# FERROUS SCRAP PREHEATING SYSTEM

## PHASE II - FINAL REPORT

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Surface Combustion

**DISCLAIMER**

## TABLE OF CONTENTS



## LIST OF FIGURES

## EXECUTIVE SUMMARY

Utilization of electric arc steel making has allowed many smaller producers to compete with the large mills. An electric arc furnace (EAF) melts scrap metal to produce a variety of steel products. Using scrap as the metal source is less costly than refining from ores, but the metal is of a lower quality due to impurities in the scrap. Over the years, methods have been developed to improve EAF metal quality and reduce the cost of production. As a result, an increasing share of total steel production is shifting to EAFs. By recent estimates, EAF production is growing at a rate of about 10% per year, and currently accounts for nearly one half of all U.S. steel production (U.S. Department of Energy and Electric Power Research Institute Project 2787-2, 1987)[1].

The subject of this report is Scrap Preheating, a new method of preheating scrap metal before it is charged into an EAF. A major benefit in the U.S. is the substitution of gas for electricity. In scrap preheating, a portion of the energy is supplied in a separate vessel, causing the EAF to use less energy, which shortens the heating time. The general effect is that the arc furnace can produce more steel in a given time at a reduced cost per ton of molten metal. Scrap preheating is practiced in Europe and Asia, but in the U.S., the energy cost structure and other physical limitations have deterred its acceptance.

The scrap preheating furnace is a stand-alone system with its own gas fueled energy source. The preheater operates under controlled conditions, specifically, a low oxygen level atmosphere in which oils and other organics in the scrap contribute to the energy of preheat. The scrap is heated in the same buckets that are normally used to transport the scrap from the yard to the melter. The unit can be installed in a remote location, possibly in the scrap yard.

Surface Combustion estimates that the proposed Scrap Preheating Furnace can reduce the cost of making steel by $11 per ton. The savings are in reduced energy cost, increased productivity and yield, reduced electrode and refractory usage, and the ability to process a lower grade of oily scrap. Typically, these systems will heat a thirty ton bucket of scrap in about thirty minutes. Most of these units will have a one or two year payback period.

Preheated scrap requires less time in the electric arc furnace, thus reducing the quantity of ozone related gases emitted per ton of steel produced. Specifically the preheating furnace generates less $NO_x$ and volatile organic compounds (VOC) than an electric arc furnace. In addition, it may be possible to melt some of the oily implant metallic wastes, and avoid disposal costs.

This program will culminate in a full sized demonstration furnace installed and operated at Washington Steel Corporation's Melt Shop in Houston Pennsylvania. The program is divided into three phases. Phase I, Marketing and Technology Evaluation, is completed with the results reported in a June, 1990 report prepared by Surface Combustion, Inc., Phase II, critical item testing and system design is the subject of this report. Phase III, will be installation and testing of the demonstration preheater. This program is sponsored by the U.S. Department of Energy (Office of Industrial Technologies) with major co-funding by a consortium of natural gas companies through the Gas Technology Industrial Commercialization Center (a Consortium of Natural Gas Suppliers), Washington Steel Corporation (the Host Site) and Surface Combustion, Inc. (prime contractor and equipment supplier)[2].

The following are critical component testing results and conclusions:

1. The configuration and materials for the seal between the hood and the top of the bucket was selected to be a fibrous rope with reinforcing rods.

2. The pressure drop of several filled buckets was measured as a function of gas flow rate. The recirculating fan flow and delivery pressure was determined from the tests.

3. The recirculating hot fan location was selected to provide constant temperature operation.

4. The anticipated emissions were estimated based upon tests in a pilot scale facility.

5. The method of transferring buckets into and out of the heating chamber and the system configuration was selected to conform to the requirements at the host site.

The results of these evaluations were incorporated into a complete set of engineering drawings. The drawings will be used in Phase III to fabricate the furnace.

