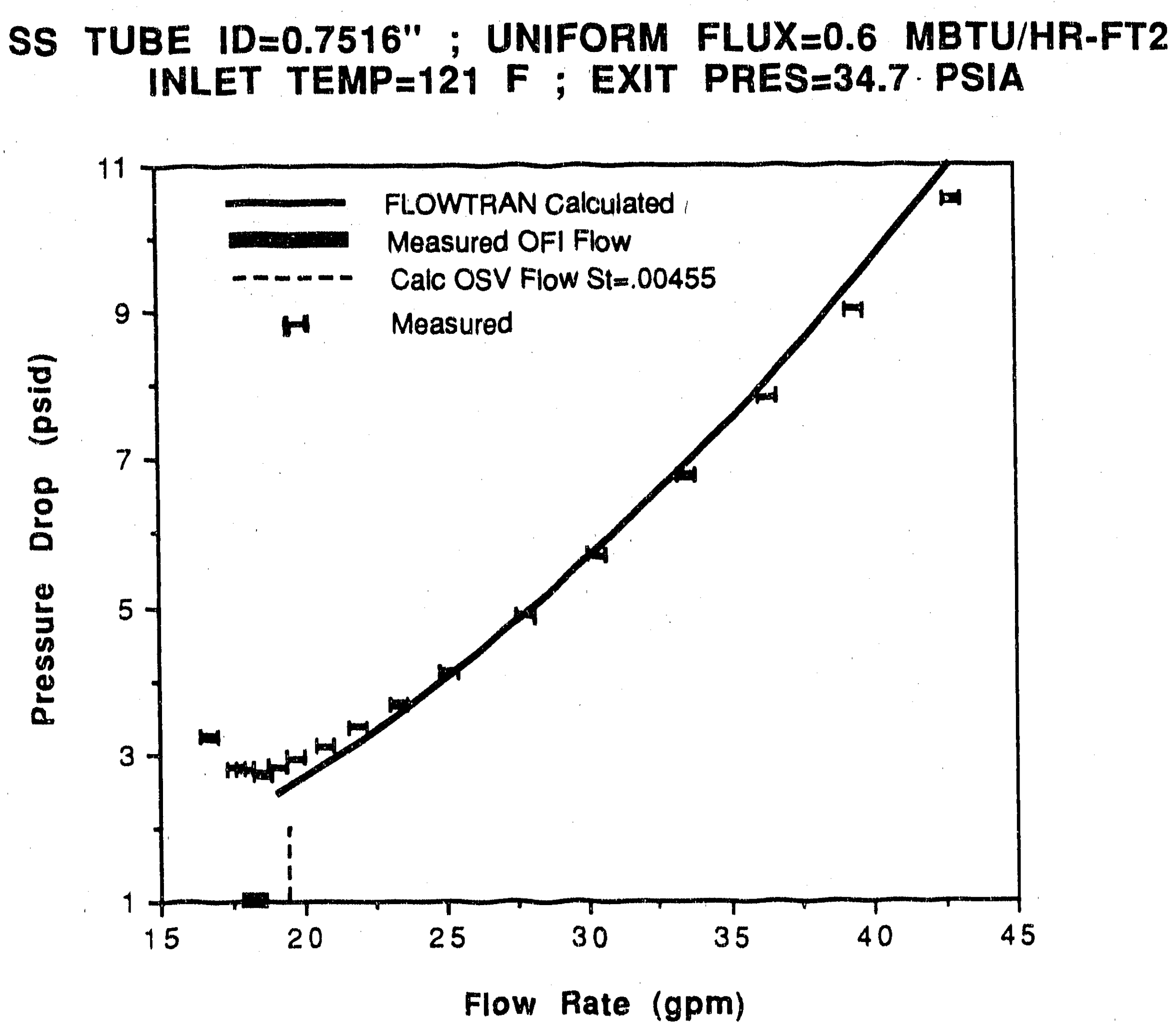

FIGURE A-42. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 04

SS TUBE ID=0.7516" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=121 F ; EXIT PRES=34.7 PSIA

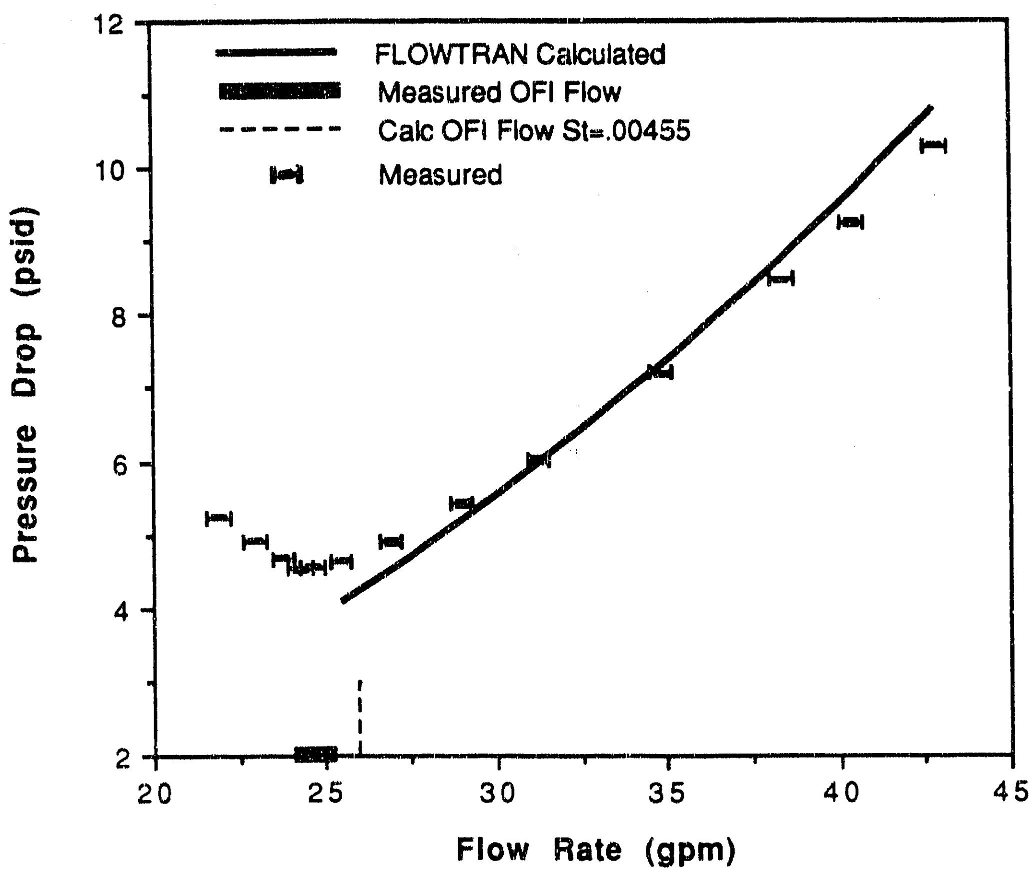

FIGURE A-43. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 05

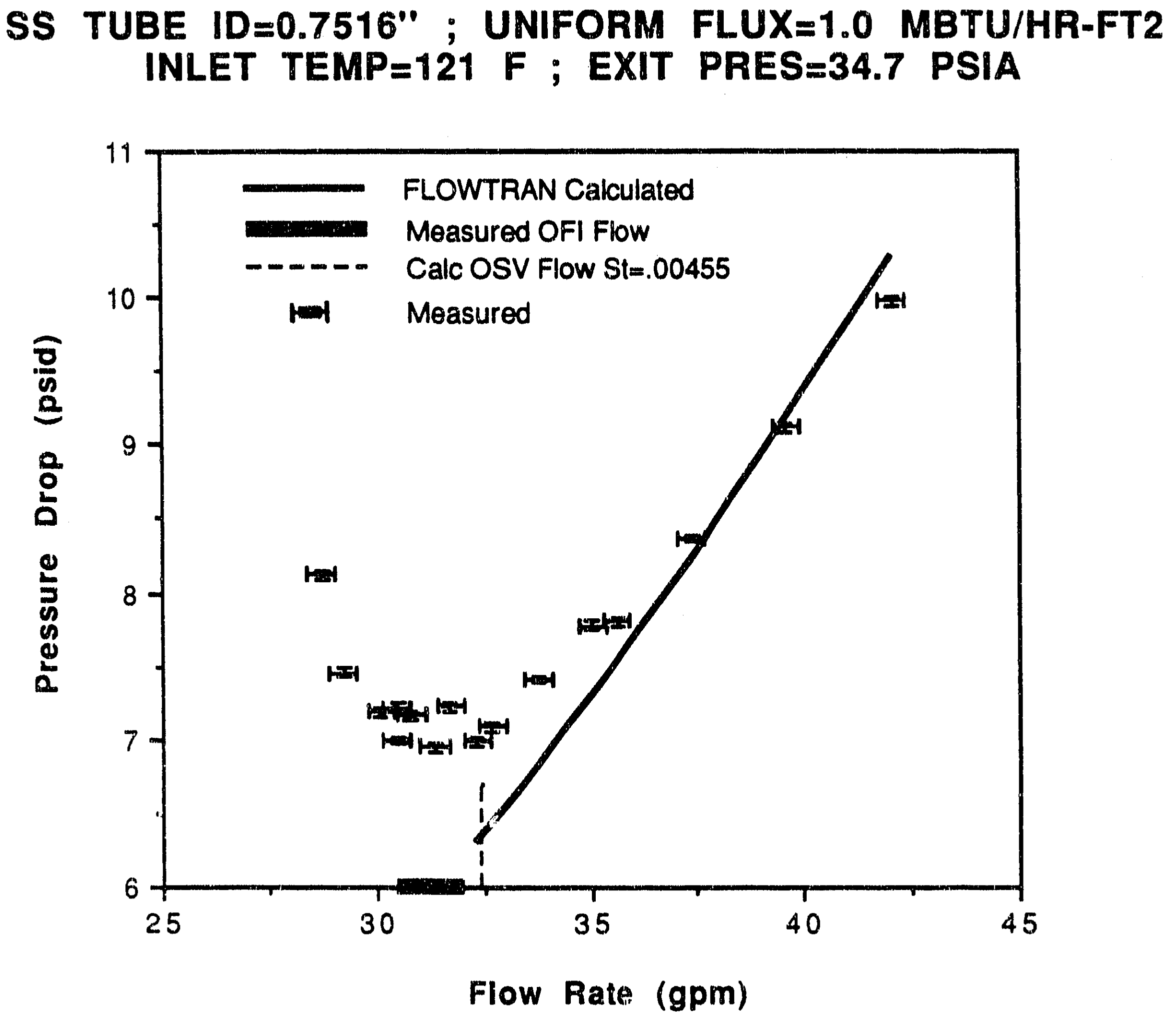

FIGURE A-44. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 06

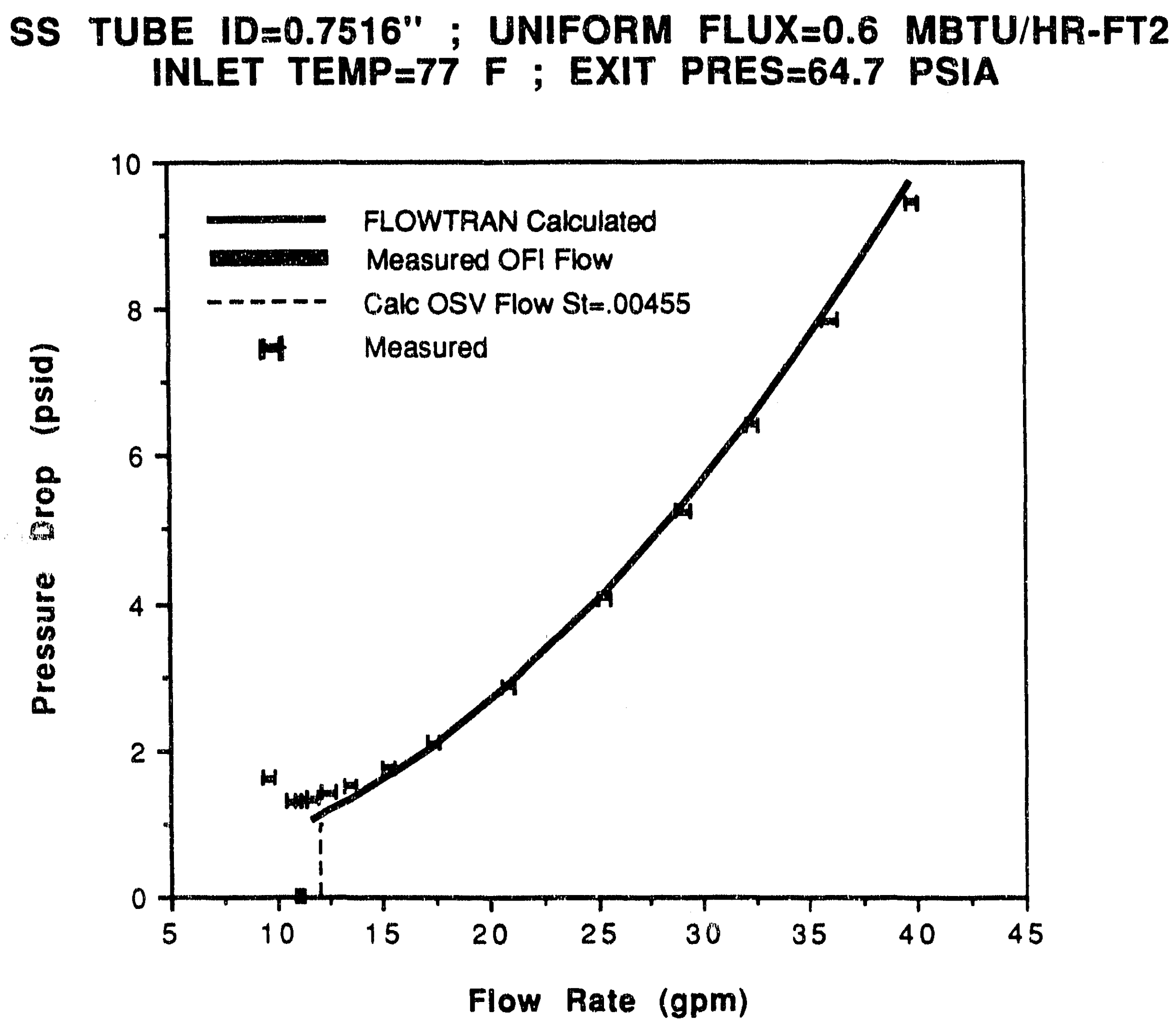

FIGURE A-45. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 07

SS TUBE ID=0.7516" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=64.7 PSIA

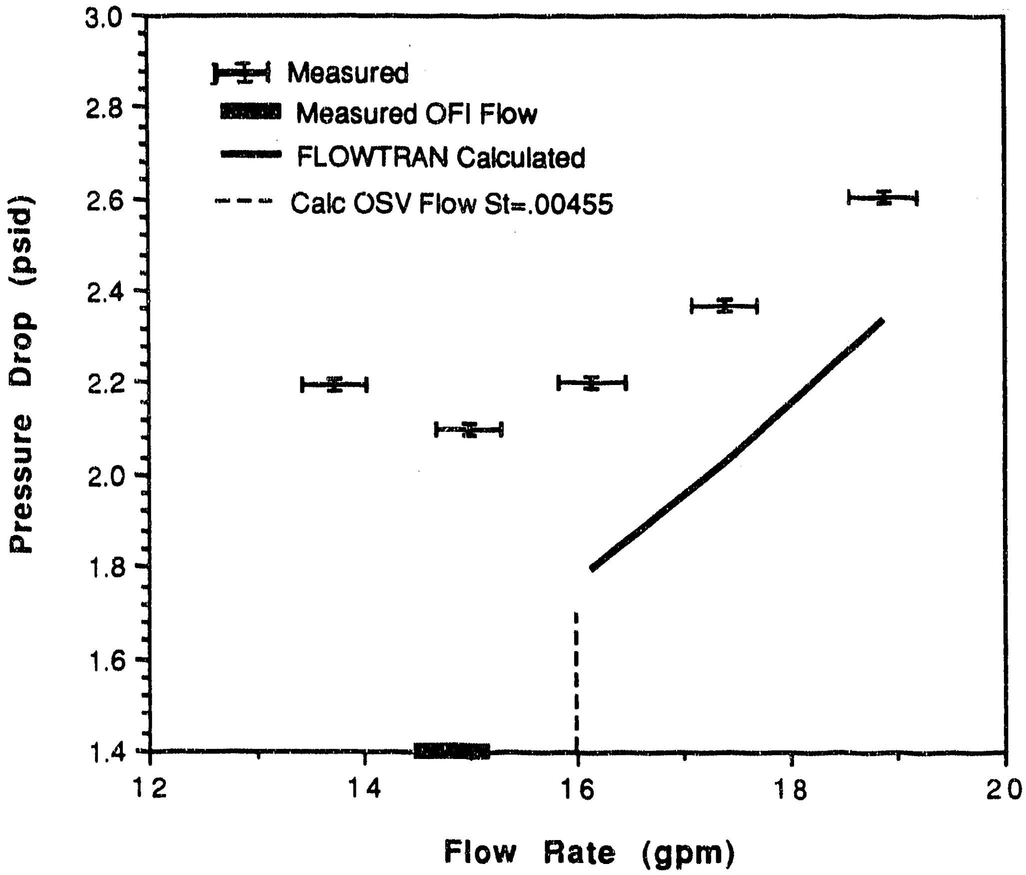

FIGURE A-46. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 08

SS TUBE ID=0.7516" ; UNIFORM FLUX=1.0 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=64.7 PSIA

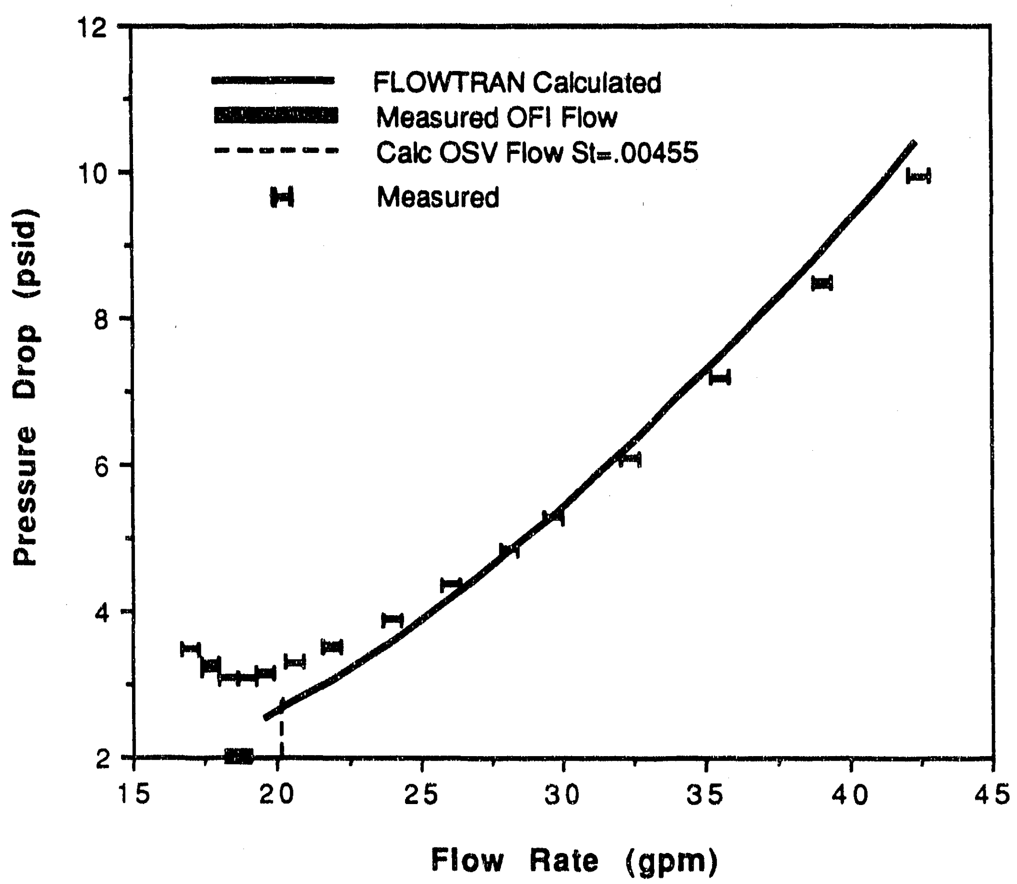

FIGURE A-47. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 09

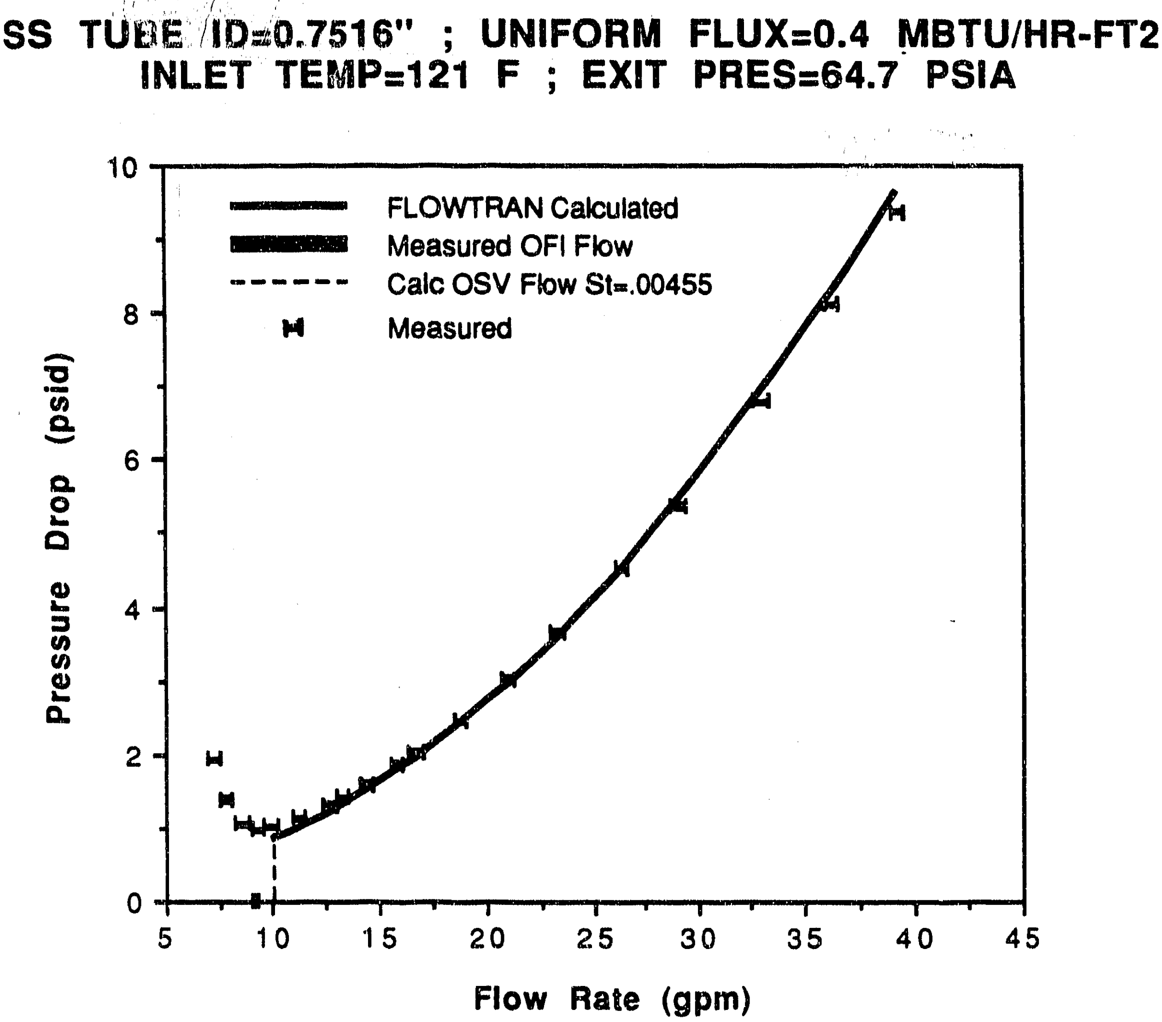

FIGURE A-48. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 10

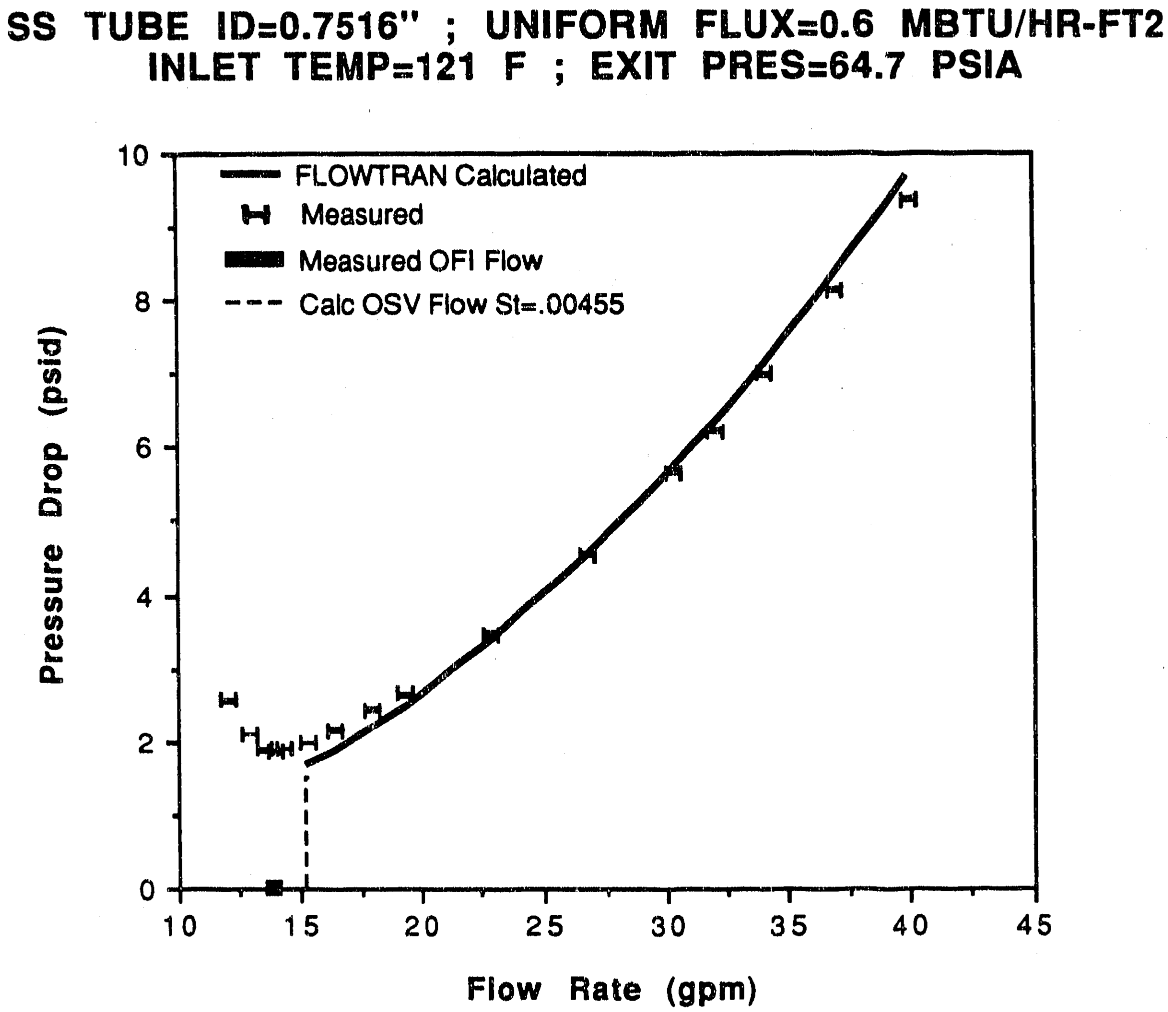

FIGURE A-49. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 11

SS TUBE ID=0.7516" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=121 F ; EXIT PRES=64.7 PSIA