## 1.0 INTRODUCTION

The U.S. steel industry is recovering from its slump in the early 1980's and is again becoming more internationally competitive. Changes in economics and technology have resulted in a smaller number of more efficient mills that have begun to make the capital investment and improvements needed to make the U.S. a world leader in steel production. One of the fastest growing sectors of steel production is the recycling of scrap steel using an Electric Arc Furnace (EAF). Melting scrap allows production of molten metal at a lower cost than is possible by refining iron ore in a blast furnace. Although the quality of metal from an arc furnace is lower, on-going improvements in quality have made the product competitive in an expanding sector of the total steel market.

The subject of this report is a thermal system which preheats scrap steel before charging into an EAF. The preheater is designed to improve overall productivity and efficiency of the melting operation. The scrap metal is loaded into a handling bucket and then transported to the preheat chamber. Thermal energy is applied to the scrap, removing moisture and oils while bringing the metal to a suitable preheat temperature for the EAF. After processing, the heated scrap is transported to the EAF. The EAF creates very high temperatures with electric arcs, creating a molten metal pool covered with slag impurities. The molten steel is then transferred to a refining vessel which adjusts the steel prior to some form of forming such as chemical composition, continuous casting. The solidified metal is rolled and milled into forms that are used to make products.

Preheating scrap for an EAF is not a new idea. It is currently practiced in various forms in Europe and Asia, but the foreign technology has not been suitable for the U.S. steel industry. The preheating approach presented in this report is a result of examining domestic needs, and designing a preheater that is specifically aimed at U.S. physical retrofit requirements and the domestic energy cost structure. A survey of EAF operators revealed considerable interest in this approach, but also a level of reluctance in investing in a system[3].

One objective of this project is to build and demonstrate a full scale scrap preheater that can be used to verify economic projections and will serve as a model for future installations. The general project is divided into three phases, including system evaluation at the Host Site. A previous report covered Phase I, the technical and market feasibility activities. This report covers Phase II, and includes testing of critical components and detailed design of the system. In the final phase, a production scale system will be installed and tested at Washington Steel in Houston, PA. The project, sponsored by the U.S. Department of Energy Office of Industrial Technologies, has substantial cost sharing by The Gas Technology Industrial Commercialization Center (a Consortium of Natural Gas Suppliers).

## 1.1 BACKGROUND

The arrival of EAF technology led to the formation of steel mini-mills and many smaller steel suppliers. From the beginning, there has been continuous improvement in the efficiency of arc furnace operations. Some of these innovations are water-cooled panels, oxy-fuel burners, and foamy slag practices. In addition, the power supplied to a given furnace has been increasing. These changes have reduced the time it takes to melt several charges of scrap from about three hours to about one hour, thereby increasing the productivity of the furnace. A DOE and EPRI publication entitled Technoeconomic Assessment of Electric Steel Making Through the Year 2000, illustrates the trends in EAF operations, and lists scrap preheating as the next logical improvement[1].

In the early 1980's, Surface Combustion, under contract with Columbia Gas Service Corporation and Southern California Gas Co., began the development that led to the current Ferrous Scrap Preheater approach. A pilot plant was built that heated 6 ton batches of scrap in a chamber while measuring the temperature and heating rate. One parameter being tested was the effect of the recirculating gas flow rate.

As predicted by a heat transfer model, the rate of thermal transfer is directly proportional to the gas recirculation rate[4]. During the heating process, hot gases enter the top of the load and lose energy as they pass downward. As a result, the top of the load starts heating first as a thermal front passes down through the load. A cycle is complete when the thermal front reaches the bottom of the load. It was found that a 1100°F inlet gas temperature resulted in an average metal temperature of 900 to 1000°F. By average, we mean that if the total thermal energy in the scrap was evenly distributed, all of the scrap would be at the average temperature. Since there are temperature gradients in the scrap, some areas will be above the average temperature while others will be lower. Two charges of preheated scrap were melted in an EAF at National Castings. In both cases melting times were decreased. The results proved that a preheater of this type was technically possible.

Surface Combustion enhanced the approach for preheating by incorporating feedback from EAF operators. A marketing effort in the mid 1980's resulted in several good potential demonstration sites, but the economics at that time were not favorable. Most of the steel mills were experiencing financial difficulties and were unwilling to make major capital investments. These mills had excess melting capacity, and there was uncertainty about natural gas prices. The project was shelved because of industry conditions. Now that the U.S. Steel industry has recovered, it is time to re-evaluate this method of enhancing steel production.

In Phase I it was determined, 1) that scrap preheating is technically and mechanically suited for enhancing steel and stainless steel production, and 2) a need exists for a scrap preheating system that can reduce the cost of producing steel.

## 2.0 PREHEATING FURNACE DESCRIPTION

The preheating furnace consists of three major components: 1) the heating chamber, 2) the recirculating fan, and 3) the Rich Fume Reactor (RFR). (The components are shown in Figure 1.) The buckets of scrap are placed in the heating chamber and sealed. Hot gases are then forced through the bucket by the recirculating fan. The gases pass through the bucket and exit through the bottom. After exiting the bucket, the gases pass to the RFR where natural gas and organics from the scrap are burned to reheat the gas stream. Finally, the gas exits the RFR and is passed through the recirculating fan back to the top of the bucket. A portion of the stream is vented downstream of the RFR. The system pressure is maintained using an exhaust fan in this vent stream.

The scrap buckets are transferred into and out of the heating chamber using transfer cars. There are two cars, each containing the lower portion of a heating chamber. A bucket is placed on the car within the lower heating chamber section and the car moves into position. The top of the heating chamber is lowered over the bucket sealing onto the lower heating chamber on the car. The hood seal is lowered to the top of the scrap bucket and the heating cycle begins. When the cycle is complete, the heating chamber cover is raised and transfer car moves to the pick-up position while the other car moves the next load plus the heating position.

The heating chamber is round and contains insulation on its interior. There are two ducts attached to the top of the chamber, one to admit the hot gases and the other to duct the return gases. When the cover is raised, the ducts also lift. When the cover is lowered, the moving ducts connect to the stationary ducts using water seals. Figure 2 is a detail of the heating chamber containing a bucket. The removable cover is the portion above the chamber split line. The portion below the split line is the lower heating chamber which is attached to the transfer car. The bucket sits in a positioning cradle which is also attached to the car. The hot gas enters through the top of the chamber and into the hood. The hood seals to the top of the bucket using a ceramic fiber material. There is an expansion joint at the top of the hood to compensate for any misalignment with the bucket or thermal expansion.