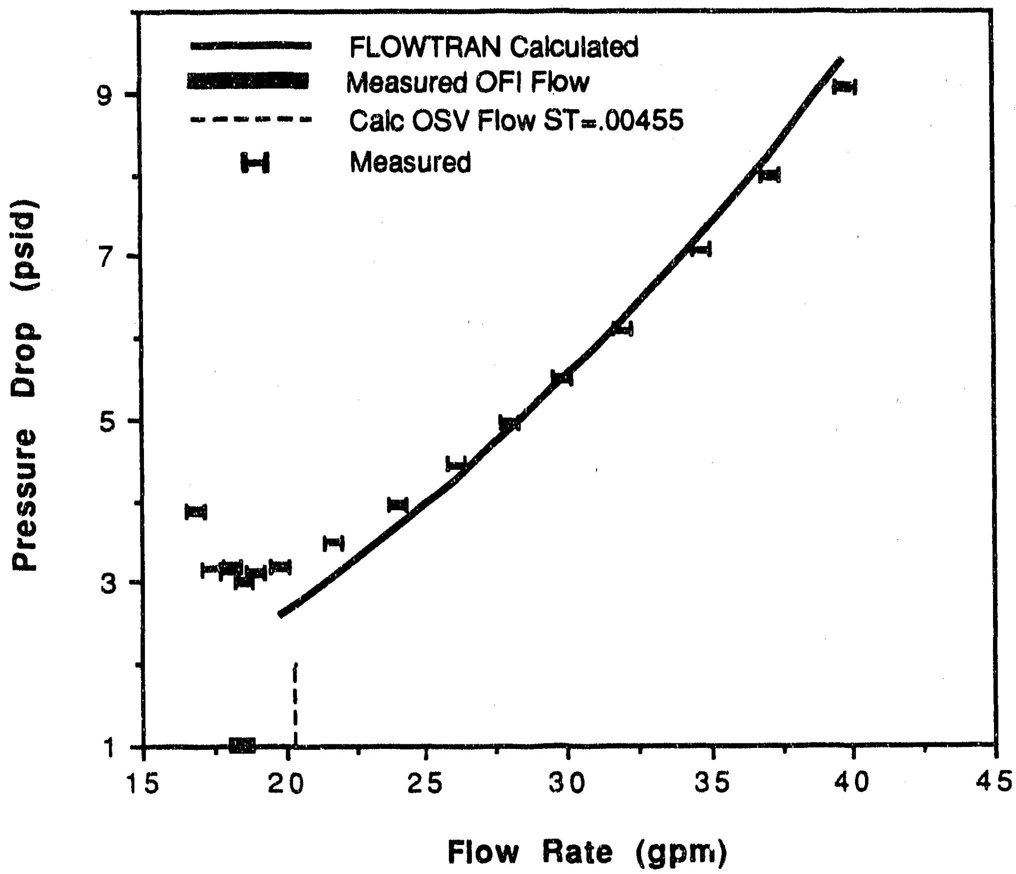

FIGURE A-50. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 12

SS TUBE ID=0.7516" ; UNIFORM FLUX=1.0 MBTU/HR-FT2
INLET TEMP=121 F ; EXIT PRES=64.7 PSIA

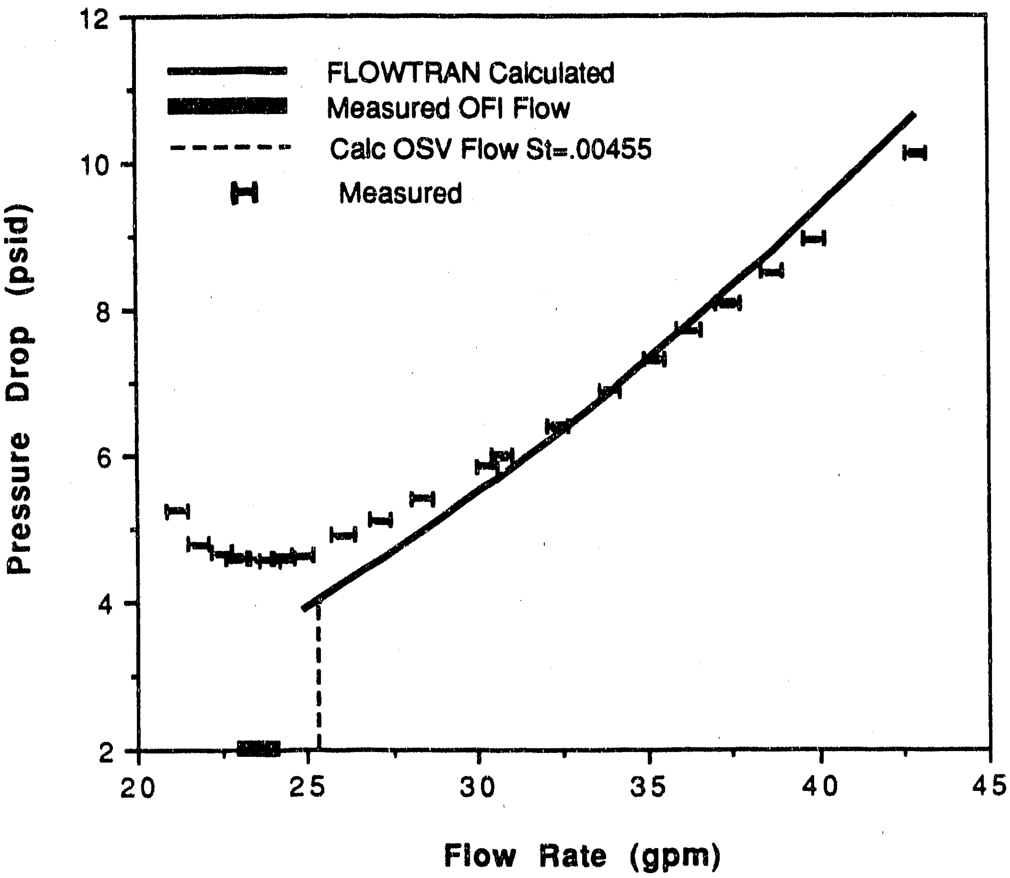

FIGURE A-51. MEASURED DATA AND FLOWTRAN PREDICTIONS FOR TEST RUN 2.1 - 13

APPENDIX - B

INDIVIDUAL TEST POINT CONDITIONS

This appendix contains the table for individual test point conditions. The table presents power, heat flux, exit pressure, inlet temperature, flow rate, measured pressure drop, FLOWTRAN calculated pressure drop, and the percent difference between FLOWTRAN calculated and measured pressure drops for all data points for all test runs. The data points that correspond to each test run are listed in Table 5.

Flow rates and measured pressure drops are associated with their measurement uncertainties. A significant amount of void is present in the flow channel if the flow rate is lower than the FLOWTRAN calculated OSV flow rate at St=0.00455. FLOWTRAN code is not designed to handle pressure drops for two-phase flows. The difference between measured and FLOWTRAN calculated pressure drops is not meaningful for flow rates lower than the FLOWTRAN calculated OSV flow rate at St=0.00455. These cases are shown as " ***** " in column "Difference".

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
598	2.1	0.001	0.001	64.831	76.875	77.000	35.175 ± 0.320	9.334 ± 0.033	9.484	1.61
599	2.1	0.001	0.001	64.781	78.713	78.988	32.246 ± 0.319	8.006 ± 0.029	8.060	0.67
600	2.1	0.001	0.001	64.608	77.700	77.837	32.195 ± 0.319	8.008 ± 0.029	7.606	-5.02
601	2.1	0.001	0.001	64.979	77.463	77.500	29.103 ± 0.318	6.792 ± 0.026	6.708	-1.24
602	2.1	0.001	0.001	64.584	77.687	77.700	26.147 ± 0.317	5.651 ± 0.023	5.520	-2.31
603	2.1	0.001	0.001	64.497	77.950	78.000	22.788 ± 0.315	4.426 ± 0.021	4.303	-2.78
604	2.1	0.001	0.001	64.682	77.912	78.000	19.989 ± 0.315	3.523 ± 0.019	3.398	-3.54
605	2.1	0.001	0.001	64.756	77.588	77.513	17.576 ± 0.314	2.790 ± 0.018	2.700	-3.24
606	2.1	0.001	0.001	64.732	77.475	77.500	15.078 ± 0.314	2.111 ± 0.017	2.053	-2.77
607	2.1	0.001	0.001	64.707	77.375	77.500	12.347 ± 0.313	1.504 ± 0.017	1.438	-4.40
608	2.1	0.001	0.001	64.707	77.375	77.500	9.655 ± 0.313	0.962 ± 0.016	0.930	-3.38
609	2.1	0.001	0.001	64.559	77.575	77.500	7.418 ± 0.313	0.612 ± 0.016	0.584	-4.64
610	2.1	0.001	0.001	64.534	77.962	78.000	5.493 ± 0.312	0.353 ± 0.016	0.344	-2.46
611	2.1	0.001	0.001	64.719	76.487	76.500	39.835 ± 0.322	11.700 ± 0.039	11.923	1.90
612	2.1	274.483	0.604	64.682	76.988	125.275	39.866 ± 0.322	9.460 ± 0.033	9.706	2.60
613	2.1	270.497	0.595	64.682	76.362	128.813	35.978 ± 0.320	7.838 ± 0.029	7.978	1.78
614	2.1	271.971	0.598	64.695	77.812	136.475	32.306 ± 0.319	6.422 ± 0.025	6.492	1.09
615	2.1	270.994	0.596	64.460	76.587	141.500	29.039 ± 0.318	5.251 ± 0.023	5.299	0.91
616	2.1	272.886	0.600	64.695	77.488	151.812	25.334 ± 0.316	4.075 ± 0.020	4.090	0.38
617	2.1	272.643	0.599	64.435	77.5[illegible]5	168.013	20.893 ± 0.315	2.878 ± 0.018	2.850	-0.97
618	2.1	271.400	0.597	64.633	76.687	185.000	17.390 ± 0.314	2.100 ± 0.017	2.036	-3.06
619	2.1	273.830	0.602	64.645	76.037	199.500	15.311 ± 0.314	1.767 ± 0.017	1.621	-8.24
620	2.1	272.236	0.599	64.905	77.113	217.500	13.523 ± 0.313	1.521 ± 0.017	1.312	-13.76
621	2.1	272.333	0.599	64.645	77.863	229.462	12.433 ± 0.313	1.427 ± 0.017	1.144	-19.84
622	2.1	271.522	0.597	64.855	77.275	239.100	11.671 ± 0.313	1.350 ± 0.016	1.035	*****
623	2.1	271.465	0.597	64.781	76.975	246.500	11.098 ± 0.313	1.331 ± 0.016	0.958	*****
624	2.1	270.714	0.595	64.868	76.750	251.500	10.759 ± 0.313	1.301 ± 0.016	0.915	*****
625	2.1	270.022	0.594	64.621	76.963	270.500	9.629 ± 0.313	1.618 ± 0.017	0.783	*****
626	2.1	181.778	0.400	64.448	120.325	152.987	39.271 ± 0.322	9.376 ± 0.033	9.622	2.62
627	2.1	182.207	0.401	64.485	121.287	156.500	36.201 ± 0.320	8.116 ± 0.029	8.232	1.43
628	2.1	182.001	0.400	64.756	121.287	160.000	32.926 ± 0.319	6.801 ± 0.026	6.873	1.06
629	2.1	181.554	0.399	64.584	120.388	164.000	29.015 ± 0.318	5.384 ± 0.023	5.412	0.52
630	2.1	180.099	0.396	64.633	120.350	167.987	26.302 ± 0.317	4.535 ± 0.021	4.501	-0.76
631	2.1	181.048	0.398	64.522	121.425	175.000	23.334 ± 0.316	3.661 ± 0.019	3.597	-1.75
632	2.1	182.619	0.402	64.534	120.713	180.950	21.008 ± 0.315	3.040 ± 0.018	2.959	-2.66
633	2.1	182.227	0.401	64.868	120.438	187.925	18.797 ± 0.314	2.452 ± 0.018	2.412	-1.63
634	2.1	180.359	0.397	64.917	121.787	196.812	16.778 ± 0.314	2.034 ± 0.017	1.965	-3.39
635	2.1	182.838	0.402	64.436	121.550	209.000	14.494 ± 0.314	1.599 ± 0.017	1.517	-5.16
636	2.1	182.141	0.400	64.806	120.588	214.987	13.336 ± 0.313	1.428 ± 0.017	1.313	-8.05

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
637	2.1	182.091	0.400	64.954	121.637	220.313	12.711 ± 0.313	1.326 ± 0.016	1.212	-8.62
638	2.1	181.003	0.398	64.769	121.000	232.500	11.307 ± 0.313	1.151 ± 0.016	1.000	-13.08
639	2.1	180.694	0.397	64.682	120.238	244.500	9.973 ± 0.313	1.030 ± 0.016	0.824	*****
640	2.1	180.612	0.397	64.830	121.562	254.950	9.321 ± 0.313	0.982 ± 0.016	0.750	*****
641	2.1	181.810	0.400	65.003	120.750	266.000	8.545 ± 0.313	1.060 ± 0.016	0.666	*****
642	2.1	181.175	0.398	64.707	120.987	278.937	7.759 ± 0.313	1.391 ± 0.016	0.593	*****
643	2.1	181.473	0.399	65.250	122.025	289.650	7.255 ± 0.313	1.935 ± 0.017	0.552	*****
644	2.1	183.038	0.402	64.510	121.387	201.500	15.881 ± 0.314	1.872 ± 0.017	1.782	-4.78
645	2.1	272.005	0.598	64.695	121.775	169.737	40.033 ± 0.322	9.377 ± 0.033	9.687	3.31
646	2.1	272.870	0.600	64.497	120.112	171.825	37.036 ± 0.321	8.141 ± 0.029	8.350	2.56
647	2.1	272.349	0.599	64.547	120.087	176.000	34.089 ± 0.320	7.000 ± 0.027	7.129	1.85
648	2.1	271.251	0.596	64.682	120.275	182.500	30.296 ± 0.318	5.673 ± 0.023	5.703	0.53
649	2.1	271.223	0.596	64.707	120.450	190.312	26.780 ± 0.317	4.553 ± 0.021	4.524	-0.63
650	2.1	274.374	0.603	64.571	119.962	202.500	22.909 ± 0.316	3.472 ± 0.019	3.385	-2.50
651	2.1	273.160	0.601	64.670	120.600	217.850	19.333 ± 0.315	2.650 ± 0.018	2.487	-6.14
652	2.1	271.992	0.598	64.855	120.813	234.613	16.460 ± 0.314	2.162 ± 0.017	1.879	-13.10
653	2.1	272.410	0.599	64.707	121.913	253.000	14.366 ± 0.313	1.907 ± 0.017	1.501	*****
654	2.1	272.103	0.598	64.942	120.813	266.700	12.885 ± 0.313	2.110 ± 0.017	1.265	*****
655	2.1	271.355	0.597	65.522	122.050	277.550	11.969 ± 0.313	2.578 ± 0.018	1.135	*****
656	2.1	270.969	0.596	64.719	121.300	259.925	13.491 ± 0.313	1.901 ± 0.017	1.358	*****
657	2.1	270.555	0.595	64.608	121.575	255.025	13.967 ± 0.313	1.870 ± 0.017	1.435	*****
658	2.1	271.520	0.597	65.188	121.837	244.463	15.288 ± 0.314	1.997 ± 0.017	1.661	-16.82
659	2.1	271.659	0.597	65.016	121.862	225.987	18.008 ± 0.314	2.447 ± 0.018	2.196	-10.25
660	2.1	275.024	0.605	64.769	120.188	181.525	31.968 ± 0.319	6.222 ± 0.025	6.313	1.47
661	2.1	362.445	0.797	64.843	120.363	184.438	39.805 ± 0.322	9.066 ± 0.032	9.389	3.57
662	2.1	360.437	0.793	64.423	121.700	189.650	37.111 ± 0.321	7.991 ± 0.029	8.217	2.83
663	2.1	364.025	0.800	64.510	121.650	195.000	34.694 ± 0.320	7.070 ± 0.027	7.230	2.26
664	2.1	361.220	0.794	64.547	121.312	200.475	31.977 ± 0.319	6.098 ± 0.024	6.198	1.64
665	2.1	364.283	0.801	64.719	121.437	211.500	28.006 ± 0.317	4.954 ± 0.022	4.838	-2.35
666	2.1	364.051	0.800	64.880	120.325	216.500	26.100 ± 0.317	4.439 ± 0.021	4.247	-4.33
667	2.1	0.001	0.000	64.892	120.962	121.000	40.074 ± 0.322	10.741 ± 0.036	11.133	3.65
668	2.1	0.001	0.000	64.596	121.625	121.687	34.799 ± 0.320	8.463 ± 0.030	8.569	1.26
669	2.1	0.001	0.000	64.645	121.525	121.500	30.213 ± 0.318	6.580 ± 0.026	6.611	0.47
670	2.1	0.001	0.000	64.744	120.100	120.000	21.009 ± 0.315	3.490 ± 0.019	3.422	-1.95
671	2.1	0.001	0.000	64.633	121.212	121.025	16.513 ± 0.314	2.265 ± 0.017	2.219	-2.03
672	2.1	0.001	0.000	64.682	121.675	122.000	12.533 ± 0.313	1.383 ± 0.016	1.363	-1.47
673	2.1	0.001	0.000	64.510	120.350	120.475	10.112 ± 0.313	0.951 ± 0.016	0.941	-1.09
674	2.1	0.001	0.000	64.818	121.275	121.000	5.674 ± 0.312	0.365 ± 0.016	0.360	-1.47
675	2.1	0.001	0.000	64.682	122.013	121.850	7.916 ± 0.313	0.638 ± 0.016	0.621	-2.73

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
676	2.1	0.001	0.000	64.719	120.713	121.000	25.353 ± 0.316	4.875 ± 0.022	4.809	-1.35
677	2.1	360.868	0.793	64.386	76.137	207.000	18.873 ± 0.314	2.607 ± 0.018	2.337	-10.35
678	2.1	362.225	0.796	64.818	76.100	218.500	17.381 ± 0.314	2.371 ± 0.017	2.026	-14.56
679	2.1	361.854	0.796	64.806	77.475	231.575	16.163 ± 0.314	2.203 ± 0.017	1.794	-18.55
680	2.1	362.551	0.797	64.695	77.875	244.500	15.016 ± 0.314	2.101 ± 0.017	1.592	*****
681	2.1	360.261	0.792	64.756	77.313	257.838	13.728 ± 0.313	2.194 ± 0.017	1.382	*****
682	2.1	365.640	0.804	64.929	120.675	226.000	24.009 ± 0.316	3.958 ± 0.020	3.649	-7.81
683	2.1	365.555	0.804	64.719	120.350	236.000	21.744 ± 0.315	3.492 ± 0.019	3.059	-12.39
684	2.1	364.514	0.801	64.584	120.300	246.500	19.779 ± 0.315	3.191 ± 0.019	2.597	*****
685	2.1	362.896	0.798	65.090	120.425	255.000	18.558 ± 0.314	3.017 ± 0.018	2.332	*****
686	2.1	361.011	0.794	64.966	120.263	262.788	17.432 ± 0.314	3.178 ± 0.019	2.101	*****
687	2.1	365.865	0.804	64.732	121.800	271.600	16.849 ± 0.314	3.886 ± 0.020	1.993	*****
688	2.1	364.939	0.802	64.374	121.662	254.000	18.964 ± 0.314	3.130 ± 0.019	2.422	*****
689	2.1	364.332	0.801	64.806	120.663	259.300	18.198 ± 0.314	3.209 ± 0.019	2.258	*****
690	2.1	365.035	0.803	64.645	121.100	260.462	18.035 ± 0.314	3.132 ± 0.019	2.226	*****
691	2.1	362.959	0.798	64.571	121.650	206.500	29.927 ± 0.318	5.497 ± 0.023	5.475	-0.40
692	2.1	451.516	0.993	65.337	121.450	201.000	39.865 ± 0.322	8.948 ± 0.032	9.287	3.79
693	2.1	455.059	1.001	64.806	120.438	203.000	38.677 ± 0.322	8.509 ± 0.030	8.766	3.02
694	2.1	456.607	1.004	64.707	120.987	206.500	37.394 ± 0.321	8.086 ± 0.029	8.222	1.68
695	2.1	455.597	1.002	64.682	120.525	208.500	36.270 ± 0.320	7.701 ± 0.028	7.761	0.78
696	2.1	454.852	1.000	64.596	120.300	210.488	35.237 ± 0.320	7.314 ± 0.027	7.351	0.51
697	2.1	454.997	1.000	64.547	121.512	215.000	33.954 ± 0.319	6.900 ± 0.026	6.859	-0.59
698	2.1	453.429	0.997	64.559	120.563	218.012	32.371 ± 0.319	6.401 ± 0.025	6.275	-1.97
699	2.1	452.532	0.995	64.547	120.338	224.000	30.269 ± 0.318	5.848 ± 0.024	5.545	-5.19
700	2.1	452.151	0.994	64.584	120.688	230.587	28.342 ± 0.317	5.416 ± 0.023	4.920	-9.17
701	2.1	453.360	0.997	64.608	120.213	235.500	27.140 ± 0.317	5.114 ± 0.022	4.550	-11.03
702	2.1	451.815	0.993	64.929	121.337	241.500	26.038 ± 0.316	4.902 ± 0.022	4.228	-13.74
703	2.1	453.927	0.998	64.793	120.275	246.000	24.864 ± 0.316	4.630 ± 0.021	3.897	*****
704	2.1	453.162	0.996	64.868	121.850	254.000	23.649 ± 0.316	4.583 ± 0.021	3.576	*****
705	2.1	453.755	0.998	64.991	121.300	259.600	22.512 ± 0.315	4.672 ± 0.021	3.285	*****
706	2.1	453.413	0.997	64.670	120.525	267.825	21.175 ± 0.315	5.247 ± 0.023	2.963	*****
707	2.1	453.565	0.997	64.596	120.338	263.000	21.823 ± 0.315	4.786 ± 0.022	3.116	*****
708	2.1	453.652	0.997	64.682	121.175	257.763	22.909 ± 0.316	4.595 ± 0.021	3.385	*****
709	2.1	453.492	0.997	64.596	121.913	253.000	23.907 ± 0.316	4.577 ± 0.021	3.644	*****
710	2.1	451.906	0.994	64.645	121.525	249.988	24.297 ± 0.316	4.600 ± 0.021	3.746	*****
711	2.1	453.562	0.997	64.991	121.762	224.450	30.679 ± 0.318	6.005 ± 0.024	5.687	-5.30
712	2.1	457.461	1.006	64.645	120.513	196.000	42.859 ± 0.324	10.115 ± 0.035	10.656	5.35
713	2.1	457.381	1.006	64.831	77.338	153.000	42.441 ± 0.324	9.946 ± 0.034	10.417	4.73
714	2.1	455.865	1.002	64.929	77.525	159.000	39.037 ± 0.322	8.471 ± 0.030	8.878	4.81

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate qpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
715	2.1	455.934	1.003	64.695	77.150	166.000	35.535 ± 0.320	7.190 ± 0.027	7.424	3.26
716	2.1	454.297	0.999	64.473	76.612	173.775	32.416 ± 0.319	6.090 ± 0.024	6.241	2.47
717	2.1	454.012	0.998	64.781	76.100	187.363	28.122 ± 0.317	4.853 ± 0.022	4.784	-1.43
718	2.1	455.161	1.001	64.695	76.625	207.500	23.914 ± 0.316	3.900 ± 0.020	3.560	-8.71
719	2.1	452.839	0.996	64.769	76.662	226.500	20.663 ± 0.315	3.312 ± 0.019	2.757	-16.76
720	2.1	453.213	0.997	64.892	76.662	240.500	18.964 ± 0.314	3.092 ± 0.019	2.385	*****
721	2.1	453.827	0.998	64.781	76.575	252.250	17.692 ± 0.314	3.212 ± 0.019	2.128	*****
722	2.1	454.029	0.998	64.670	76.487	258.488	16.980 ± 0.314	3.489 ± 0.019	1.992	*****
723	2.1	456.223	1.003	64.547	76.462	251.963	17.738 ± 0.314	3.283 ± 0.019	2.138	*****
724	2.1	454.147	0.999	64.645	76.437	246.500	18.284 ± 0.314	3.099 ± 0.019	2.247	*****
725	2.1	454.534	0.999	64.559	76.437	235.437	19.620 ± 0.315	3.161 ± 0.019	2.526	*****
726	2.1	455.183	1.001	64.510	76.512	219.063	21.902 ± 0.315	3.524 ± 0.019	3.050	-13.46
727	2.1	455.823	1.002	64.818	77.038	198.000	25.996 ± 0.316	4.376 ± 0.021	4.142	-5.36
728	2.1	458.032	1.007	64.966	77.675	184.500	29.667 ± 0.318	5.287 ± 0.023	5.285	-0.03
729	2.1	181.873	0.400	34.414	120.513	152.750	39.824 ± 0.322	9.606 ± 0.033	9.881	2.87
730	2.1	181.375	0.399	34.784	121.500	156.962	36.307 ± 0.321	8.134 ± 0.029	8.278	1.78
731	2.1	180.375	0.397	34.908	120.250	158.500	32.972 ± 0.319	6.827 ± 0.026	6.899	1.05
732	2.1	182.341	0.401	34.624	121.437	165.038	28.995 ± 0.318	5.408 ± 0.023	5.404	-0.08
733	2.1	181.078	0.398	34.747	121.525	171.000	25.437 ± 0.316	4.298 ± 0.021	4.223	-1.73
734	2.1	183.147	0.403	34.797	121.900	157.500	36.143 ± 0.320	8.023 ± 0.029	8.208	2.30
735	2.1	182.721	0.402	34.871	120.037	170.350	25.263 ± 0.316	4.230 ± 0.020	4.167	-1.48
736	2.1	180.450	0.397	34.673	121.712	180.013	21.463 ± 0.315	3.129 ± 0.019	3.079	-1.61
737	2.1	182.770	0.402	34.908	121.425	190.000	18.400 ± 0.314	2.394 ± 0.018	2.321	-3.05
738	2.1	181.726	0.400	34.846	121.037	199.500	15.974 ± 0.314	1.867 ± 0.017	1.800	-3.61
739	2.1	180.905	0.398	34.797	121.750	217.075	13.057 ± 0.313	1.423 ± 0.017	1.273	-10.52
740	2.1	180.451	0.397	34.648	121.512	229.925	11.484 ± 0.313	1.282 ± 0.016	1.035	*****
741	2.1	183.571	0.404	35.352	120.037	235.500	10.940 ± 0.313	1.439 ± 0.017	0.959	*****
742	2.1	182.915	0.402	35.216	120.425	243.000	10.304 ± 0.313	1.937 ± 0.017	0.878	*****
743	2.1	181.912	0.400	34.883	120.300	225.800	11.899 ± 0.313	1.347 ± 0.016	1.094	*****
744	2.1	181.762	0.400	34.661	120.950	220.663	12.486 ± 0.313	1.366 ± 0.016	1.183	*****
745	2.1	181.242	0.399	34.451	121.275	206.625	14.802 ± 0.314	1.689 ± 0.017	1.576	-6.70
746	2.1	271.988	0.598	34.661	121.888	166.987	42.783 ± 0.324	10.527 ± 0.036	11.003	4.53
747	2.1	271.967	0.598	34.871	120.588	169.500	39.339 ± 0.322	9.018 ± 0.032	9.371	3.92
748	2.1	273.997	0.602	34.784	121.850	174.500	36.279 ± 0.321	7.843 ± 0.029	8.023	2.30
749	2.1	272.716	0.600	34.809	121.300	178.400	33.481 ± 0.319	6.774 ± 0.026	6.887	1.67
750	2.1	271.714	0.597	34.797	121.037	183.500	30.383 ± 0.318	5.689 ± 0.024	5.733	0.77
751	2.1	270.684	0.595	34.636	120.087	194.500	25.126 ± 0.316	4.123 ± 0.020	4.018	-2.55
752	2.1	272.607	0.599	35.105	120.738	201.000	23.325 ± 0.316	3.666 ± 0.019	3.503	-4.44
753	2.1	271.189	0.596	34.784	121.812	212.025	20.737 ± 0.315	3.103 ± 0.019	2.833	-8.69

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
754	2.1	270.005	0.594	35.130	121.387	221.563	18.560 ± 0.314	2.714 ± 0.018	2.331	*****
755	2.1	272.131	0.598	34.858	121.475	228.475	17.599 ± 0.314	2.798 ± 0.018	2.129	*****
756	2.1	271.684	0.597	34.352	121.275	233.500	16.712 ± 0.314	3.229 ± 0.019	1.952	*****
757	2.1	272.571	0.599	34.636	121.625	227.000	17.878 ± 0.314	2.777 ± 0.018	2.188	*****
758	2.1	272.511	0.599	34.648	120.213	215.500	19.683 ± 0.315	2.934 ± 0.018	2.583	-11.96
759	2.1	273.411	0.601	34.611	121.025	219.500	19.110 ± 0.315	2.825 ± 0.018	2.453	*****
760	2.1	273.965	0.602	34.525	120.538	206.738	21.909 ± 0.315	3.363 ± 0.019	3.127	*****
761	2.1	274.918	0.604	34.525	121.012	190.000	27.830 ± 0.317	4.872 ± 0.022	4.859	-0.26
762	2.1	366.689	0.806	34.957	120.588	181.000	42.817 ± 0.324	10.301 ± 0.035	10.787	4.72
763	2.1	363.310	0.799	34.636	121.825	188.500	38.373 ± 0.321	8.477 ± 0.030	8.750	3.23
764	2.1	361.994	0.796	34.797	121.800	194.500	34.852 ± 0.320	7.210 ± 0.027	7.293	1.15
765	2.1	363.668	0.800	34.735	120.563	201.500	31.259 ± 0.318	6.023 ± 0.024	5.945	-1.30
766	2.1	360.678	0.793	34.673	121.350	207.988	29.039 ± 0.318	5.425 ± 0.023	5.188	-4.36
767	2.1	360.081	0.792	35.340	121.725	214.500	26.948 ± 0.317	4.903 ± 0.022	4.527	-7.67
768	2.1	363.448	0.799	34.772	121.475	220.500	25.465 ± 0.316	4.649 ± 0.021	4.089	*****
769	2.1	363.168	0.799	35.006	120.613	224.112	24.279 ± 0.316	4.537 ± 0.021	3.755	*****
770	2.1	362.242	0.797	35.019	121.787	231.463	22.963 ± 0.316	4.918 ± 0.022	3.407	*****
771	2.1	362.045	0.796	34.957	120.563	234.500	21.916 ± 0.315	5.244 ± 0.023	3.140	*****
772	2.1	363.994	0.800	34.587	120.550	226.037	23.770 ± 0.316	4.675 ± 0.021	3.619	*****
773	2.1	364.165	0.801	34.846	120.738	222.500	24.611 ± 0.316	4.566 ± 0.021	3.848	*****
774	2.1	363.921	0.800	35.006	120.263	183.100	40.376 ± 0.322	9.260 ± 0.032	9.648	4.19
775	2.1	365.143	0.803	34.747	76.375	137.000	42.386 ± 0.323	10.148 ± 0.035	10.612	4.57
776	2.1	365.663	0.804	34.723	77.563	142.000	39.842 ± 0.322	9.077 ± 0.032	9.420	3.77
777	2.1	365.948	0.805	34.525	77.275	147.500	36.488 ± 0.321	7.716 ± 0.028	7.957	3.13
778	2.1	363.969	0.800	34.723	76.150	151.500	33.597 ± 0.319	6.631 ± 0.026	6.799	2.54
779	2.1	361.811	0.796	34.883	76.550	162.000	29.303 ± 0.318	5.228 ± 0.023	5.249	0.39
780	2.1	361.479	0.795	34.686	76.500	172.500	26.128 ± 0.317	4.314 ± 0.021	4.235	-1.84
781	2.1	365.121	0.803	34.945	77.125	190.175	22.252 ± 0.315	3.448 ± 0.019	3.157	-8.44
782	2.1	362.744	0.798	34.920	77.638	209.650	18.845 ± 0.314	2.881 ± 0.018	2.361	*****
783	2.1	362.357	0.797	34.599	76.725	233.000	15.865 ± 0.314	4.017 ± 0.020	1.770	*****
784	2.1	363.231	0.799	34.599	76.850	214.987	18.070 ± 0.314	2.876 ± 0.018	2.198	*****
785	2.1	362.514	0.797	34.772	76.950	221.887	17.161 ± 0.314	3.154 ± 0.019	2.015	*****
786	2.1	363.879	0.800	34.648	77.188	203.000	19.808 ± 0.315	3.012 ± 0.018	2.573	-14.57
787	2.1	362.692	0.797	34.661	77.550	207.928	19.059 ± 0.314	2.913 ± 0.018	2.408	*****
788	2.1	366.050	0.805	34.698	78.000	198.475	20.925 ± 0.315	3.220 ± 0.019	2.833	-12.03
789	2.1	365.917	0.805	34.809	76.400	156.000	32.058 ± 0.319	6.091 ± 0.024	6.219	2.11
790	2.1	454.124	0.999	35.044	76.200	151.500	42.354 ± 0.323	9.888 ± 0.034	10.381	4.99
791	2.1	452.874	0.996	34.402	76.637	157.100	39.137 ± 0.322	8.588 ± 0.031	8.926	3.93
792	2.1	452.147	0.994	34.772	76.537	164.350	35.785 ± 0.320	7.358 ± 0.027	7.529	2.32

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
793	2.1	456.774	1.004	34.772	76.512	172.000	33.244 ± 0.319	6.518 ± 0.025	6.549	0.48
794	2.1	454.796	1.000	34.883	76.275	182.225	29.677 ± 0.318	5.532 ± 0.023	5.303	-4.14
795	2.1	455.583	1.002	34.747	76.762	190.738	27.649 ± 0.317	5.073 ± 0.022	4.663	-8.09
796	2.1	454.152	0.999	34.834	76.825	201.112	25.183 ± 0.316	4.510 ± 0.021	3.946	-12.51
797	2.1	455.404	1.001	34.895	76.537	208.813	23.798 ± 0.316	4.259 ± 0.021	3.573	*****
798	2.1	453.282	0.997	34.982	76.525	214.000	22.637 ± 0.315	4.128 ± 0.020	3.276	*****
799	2.1	452.811	0.996	34.969	76.975	223.000	21.233 ± 0.315	4.885 ± 0.022	2.936	*****
800	2.1	453.690	0.998	34.636	77.075	219.700	21.839 ± 0.315	4.598 ± 0.021	3.082	*****
801	2.1	452.105	0.994	34.932	77.288	215.500	22.552 ± 0.315	4.332 ± 0.021	3.256	*****
802	2.1	453.512	0.997	34.846	77.475	212.500	23.165 ± 0.316	4.262 ± 0.021	3.411	*****
803	2.1	451.033	0.992	34.636	77.550	205.500	24.311 ± 0.316	4.413 ± 0.021	3.710	*****
804	2.1	457.019	1.005	35.044	77.063	161.500	37.725 ± 0.321	8.051 ± 0.029	8.325	3.41
805	2.1	455.108	1.001	34.994	120.525	196.500	42.052 ± 0.323	9.982 ± 0.034	10.279	2.97
806	2.1	453.351	0.997	34.809	121.825	202.500	39.575 ± 0.322	9.118 ± 0.032	9.166	0.53
807	2.1	453.501	0.997	34.895	121.362	206.388	37.380 ± 0.321	8.370 ± 0.030	8.235	-1.61
808	2.1	452.317	0.995	34.908	120.450	209.500	35.639 ± 0.320	7.808 ± 0.029	7.534	-3.51
809	2.1	452.039	0.994	34.686	119.987	213.387	33.780 ± 0.319	7.416 ± 0.028	6.825	-7.97
810	2.1	452.193	0.994	34.698	120.338	216.537	32.671 ± 0.319	7.092 ± 0.027	6.421	-9.46
811	2.1	454.321	0.999	35.081	121.262	221.975	31.346 ± 0.318	6.950 ± 0.026	5.957	*****
812	2.1	453.647	0.997	34.920	120.425	225.675	30.798 ± 0.318	7.173 ± 0.027	5.770	*****
813	2.1	453.511	0.997	34.537	121.512	228.462	29.236 ± 0.318	7.458 ± 0.028	5.260	*****
814	2.1	453.143	0.996	34.463	121.975	230.962	28.751 ± 0.317	8.126 ± 0.029	5.108	*****
815	2.1	454.075	0.998	34.797	121.612	226.500	30.094 ± 0.318	7.191 ± 0.027	5.539	*****
816	2.1	452.976	0.996	34.846	122.025	227.337	30.485 ± 0.318	7.222 ± 0.027	5.669	*****
817	2.1	451.800	0.993	34.908	121.475	225.000	30.494 ± 0.318	6.995 ± 0.027	5.670	*****
818	2.1	452.661	0.995	34.648	121.788	222.713	31.715 ± 0.319	7.230 ± 0.027	6.088	*****
819	2.1	451.796	0.993	34.636	120.525	218.600	32.337 ± 0.319	6.992 ± 0.027	6.303	*****
820	2.1	452.659	0.995	34.920	121.012	212.025	35.043 ± 0.320	7.775 ± 0.029	7.305	-6.05
821	4	0.001	0.000	64.621	76.275	76.450	20.419 ± 0.318	9.345 ± 0.064	9.305	-0.42
822	4	0.000	0.000	64.855	76.175	76.475	30.997 ± 0.318	19.409 ± 0.060	19.752	1.77
823	4	0.000	0.000	64.658	77.500	77.500	29.148 ± 0.317	17.366 ± 0.056	17.610	1.40
824	4	0.001	0.000	64.584	76.950	77.000	27.156 ± 0.316	15.391 ± 0.051	15.517	0.82
825	4	0.000	0.000	64.719	76.075	76.425	25.216 ± 0.315	13.504 ± 0.046	13.606	0.75
826	4	0.000	0.000	64.806	76.125	76.500	22.679 ± 0.315	11.221 ± 0.040	11.240	0.17
827	4	0.002	0.000	64.645	76.500	76.538	19.300 ± 0.314	8.461 ± 0.036	8.405	-0.66
828	4	0.001	0.000	64.460	77.462	77.500	16.455 ± 0.313	6.364 ± 0.033	6.303	-0.97
829	4	0.000	0.000	64.793	77.738	77.950	12.758 ± 0.313	4.042 ± 0.031	4.002	-1.00
830	4	0.001	0.000	64.744	77.512	77.613	9.706 ± 0.313	2.477 ± 0.031	2.466	-0.45
831	4	0.001	0.000	64.584	76.762	77.000	7.584 ± 0.312	1.623 ± 0.031	1.599	-1.50

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
832	4	0.000	0.000	64.781	76.500	76.500	5.125 ± 0.315	0.812 ± 0.043	0.804	-1.04
833	4	0.000	0.000	64.584	121.900	121.988	22.143 ± 0.316	9.824 ± 0.047	9.753	-0.72
834	4	0.000	0.000	64.744	121.475	121.500	24.745 ± 0.317	11.887 ± 0.053	11.939	0.44
835	4	0.000	0.000	64.917	120.162	120.312	27.298 ± 0.318	14.087 ± 0.058	14.306	1.56
836	4	0.000	0.000	65.028	121.500	121.500	29.547 ± 0.319	16.117 ± 0.062	16.490	2.31
837	4	0.000	0.000	64.695	120.212	120.337	31.712 ± 0.315	18.260 ± 0.039	18.806	2.99
838	4	0.000	0.000	64.682	121.725	121.712	19.853 ± 0.314	8.084 ± 0.036	8.007	-0.96
839	4	0.000	0.000	64.868	120.250	120.025	17.107 ± 0.313	6.178 ± 0.033	6.144	-0.56
840	4	0.000	0.000	64.707	121.500	121.500	14.029 ± 0.313	4.323 ± 0.032	4.299	-0.56
841	4	0.000	0.000	64.571	121.825	121.800	11.992 ± 0.313	3.252 ± 0.031	3.251	-0.03
842	4	0.000	0.000	65.016	121.050	121.000	9.822 ± 0.313	2.286 ± 0.031	2.289	0.15
843	4	0.000	0.000	64.584	120.500	120.500	8.083 ± 0.312	1.652 ± 0.031	1.630	-1.31
844	4	0.000	0.000	64.596	121.275	121.000	6.102 ± 0.319	1.018 ± 0.059	1.003	-1.43
845	4	224.891	0.598	64.633	77.688	127.500	31.993 ± 0.318	16.753 ± 0.055	17.330	3.45
846	4	224.759	0.598	64.929	77.387	129.500	30.018 ± 0.317	15.005 ± 0.049	15.353	2.32
847	4	224.423	0.597	64.633	76.500	133.000	27.597 ± 0.316	12.746 ± 0.044	13.094	2.73
848	4	224.141	0.596	64.658	76.400	138.500	24.838 ± 0.315	10.555 ± 0.041	10.723	1.59
849	4	223.633	0.595	64.658	77.500	146.000	22.557 ± 0.315	8.834 ± 0.037	8.932	1.11
850	4	223.711	0.595	64.670	76.912	154.500	19.748 ± 0.314	6.874 ± 0.034	6.953	1.15
851	4	223.416	0.594	64.892	76.363	167.500	16.794 ± 0.314	5.058 ± 0.033	5.134	1.50
852	4	223.822	0.595	64.744	76.775	180.500	14.788 ± 0.313	4.007 ± 0.032	4.053	1.14
853	4	223.530	0.595	64.892	77.500	192.500	13.287 ± 0.313	3.307 ± 0.032	3.328	0.63
854	4	223.550	0.595	64.460	77.025	203.500	12.150 ± 0.313	2.771 ± 0.031	2.829	2.10
855	4	223.926	0.596	64.497	76.288	221.000	10.613 ± 0.313	2.322 ± 0.031	2.224	-4.22
856	4	224.090	0.596	64.670	77.200	244.500	9.135 ± 0.313	1.981 ± 0.031	1.723	*****
857	4	224.016	0.596	64.917	77.062	263.488	8.160 ± 0.313	1.975 ± 0.031	1.437	*****
858	4	224.140	0.596	65.053	76.950	273.500	7.749 ± 0.313	2.372 ± 0.032	1.327	*****
859	4	224.528	0.597	64.719	76.962	281.000	7.411 ± 0.313	3.073 ± 0.031	1.242	*****
860	4	224.488	0.597	64.682	76.588	231.000	10.036 ± 0.313	2.200 ± 0.031	2.020	-7.97
861	4	224.468	0.597	64.584	76.425	260.313	8.355 ± 0.319	1.920 ± 0.059	1.491	*****
862	4	225.107	0.599	64.695	120.500	169.575	32.216 ± 0.318	16.753 ± 0.054	17.083	1.97
863	4	225.194	0.599	64.411	121.175	173.500	30.183 ± 0.317	15.005 ± 0.048	15.092	0.58
864	4	225.342	0.599	64.793	121.000	178.500	27.300 ± 0.316	12.327 ± 0.041	12.484	1.27
865	4	224.833	0.598	64.830	120.475	188.000	22.998 ± 0.315	9.091 ± 0.038	9.045	-0.51
866	4	225.059	0.599	64.732	121.788	198.000	20.289 ± 0.314	7.211 ± 0.035	7.154	-0.80
867	4	224.935	0.598	64.707	121.950	211.500	17.269 ± 0.313	5.332 ± 0.033	5.308	-0.45
868	4	224.793	0.598	64.732	121.213	231.500	14.085 ± 0.313	3.809 ± 0.032	3.665	-3.78
869	4	224.616	0.597	64.719	121.500	249.950	12.045 ± 0.313	3.095 ± 0.032	2.783	-7.97
870	4	224.788	0.598	64.966	120.863	266.500	10.632 ± 0.313	2.857 ± 0.032	2.253	*****

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
871	4	224.376	0.597	65.090	121.038	277.275	9.845 ± 0.313	3.416 ± 0.032	1.987	*****
872	4	224.159	0.596	64.868	121.000	253.888	11.646 ± 0.313	3.015 ± 0.032	2.627	*****
873	4	224.614	0.597	64.818	120.412	259.950	11.057 ± 0.313	2.870 ± 0.032	2.405	*****
874	4	224.011	0.596	65.176	121.025	273.500	10.086 ± 0.316	3.032 ± 0.045	2.066	*****
875	4	224.807	0.598	64.472	121.462	183.500	25.258 ± 0.319	10.747 ± 0.058	10.787	0.37
876	4	299.600	0.797	64.831	121.525	187.000	32.244 ± 0.318	16.321 ± 0.052	16.751	2.63
877	4	299.274	0.796	64.756	121.500	192.462	29.565 ± 0.317	13.935 ± 0.046	14.214	2.01
878	4	298.692	0.795	64.695	121.487	199.762	26.521 ± 0.316	11.434 ± 0.041	11.584	1.31
879	4	298.923	0.795	64.954	121.500	210.000	23.318 ± 0.315	9.144 ± 0.036	9.102	-0.45
880	4	299.957	0.798	64.769	121.500	223.150	20.236 ± 0.314	7.207 ± 0.035	6.996	-2.93
881	4	299.913	0.798	64.435	120.537	240.138	17.295 ± 0.314	5.629 ± 0.034	5.254	-6.66
882	4	296.322	0.788	64.917	121.625	248.662	15.982 ± 0.314	4.985 ± 0.034	4.564	-8.45
883	4	299.329	0.796	64.843	121.737	263.713	14.487 ± 0.313	4.737 ± 0.034	3.843	*****
884	4	299.731	0.797	64.744	121.487	271.975	13.660 ± 0.313	5.105 ± 0.035	3.476	*****
885	4	299.019	0.795	64.855	120.687	275.000	13.271 ± 0.313	5.349 ± 0.034	3.310	*****
886	4	299.060	0.795	65.139	120.687	267.000	13.988 ± 0.314	4.798 ± 0.034	3.619	*****
887	4	298.961	0.795	64.608	120.988	256.550	15.158 ± 0.316	4.847 ± 0.044	4.159	*****
888	4	299.134	0.796	64.744	121.500	203.500	25.307 ± 0.319	10.576 ± 0.058	10.611	0.33
889	4	301.286	0.801	64.645	76.500	142.500	31.944 ± 0.317	16.253 ± 0.050	16.785	3.28
890	4	301.056	0.801	64.769	77.688	152.000	28.205 ± 0.316	12.856 ± 0.044	13.237	2.97
891	4	299.676	0.797	64.756	77.688	160.450	24.979 ± 0.315	10.347 ± 0.039	10.519	1.66
892	4	299.777	0.797	64.559	77.225	172.513	21.477 ± 0.314	7.818 ± 0.035	7.917	1.27
893	4	299.911	0.798	64.830	77.412	189.988	18.165 ± 0.314	5.727 ± 0.033	5.790	1.10
894	4	298.602	0.794	64.719	77.888	211.000	15.380 ± 0.313	4.349 ± 0.033	4.265	-1.94
895	4	298.812	0.795	64.682	77.825	226.525	13.672 ± 0.313	3.721 ± 0.032	3.454	-7.18
896	4	298.374	0.794	64.769	77.500	248.987	11.876 ± 0.313	3.207 ± 0.032	2.706	*****
897	4	298.852	0.795	64.707	77.375	268.000	10.653 ± 0.313	3.496 ± 0.033	2.259	*****
898	4	299.250	0.796	65.028	77.475	274.037	10.339 ± 0.313	4.099 ± 0.032	2.153	*****
899	4	299.735	0.797	64.917	77.500	261.500	11.092 ± 0.313	3.303 ± 0.032	2.414	*****
900	4	300.008	0.798	64.892	77.500	243.912	12.280 ± 0.313	3.388 ± 0.032	2.866	*****
901	4	299.539	0.797	64.645	77.500	235.250	12.988 ± 0.313	3.604 ± 0.033	3.157	-12.41
902	4	300.317	0.799	64.781	76.438	222.938	14.011 ± 0.313	3.904 ± 0.032	3.607	-7.60
903	4	300.478	0.799	64.584	77.500	253.437	11.656 ± 0.313	3.279 ± 0.033	2.622	*****
904	4	300.023	0.798	64.645	77.688	229.475	13.556 ± 0.318	3.772 ± 0.053	3.403	-9.78
905	4	301.535	0.802	64.608	76.500	146.850	29.995 ± 0.318	14.363 ± 0.052	14.895	3.71
906	4	373.672	0.994	64.954	77.500	164.275	29.884 ± 0.319	13.940 ± 0.057	14.476	3.84
907	4	372.098	0.990	64.633	77.950	159.062	32.097 ± 0.317	15.890 ± 0.047	16.581	4.35
908	4	371.657	0.989	64.633	77.250	171.500	27.349 ± 0.316	11.905 ± 0.043	12.245	2.86
909	4	371.322	0.988	64.571	77.875	181.475	24.784 ± 0.315	9.980 ± 0.039	10.170	1.91

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
910	4	372.204	0.990	64.534	77.150	193.300	21.979 ± 0.315	8.073 ± 0.037	8.123	0.63
911	4	375.260	0.998	64.818	77.550	209.512	19.435 ± 0.314	6.613 ± 0.035	6.466	-2.22
912	4	374.678	0.997	64.621	77.788	225.988	17.270 ± 0.314	5.627 ± 0.034	5.218	-7.26
913	4	374.408	0.996	65.077	77.500	252.513	14.552 ± 0.313	4.738 ± 0.039	3.863	*****
914	4	374.432	0.996	65.460	76.962	283.500	12.249 ± 0.313	8.213 ± 0.034	2.897	*****
915	4	374.350	0.996	64.905	76.875	256.500	14.255 ± 0.313	4.834 ± 0.035	3.730	*****
916	4	375.098	0.998	64.707	77.825	267.500	13.484 ± 0.314	5.442 ± 0.034	3.396	*****
917	4	374.840	0.997	64.695	76.500	246.500	15.076 ± 0.314	4.972 ± 0.034	4.107	*****
918	4	374.088	0.995	64.547	76.438	235.500	16.030 ± 0.317	5.279 ± 0.049	4.571	-13.41
919	4	375.219	0.998	64.806	77.500	170.000	28.221 ± 0.319	12.639 ± 0.057	12.988	2.76
920	4	374.687	0.997	64.695	120.475	202.000	32.264 ± 0.318	16.072 ± 0.052	16.522	2.80
921	4	374.077	0.995	64.547	121.075	209.000	29.696 ± 0.317	13.879 ± 0.048	14.127	1.78
922	4	373.300	0.993	64.621	121.925	217.000	27.361 ± 0.316	12.042 ± 0.044	12.112	0.58
923	4	373.512	0.994	64.707	120.300	223.000	25.140 ± 0.316	10.496 ± 0.042	10.345	-1.44
924	4	373.526	0.994	64.596	120.337	231.138	23.197 ± 0.315	9.334 ± 0.039	8.913	-4.51
925	4	374.074	0.995	64.830	120.375	241.500	21.227 ± 0.314	8.225 ± 0.037	7.577	-7.88
926	4	374.192	0.995	65.077	121.163	257.500	18.854 ± 0.314	7.151 ± 0.038	6.124	*****
927	4	374.122	0.995	65.065	120.000	273.000	16.750 ± 0.314	7.552 ± 0.044	4.978	*****
928	4	373.958	0.995	65.016	121.100	283.200	15.765 ± 0.314	10.268 ± 0.037	4.489	*****
929	4	373.936	0.995	64.942	120.350	266.563	17.479 ± 0.314	7.147 ± 0.037	5.361	*****
930	4	373.504	0.993	64.880	121.475	263.550	17.959 ± 0.315	7.052 ± 0.038	5.622	*****
931	4	374.238	0.995	64.547	121.512	252.000	19.748 ± 0.315	7.659 ± 0.039	6.653	-13.14
932	4	374.156	0.995	64.756	120.700	248.000	20.192 ± 0.314	7.818 ± 0.038	6.923	-11.45
933	4	373.846	0.994	64.868	120.362	256.000	18.887 ± 0.315	7.286 ± 0.039	6.143	*****
934	4	373.684	0.994	64.769	120.487	241.500	21.197 ± 0.319	8.241 ± 0.060	7.558	-8.28
935	4	147.933	0.394	64.695	120.750	153.500	32.000 ± 0.318	17.002 ± 0.053	17.370	2.16
936	4	147.925	0.393	64.806	121.150	156.500	29.190 ± 0.317	14.456 ± 0.047	14.600	1.00
937	4	150.180	0.399	64.880	121.350	161.450	26.068 ± 0.316	11.739 ± 0.042	11.789	0.42
938	4	149.740	0.398	64.645	121.500	166.213	23.165 ± 0.315	9.522 ± 0.038	9.438	-0.88
939	4	149.173	0.397	64.769	120.988	171.000	20.474 ± 0.314	7.586 ± 0.036	7.497	-1.17
940	4	149.243	0.397	64.756	121.525	178.788	18.021 ± 0.314	6.007 ± 0.033	5.909	-1.62
941	4	148.922	0.396	64.769	120.612	188.012	15.346 ± 0.313	4.437 ± 0.032	4.393	-0.99
942	4	149.005	0.396	64.423	121.013	195.500	13.862 ± 0.313	3.676 ± 0.032	3.646	-0.82
943	4	148.606	0.395	64.386	120.512	201.575	12.605 ± 0.313	3.151 ± 0.032	3.068	-2.63
944	4	148.169	0.394	64.534	120.500	208.513	11.526 ± 0.313	2.700 ± 0.031	2.613	-3.24
945	4	147.896	0.393	64.584	120.100	216.500	10.535 ± 0.313	2.311 ± 0.031	2.227	-3.62
946	4	147.806	0.393	64.386	121.525	227.525	9.571 ± 0.313	1.988 ± 0.031	1.884	-5.25
947	4	150.039	0.399	64.695	120.850	240.537	8.532 ± 0.313	1.708 ± 0.031	1.550	-9.28
948	4	150.384	0.400	64.707	120.600	255.037	7.562 ± 0.312	1.502 ± 0.031	1.275	*****

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
949	4	150.271	0.400	64.584	120.400	275.525	6.478 ± 0.312	1.614 ± 0.032	1.010	*****
950	4	149.904	0.399	64.695	121.525	295.425	5.886 ± 0.312	2.812 ± 0.031	0.886	*****
951	4	150.137	0.399	64.744	120.612	266.037	6.949 ± 0.314	1.446 ± 0.035	1.120	*****
952	4	150.570	0.401	64.806	121.525	182.525	17.121 ± 0.319	5.397 ± 0.061	5.373	-0.44
953	4	150.599	0.401	65.028	76.063	109.838	31.635 ± 0.317	17.297 ± 0.053	17.669	2.15
954	4	150.685	0.401	64.547	77.538	114.537	28.363 ± 0.316	14.155 ± 0.047	14.344	1.33
955	4	148.820	0.396	64.682	76.088	117.088	25.362 ± 0.315	11.560 ± 0.042	11.632	0.62
956	4	148.988	0.396	64.892	76.850	122.063	22.608 ± 0.315	9.371 ± 0.037	9.360	-0.11
957	4	148.895	0.396	64.769	77.550	130.550	19.474 ± 0.314	7.018 ± 0.034	7.059	0.58
958	4	148.926	0.396	64.905	76.050	139.175	16.218 ± 0.313	5.028 ± 0.032	5.011	-0.34
959	4	148.868	0.396	64.485	77.913	153.537	13.572 ± 0.313	3.581 ± 0.032	3.589	0.21
960	4	148.596	0.395	64.756	77.700	164.050	11.794 ± 0.313	2.804 ± 0.031	2.768	-1.28
961	4	148.514	0.395	64.695	77.562	181.175	9.790 ± 0.313	2.034 ± 0.031	1.971	-3.09
962	4	148.078	0.394	64.571	77.550	203.050	7.998 ± 0.312	1.448 ± 0.031	1.378	-4.83
963	4	148.393	0.395	64.744	77.650	219.212	7.049 ± 0.312	1.213 ± 0.031	1.113	-8.26
964	4	148.055	0.394	64.744	77.925	243.800	5.735 ± 0.312	0.957 ± 0.031	0.807	*****
965	4	148.269	0.394	64.744	76.063	249.625	5.753 ± 0.312	0.957 ± 0.031	0.810	*****
966	4	147.829	0.393	64.991	76.588	267.762	5.261 ± 0.312	1.003 ± 0.031	0.715	*****
967	4	147.931	0.394	64.954	77.137	278.075	4.997 ± 0.312	1.305 ± 0.031	0.669	*****
968	4	148.063	0.394	64.806	77.763	232.175	6.470 ± 0.313	1.072 ± 0.031	0.970	-9.56
969	4	148.116	0.394	64.608	77.562	191.550	8.977 ± 0.318	1.706 ± 0.057	1.689	-0.99
970	4	148.616	0.395	64.880	77.000	112.075	30.020 ± 0.321	15.649 ± 0.066	16.010	2.31
971	4	148.861	0.396	34.809	121.900	150.500	36.874 ± 0.319	21.954 ± 0.063	22.682	3.32
972	4	148.532	0.395	34.908	120.500	151.487	33.945 ± 0.318	18.862 ± 0.058	19.417	2.94
973	4	148.455	0.395	34.698	121.025	154.012	31.454 ± 0.318	16.514 ± 0.053	16.806	1.77
974	4	148.067	0.394	34.760	121.900	157.500	29.164 ± 0.316	14.289 ± 0.046	14.563	1.92
975	4	148.151	0.394	34.797	121.513	161.737	25.745 ± 0.316	11.443 ± 0.042	11.519	0.67
976	4	148.072	0.394	34.698	120.950	164.500	23.568 ± 0.315	9.734 ± 0.039	9.764	0.31
977	4	150.590	0.401	34.760	120.237	169.500	21.143 ± 0.314	7.950 ± 0.035	7.966	0.20
978	4	150.460	0.400	34.797	121.000	178.500	18.042 ± 0.314	5.944 ± 0.034	5.920	-0.41
979	4	149.982	0.399	34.537	121.000	187.000	15.873 ± 0.313	4.665 ± 0.033	4.672	0.15
980	4	149.524	0.398	34.994	120.450	195.050	13.965 ± 0.313	3.699 ± 0.032	3.695	-0.11
981	4	149.584	0.398	34.698	121.400	207.000	12.199 ± 0.313	2.917 ± 0.031	2.891	-0.90
982	4	150.065	0.399	34.797	121.400	218.863	10.644 ± 0.313	2.386 ± 0.031	2.269	-4.91
983	4	149.640	0.398	34.945	122.013	233.500	9.244 ± 0.313	2.050 ± 0.032	1.782	*****
984	4	149.259	0.397	35.068	121.087	243.900	8.371 ± 0.313	2.607 ± 0.032	1.512	*****
985	4	149.274	0.397	35.303	120.200	249.000	7.931 ± 0.313	3.041 ± 0.031	1.386	*****
986	4	148.900	0.396	35.007	121.588	241.000	8.594 ± 0.313	2.363 ± 0.031	1.579	*****
987	4	149.014	0.396	34.760	120.987	223.575	10.047 ± 0.313	2.309 ± 0.031	2.053	*****

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
988	4	149.114	0.397	35.229	120.850	234.500	9.075 ± 0.313	2.061 ± 0.031	1.727	*****
989	4	149.001	0.396	34.661	120.062	230.738	9.376 ± 0.317	2.060 ± 0.050	1.824	*****
990	4	149.142	0.397	34.599	121.375	159.438	27.618 ± 0.321	13.002 ± 0.066	13.147	1.11
991	4	224.178	0.596	34.686	121.563	164.588	36.983 ± 0.319	21.354 ± 0.062	22.196	3.94
992	4	223.982	0.596	34.710	120.613	167.000	33.950 ± 0.318	18.299 ± 0.055	18.875	3.15
993	4	223.746	0.595	34.710	121.763	173.038	30.506 ± 0.317	15.151 ± 0.047	15.400	1.64
994	4	223.500	0.595	34.587	120.187	178.500	26.831 ± 0.316	11.951 ± 0.044	12.095	1.20
995	4	224.143	0.59[illegible]	34.611	121.125	184.238	24.699 ± 0.315	10.272 ± 0.039	10.343	0.69
996	4	223.744	0.595	34.846	120.912	193.425	21.417 ± 0.314	7.892 ± 0.035	7.918	0.32
997	4	222.489	0.592	34.710	121.413	210.000	17.455 ± 0.314	5.579 ± 0.034	5.419	-2.86
998	4	223.460	0.594	34.747	121.613	223.000	15.283 ± 0.313	4.593 ± 0.033	4.257	-7.31
999	4	222.982	0.593	34.772	121.000	238.000	13.245 ± 0.313	4.441 ± 0.035	3.305	*****
1000	4	222.911	0.593	35.093	121.012	246.100	12.280 ± 0.313	5.817 ± 0.033	2.901	*****
1001	4	223.134	0.594	34.649	121.000	229.500	14.225 ± 0.313	4.250 ± 0.033	3.748	*****
1002	4	223.166	0.594	34.834	121.012	235.013	13.603 ± 0.314	4.247 ± 0.033	3.463	*****
1003	4	223.383	0.594	35.044	120.975	225.513	14.810 ± 0.315	4.430 ± 0.037	4.025	*****
1004	4	223.232	0.594	34.821	120.175	200.000	19.484 ± 0.317	6.690 ± 0.050	6.644	-0.69
1005	4	222.289	0.591	34.661	121.500	176.963	28.452 ± 0.321	13.238 ± 0.066	13.507	2.03
1006	4	300.433	0.799	34.735	121.012	178.450	37.117 ± 0.320	21.001 ± 0.062	21.889	4.23
1007	4	299.894	0.798	34.698	121.100	183.000	34.342 ± 0.318	18.312 ± 0.055	18.880	3.10
1008	4	299.457	0.797	34.957	121.150	189.000	31.004 ± 0.317	15.122 ± 0.049	15.553	2.85
1009	4	299.825	0.798	34.871	120.550	195.925	27.797 ± 0.316	12.493 ± 0.044	12.657	1.31
1010	4	299.811	0.797	34.661	121.500	205.000	25.045 ± 0.315	10.519 ± 0.040	10.402	-1.11
1011	4	299.718	0.797	34.821	120.162	215.000	21.958 ± 0.314	8.513 ± 0.037	8.148	-4.29
1012	4	300.037	0.798	34.945	121.012	230.025	18.890 ± 0.314	7.054 ± 0.038	6.192	*****
1013	4	299.640	0.797	35.253	121.012	238.512	17.594 ± 0.314	7.507 ± 0.044	5.453	*****
1014	4	299.474	0.797	35.019	120.500	248.012	16.204 ± 0.314	10.641 ± 0.038	4.718	*****
1015	4	299.991	0.798	34.710	121.075	237.012	17.957 ± 0.314	7.530 ± 0.038	5.656	*****
1016	4	299.802	0.797	34.463	121.975	233.125	18.600 ± 0.315	7.287 ± 0.038	6.024	*****
1017	4	300.238	0.799	34.649	121.012	227.013	19.651 ± 0.315	7.375 ± 0.039	6.651	*****
1018	4	300.136	0.798	34.686	121.000	221.500	20.691 ± 0.319	7.867 ± 0.060	7.305	-7.14
1019	4	300.497	0.799	34.624	120.087	184.525	32.898 ± 0.320	16.825 ± 0.066	17.411	3.49
1020	4	149.533	0.398	34.834	76.025	105.525	35.837 ± 0.319	21.726 ± 0.063	22.400	3.10
1021	4	149.079	0.397	34.525	77.012	108.487	33.270 ± 0.318	18.968 ± 0.058	19.438	2.48
1022	4	148.849	0.396	34.599	76.987	111.000	30.524 ± 0.317	16.195 ± 0.049	16.513	1.96
1023	4	148.492	0.395	34.797	76.812	115.500	26.687 ± 0.316	12.637 ± 0.042	12.808	1.36
1024	4	148.320	0.395	34.673	77.525	122.000	23.153 ± 0.315	9.700 ± 0.038	9.787	0.90
1025	4	148.371	0.395	34.673	77.563	129.038	19.938 ± 0.314	7.343 ± 0.035	7.382	0.53
1026	4	148.133	0.394	34.784	77.475	137.000	17.174 ± 0.313	5.541 ± 0.033	5.577	0.65

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1027	4	149.974	0.399	34.834	78.012	152.325	13.932 ± 0.313	3.797 ± 0.032	3.767	-0.79
1028	4	150.075	0.399	34.809	77.800	163.513	12.068 ± 0.313	2.956 ± 0.031	2.885	-2.40
1029	4	149.787	0.398	34.686	77.500	173.500	10.799 ± 0.313	2.437 ± 0.031	2.354	-3.41
1030	4	149.923	0.399	34.686	77.438	186.500	9.478 ± 0.313	1.975 ± 0.031	1.859	-5.88
1031	4	149.714	0.398	34.895	77.338	198.562	8.466 ± 0.313	1.700 ± 0.031	1.523	-10.42
1032	4	149.786	0.398	34.895	77.400	209.513	7.750 ± 0.312	1.513 ± 0.031	1.309	-13.47
1033	4	149.965	0.399	34.747	77.500	226.500	6.868 ± 0.312	1.354 ± 0.031	1.074	*****
1034	4	150.046	0.399	34.846	77.613	235.438	6.424 ± 0.312	1.515 ± 0.031	0.968	*****
1035	4	150.049	0.399	34.932	77.987	251.487	5.862 ± 0.313	2.577 ± 0.031	0.845	*****
1036	4	150.098	0.399	34.809	77.500	216.500	7.357 ± 0.316	1.459 ± 0.046	1.201	-17.67
1037	4	150.591	0.401	34.661	76.937	119.013	25.195 ± 0.321	11.280 ± 0.066	11.477	1.75
1038	4	224.807	0.598	34.747	76.587	120.000	36.495 ± 0.319	21.452 ± 0.062	22.294	3.93
1039	4	224.659	0.598	34.723	77.550	125.000	33.325 ± 0.318	18.118 ± 0.056	18.733	3.40
1040	4	224.478	0.597	34.624	76.962	128.000	30.709 ± 0.317	15.645 ± 0.048	16.040	2.52
1041	4	224.628	0.598	34.673	76.725	134.550	26.982 ± 0.316	12.235 ± 0.042	12.543	2.52
1042	4	224.494	0.597	34.661	77.525	143.500	23.599 ± 0.315	9.539 ± 0.037	9.724	1.94
1043	4	224.536	0.597	34.624	77.900	154.500	20.199 ± 0.314	7.148 ± 0.035	7.248	1.41
1044	4	225.205	0.599	34.611	77.500	165.000	17.731 ± 0.314	5.621 ± 0.033	5.676	0.97
1045	4	224.665	0.598	34.624	77.012	183.013	14.594 ± 0.313	4.100 ± 0.032	3.953	-3.60
1046	4	224.449	0.597	34.982	76.013	201.587	12.315 ± 0.313	3.178 ± 0.032	2.905	-8.60
1047	4	224.095	0.596	34.858	76.200	214.400	11.147 ± 0.313	2.807 ± 0.032	2.437	*****
1048	4	224.208	0.596	34.710	77.688	224.013	10.585 ± 0.313	2.711 ± 0.032	2.230	*****
1049	4	223.982	0.596	34.735	77.588	238.912	9.548 ± 0.313	3.344 ± 0.032	1.875	*****
1050	4	224.156	0.596	34.821	77.000	229.788	10.130 ± 0.313	2.748 ± 0.032	2.069	*****
1051	4	224.315	0.597	35.167	76.038	233.513	9.810 ± 0.313	2.820 ± 0.034	1.960	*****
1052	4	224.057	0.596	34.463	76.013	248.000	9.012 ± 0.318	4.900 ± 0.052	1.706	*****
1053	4	225.796	0.601	34.661	77.525	132.025	29.001 ± 0.321	13.935 ± 0.066	14.382	3.21
1054	4	297.672	0.792	34.895	76.587	133.500	36.755 ± 0.319	20.977 ± 0.061	21.967	4.72
1055	4	299.191	0.796	34.649	77.000	139.500	33.479 ± 0.318	17.637 ± 0.052	18.368	4.15
1056	4	298.226	0.793	34.723	76.862	147.013	29.691 ± 0.317	14.054 ± 0.046	14.611	3.96
1057	4	296.576	0.789	34.673	76.512	155.500	26.154 ± 0.315	11.222 ± 0.039	11.493	2.41
1058	4	297.782	0.792	34.574	77.012	170.012	22.101 ± 0.314	8.235 ± 0.036	8.362	1.54
1059	4	298.109	0.793	34.821	77.875	187.500	18.667 ± 0.314	6.257 ± 0.034	6.095	-2.58
1060	4	296.883	0.790	34.821	77.575	209.425	15.598 ± 0.313	4.799 ± 0.034	4.394	-8.44
1061	4	297.000	0.790	35.130	76.175	232.388	13.081 ± 0.313	4.590 ± 0.038	3.226	*****
1062	4	298.884	0.795	35.031	76.288	245.513	12.115 ± 0.313	7.321 ± 0.035	2.833	*****
1063	4	298.953	0.795	35.118	77.688	240.000	12.663 ± 0.313	5.880 ± 0.033	3.055	*****
1064	4	298.746	0.795	34.883	77.225	225.150	13.877 ± 0.314	4.472 ± 0.033	3.575	*****
1065	4	298.540	0.794	34.624	77.000	219.000	14.570 ± 0.314	4.477 ± 0.034	3.894	*****

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1066	4	298.301	0.793	34.574	76.562	213.025	15.056 ± 0.314	4.643 ± 0.035	4.126	*****
1067	4	298.668	0.794	34.784	76.950	197.988	16.984 ± 0.316	5.412 ± 0.042	5.126	-5.29
1068	4	298.795	0.795	34.871	77.550	163.538	24.123 ± 0.321	9.663 ± 0.065	9.856	2.00
1069	4	375.439	0.999	34.686	76.887	148.500	36.899 ± 0.319	20.637 ± 0.061	21.623	4.78
1070	4	375.368	0.998	34.797	77.850	155.350	33.949 ± 0.318	17.640 ± 0.054	18.437	4.52
1071	4	374.632	0.996	34.611	76.025	161.025	30.760 ± 0.317	14.687 ± 0.049	15.293	4.13
1072	4	374.252	0.995	34.747	76.025	168.525	28.108 ± 0.316	12.492 ± 0.044	12.893	3.21
1073	4	373.891	0.995	34.784	77.175	180.500	25.010 ± 0.315	10.298 ± 0.040	10.342	0.43
1074	4	373.589	0.994	34.858	77.650	195.500	21.867 ± 0.315	8.387 ± 0.037	8.054	-3.97
1075	4	372.661	0.991	34.747	76.625	209.075	19.331 ± 0.314	7.098 ± 0.036	6.433	-9.38
1076	4	372.895	0.992	34.661	76.787	221.975	17.624 ± 0.314	6.508 ± 0.037	5.454	*****
1077	4	372.847	0.992	35.007	77.438	231.513	16.583 ± 0.314	6.946 ± 0.039	4.901	*****
1078	4	372.532	0.991	35.031	76.250	236.013	16.021 ± 0.314	7.893 ± 0.036	4.615	*****
1079	4	372.562	0.991	34.587	76.100	226.763	17.030 ± 0.314	6.537 ± 0.037	5.134	*****
1080	4	372.700	0.991	34.599	77.962	220.013	17.947 ± 0.314	6.651 ± 0.037	5.633	*****
1081	4	373.079	0.992	34.735	77.463	215.000	18.620 ± 0.315	6.828 ± 0.039	6.015	*****
1082	4	373.304	0.993	34.710	76.937	201.638	20.572 ± 0.316	7.748 ± 0.042	7.203	-7.04
1083	4	374.044	0.995	34.574	78.000	187.000	23.708 ± 0.319	9.481 ± 0.058	9.358	-1.30
1084	4	374.080	0.995	34.883	76.425	157.025	32.408 ± 0.321	16.209 ± 0.066	16.893	4.22
1085	4	374.448	0.996	34.920	120.837	191.550	37.289 ± 0.320	20.953 ± 0.064	21.742	3.77
1086	4	374.259	0.995	34.611	121.513	196.013	35.358 ± 0.319	19.072 ± 0.060	19.648	3.02
1087	4	374.557	0.996	34.821	122.013	201.025	33.161 ± 0.318	17.005 ± 0.056	17.395	2.29
1088	4	374.077	0.995	34.883	121.525	205.000	31.438 ± 0.318	15.618 ± 0.053	15.729	0.71
1089	4	374.173	0.995	34.846	121.500	210.025	29.491 ± 0.317	14.100 ± 0.049	13.948	-1.08
1090	4	374.933	0.997	34.920	121.975	216.600	27.533 ± 0.317	12.799 ± 0.048	12.266	-4.16
1091	4	374.622	0.996	34.883	122.013	221.513	26.268 ± 0.316	11.985 ± 0.046	11.242	-6.20
1092	4	374.368	0.996	34.871	120.513	223.012	25.383 ± 0.316	11.390 ± 0.045	10.555	-7.33
1093	4	374.500	0.996	34.920	120.463	229.000	23.968 ± 0.316	10.738 ± 0.045	9.502	*****
1094	4	374.604	0.996	34.772	120.950	234.538	22.833 ± 0.315	10.973 ± 0.047	8.701	*****
1095	4	374.088	0.995	35.229	120.475	238.437	21.986 ± 0.316	11.756 ± 0.044	8.126	*****
1096	4	374.694	0.997	34.969	120.950	231.525	23.506 ± 0.316	10.607 ± 0.045	9.171	*****
1097	4	374.870	0.997	34.587	120.500	227.200	24.332 ± 0.316	10.866 ± 0.046	9.768	*****
1098	4	374.746	0.997	34.673	121.863	226.500	24.893 ± 0.320	11.173 ± 0.062	10.183	*****
1099	4	374.912	0.997	34.858	120.513	197.013	34.527 ± 0.317	17.862 ± 0.046	18.787	5.18
1490	7	0.000	0.000	64.725	76.725	76.500	29.781 ± 0.318	20.147 ± 0.065	20.703	2.76
1491	7	0.000	0.000	64.638	77.388	77.000	27.572 ± 0.317	17.790 ± 0.062	17.959	0.95
1492	7	0.001	0.000	64.688	77.500	77.500	25.513 ± 0.316	15.589 ± 0.056	15.588	0.00
1493	7	0.000	0.000	64.688	76.537	76.475	22.821 ± 0.315	12.860 ± 0.050	12.760	-0.77
1494	7	0.000	0.000	64.588	77.538	77.500	20.321 ± 0.315	10.423 ± 0.044	10.317	-1.01

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1495	7	0.000	0.000	64.837	77.100	76.962	18.463 ± 0.314	8.699 ± 0.040	8.687	-0.14
1496	7	0.000	0.000	64.575	77.500	77.000	16.480 ± 0.314	7.122 ± 0.037	7.072	-0.70
1497	7	-0.001	0.000	64.775	77.887	77.500	13.194 ± 0.313	4.796 ± 0.034	4.741	-1.15
1498	7	0.001	0.000	64.426	77.513	77.475	10.514 ± 0.313	3.240 ± 0.032	3.165	-2.33
1499	7	0.000	0.000	64.463	76.962	76.500	8.286 ± 0.313	2.135 ± 0.031	2.076	-2.74
1500	7	0.000	0.000	64.451	78.025	77.500	6.190 ± 0.312	1.262 ± 0.031	1.237	-1.98
1501	7	-0.001	0.000	64.388	76.975	76.500	3.908 ± 0.312	0.564 ± 0.031	0.553	-1.94
1502	7	0.000	0.000	64.438	76.500	76.038	8.251 ± 0.313	2.085 ± 0.031	2.066	-0.93
1503	7	0.000	0.000	64.999	78.050	77.875	15.424 ± 0.314	6.357 ± 0.036	6.273	-1.32
1504	7	0.000	0.000	64.862	77.500	77.175	25.465 ± 0.316	15.495 ± 0.056	15.539	0.28
1505	7	0.000	0.000	64.949	120.675	120.488	30.171 ± 0.318	18.891 ± 0.064	19.532	3.39
1506	7	0.000	0.000	64.949	121.500	121.000	28.222 ± 0.317	17.242 ± 0.061	17.243	0.01
1507	7	0.000	0.000	64.650	121.500	121.000	26.342 ± 0.317	15.091 ± 0.055	15.186	0.63
1508	7	0.000	0.000	65.074	121.500	121.000	24.141 ± 0.316	12.994 ± 0.050	12.937	-0.44
1509	7	0.000	0.000	64.600	120.500	120.275	22.169 ± 0.315	11.142 ± 0.046	11.085	-0.51
1510	7	0.000	0.000	64.738	120.400	119.687	20.173 ± 0.315	9.392 ± 0.042	9.332	-0.64
1511	7	0.000	0.000	64.875	121.713	121.012	18.043 ± 0.314	7.647 ± 0.038	7.601	-0.60
1512	7	0.000	0.000	64.538	121.500	121.012	16.062 ± 0.314	6.175 ± 0.036	6.159	-0.26
1513	7	0.000	0.000	64.551	121.000	120.425	13.941 ± 0.313	4.832 ± 0.034	4.775	-1.18
1514	7	0.000	0.000	64.713	122.000	121.500	11.943 ± 0.313	3.647 ± 0.032	3.613	-0.93
1515	7	0.000	0.000	64.314	121.538	121.288	10.073 ± 0.313	2.701 ± 0.032	2.671	-1.12
1516	7	0.000	0.000	64.750	121.988	121.025	7.888 ± 0.313	1.773 ± 0.031	1.735	-2.14
1517	7	0.000	0.000	64.713	122.000	121.500	5.807 ± 0.312	1.044 ± 0.031	1.021	-2.19
1518	7	0.000	0.000	64.638	119.962	119.487	4.010 ± 0.312	0.570 ± 0.031	0.549	-3.70
1519	7	0.000	0.000	64.775	120.500	119.500	3.994 ± 0.312	0.554 ± 0.031	0.546	-1.49
1520	7	0.000	0.000	64.177	120.975	120.500	15.158 ± 0.314	5.605 ± 0.035	5.556	-0.87
1521	7	145.729	0.398	64.339	120.000	152.000	31.673 ± 0.319	19.158 ± 0.065	19.595	2.28
1522	7	146.919	0.401	64.638	121.500	154.713	30.463 ± 0.318	18.186 ± 0.063	18.167	-0.10
1523	7	145.942	0.398	64.900	121.500	157.487	28.452 ± 0.317	16.058 ± 0.058	15.955	-0.64
1524	7	147.973	0.404	64.812	120.000	159.500	26.219 ± 0.317	13.876 ± 0.052	13.669	-1.49
1525	7	145.687	0.398	63.703	120.500	162.413	24.243 ± 0.316	11.959 ± 0.047	11.784	-1.46
1526	7	147.538	0.403	64.613	120.838	166.500	22.461 ± 0.315	10.317 ± 0.044	10.196	-1.18
1527	7	147.087	0.402	65.136	120.875	171.000	20.235 ± 0.315	8.448 ± 0.040	8.369	-0.94
1528	7	146.552	0.400	64.501	121.500	178.175	18.177 ± 0.314	6.783 ± 0.037	6.843	0.88
1529	7	147.688	0.403	64.912	121.000	195.500	13.730 ± 0.313	4.159 ± 0.033	4.062	-2.34
1530	7	146.462	0.400	65.274	121.775	206.000	12.004 ± 0.313	3.229 ± 0.032	3.177	-1.62
1531	7	146.366	0.400	65.161	121.500	219.500	10.249 ± 0.313	2.506 ± 0.031	2.392	-4.54
1532	7	145.419	0.397	64.401	121.500	234.537	8.864 ± 0.313	1.986 ± 0.031	1.856	-6.55
1533	7	145.653	0.398	64.326	121.500	243.500	8.202 ± 0.313	1.763 ± 0.031	1.627	-7.70

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1534	7	146.620	0.400	65.274	122.000	257.925	7.441 ± 0.313	1.621 ± 0.031	1.387	*****
1535	7	146.152	0.399	65.012	121.500	267.500	7.025 ± 0.312	1.560 ± 0.031	1.267	*****
1536	7	145.953	0.398	65.149	120.575	277.875	6.434 ± 0.312	1.773 ± 0.031	1.107	*****
1537	7	147.938	0.404	65.074	120.300	287.050	6.072 ± 0.312	2.353 ± 0.031	1.019	*****
1538	7	147.279	0.402	65.648	120.513	298.175	5.558 ± 0.312	3.598 ± 0.032	0.904	*****
1539	7	145.879	0.398	64.812	119.987	183.550	16.018 ± 0.314	5.492 ± 0.035	5.411	-1.47
1540	7	145.971	0.399	65.336	121.938	168.913	21.523 ± 0.315	9.492 ± 0.042	9.397	-1.00
1541	7	145.890	0.398	64.912	76.500	108.775	31.056 ± 0.318	19.039 ± 0.065	19.518	2.52
1542	7	145.711	0.398	64.875	76.300	110.713	29.083 ± 0.318	17.376 ± 0.061	17.226	-0.86
1543	7	146.070	0.399	64.488	77.500	115.850	26.214 ± 0.317	14.184 ± 0.053	14.120	-0.45
1544	7	147.122	0.402	64.575	77.500	121.500	23.383 ± 0.316	11.388 ± 0.046	11.356	-0.28
1545	7	147.701	0.403	64.551	77.500	127.000	20.628 ± 0.315	8.942 ± 0.041	8.946	0.04
1546	7	146.338	0.400	64.625	77.750	134.500	17.757 ± 0.314	6.810 ± 0.037	6.738	-1.06
1547	7	146.282	0.399	64.600	76.500	145.600	14.803 ± 0.314	4.815 ± 0.034	4.789	-0.53
1548	7	145.447	0.397	64.463	77.625	158.000	12.644 ± 0.313	3.576 ± 0.032	3.565	-0.32
1549	7	145.291	0.397	64.775	76.500	171.825	10.458 ± 0.313	2.542 ± 0.031	2.512	-1.18
1550	7	147.497	0.403	64.538	77.700	187.713	9.267 ± 0.313	2.053 ± 0.031	2.014	-1.92
1551	7	146.533	0.400	64.887	77.000	201.213	8.105 ± 0.313	1.614 ± 0.031	1.585	-1.79
1552	7	145.201	0.396	64.787	77.575	226.663	6.666 ± 0.312	1.244 ± 0.031	1.135	-8.74
1553	7	145.490	0.397	64.962	76.500	253.562	5.682 ± 0.312	1.044 ± 0.031	0.882	*****
1554	7	147.265	0.402	64.987	77.438	289.500	4.712 ± 0.312	1.919 ± 0.031	0.684	*****
1555	7	147.048	0.401	65.124	76.013	267.500	5.248 ± 0.312	1.088 ± 0.031	0.788	*****
1556	7	147.300	0.402	66.695	77.500	269.500	5.333 ± 0.312	1.092 ± 0.031	0.807	*****
1557	7	145.418	0.397	65.261	78.000	131.575	18.836 ± 0.314	7.556 ± 0.038	7.537	-0.26
1558	7	289.247	0.790	64.625	76.625	140.575	31.454 ± 0.318	18.302 ± 0.063	18.778	2.60
1559	7	293.588	0.802	64.775	76.025	140.975	31.232 ± 0.318	18.156 ± 0.063	18.512	1.96
1560	7	292.126	0.798	64.538	77.500	145.500	29.719 ± 0.318	16.761 ± 0.059	16.817	0.34
1561	7	293.642	0.802	64.663	76.263	153.500	26.472 ± 0.317	13.330 ± 0.051	13.487	1.18
1562	7	292.699	0.799	64.675	77.500	164.675	23.417 ± 0.316	10.554 ± 0.044	10.674	1.13
1563	7	292.070	0.797	64.762	76.500	175.500	20.746 ± 0.315	8.142 ± 0.039	8.493	4.31
1564	7	292.213	0.798	64.563	76.500	206.000	15.387 ± 0.314	4.933 ± 0.034	4.862	-1.44
1565	7	292.392	0.798	64.700	77.500	225.000	14.111 ± 0.313	4.190 ± 0.033	4.153	-0.88
1566	7	292.735	0.799	64.688	76.575	229.500	13.445 ± 0.313	4.051 ± 0.033	3.807	-6.01
1567	7	291.997	0.797	64.825	76.500	186.500	18.662 ± 0.314	6.743 ± 0.037	6.962	3.25
1568	7	293.188	0.800	65.062	77.900	236.988	12.679 ± 0.313	3.816 ± 0.033	3.430	-10.12
1569	7	292.134	0.798	64.526	78.000	249.000	11.811 ± 0.313	3.484 ± 0.032	3.033	*****
1570	7	290.917	0.794	64.974	77.000	268.000	10.600 ± 0.313	3.710 ± 0.033	2.523	*****
1572	7	294.338	0.804	65.024	77.500	197.988	17.009 ± 0.314	5.866 ± 0.035	5.854	-0.20
1573	7	293.503	0.801	64.987	77.087	157.500	25.444 ± 0.316	12.418 ± 0.049	12.500	0.66

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1574	7	294.242	0.803	64.688	121.475	186.000	31.675 ± 0.319	18.439 ± 0.064	18.714	1.49
1575	7	293.224	0.801	64.787	121.500	190.500	29.693 ± 0.318	16.462 ± 0.059	16.543	0.49
1576	7	291.729	0.796	64.750	121.500	197.412	26.743 ± 0.317	13.616 ± 0.051	13.560	-0.41
1577	7	291.663	0.796	64.862	121.988	206.400	23.988 ± 0.316	11.106 ± 0.046	11.038	-0.61
1578	7	290.075	0.792	65.136	121.613	210.500	22.651 ± 0.315	10.045 ± 0.043	9.911	-1.33
1579	7	291.677	0.796	64.675	121.500	214.000	21.934 ± 0.315	9.442 ± 0.042	9.331	-1.18
1580	7	294.116	0.803	64.675	121.588	225.825	19.885 ± 0.315	7.959 ± 0.039	7.764	-2.44
1581	7	294.282	0.803	64.675	120.550	233.212	18.288 ± 0.314	6.941 ± 0.037	6.650	-4.20
1582	7	293.790	0.802	65.136	121.000	245.512	16.385 ± 0.314	5.850 ± 0.035	5.441	-6.98
1583	7	291.006	0.795	64.451	121.062	246.100	16.438 ± 0.314	5.812 ± 0.035	5.475	-5.80
1584	7	291.798	0.797	65.099	120.500	258.500	14.768 ± 0.314	5.192 ± 0.034	4.519	*****
1585	7	286.300	0.782	65.236	120.000	262.987	14.173 ± 0.313	5.092 ± 0.034	4.202	*****
1586	7	293.871	0.802	64.974	120.000	268.500	13.783 ± 0.313	5.154 ± 0.034	4.003	*****
1587	7	291.019	0.795	65.062	121.000	276.213	13.115 ± 0.313	5.672 ± 0.035	3.677	*****
1588	7	292.306	0.798	65.498	121.513	285.500	12.289 ± 0.313	7.342 ± 0.038	3.291	*****
1589	7	295.716	0.807	64.613	120.000	200.325	25.710 ± 0.316	12.752 ± 0.049	12.588	-1.29
1590	7	292.902	0.800	65.112	120.500	192.187	28.256 ± 0.317	15.161 ± 0.055	15.043	-0.78
1663	9	0.000	0.000	65.024	77.588	77.500	14.533 ± 0.314	72.471 ± 0.372	74.518	2.82
1664	9	0.000	0.000	64.825	77.538	77.500	13.463 ± 0.313	62.786 ± 0.356	64.357	2.50
1665	9	0.000	0.000	64.650	77.000	76.637	12.721 ± 0.313	56.559 ± 0.346	57.926	2.42
1666	9	0.000	0.000	64.588	76.500	76.000	11.586 ± 0.313	47.532 ± 0.333	48.689	2.44
1667	9	0.000	0.000	64.750	76.500	76.000	10.558 ± 0.313	40.050 ± 0.324	40.954	2.26
1668	9	0.000	0.000	64.613	76.500	76.000	9.583 ± 0.313	33.451 ± 0.317	34.214	2.28
1669	9	0.000	0.000	64.725	76.500	76.000	8.569 ± 0.313	27.359 ± 0.312	27.822	1.69
1670	9	0.000	0.000	64.850	76.500	76.000	7.974 ± 0.313	23.918 ± 0.309	24.367	1.88
1671	9	0.000	0.000	64.663	76.500	76.000	7.296 ± 0.313	20.455 ± 0.307	20.695	1.17
1672	9	0.000	0.000	64.575	76.500	76.000	6.869 ± 0.312	18.325 ± 0.305	18.530	1.12
1673	9	0.000	0.000	64.688	76.500	76.000	6.083 ± 0.312	14.776 ± 0.304	14.839	0.43
1674	9	0.000	0.000	64.725	76.500	76.000	5.079 ± 0.312	10.638 ± 0.302	10.690	0.48
1675	9	0.000	0.000	64.713	76.500	76.000	4.129 ± 0.312	7.374 ± 0.301	7.353	-0.29
1676	9	0.000	0.000	64.787	76.500	76.000	3.420 ± 0.312	5.349 ± 0.301	5.242	-2.00
1677	9	0.000	0.000	64.688	76.500	76.113	5.786 ± 0.312	13.416 ± 0.303	13.548	0.99
1678	9	0.000	0.000	64.713	76.500	76.075	6.980 ± 0.312	18.910 ± 0.306	19.083	0.92
1679	9	0.000	0.000	64.925	76.500	76.500	13.915 ± 0.313	66.717 ± 0.362	68.600	2.82
1680	9	-0.001	0.000	64.787	122.738	122.500	13.927 ± 0.313	64.321 ± 0.358	64.589	0.42
1681	9	-0.001	0.000	64.837	121.500	121.000	13.022 ± 0.313	56.597 ± 0.346	56.910	0.55
1682	9	-0.001	0.000	64.750	121.425	120.950	12.080 ± 0.313	49.082 ± 0.335	49.352	0.55
1683	9	-0.001	0.000	64.750	121.000	120.500	11.055 ± 0.313	41.425 ± 0.326	41.745	0.77
1684	9	0.000	0.000	64.962	121.925	121.500	9.815 ± 0.313	33.231 ± 0.317	33.314	0.25

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1685	9	0.000	0.000	64.787	122.000	121.500	8.780 ± 0.313	26.912 ± 0.311	27.017	0.39
1686	9	0.000	0.000	64.650	122.500	121.963	7.758 ± 0.313	21.260 ± 0.307	21.418	0.74
1687	9	0.000	0.000	64.663	122.500	121.913	6.918 ± 0.312	17.512 ± 0.305	17.301	-1.20
1688	9	0.000	0.000	64.962	122.500	121.838	5.860 ± 0.312	12.881 ± 0.303	12.722	-1.24
1689	9	0.000	0.000	64.750	122.000	121.500	4.886 ± 0.312	9.247 ± 0.302	9.113	-1.44
1690	9	0.000	0.000	64.613	122.000	121.100	3.912 ± 0.312	6.182 ± 0.301	6.076	-1.71
1691	9	0.000	0.000	64.887	121.500	120.800	3.224 ± 0.312	4.489 ± 0.301	4.288	-4.48
1692	9	-0.001	0.000	64.675	121.000	120.162	4.299 ± 0.312	7.367 ± 0.301	7.227	-1.91
1693	9	0.000	0.000	64.949	122.000	121.975	7.190 ± 0.313	18.982 ± 0.306	18.604	-1.99
1694	9	0.000	0.000	64.401	121.963	122.000	7.532 ± 0.313	20.755 ± 0.307	20.285	-2.26
1695	9	87.522	0.399	64.725	76.937	118.012	14.501 ± 0.314	68.497 ± 0.365	69.061	0.82
1696	9	87.614	0.400	64.575	77.937	123.500	13.192 ± 0.313	56.979 ± 0.347	57.487	0.89
1697	9	87.470	0.399	64.625	76.500	127.500	11.694 ± 0.313	45.219 ± 0.330	45.629	0.91
1698	9	87.411	0.399	64.725	77.162	137.500	9.921 ± 0.313	32.868 ± 0.317	33.249	1.16
1699	9	87.385	0.399	64.937	76.000	145.500	8.592 ± 0.313	24.839 ± 0.310	25.264	1.71
1700	9	87.194	0.398	64.900	77.000	155.987	7.506 ± 0.313	19.332 ± 0.306	19.499	0.86
1701	9	87.253	0.398	64.563	77.500	165.450	6.814 ± 0.312	16.239 ± 0.304	16.210	-0.18
1702	9	87.748	0.400	65.224	76.500	174.000	6.070 ± 0.312	13.228 ± 0.303	13.018	-1.59
1703	9	87.108	0.397	64.700	77.500	176.000	6.028 ± 0.312	12.961 ± 0.303	12.860	-0.78
1704	9	88.092	0.402	64.538	76.500	190.500	5.275 ± 0.312	10.093 ± 0.302	9.980	-1.11
1705	9	87.222	0.398	64.750	76.500	197.000	4.906 ± 0.312	8.802 ± 0.302	8.706	-1.09
1706	9	88.755	0.405	64.600	77.000	200.500	4.816 ± 0.312	8.290 ± 0.301	8.403	1.37
1707	9	86.884	0.396	64.862	76.500	204.000	4.658 ± 0.312	7.972 ± 0.301	7.897	-0.94
1708	9	87.826	0.401	64.513	77.912	220.987	4.145 ± 0.312	6.294 ± 0.301	6.347	0.84
1709	9	87.383	0.399	64.625	77.500	232.500	3.763 ± 0.312	5.276 ± 0.301	5.307	0.59
1710	9	86.735	0.396	64.725	77.000	252.600	3.274 ± 0.312	4.121 ± 0.301	4.119	-0.04
1711	9	87.261	0.398	64.850	77.000	273.500	2.933 ± 0.312	3.486 ± 0.301	3.387	*****
1712	9	86.903	0.397	65.211	76.000	273.262	2.932 ± 0.312	3.493 ± 0.301	3.386	*****
1713	9	87.699	0.400	64.551	76.500	287.488	2.764 ± 0.312	4.059 ± 0.301	3.055	*****
1714	9	87.242	0.398	65.174	76.088	295.487	2.544 ± 0.312	5.896 ± 0.301	2.654	*****
1715	9	87.218	0.398	64.538	122.500	165.000	14.031 ± 0.313	62.918 ± 0.356	62.857	-0.10
1716	9	87.484	0.399	64.625	121.500	168.312	12.723 ± 0.313	52.193 ± 0.340	52.034	-0.30
1717	9	86.671	0.395	64.526	121.613	172.000	11.820 ± 0.313	45.189 ± 0.330	45.139	-0.11
1718	9	87.421	0.399	64.588	121.500	175.500	11.009 ± 0.313	39.465 ± 0.323	39.359	-0.27
1719	9	87.429	0.399	64.775	121.000	180.500	10.002 ± 0.313	32.706 ± 0.316	32.726	0.06
1720	9	87.123	0.398	64.912	121.325	187.000	8.989 ± 0.313	26.674 ± 0.311	26.656	-0.07
1721	9	86.715	0.396	64.837	122.000	194.500	8.115 ± 0.313	21.895 ± 0.308	21.912	0.08
1722	9	88.186	0.402	64.638	122.000	204.515	7.186 ± 0.313	17.524 ± 0.305	17.373	-0.86
1723	9	87.476	0.399	64.825	122.500	213.375	6.516 ± 0.312	14.636 ± 0.304	14.420	-1.48

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1724	9	86.961	0.397	64.663	122.500	222.500	5.922 ± 0.312	12.163 ± 0.303	12.041	-1.00
1725	9	88.266	0.403	64.800	121.500	231.500	5.430 ± 0.312	10.428 ± 0.302	10.232	-1.87
1726	9	87.764	0.400	64.551	122.550	245.000	4.890 ± 0.312	8.517 ± 0.301	8.408	-1.28
1727	9	87.442	0.399	64.650	121.500	251.500	4.506 ± 0.312	7.342 ± 0.301	7.230	-1.53
1728	9	87.905	0.401	64.787	121.475	270.500	3.937 ± 0.312	5.739 ± 0.301	5.646	-1.62
1745	9	87.410	0.399	64.713	121.500	138.488	4.211 ± 0.312	6.299 ± 0.301	6.382	1.32
1746	9	87.570	0.400	65.074	121.000	151.500	3.649 ± 0.312	5.121 ± 0.301	4.923	*****
1851	9	88.316	0.403	64.501	122.500	161.212	4.003 ± 0.312	5.956 ± 0.301	5.820	*****
1852	9	88.524	0.404	64.638	121.500	179.500	3.505 ± 0.312	6.329 ± 0.301	4.585	*****
1729	9	130.569	0.596	64.600	77.000	195.812	14.490 ± 0.314	66.462 ± 0.362	67.678	1.83
1730	9	132.048	0.503	64.775	77.500	208.000	12.211 ± 0.313	47.594 ± 0.333	48.566	2.04
1731	9	131.807	0.601	64.663	76.088	221.500	10.281 ± 0.313	33.621 ± 0.317	34.873	3.72
1732	9	130.719	0.596	64.725	76.500	237.500	8.648 ± 0.313	24.339 ± 0.309	25.021	2.80
1733	9	131.925	0.602	64.800	77.500	256.850	7.594 ± 0.313	19.195 ± 0.306	19.504	1.61
1734	9	131.373	0.599	64.925	76.500	208.675	6.780 ± 0.312	15.466 ± 0.304	15.726	1.68
1735	9	130.669	0.596	64.588	76.000	241.525	6.095 ± 0.312	12.651 ± 0.303	12.863	1.68
1736	9	131.987	0.602	64.862	77.500	258.000	5.498 ± 0.312	10.375 ± 0.302	10.588	2.06
1737	9	132.728	0.606	64.600	77.500	270.950	4.931 ± 0.312	8.555 ± 0.301	8.646	1.06
1738	9	132.354	0.604	64.625	76.500	282.275	6.818 ± 0.312	15.436 ± 0.304	15.891	2.95
1739	9	131.624	0.601	64.713	76.975	287.325	5.403 ± 0.312	9.920 ± 0.302	10.249	3.32
1740	9	131.180	0.599	64.775	76.500	292.025	4.877 ± 0.312	8.152 ± 0.301	8.476	3.98
1741	9	131.518	0.600	65.112	76.975	259.000	4.525 ± 0.312	7.262 ± 0.301	7.387	1.72
1742	9	130.238	0.594	65.112	76.013	276.837	4.228 ± 0.312	7.462 ± 0.301	6.533	*****
1743	9	131.556	0.600	65.274	77.000	164.550	4.237 ± 0.312	7.819 ± 0.301	6.556	*****
1744	9	130.526	0.596	64.825	77.225	170.500	4.054 ± 0.312	9.320 ± 0.302	6.058	*****
1747	9	173.685	0.793	64.725	77.500	179.000	13.672 ± 0.313	59.190 ± 0.350	59.653	0.78
1748	9	175.400	0.800	64.688	76.475	184.000	12.697 ± 0.313	51.078 ± 0.338	51.703	1.22
1749	9	174.979	0.798	64.650	76.000	190.500	11.596 ± 0.313	42.681 ± 0.327	43.396	1.68
1750	9	173.864	0.793	64.750	76.000	197.500	11.028 ± 0.313	38.765 ± 0.323	39.403	1.65
1751	9	173.880	0.793	64.650	77.500	202.000	10.548 ± 0.313	35.479 ± 0.319	36.151	1.89
1752	9	174.579	0.797	64.962	78.000	210.000	9.968 ± 0.313	31.783 ± 0.315	32.418	2.00
1753	9	174.847	0.798	64.837	77.500	217.000	9.535 ± 0.313	29.222 ± 0.313	29.776	1.90
1754	9	176.198	0.804	64.800	76.987	226.500	8.980 ± 0.313	25.914 ± 0.311	26.547	2.44
1755	9	174.161	0.795	64.713	76.500	235.500	8.431 ± 0.313	23.048 ± 0.308	23.545	2.16
1756	9	176.523	0.805	64.937	76.000	242.000	7.940 ± 0.313	20.563 ± 0.307	21.009	2.17
1757	9	174.574	0.797	64.675	76.150	247.000	7.526 ± 0.313	18.627 ± 0.306	18.978	1.89
1758	9	175.789	0.802	64.600	76.113	260.000	7.199 ± 0.313	17.144 ± 0.305	17.453	1.80
1759	9	175.510	0.801	65.012	76.000	266.500	6.946 ± 0.312	16.127 ± 0.304	16.314	1.16
1760	9	173.878	0.793	64.713	76.500	189.500	6.435 ± 0.312	14.049 ± 0.303	14.138	0.63

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1761	9	174.090	0.794	65.012	76.500	193.987	6.198 ± 0.312	13.096 ± 0.303	13.185	0.68
1798	9	176.265	0.804	64.551	77.000	197.500	7.092 ± 0.313	16.827 ± 0.305	16.961	0.80
1799	9	174.517	0.796	65.024	77.000	202.475	6.414 ± 0.312	13.988 ± 0.303	14.050	0.44
1800	9	174.556	0.796	64.937	77.500	207.500	5.975 ± 0.312	12.573 ± 0.303	12.317	*****
1801	9	173.760	0.793	64.738	76.325	215.513	5.652 ± 0.312	12.953 ± 0.303	11.125	*****
1802	9	175.760	0.802	64.787	76.500	222.000	5.566 ± 0.312	15.224 ± 0.304	10.817	*****
1762	9	217.774	0.994	64.775	77.663	227.500	13.301 ± 0.313	55.776 ± 0.345	56.039	0.47
1763	9	217.651	0.993	64.837	77.500	232.363	12.773 ± 0.313	51.503 ± 0.339	51.826	0.63
1764	9	217.267	0.991	64.812	76.500	237.500	12.267 ± 0.313	47.792 ± 0.334	47.956	0.34
1765	9	217.530	0.993	64.800	76.000	244.000	11.730 ± 0.313	43.768 ± 0.328	44.003	0.54
1766	9	217.581	0.993	64.600	76.000	250.500	11.266 ± 0.313	40.440 ± 0.325	40.718	0.69
1767	9	218.178	0.996	64.762	76.500	258.000	10.664 ± 0.313	36.462 ± 0.320	36.639	0.49
1768	9	217.453	0.992	64.900	77.000	267.000	10.236 ± 0.313	33.638 ± 0.317	33.872	0.70
1769	9	217.757	0.994	64.850	77.000	277.213	9.859 ± 0.313	31.330 ± 0.315	31.530	0.64
1770	9	217.175	0.991	65.074	77.000	253.000	9.525 ± 0.313	29.357 ± 0.313	29.526	0.57
1771	9	217.458	0.992	64.974	77.000	284.038	9.216 ± 0.313	27.612 ± 0.312	27.731	0.43
1772	9	218.257	0.996	64.974	76.987	287.937	8.878 ± 0.313	25.711 ± 0.310	25.831	0.47
1773	9	217.263	0.991	64.825	76.500	290.363	8.491 ± 0.313	23.726 ± 0.309	23.746	0.08
1774	9	217.003	0.990	65.087	76.025	293.500	8.135 ± 0.313	21.825 ± 0.308	21.908	0.38
1775	9	217.583	0.993	64.912	75.963	298.500	7.732 ± 0.313	19.880 ± 0.306	19.918	0.19
1776	9	217.136	0.991	64.663	76.425	211.500	7.380 ± 0.313	19.140 ± 0.306	18.261	*****
1777	9	217.145	0.991	65.311	76.987	215.975	8.398 ± 0.313	22.921 ± 0.308	23.256	1.46
1778	9	218.012	0.995	65.623	76.537	219.788	7.117 ± 0.313	19.402 ± 0.306	17.071	*****
1779	9	221.015	1.008	64.089	76.975	226.000	7.104 ± 0.313	22.823 ± 0.308	17.020	*****
1780	9	220.426	1.006	64.039	76.175	235.513	6.982 ± 0.312	24.261 ± 0.309	16.490	*****
1781	9	220.393	1.006	64.787	77.000	247.037	6.919 ± 0.312	25.341 ± 0.310	16.213	*****
1782	9	220.022	1.004	65.635	76.500	254.812	6.717 ± 0.312	27.037 ± 0.311	15.356	*****
1783	9	176.628	0.806	64.551	121.025	258.550	13.417 ± 0.313	56.627 ± 0.346	56.573	-0.10
1784	9	175.772	0.802	65.087	121.012	265.513	12.765 ± 0.313	51.293 ± 0.338	51.378	0.17
1785	9	175.210	0.799	64.738	121.200	275.525	12.200 ± 0.313	47.052 ± 0.333	47.077	0.05
1786	9	174.991	0.798	64.426	121.475	283.500	11.479 ± 0.313	41.790 ± 0.326	41.859	0.16
1787	9	175.973	0.803	64.837	121.338	285.737	10.614 ± 0.313	35.901 ± 0.320	36.005	0.29
1788	9	175.655	0.802	64.713	121.513	289.537	9.630 ± 0.313	29.882 ± 0.314	29.883	0.00
1789	9	175.261	0.800	64.862	122.500	292.500	8.940 ± 0.313	26.007 ± 0.311	25.929	-0.30
1790	9	176.364	0.805	65.049	121.025	296.975	8.754 ± 0.313	24.954 ± 0.310	24.923	-0.12
1791	9	175.590	0.801	64.750	121.513	246.100	8.334 ± 0.313	22.811 ± 0.308	22.703	-0.47
1792	9	174.508	0.796	65.049	121.763	261.500	7.799 ± 0.313	20.248 ± 0.307	20.032	*****
1793	9	175.889	0.803	64.314	122.900	275.500	7.454 ± 0.313	19.940 ± 0.306	18.400	*****
1794	9	176.416	0.805	64.625	121.062	284.475	7.276 ± 0.313	20.000 ± 0.306	17.596	*****

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1795	9	176.454	0.805	64.201	121.000	290.188	7.119 ± 0.313	21.870 ± 0.308	16.897	*****
1796	9	176.114	0.804	64.650	121.663	166.000	7.013 ± 0.312	23.071 ± 0.308	16.431	*****
1797	9	175.038	0.799	64.526	121.513	176.500	6.783 ± 0.312	24.871 ± 0.310	15.446	*****
1803	9	175.235	0.800	34.655	77.688	189.500	13.635 ± 0.313	58.617 ± 0.349	59.313	1.19
1804	9	175.043	0.799	34.730	76.675	203.050	12.039 ± 0.313	45.959 ± 0.331	46.642	1.49
1805	9	175.292	0.800	34.718	76.500	217.250	10.544 ± 0.313	35.566 ± 0.319	36.126	1.57
1806	9	174.092	0.794	34.855	77.563	235.300	9.492 ± 0.313	28.930 ± 0.313	29.519	2.04
1807	9	175.370	0.800	34.792	76.000	247.500	8.511 ± 0.313	23.468 ± 0.309	23.979	2.18
1808	9	174.414	0.796	34.979	77.450	241.025	7.556 ± 0.313	18.800 ± 0.306	19.123	1.72
1809	9	175.691	0.802	35.204	76.288	252.000	6.978 ± 0.312	18.807 ± 0.306	16.474	*****
1810	9	175.804	0.802	34.643	76.000	211.500	7.288 ± 0.313	18.227 ± 0.305	17.874	*****
1811	9	174.922	0.798	35.154	76.650	212.887	6.785 ± 0.312	20.970 ± 0.307	15.631	*****
1812	9	174.826	0.798	34.767	121.500	218.500	13.598 ± 0.313	58.875 ± 0.350	58.065	-1.38
1813	9	174.523	0.796	34.805	121.500	221.500	13.038 ± 0.313	54.271 ± 0.343	53.528	-1.37
1814	9	173.694	0.793	34.680	122.988	224.950	12.439 ± 0.313	49.605 ± 0.336	48.857	-1.51
1815	9	174.228	0.795	34.792	121.500	229.413	11.951 ± 0.313	46.011 ± 0.331	45.248	-1.66
1816	9	173.963	0.794	34.767	121.500	235.012	11.551 ± 0.313	43.113 ± 0.328	42.372	-1.72
1817	9	173.804	0.793	34.680	121.925	240.000	11.086 ± 0.313	39.857 ± 0.324	39.143	-1.79
1818	9	175.731	0.802	34.880	121.550	244.000	10.610 ± 0.313	36.884 ± 0.321	35.986	-2.44
1819	9	176.047	0.803	35.279	121.000	249.000	10.142 ± 0.313	34.026 ± 0.318	33.009	*****
1820	9	175.086	0.799	34.880	122.000	120.000	9.822 ± 0.313	32.856 ± 0.317	31.038	*****
1821	9	176.275	0.804	33.122	122.638	121.575	9.557 ± 0.313	35.809 ± 0.319	29.459	*****
1822	9	88.108	0.402	34.643	78.000	126.138	14.314 ± 0.313	65.814 ± 0.361	67.275	2.22
1823	9	88.046	0.402	34.668	76.500	131.500	13.307 ± 0.313	57.094 ± 0.347	58.511	2.48
1824	9	88.146	0.402	34.755	76.500	136.000	12.080 ± 0.313	47.344 ± 0.333	48.556	2.56
1825	9	87.398	0.399	34.743	77.500	142.000	11.064 ± 0.313	39.915 ± 0.324	40.978	2.66
1826	9	87.307	0.398	34.730	76.500	150.850	10.045 ± 0.313	33.106 ± 0.317	34.074	2.92
1827	9	87.523	0.399	34.755	76.462	156.500	9.057 ± 0.313	27.104 ± 0.311	27.937	3.07
1828	9	87.647	0.400	34.743	76.000	162.500	7.981 ± 0.313	21.235 ± 0.307	21.938	3.31
1829	9	87.811	0.401	34.680	76.500	176.513	7.460 ± 0.313	18.850 ± 0.306	19.273	2.24
1830	9	87.179	0.398	34.605	76.500	193.500	6.921 ± 0.312	16.287 ± 0.304	16.709	2.59
1831	9	87.333	0.398	34.730	78.000	213.500	6.012 ± 0.312	12.416 ± 0.303	12.771	2.86
1832	9	87.203	0.398	34.792	77.500	225.500	5.112 ± 0.312	9.120 ± 0.302	9.401	3.09
1833	9	87.186	0.398	34.917	76.500	241.000	4.313 ± 0.312	6.602 ± 0.301	6.841	3.61
1834	9	87.297	0.398	35.129	76.000	246.050	3.917 ± 0.312	5.551 ± 0.301	5.723	3.10
1835	9	88.283	0.403	34.743	78.000	164.000	3.614 ± 0.312	5.011 ± 0.301	4.931	*****
1836	9	88.053	0.402	34.905	77.000	168.837	3.225 ± 0.312	5.839 ± 0.301	4.018	*****
1837	9	86.972	0.397	34.817	121.988	176.500	14.007 ± 0.313	62.303 ± 0.355	62.677	0.60
1838	9	87.073	0.397	34.743	121.438	181.287	12.506 ± 0.313	50.103 ± 0.337	50.344	0.48

Test Point	Test Number	Power KW	Heat Flux MBtu/hr-ft2	Exit Pressure psia	Inlet Temp F	Outlet Temp F	Flow Rate gpm	Meas Pressure Drop psid	Calc Pres Drop psid	Difference %
1839	9	86.913	0.397	34.655	122.275	188.162	11.007 ± 0.313	39.160 ± 0.323	39.330	0.43
1840	9	87.404	0.399	34.842	122.000	201.000	10.018 ± 0.313	32.741 ± 0.316	32.812	0.22
1841	9	86.771	0.396	34.643	122.000	208.938	9.025 ± 0.313	26.742 ± 0.311	26.855	0.42
1842	9	88.280	0.403	34.668	121.975	214.000	7.619 ± 0.313	19.585 ± 0.306	19.423	-0.83
1843	9	88.327	0.403	34.693	122.500	222.262	6.990 ± 0.312	16.627 ± 0.305	16.474	-0.92
1844	9	88.064	0.402	34.780	122.000	228.500	6.530 ± 0.312	14.596 ± 0.304	14.484	-0.77
1845	9	88.394	0.403	34.693	122.850	237.450	6.023 ± 0.312	12.543 ± 0.303	12.425	-0.94
1846	9	88.303	0.403	34.655	121.488	242.500	5.592 ± 0.312	10.955 ± 0.302	10.812	-1.31
1847	9	88.514	0.404	34.830	122.500	250.063	5.241 ± 0.312	9.750 ± 0.302	9.570	*****
1848	9	88.489	0.404	34.942	121.875	251.475	4.946 ± 0.312	8.762 ± 0.302	8.593	*****
1849	9	87.388	0.399	34.668	121.012	271.500	4.531 ± 0.312	9.195 ± 0.302	7.311	*****
1850	9	87.420	0.399	35.117	121.800	290.500	4.780 ± 0.312	7.774 ± 0.301	8.068	3.78

APPENDIX - C

SAMPLE PRESSURE DROP COMPARISONS USING VOID MODEL

UNCERT is a modified version of FLOWTRAN which includes acceleration pressure drop and two-phase multiplier effect to calculate the pressure drop This appendix contains a few sample comparisons among measured, FLOWTRAN calculated, and UNCERT calculated pressure drops. Appendix B presents the comparison between measured and FLOWTRAN calculated pressure drops. The figures in Appendix B show that for large tube diameters, 0.600", 0.6125", and 0.7516", the agreement between measured and FLOWTRAN calculated pressure drops is not good around OSV regions for high heat flux cases (0.8 and 1.0 MBtu/hr-ft^2). Several cases with the worst agreement between measured and FLOWTRAN calculated pressure drops were chosen for these tubes to demonstrate UNCERT pressure drop calculations. Since FLOWTRAN accurately calculated pressure drops up to OSV for the 0.359" tube for all heat fluxes, there were not any sample cases selected for this tube.

For these large tubes the pressure drops around OSV flow range are low (2 to 5 psi), and the two-phase contribution to the total pressure drop is significant. FLOWTRAN is a single-phase code, so its calculated pressure drops are low for these cases. The figures in this appendix show that UNCERT does not give anticipated improved agreement. The VOID model in UNCERT with the two-phase frictional multiplier and acceleration pressure drop needs revision to improve the agreement between measured and calculated pressure drops for large diameter tubes at high heat fluxes. As discussed in section 4.3, the acceleration pressure drop and the two-phase multiplier are not important to the total channel pressure drop calculation in SRS fuel assemblies.

SS TUBE ID=0.600" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=121 F ; EXIT PRES=64.7 PSIA

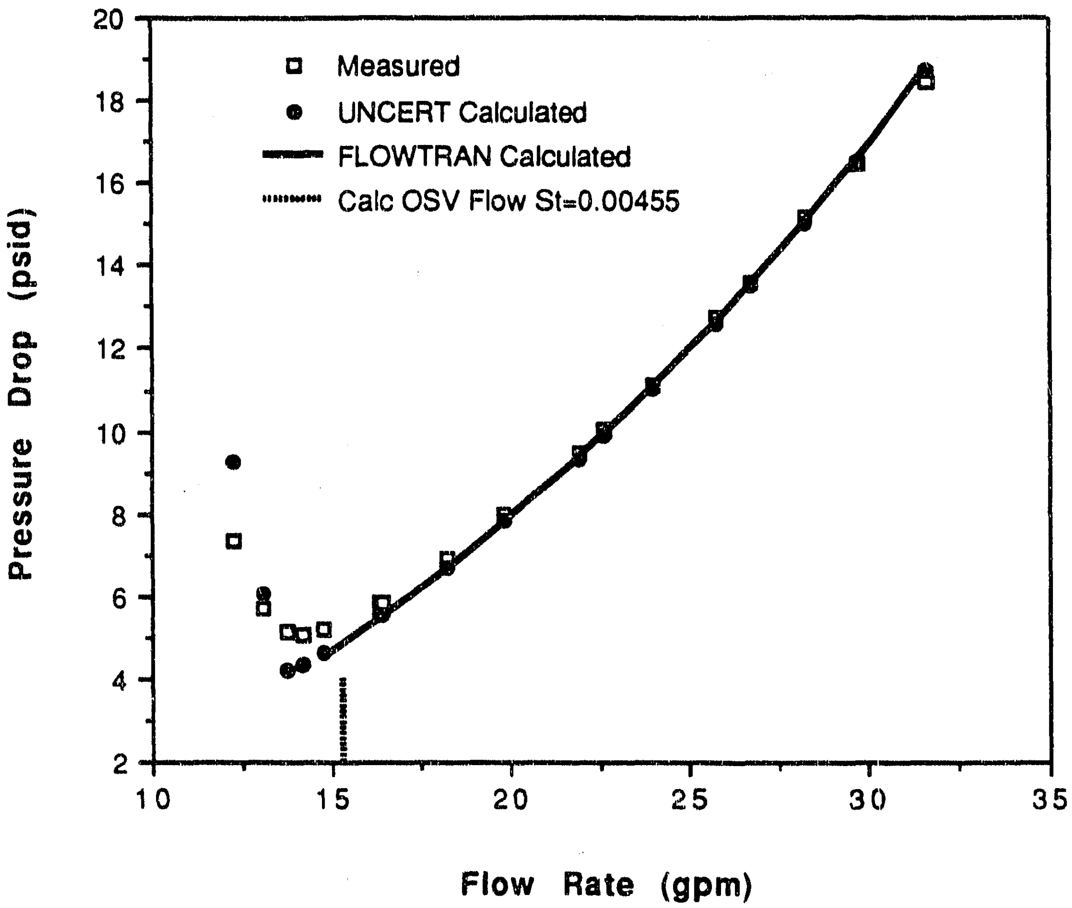

FIGURE C-1. MEASURED DATA, FLOWTRAN, AND UNCERT PREDICTIONS - SAMPLE 1

INC TUBE ID=0.6125" ; UNIFORM FLUX=0.8 MBTU/HR-FT2
INLET TEMP=121 F ; EXIT PRES=64.7 PSIA

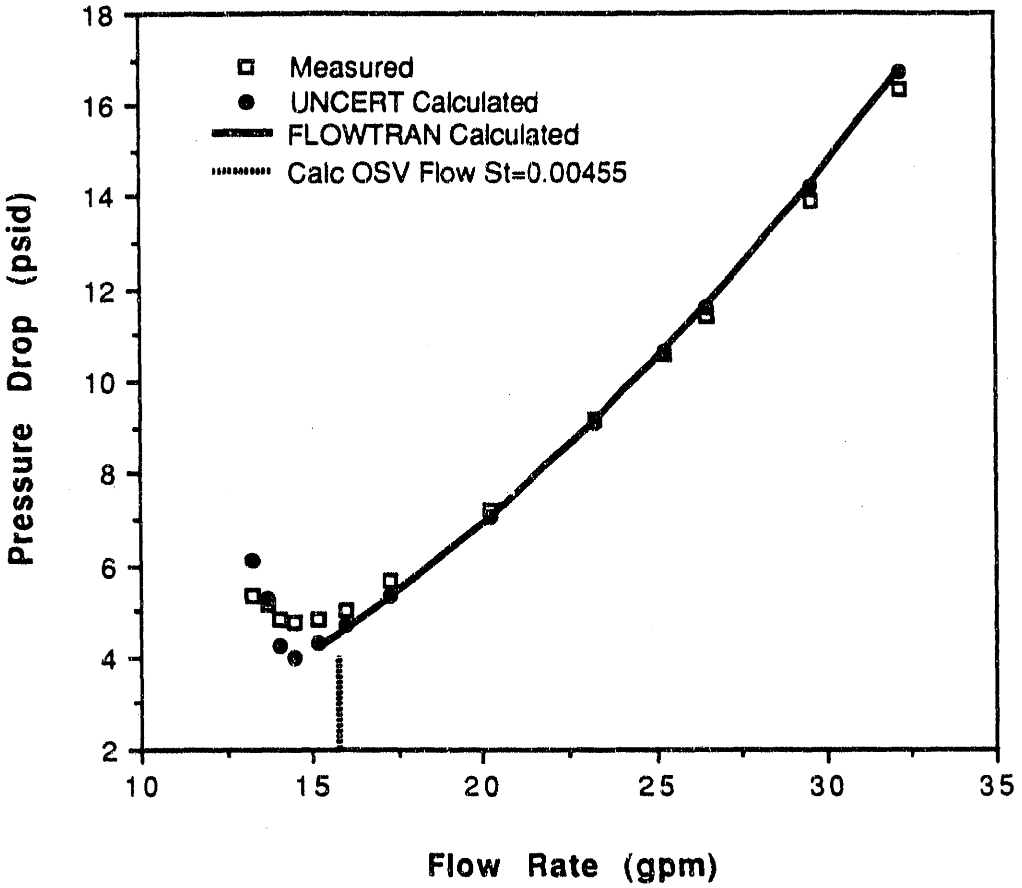

FIGURE C-2. MEASURED DATA, FLOWTRAN, AND UNCERT PREDICTIONS - SAMPLE 2

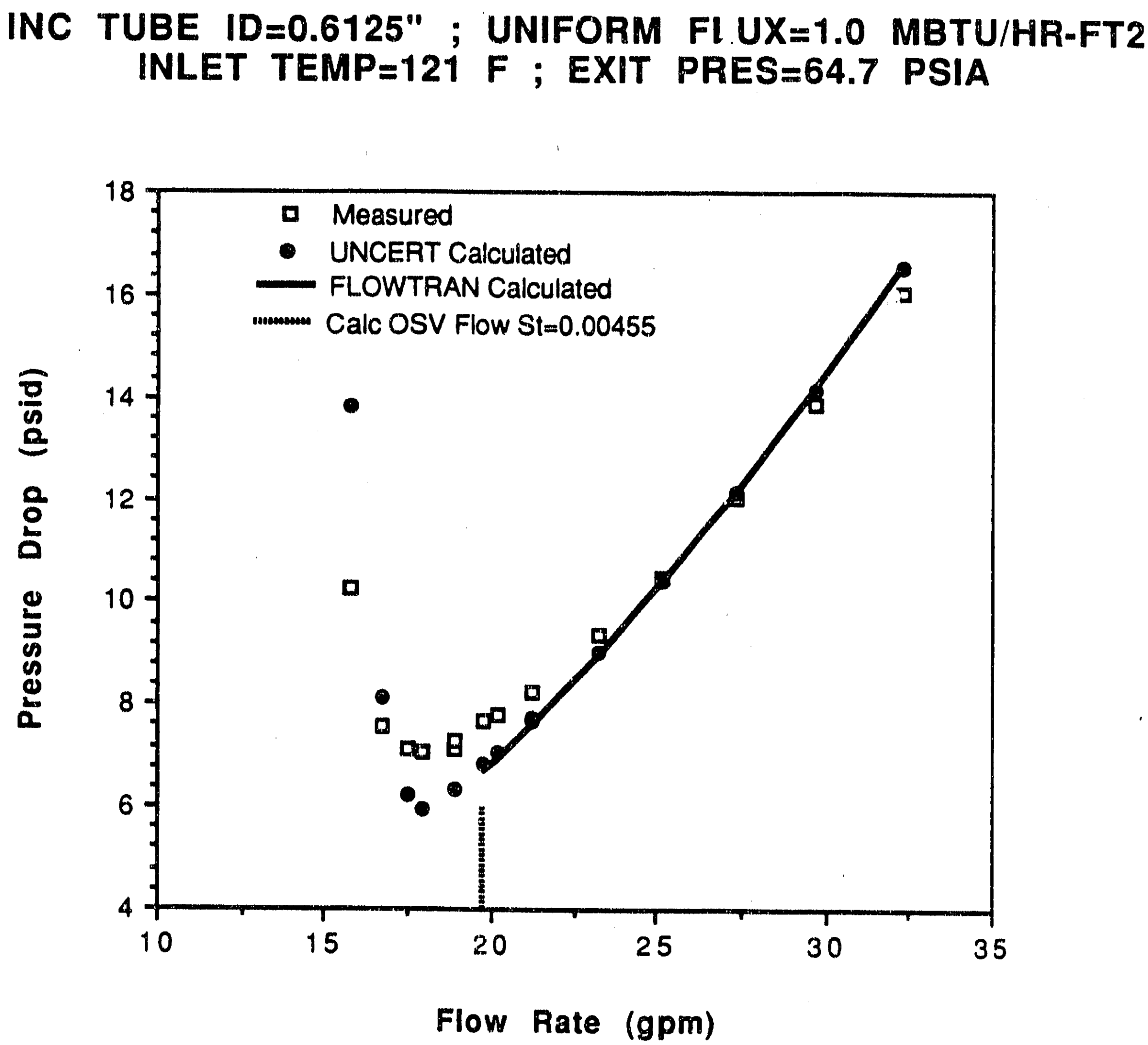

FIGURE C-3. MEASURED DATA, FLOWTRAN, AND UNCERT PREDICTIONS - SAMPLE 3

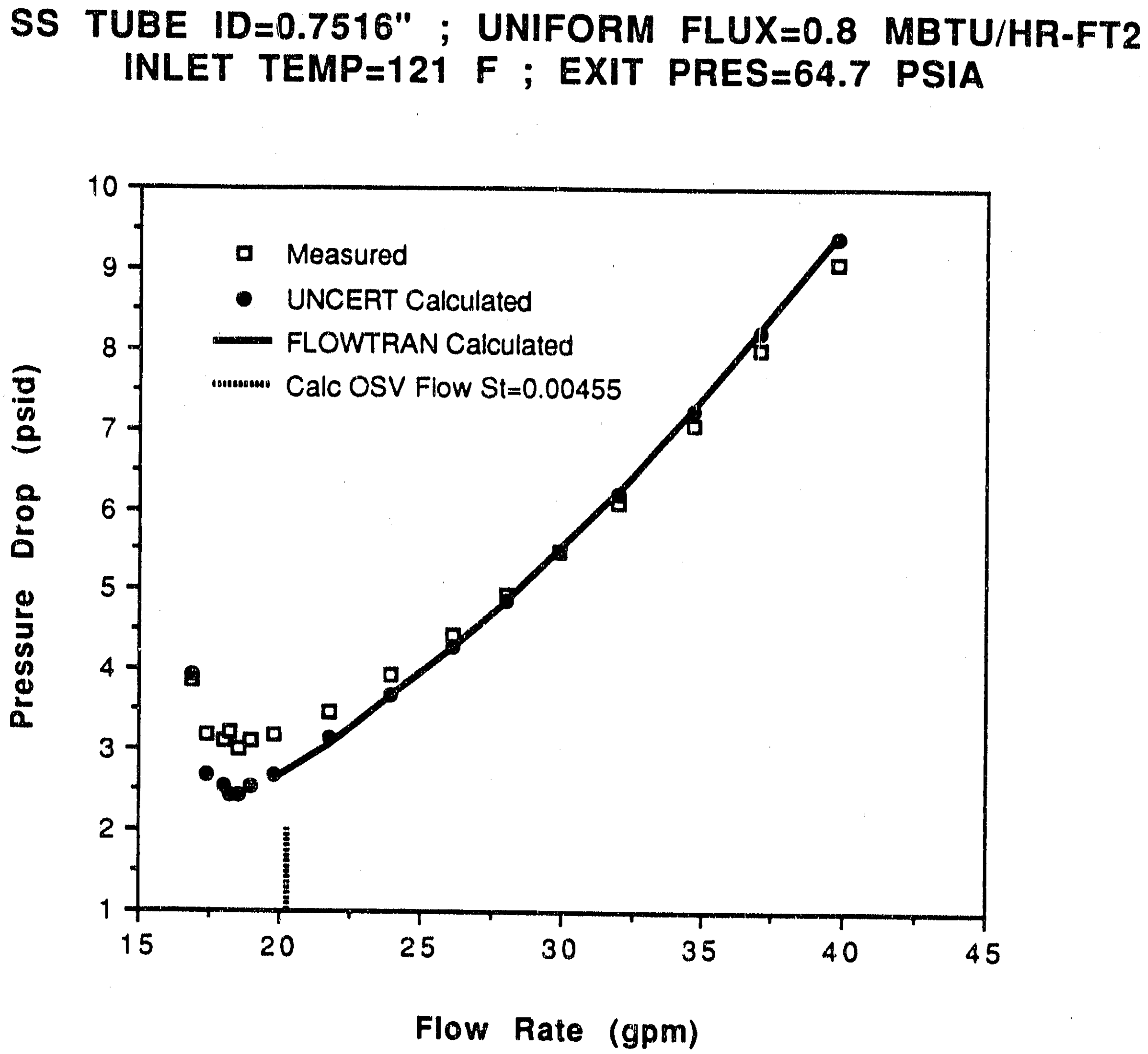

FIGURE C-4. MEASURED DATA, FLOWTRAN, AND UNCERT PREDICTIONS - SAMPLE 4

SS TUBE ID=0.7516" ; UNIFORM FLUX=1.0 MBTU/HR-FT2
INLET TEMP=77 F ; EXIT PRES=34.7 PSIA

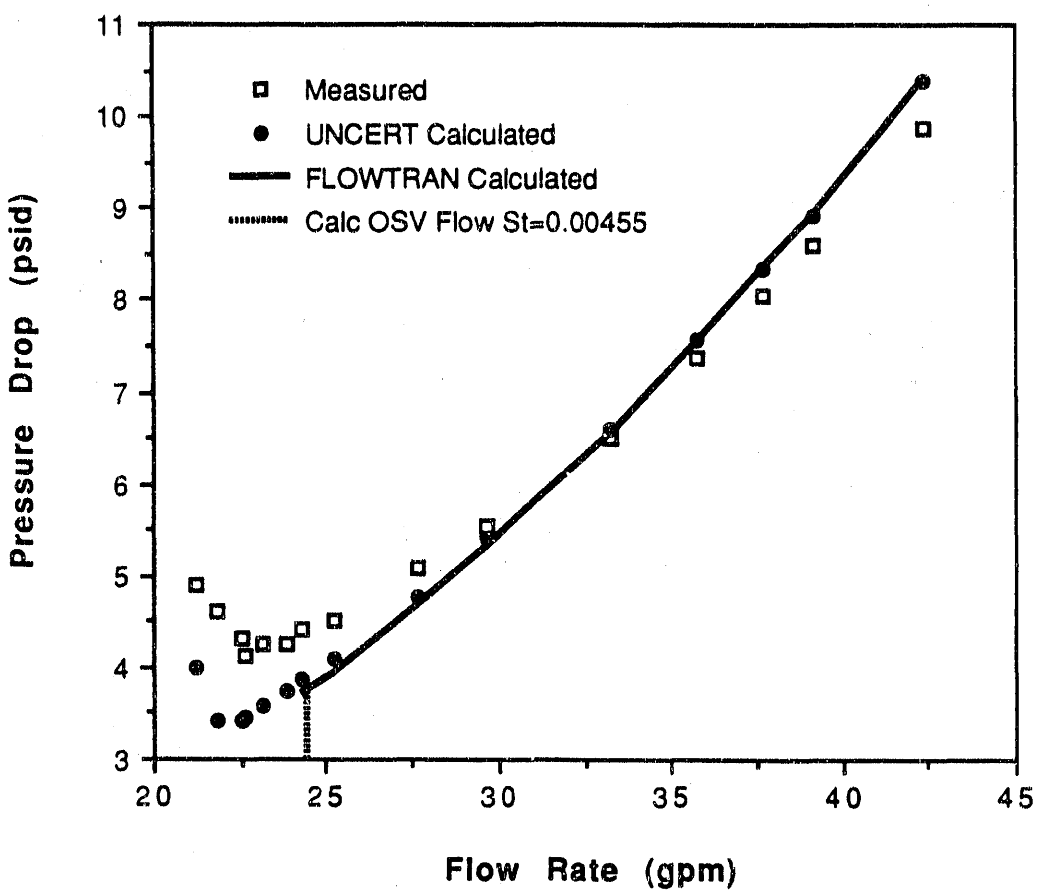

FIGURE C-5. MEASURED DATA, FLOWTRAN, AND UNCERT PREDICTIONS - SAMPLE 5

APPENDIX - D

SAMPLE FLOWTRAN INPUT

This appendix contains a FLOWTRAN model test section node diagram. FLOWTRAN models the test section between the pressure taps which is 100.5 inches. The 96 inch heated length is divided into 48 equally spaced axial nodes. The 2.25 inch length bounding the heated length at each end is divided into 5 axial nodes. The details are shown in Figure D-1.

This appendix also contains a sample FLOWTRAN input file for the OSV calculation for St=0.00455. FLOWTRAN iterates to calculate the power needed to achieve OSV for a particular flow rate. Different flow rate inputs are used to reiterate the OSV flow rate for a given power, inlet temperature, and exit pressure until the calculated power agrees with the given power. Chapter 5, Reference 1, is a guide to prepare the FLOWTRAN input deck.

A: 96" - HEATED CHANNEL LENGTH
B: 100.5" - FRICTIONAL CHANNEL LENGTH
C: 105" - TOTAL CORE LENGTH
D: 105.35" - TOTAL MODEL LENGTH
E: 2.425" - TOP/BOTTOM FORM LENGTH
F: 0.175" - TOP/BOTTOM SETUP LENGTH

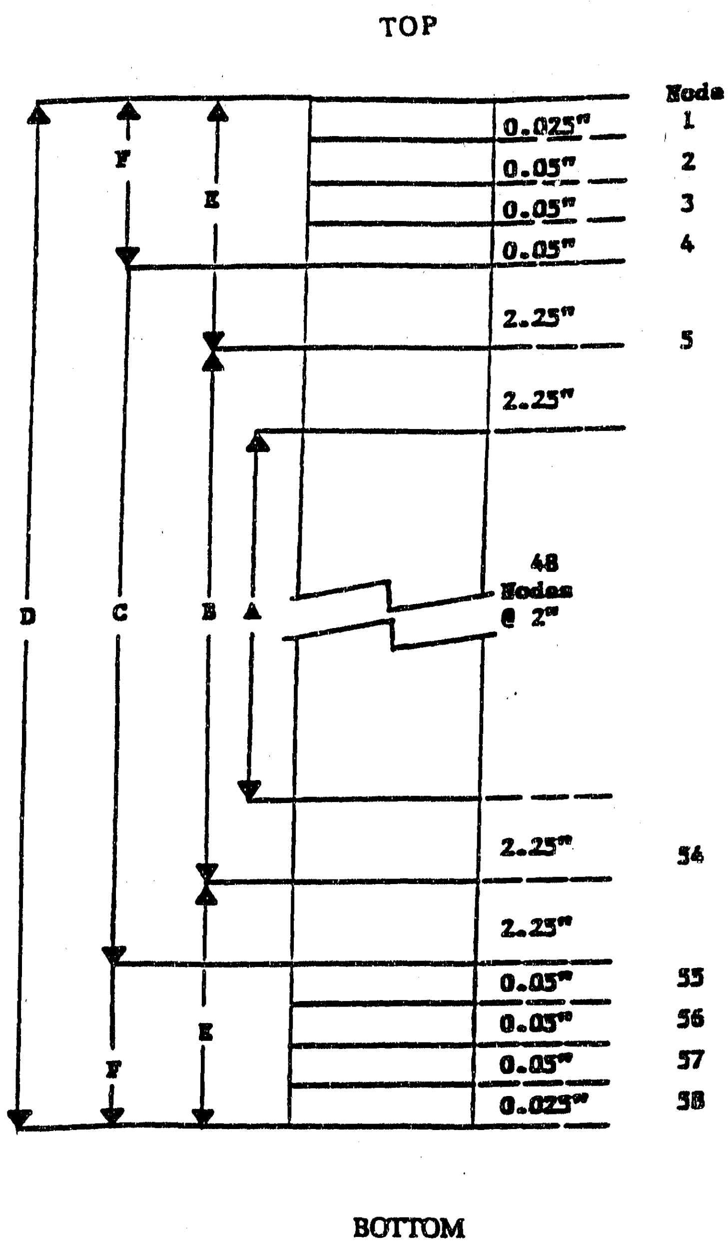

FIGURE D-1. FLOWTRAN MODEL NODES

```
/COLUMBIA .6125 PW 0.22409 MW P64.7 T77F FW GPM OSV V16.1/
/RUN TIME (SEC), NZONE, TMIN, TIME ZONE DATA/
0   1    0.0
1.0  1
/IPRTF, IPRTS, IPRTP, IDMPS, IBALN, ICRIT, IPRTSS/
1   1   1
100  1   1   1   0   0
/CRITERIA CHECKING FLAGS: ONB, TSAT, CHF, OSV/
0   0   0   1   0
/TOLERANCES, ITERATIONS, AND INITIAL POWER/
1.0D-5    20     0.22409
1.0D-5    50
1.0D-5    50
/FLUID ITERATIONS, TOLERANCES, AND OPTIONS/
0   100    1.0D-6
0   100    1.0D-6
1   1   1   2   1   1   1   1   1
1
/POWER ARRAY PARAMETERS/
5   2   1
2   2   2   2   2   2   2   2   2   2   2
/MA MCYLIN ICENT AND NCELLS/
1   1   0
4   50   4
/RADIAL CELLS AND SUBCHANNELS/
5
1
/SURFACE CHECK FLAGS/
0   1   0
/CYLINDER #1/
1.0  1
0  0.0   0.0
48  3   3   3   3   3
 0.6125
 0.63964
 0.66678
 0.69392
 0.72106
 0.7482
/FLUID GEOMETRIC DATA SET/
 105.0000      96.00000      4.500000      4.675000      1.000000
0.294647029      0.294647029
1.0
1.0
 0.294647029
 0.6125
0.
0.
0.
 2.5000000000000000E-05
1   0.00368309    0.29464704     0.000   1.0     0.0
1   0.00736618    0.29464704     0.025   0.0     0.0
```

```
2   0.01104927   0.29464704   0.000  1.0   0.0
2   0.01473236   0.29464704   0.050  0.0   0.0
3   0.01473236   0.29464704   0.000  1.0   0.0
3   0.01473236   0.29464704   0.050  0.0   0.0
4   0.01473236   0.29464704   0.000  1.0   0.0
4   0.01473236   0.29464704   0.050  0.0   0.0
1   0.01473236   0.29464704   0.050  0.0   0.0
1   0.01473236   0.29464704   0.000  1.0   0.0
2   0.01473236   0.29464704   0.050  0.0   0.0
2   0.01473236   0.29464704   0.000  1.0   0.0
3   0.01473236   0.29464704   0.050  0.0   0.0
3   0.01104927   0.29464704   0.000  1.0   0.0
4   0.00736618   0.29464704   0.025  0.0   0.0
4   0.00368309   0.29464704   0.000  1.0   0.0
1.0   0.21
/POWER FRACTIONS/
1 1
1.0     0.0     0.0     0.0
/RADIAL SHAPES/
1   5   2
1   0   0   0   0
  1.0    0.0
  1.0    0.0
  1.0    0.0
  1.0    0.0
  1.0    0.0
/WET TANK SHAPE POWER FRACTIONS/
 0
/DRY TANK SHAPE POWER FRACTIONS/
 0
/AZIMUTHAL SHAPES/
1   1   1
1   0   0   0   0
1.0
1.0
/ASSEMBLY POWER TRANSIENT/
3
    0.  1.000000
    5.  1.000000
   10.  1.000000
/AXIAL POWER SPLINE/
3   2
  0.0    10.0
  0.0     1.0
  0.5     1.0
  1.0    1.0
         1.0
         1.0
         1.0
/ASSEMBLY FLOW TRANSIENT/
3
    0.     9.371447699
    5.    9.38000
   10.     9.38000
```

```
/TBOT PRESS SPLINE/
3
     0.    64.80596
     5.    64.80595
    10.    64.80595
/ASSEMBLY INLET SPLINE/
3
     0.    24.95180
     5.    25.00000
    10.    25.00000
/TANK LEVEL SPLINE/
3
  0.0      1.0
  5.0      1.0
  10.0     1.0
/FLUID INITIAL GUESS/
1.0
  9.550   85.000   25.000    0.000
1.0
0.0D0     0.0D0     0.0D0
0.0    30.0     19.7
3.937D-5     1.0  1.0  1.0  0.7   100.0
/INITIAL SOLID TEMPERATURES/
25.0    25.0
```

APPENDIX - E

COMPUTER PROGRAMS SOURCE LISTINGS

This appendix contains ENBALSTPE.FOR and UNCERSTPE.FOR computer programs source listings. ENBALSTPE.FOR is written to calculate Stanton and Peclet numbers at the OFI conditions. UNCERSTPE.FOR is used to calculate Stanton and Peclet number uncertainties. These source codes are written in VAX FORTRAN-77 and contain input/output codes specific to VAX compilers. These source codes may not be transportable to other FORTRAN compilers.

```
C      *****************************************************************
C      *                                                               *
C      *                      ENBALSTPE.FOR                            *
C      *                                                               *
C      *     This Program Calculates Outlet Temperature from an        *
C      *     Energy Balance, Calculates Uncertainty on the Calculated  *
C      *     Temperature, Calculates Peclet and Stanton Numbers        *
C      *     both from Measured and Calculated Outlet Temperatures,    *
C      *     Contribution of Each Energy Terms                         *
C      *                                                               *
C      *     The Program interactively asks one input and one output   *
C      *     file names                                                *
C      *                                                               *
C      *     Input File: One Input File - Free Formatted :             *
C      *                 First record is hydraulic diameter (inch)     *
C      *                 Each Subsequent record consists of            *
C      *                 Flow Rate (gpm), Pressure Drop (psi),         *
C      *                 Power (KW), Inlet Temp (F), Exit Pressure,    *
C      *                 Measured Outlet Temp (F)                      *
C      *                                                               *
C      *****************************************************************
C
C      TI = Inlet Temperature (F)
C      Q  = Volumetric OFI flow rate (gpm)
C      W  = Power (MW)
C      WKW = Power (KW)
C      HF = Heat Flux (Btu/s-ft2)
C      PE = Exit Pressure (psia)
C      TM = Measured Outlet Temperature (F)
C      TC = Calculated Outlet Temperature (F)
C      TU = Uncertainty on Calculated Temp (F)
C      PEN = Peclet Number
C      STN = Stanton Number
C      DP = Pressure Drop (psi)
C      F = Mass Velocity (lbm/s)
C      G = Mass Flux (lbm/s-ft2)
C      PCT = Energy Term Percent
C      DH = Hydraulic Diameter (inch)
C
       DIMENSION TI(30),
      +          Q(30),
      +          W(30),
      +          HF(30),
      +          PE(30),
      +          TM(30),
      +          TC(30),
      +          TU(30)
       DIMENSION PEN(2,30),
      +          STN(2,30),
      +          DP(30),
      +          F(30),
      +          G(30),
      +          PCT(4,30)
C
       CHARACTER C(4)*8/'I       ',
      +                 'O       ',
      +                 'EXTERNAL',
      +                 'MEASURED'/
```

```
C
      DATA AT,AM,AP,AK/948.056,
     +                 -0.18509,
     +                  1.071122E-04,
     +                  0.414252/
      DATA TL,HL,PI/100.5,
     +               96.0,
     +               3.14159265/
C
C     Set up Character Variables for Reading Records
C
      CHARACTER RECORD*80,
     +          DUMMY*80,
     +          OUTFIL*25,
     +          INFIL*25
C
C     Set up Character Record Formats
C
100   FORMAT(A80)
101   FORMAT(A25)
102   FORMAT(A1)
C
C     Open OFI Input File
C
      PRINT 104
104   FORMAT(' ENTER THE OFI INPUT DATA FILE NAME ? ',$)
      ACCEPT 101, INFIL
      OPEN(2,FILE=INFIL,STATUS='OLD',ERR=995,
     +     ACCESS='SEQUENTIAL',FORM='FORMATTED',
     +     ORGANIZATION='SEQUENTIAL',RECORDTYPE='VARIABLE')
C
C     Open Calculations Output File
C
      PRINT 105
105   FORMAT(' ENTER THE CALCULATION RESULTS OUTPUT FILE NAME ? ',$)
      ACCEPT 101, OUTFIL
      OPEN(3,FILE=OUTFIL,STATUS='UNKNOWN',ERR=990,
     +     ACCESS='SEQUENTIAL',FORM='FORMATTED',
     +     ORGANIZATION='SEQUENTIAL',RECORDTYPE='VARIABLE')
C
C     Get Hydraulic Diameter
C
      READ(2,*) DH
      CSA = (PI/4.0) * DH * DH                    ! CROSS SECTIONAL AREA
C
C     Get the Other Input Data
C
      I = 1
10    READ(2,*,END=15) Q(I), DP(I), WKW, TI(I), PE(I), TM(I)
      W(I) = WKW / 1000.0                         ! CONVERT TO MEGAWATT
      I = I + 1
      GOTO 10
15    NR = I - 1
C
      DO 25 I=1,NR
C       Calculate Inlet Density in lbm/ft3
        CALL DENSITY(DENSI,TI(I))                 ! CALL FOR DENSITY
C       Calculate Inlet Energy Equivalent
```

```
      CALL HTCAP(CPI,TI(I),2)                    ! INLET ENERGY
      F(I) = DENSI * Q(I) / 448.83               ! MASS VELOCITY (LBM/S)
C     Initial Outlet Temperature Guess
      TO1 = TI(I) + W(I) * AT / F(I)
C     Calculate Outlet Density in lbm/ft3
20    CALL DENSITY(DENSO,TO1)                    ! CALL FOR DENSITY
      DAVE = (DENSI + DENSO) / 2.0               ! AVERAGE DENSITY
      DEND = 1.0/DENSI**2 - 1.0/DENSO**2         ! DENSITY DIFFERENCE
      CKE = AK * (F(I)/CSA)**2 * DEND            ! KINETIC ENERGY
      CPE = AP * TL                              ! POTENTIAL ENERGY
      CME = AM * DP(I) / DAVE                    ! MECHANICAL ENERGY
      CTE = AT * W(I) / F(I)                     ! THERMAL ENERGY
      DES = CTE + CKE + CPE + CME                ! DIFF. ENERGY SUM
C     Calculate Outlet Energy Equivalent
      CALL HTCAP(CPO,TO1,2)                      ! OUTLET ENERGY
      DCP = CPO - CPI                            ! DIFF. ENERGY EQUIV.
      CPA = DCP / (TO1 - TI(I))                  ! AVERAGE HEAT CAPACITY
      ER = DCP / DES                             ! DIFF. ENERGY RATIO
C     Check Energy Balance
      IF (ABS (ER-1.0) .LT. 0.0010) GOTO 30
      TO1 = TI(I) + (TO1 - TI(I)) / ER
      GOTO 20
C
30    TC(I) = TO1
C
C     Calculate Outlet Temperature Uncertainty
C
      CALL TOUTUNC(TU(I),TI(I),W(I),Q(I),DENSI,CPA)
      PCT(1,I) = 100.0 * CTE / DES               ! THERMAL ENERGY %
      PCT(2,I) = 100.0 * CKE / DES               ! KINETIC ENERGY %
      PCT(3,I) = 100.0 * CPE / DES               ! POTENTIAL ENERGY %
      PCT(4,I) = 100.0 * CME / DES               ! MECHANICAL ENERGY %
25    CONTINUE
C
      WRITE(3,111) C(1), C(2), C(4), C(2), C(2)
111   FORMAT(' NO  GPM      MW      PSI_FR',3('  T(F)_',A1),
     +       '  TM-TO PSIA_',A1,'  UNC_',A1)
112   FORMAT(1X,I2,1X,F7.4,1X,F8.6,1X,F6.3,3(1X,F7.3),3(1X,F6.3))
      DO 40 I=1,NR
        DT = TM(I) - TC(I)
        WRITE(3,112) I,Q(I),W(I),DP(I),TI(I),TC(I),TM(I),DT,PE(I),TU(I)
40    CONTINUE
C
C     Begin Peclet and Stanton Number Calculations
C
      DO 50 J=1,2
        WRITE(3,113) C(J+2)
113     FORMAT(/' PECLET - STANTON NUMBERS WITH OUTLET TEMPERATURE',
     +          ' FROM ',A8,' CALCULATIONS',
     +         /' NO  LB/S-FT2 BTU/S-FT2 BTU/LB-F BTU/S-FT-F',
     +          ' T_SAT_F T_OUT_F PECLET    STANTON')
C
      DO 50 I=1,NR
        IF(J .EQ. 1) THEN
          TO = TC(I)                             ! CALCULATED OUTLET TEMP
        ELSE IF(J .EQ. 2) THEN
          TO = TM(I)                             ! MEASURED OUTLET TEMP
        END IF
```

```
          CALL HTCAP(CPO,TO,1)                          ! HEAT CAPACITY
C
C         Calculate Heat Flux
C
          HF(I) = 144.0 * AT * W(I) / (PI*DH*HL)          ! BTU/S-FT2
          G(I) = 144.0 * F(I) / CSA                       ! LBM/S-FT2
          CALL THCOND(CK,TO)                              ! THERMAL COND
          CALL SATEMP(TS,PE(I))                           ! SATURATED TEMP
C
C         Calculate Peclet Number
C
          PEN(J,I) = G(I) * (DH/12.0) * CPO / CK          ! PECLET NUMBER
C
C         Calculate Stanton Number
C
          STN(J,I) = HF(I) / (G(I)*CPO*(TS - TO))         ! STANTON NUMBER
          WRITE(3,114) I, G(I), HF(I), CPO, CK,TS,TO,PEN(J,I),STN(J,I)
50      CONTINUE
114     FORMAT(1X,I2,2(1X,F9.3),1X,F8.6,1X,E10.4,2(1X,F7.3),
     +         1X,F7.0,1X,F10.8)
C
        WRITE(3,115)
115     FORMAT(/4X,'ENERGY TERMS PERCENT CONTRIBUTION',
     +          /' NO       THERMAL',6X,
     +           'KINETIC      POTENTIAL   MECHANICAL')
C
C       Write Energy Terms Percent Contribution
C
        DO 60 I=1,NR
          WRITE(3,116) I,(PCT(J,I),J=1,4)
60      CONTINUE
116     FORMAT(1X,I2,2X,4(E12.5,2X))
        CLOSE (3)
        GOTO 999
C
990     PRINT *, ' PECLET STANTON FILE OPEN ERROR'
999     CLOSE (2)
        GOTO 998
995     PRINT *, ' OFI INPUT FILE OPEN ERROR'
998     CONTINUE
C
        STOP
        END
C
C
        SUBROUTINE TOUTUNC(TUNC,T1,W,Q,D,C)
C
C       ***********************************************************************
C       *                                                                     *
C       *  The Routine Determines Calculated Outlet Temperature Uncertainty   *
C       *  TUNC(F) with Regard to Inlet Temperature T1(F), Power W(MW),       *
C       *  Flow Rate Q(GPM), Inlet Density D(LBM/FT3), and Average Heat       *
C       *  Capacity C(BTU/LBM-F)                                              *
C       *                                                                     *
C       ***********************************************************************
C
        DATA A1,AP/425516.5433,
     +             1.071122E-04/
```

```
      DATA DT,DW,DQ,DL/0.6,
     +                 0.008,
     +                 0.02,
     +                 0.004833/
C
C     Calculate Outlet Temperature Uncertainty
C
      B = A1 / (D * Q * C)
      TUNC = SQRT(DT**2 + (B*DW*W)**2 + (B*W*DQ/Q)**2 + (AP*DL)**2)
C
      RETURN
      END
C
C
      SUBROUTINE DENSITY(D,TF)
C
C     ******************************************************************
C     *                                                                *
C     *    Routine calculates saturated liquid density for temp "T"    *
C     *    The regression equation was used from FLOWTRAN Manual       *
C     *    TF = Temperature (F), Pass in argument                      *
C     *    D = Density (LBM/CU-FT), Pass out argument                  *
C     *    Valid Range: 10 C <= T =< 300 C                             *
C     *                                                                *
C     ******************************************************************
C
      DIMENSION CD(4)
C
      DATA (CD(I),I=1,4)/0.10048897E+4,
     +                  -0.26847207E+0,
     +                  -0.18136391E-2,
     +                  -0.17041217E-5/
C
      P = 0.0                                  ! INITIALIZE SUM
C
C     Calculate Saturated Density in lbm/cu-ft
C
      T = (TF - 32.0) / 1.8                    ! CONVERT TO DEG C
      DO 10 I=1,4
        P = P + CD(I)*T**(I-1)
10    CONTINUE
      D = P * 0.06242800                       ! LBM/CU_FT
C
      RETURN
      END
C
C
      SUBROUTINE HTCAP(PP,T,IP)
C
C     ******************************************************************
C     *                                                                *
C     *      Routine to Calculate Heat Capacity                        *
C     *      T = Temperature (F), pass in argument                     *
C     *      IP = Option, Pass in argument                             *
C     *         = 1, for normal heat capacity                          *
C     *         = 2, for integrated heat capacity                      *
C     *      PP = Heat capacity (BTU/LBM-F), Pass out argument         *
C     *      Valid Range: 50 F <= T =< 500 F                           *
```

```
C      *                                                                *
C      ******************************************************************
C
       DIMENSION CP(6)
C
       DATA (CP(I),I=1,6)/1.0105,
     +                   -2.7630E-4,
     +                    1.8461E-6,
     +                   -4.1051E-9,
     +                    5.7686E-12,
     +                    0.0/
C
       P = 0.0                                    ! INITIALIZE SUM
C
       IF(IP .EQ. 1) THEN                         ! DETERMINE PROPERTY
C      Calculate Heat Capacity in Btu/lbm
       DO 30 I=1,6
         P = P + CP(I)*T**(I-1)                   ! BTU/LBM-F
30     CONTINUE
       ELSE IF(IP .EQ. 2) THEN
C      Calculate Integrated Heat Capacity in Btu/lbm
       DO 20 I=1,6
         P = P + (CP(I)/I)*T**I                   ! BTU/LBM
20     CONTINUE
       END IF
       PP = P
C
       RETURN
       END
C
C
       SUBROUTINE SATEMP(T,P)
C
C      ******************************************************************
C      *                                                                *
C      *   Routine calculates saturated temperature for pressure "P"    *
C      *   The regression equation was used from FLOWTRAN Manual        *
C      *   P = Pressure (psia), Pass in argument                        *
C      *   T = Saturation Temperature (F), Pass out argument            *
C      *   Valid Range:  0.178 psi <= P =< 1246 psi                     *
C      *                                                                *
C      ******************************************************************
C
       DIMENSION C(6)
C
       DATA (C(J),J=1,6)/0.37546530E+3,
     +                  0.89679811E+2,
     +                  0.11149468E+2,
     +                  0.99075812E+0,
     +                  0.52882025E-1,
     +                  0.12471856E-2/
C
       TS = 0.0                                   ! INITIALIZE TEMPERATURE
C
C      Calculate Reduced Pressure
C
       PR = P / (217.6 * 14.696)                  ! REDUCED PRESSURE
       Y = ALOG(PR)
```

```
      DO 10 I=1,6
        TS = TS + C(I)*Y**(I-1)
10    CONTINUE
      T = 1.8*TS + 32.0                              ! CONVERT TO DEG F
C
      RETURN
      END
C
C
      SUBROUTINE THCOND(CK,TF)
C
C     ****************************************************************
C     *                                                              *
C     *  Routine calculates liquid thermal conductivity for temp "T" *
C     *  The regression equation was used from FLOWTRAN Manual       *
C     *  TF = Temperature (F), pass in argument                      *
C     *  CK = Thermal conductivity (BTU/S-FT-F), pass out argument   *
C     *  Valid Range: 10 C <= T =< 300 C                             *
C     *                                                              *
C     ****************************************************************
C
      DIMENSION C(4)
C
      DATA (C(J),J=1,4)/0.57032432E+3,
     +                  0.17996615E+1,
     +                 -0.72881959E-2,
     +                  0.32412245E-5/
C
      T = (TF - 32.0) / 1.8                          ! CONVERT TO DEG C
      F = 0.0                                        ! INITIAL SUM
      DO 10 I=1,4
        F = F + C(I)*T**(I-1)
10    CONTINUE
      CK = F * 1.604969E-7                           ! BTU/S-FT-F
C
      RETURN
      END
```

```
C     *****************************************************************
C     *                                                               *
C     *                       UNCERSTPE.FOR                           *
C     *                                                               *
C     *     This Program Calculates Mean and Standard Deviation      *
C     *     of Power, Heat Flux, Inlet Temp, and Exit Pressure.      *
C     *     This Program also Calculates Uncertainties in            *
C     *     Peclet & Stanton Numbers                                 *
C     *                                                               *
C     *     The Program interactively asks two input and one         *
C     *     output file names                                        *
C     *                                                               *
C     *     Input Files: Two Input Files - Free Formatted            *
C     *                                                               *
C     *     First File - The First Input File is the OFI Conditions  *
C     *                  File. The First Record is tube ID, the      *
C     *                  Second Record is Uncertainty on ID, the     *
C     *                  Third Record is Ratio of Flow Rate          *
C     *                  Uncertainty to the Flow Rate (which is      *
C     *                  Const. for all Flow Rates), the Fourth      *
C     *                  Record is the No. of Test Cases and the     *
C     *                  Fifth is the No. of Sample Cases in Each    *
C     *                  Test Case. The Subsequent Records are       *
C     *                  Flow Rate (gpm), Peclet No., Stanton No.,   *
C     *                  Measured Outlet Temp at OFI Condition (F)   *
C     *                  for Each Test Case.                         *
C     *                                                               *
C     *    Second File - The Second File is the test Conditions File *
C     *                  Each Record Consists of Test Conditions     *
C     *                  Power, Heat Flux, Exit Pres, Inlet Temp,    *
C     *                  Ratio of Uncertainty of Power to Power      *
C     *                                                               *
C     *****************************************************************
C
      DIMENSION  AVPOWER(30),
     +           SDPOWER(30),
     +           AVHTFLX(30),
     +           SDHTFLX(30),
     +           AVIT(30),
     +           SDIT(30),
     +           AVEP(30),
     +           SDEP(30),
     +           AVUNPOW(30),
     +           SDUNPOW(30),
     +           DPOWERMESR(30),
     +           DTINMES(30),
     +           DTINLET(30),
     +           TSAT(30),
     +           TSUB(30),
     +           NN(30)
C
      DIMENSION  TOUT(30),
     +           QMES(30),
     +           PE(30),
     +           DELPE(30),
     +           ST(30),
     +           DELST(30),
     +           DPOWERR(30),
```

```
     +           DELHFLXR(30)
C
      REAL  PE,
     +      L
      REAL*8  SQUNPOW,
     +        SUMSQUNPOW,
     +        SUMUNPOW,
     +        AVUNPOW,
     +        SDUNPOW
C
      CHARACTER*25 INFILE1,
     +             INFILE2,
     +             OUTFILE
C
C     L = Length of The Tube (inch)
C     DELL = Uncertainty of Tube Length (inch)
C     DELD = Uncertainty in Tube ID (inch)
C     DELQMESR = Uncertainty in Flow Ratio (%)
C     DELRHOR = Uncertainty in Density (%)
C     DELCPR = Uncertainty in Specific Heat Ratio (%)
C     DELKR = Uncertainty in Thermal Conductivity Ratio (%)
C     DPOWERMESR = Uncertainty in Meas Power Ratio (%)
C     DELTOUT = Uncertainty in T Out (C)
C     DELTSAT = Uncertainty in Saturation Temp (C)
C     D = Tube Inside Diameter (inch)
C     N = Number of Test Cases
C     NN = Number of Samples in Each Test Case
C     QMES = Measured Flow Rate (gpm)
C     PE = Peclet Number
C     ST = Stanton Number
C     TEMPPOWER = Power in the Sample (KW)
C     TEMPHTFLX = HT Flux in the Sample (MBtu/hr-ft2)
C     TEMPEP = Exit Pressure in the sample (psia)
C     TEMPIT = Inlet Temperature in the Sample (F)
C     TEMPUNPOW = Measured Power Uncertainty Ratio in the Sample
C     AVPOWER = Average Power of the Test Case (KW)
C     AVHTFLX = Average Heat Flux of the Test Case (MBtu/hr-ft2)
C     AVIT = Average Inlet Temp of the Test Case (C)
C     AVEP = Average Exit Pressure of the Test Case (psia)
C     AVUNPOW = Average Measure Power Uncertainty Ratio of the Test Case
C     SDPOWER = S.D. of Power in the Test Case (KW)
C     SDHTFLX = S.D of Heat Flux in the Test Case (MBtu/hr-ft2)
C     SDIT = S.D of Inlet Temp in the Test Case (C)
C     SDEP = S.D of Exit Pressure in the Test Case (PSIA)
C     SDUNPOW = S.D. OF Measured Power Uncertainty Ratio
C     DTINMES = Uncertainty in I. Temp Measurement (C)
C     DTINLET = Total Uncertainty in I. Temp (C)
C     DPOWERR = Ratio of Uncertainty of Power to Power
C     DELHFLXR = Ratio of Uncetainty of HT Flux to HT Flux
C     TSAT = Saturation Temperature (C)
C     TOUT = Exit Temperature (C)
C     DELGR = Ratio of Uncertainty of Flow Rate to Flow Rate
C     DELPE = Uncertainty in Peclet Number
C     DELST = Uncertainty in Stanton Number
C
C     Set up Input File Name Record Format
C
1001  FORMAT(A25)
```

```
C
C     Open the OFI Input File
C
      PRINT 1002
1002  FORMAT(' ENTER THE OFI INPUT DATA FILE NAME ? ',$)
      ACCEPT 1001, INFILE1
      OPEN(2,FILE=INFILE1,STATUS='OLD',ERR=991,
     +     ACCESS='SEQUENTIAL',FORM='FORMATTED',
     +     ORGANIZATION='SEQUENTIAL',RECORDTYPE='VARIABLE')
C
C     Open the Test Conditions Data File
C
      PRINT 1004
1004  FORMAT(' ENTER THE TEST CONDITIONS INPUT DATA FILE NAME ? ',$)
      ACCEPT 1001, INFILE2
      OPEN(3,FILE=INFILE2,STATUS='OLD',ERR=993,
     +     ACCESS='SEQUENTIAL',FORM='FORMATTED',
     +     ORGANIZATION='SEQUENTIAL',RECORDTYPE='VARIABLE')
C
C     Open the Output File
C
      PRINT 1006
1006  FORMAT(' ENTER THE OUTPUT FILE NAME ? ',$)
      ACCEPT 1001, OUTFILE
      OPEN(4,FILE=OUTFILE,STATUS='UNKNOWN',ERR=995,
     +     ACCESS='SEQUENTIAL',FORM='FORMATTED',
     +     ORGANIZATION='SEQUENTIAL',RECORDTYPE='VARIABLE')

C     Static Input Values
C
      L = 96.0
      DELL = 0.038
      DELRHOR = 0.001
      DELCPR = 0.001
      DELKR = 0.001
      DELTOUT = 1.0
      DELTSAT = 0.024
C
C     Read Tube ID, ID Uncertainty, Flow Rate Uncertainty Ratio
C     # of Test Cases, # of Sample in the Test Case,
C     OFI Flow Rate, Peclet #, Stanton #, Measured Outlet Temp at OFI
C
      READ(2,*) D
      READ(2,*) DELD
      READ(2,*) DELQMESR
      READ(2,*) N
      READ(2,*) (NN(I),I=1,N)
C
      DO 10 I=1,N
        READ(2,*) QMES(I),PE(I),ST(I),TOUT(I)
10    CONTINUE
C
C     Echo of Input
C
      WRITE(4,1010)
1010  FORMAT(20X,'Echo of Input')
      WRITE(4,1020) N
1020  FORMAT(//5X,'No. of Test Case = ',I4)
```

```
      WRITE(4,1030)
1030  FORMAT(/5X,' TEST CASE       NO. OF SAMPLES'/)
      WRITE(4,1040) (I,NN(I),I=1,N)
1040  FORMAT(2(10X,I4))
      WRITE(4,1050)
1050  FORMAT(//5X,'FLOW RATE (GPM)      PECLET #       STANTON #',
     +          '    MEAS OUTLET TEMP (F)'/)
      DO 20 I=1,N
        WRITE(4,1060) QMES(I),PE(I),ST(I),TOUT(I)
1060    FORMAT(5X,F8.3,7X,F12.0,5X,F10.8,5X,F10.2)
20    CONTINUE
C
C     Calculation of Average & S.D. of the Sample
C
      DO 30 I=1,N
        SUMSQPOWER=0.0
        SUMSQHTFLX=0.0
        SUMSQIT=0.0
        SUMSQEP=0.0
        SUMSQUNPOW=0.0
        SUMPOWER=0.0
        SUMHTFLX=0.0
        SUMIT=0.0
        SUMEP=0.0
        SUMUNPOW=0.0
        DO 25 J=1,NN(I)
          READ(3,*) TEMPPOWER, TEMPHTFLX, TEMPEP, TEMPIT, TEMPUNPOW
          SQPOWER=TEMPPOWER*TEMPPOWER
          SQHTFLX=TEMPHTFLX*TEMPHTFLX
          SQIT=TEMPIT*TEMPIT
          SQEP=TEMPEP*TEMPEP
          SQUNPOW=TEMPUNPOW*TEMPUNPOW
          SUMSQPOWER=SUMSQPOWER+SQPOWER
          SUMSQHTFLX=SUMSQHTFLX+SQHTFLX
          SUMSQIT=SUMSQIT+SQIT
          SUMSQEP=SUMSQEP+SQEP
          SUMSQUNPOW=SUMSQUNPOW+SQUNPOW
          SUMPOWER=SUMPOWER+TEMPPOWER
          SUMHTFLX=SUMHTFLX+TEMPHTFLX
          SUMIT=SUMIT+TEMPIT
          SUMEP=SUMEP+TEMPEP
          SUMUNPOW=SUMUNPOW+TEMPUNPOW
25      CONTINUE
C
        AVPOWER(I)=SUMPOWER/NN(I)
        AVHTFLX(I)=SUMHTFLX/NN(I)
        AVIT(I)=SUMIT/NN(I)
        AVEP(I)=SUMEP/NN(I)
        AVUNPOW(I)=SUMUNPOW/NN(I)
        SDPOWER(I)=SQRT((SUMSQPOWER-NN(I)*AVPOWER(I)*AVPOWER(I))/
     +                  (NN(I)-1))
        SDHTFLX(I)=SQRT((SUMSQHTFLX-NN(I)*AVHTFLX(I)*AVHTFLX(I))/
     +                  (NN(I)-1))
        SDIT(I)=SQRT((SUMSQIT-NN(I)*AVIT(I)*AVIT(I))/(NN(I)-1))
        SDEP(I)=SQRT((SUMSQEP-NN(I)*AVEP(I)*AVEP(I))/(NN(I)-1))
        SDUNPOW(I)=SQRT((SUMSQUNPOW-NN(I)*AVUNPOW(I)*AVUNPOW(I))/
     +                  (NN(I)-1))
30    CONTINUE
```

```
C
      WRITE(4,3000)
3000  FORMAT('1')
      WRITE(4,3010)
3010  FORMAT(1X,'AV POWER  SD POWER   AV HT FLX   SD HT FLX',
     +          '   AV MES POW UNR   SD MES POW UN'/
     +    1X,'  (KW)       (KW)     (MBTU/HR-FT2)  (MBTU/HR-FT2)',
     +          '           (%)                 (%)'/)
      DO 110 I=1,N
        WRITE(4,3020) AVPOWER(I),SDPOWER(I),AVHTFLX(I),SDHTFLX(I),
     +                AVUNPOW(I),SDUNPOW(I)
3020    FORMAT(1X,3(F10.6,2X),3(F10.6,2X))
110   CONTINUE
C
      WRITE(4,3030)
3030  FORMAT(/5X,'AV I. TEMP  SD I. TEMP   AV E. PRES'
     +          '   SD E. PRES'/
     +         5X,'    (C)          (C)           (PSIA)    '
     +          '      (PSIA)  '/)
      DO 120 I=1,N
        WRITE(4,3040) AVIT(I),SDIT(I),AVEP(I),SDEP(I)
3040    FORMAT(5X,4(F10.4,2X))
120   CONTINUE
C
C     Calculate Error in Inlet Temp Measurement
C
      DO 40 I=1,N
        DTINMES(I)=SQRT((0.25*0.25)+0.00005*AVIT(I)*0.00005*AVIT(I)+
     +                  (0.02*0.02))
        DTINMES(I)=DTINMES(I)*5.0/9.0
        SDIT(I)=SDIT(I)*5.0/9.0
        DTINLET(I)=SQRT(SDIT(I)*SDIT(I)+DTINMES(I)*DTINMES(I))
40    CONTINUE
C
C     Calculate Error in Power
C
      DO 50 I=1,N
        DPOWERMESR(I)=AVUNPOW(I)+2.0*SDUNPOW(I)
        DPOWERR(I)=SQRT(2.0*SDPOWER(I)/AVPOWER(I)*
     +             2.0*SDPOWER(I)/AVPOWER(I)+
     +             DPOWERMESR(I)*DPOWERMESR(I))
50    CONTINUE
C
C     Calculation of Saturation Temp
C
      CT1 = 0.37546530E+3
      CT2 = 0.89679811E+2
      CT3 = 0.11149468E+2
      CT4 = 0.99075812E+0
      CT5 = 0.52882025E-1
      CT6 = 0.12471856E-2
      PC = 22.064
      DO 70 I=1,N
        PR = (AVEP(I)/(14.5*10.0))/PC
        Y = ALOG(PR)
        TSAT(I) = CT1+CT2*Y+CT3*Y**2+CT4*Y**3+CT5*Y**4+CT6*Y**5
70    CONTINUE
C
```

```
C      Calculate Subcooling
C
       DO 87 I=1,N
         TOUT(I)=(TOUT(I)-32.0)/1.8
         TSUB(I)=TSAT(I)-TOUT(I)
87     CONTINUE
C
C      Calculation of Uncertainties
C
C      Calculation of Uncertainty of Peclet Number
C
       DO 90 I=1,N
         DELPE(I) = PE(I)*SQRT(DELCPR*DELCPR+(DELD/D)*(DELD/D)+
     +             (DELQMESR)*(DELQMESR)+DELKR*DELKR+DELRHOR*DELRHOR)
90     CONTINUE
C
C      Calculation of Uncertainty of Stant on Number
C
       DO 100 I=1,N
         A1 = (DELCPR*DELCPR+DELQMESR*DELQMESR+DPOWERR(I)*DPOWERR(I)+
     +        DELRHOR*DELRHOR)
         A2 = (DELD/D)*(DELD/D)+(DELL/L)*(DELL/L)
         A = A1+A2
         B = (DELTOUT*DELTOUT+DELTSAT*DELTSAT)/
     +       ((TSAT(I)-TOUT(I))*(TSAT(I)-TOUT(I)))
         DELST(I) = ST(I)*SQRT(A+B)
100    CONTINUE
C
C      Write the Output
C
       WRITE(4,2010)
2010   FORMAT(//10X,' Output of Uncertainty Calculation ')
       WRITE(4,2012) L
2012   FORMAT(/5X,'Heated Length (inch) = ',F6.2)
       WRITE(4,2014) DELL
2014   FORMAT(5X,'Uncertainty in Heated Length (inch) = ',F8.5)
       WRITE(4,2016) D
2016   FORMAT(5X,'Inside Diameter of Heater Tube (inch) = ',F8.5)
       WRITE(4,2018) DELD
2018   FORMAT(5X,'Uncertainty in Inside Diameter (inch) = ',F8.5)
       TEMP=DELQMESR*100.0
       WRITE(4,2020) TEMP
2020   FORMAT(5X,'Uncertainty in Measured Flow Rate (%) = ',F6.3)
       TEMP=DELRHOR*100.0
       WRITE(4,2040) TEMP
2040   FORMAT(5X,'Uncertainty in Density (%) = ',F6.3)
       TEMP=DELCPR*100.0
       WRITE(4,2060) TEMP
2060   FORMAT(5X,'Uncertainty in Specific Heat (%) = ',F6.3)
       TEMP=DELKR*100.0
       WRITE(4,2080) TEMP
2080   FORMAT(5X,'Uncertainty in Thermal Conductivity (%) = ',F6.3)
       WRITE(4,2100) DELTOUT
2100   FORMAT(5X,'Uncertainty in Exit Temperature (C) = ',F6.3)
       WRITE(4,2110) DELTSAT
2110   FORMAT(5X,'Uncertainty in Saturation Temperature (C) = ',F6.3)
C
       WRITE(4,3050)
```

```
3050  FORMAT(/5X,'SAT TEMP       EXIT TEMP       SUB COOL'/
     +         5X,'  (C)            (C)             (C)'/)
      DO 130 I=1,N
        WRITE(4,3060) TSAT(I),TOUT(I),TSUB(I)
3060    FORMAT(5X,3(F10.4,2X))
130   CONTINUE
C
      WRITE(4,4000)
4000  FORMAT('1')
      WRITE(4,4010)
4010  FORMAT(//10X,'Uncertainty in PECLET numbers')
      WRITE(4,4020)
4020  FORMAT(/3X,'FLOW RATE(GPM)   PECLET NUMBER   DEL PECLET NUMBER'
     +            '     UNCER PE  (%)'/)
      DO 210 I=1,N
        TEMP=DELPE(I)*100.0/PE(I)
        WRITE(4,4030) QMES(I),PE(I),DELPE(I),TEMP
4030    FORMAT(6X,F5.2,10X,2(F8.0,10X),F5.2)
210   CONTINUE
C
      WRITE(4,5010)
5010  FORMAT(//10X,'Uncertainty in STANTON numbers')
      WRITE(4,5020)
5020  FORMAT(/3X,'FLOW RATE(GPM)  STANTON NUMBER  DEL STANTON NUMBER'
     +            '  ST-DELST      UNCER ST  (%)'/)
      DO 305 I=1,N
        TEMP=ST(I)-DELST(I)
        TEMP1=DELST(I)*100.0/ST(I)
        WRITE(4,5030) QMES(I),ST(I),DELST(I),TEMP,TEMP1
5030  FORMAT(6X,F5.2,9X,3(F10.8,7X),F5.2)
305   CONTINUE
C
      GOTO 999
C
991   PRINT *, ' ERROR TO OPEN OFI INPUT FILE '
      GOTO 999
993   PRINT *, ' ERROR TO OPEN TEST CONDITIONS FILE '
      GOTO 999
995   PRINT *, ' ERROR TO OPEN OUTPUT FILE '
      GOTO 999
C
999   CONTINUE
      CLOSE (2)
      CLOSE (3)
      CLOSE (4)
C
      STOP
      END
```

END

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8/19/92