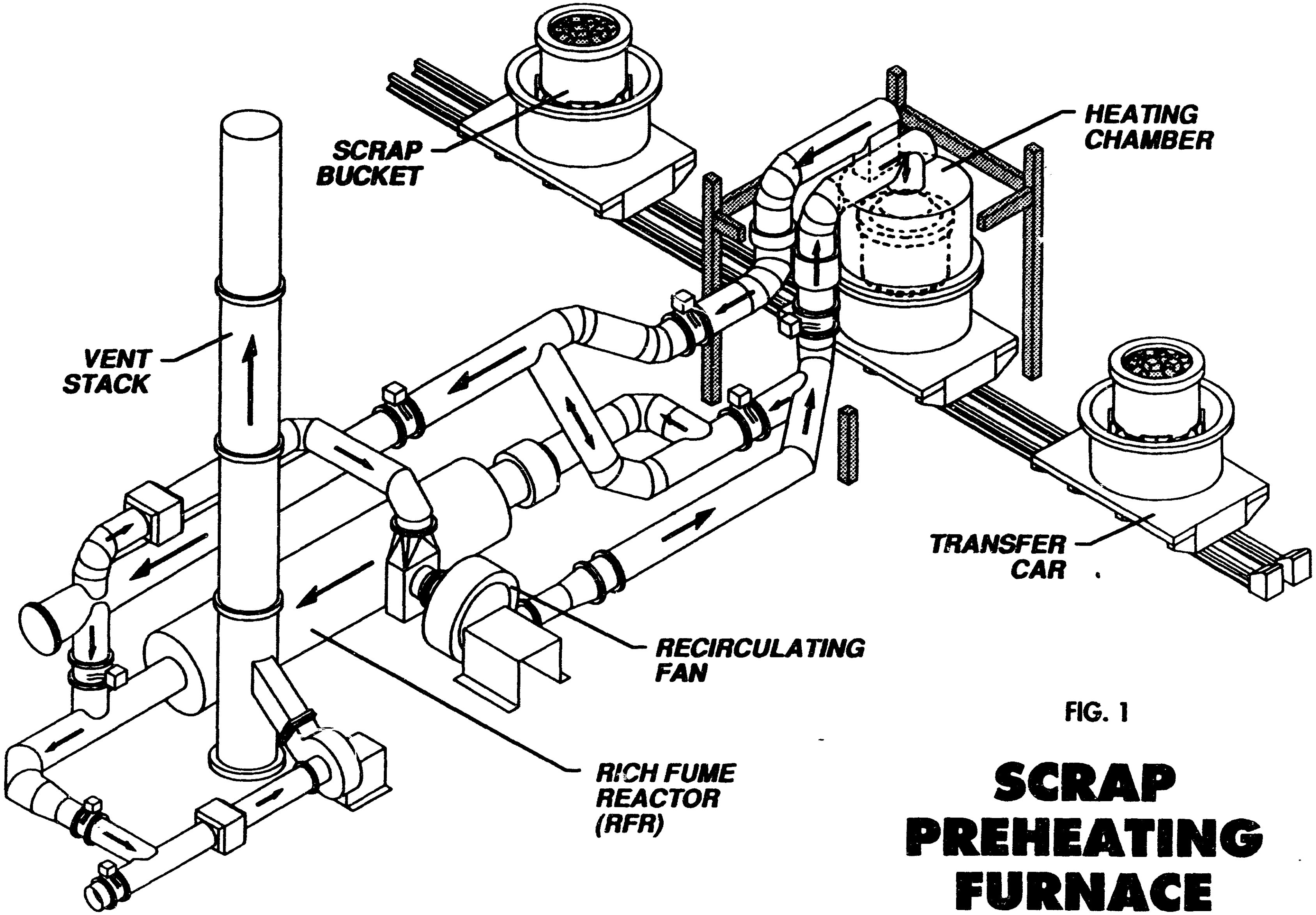



FIG. 1

**SCRAP PREHEATING FURNACE**

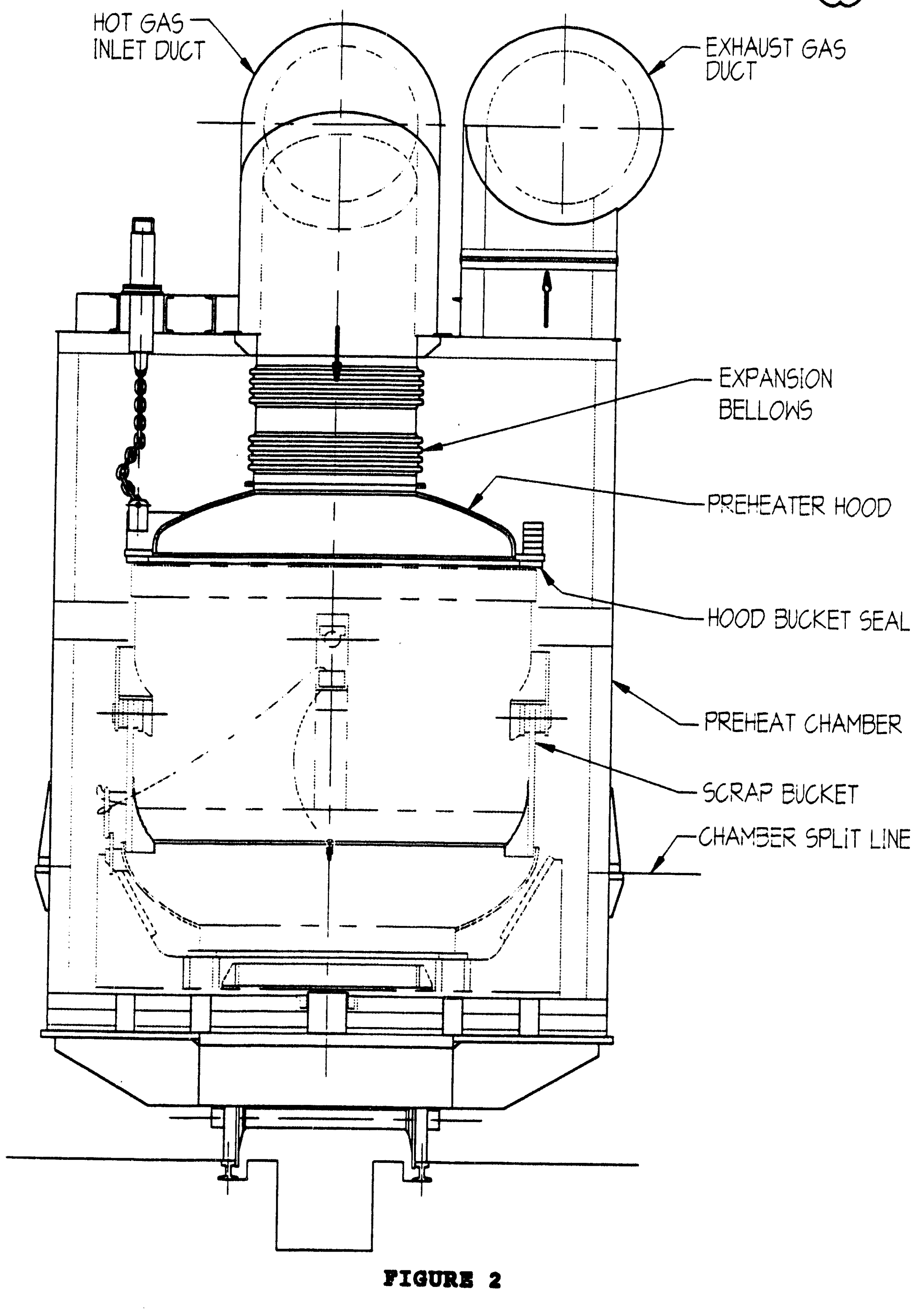



**FIGURE 2**

**PREHEATER CHAMBER AND CAR**

The RFR is capable of operating at 1400°F to 1600°F and completely burning natural gas and organics with a resulting flue gas having less than 2% oxygen. Two natural gas burners fire tangentially at the upstream end of the RFR providing stable combustion. Auxiliary natural gas is added to the flue gas stream of these burners. The recycling gases enter the RFR axially through a duct that is surrounded by the combustion air inlet. This mixing arrangement makes the RFR capable of operating over a wide range of conditions. Down-stream of the mixing area, a residence chamber completes the combustion reaction. The flows of combustion air and auxiliary fuel vary to control the oxygen level and the temperature of the RFR exhaust as process needs change. Cutting oils, water, and other organics, driven-off the scrap as it is heated, will pass to the RFR and are thermally oxidized.

The anticipated temperature of the gas entering the preheating chamber is 1100°F. A portion of the recycle stream will by-pass the RFR which operates at 1400°F to 1600°F, and mix with the RFR off-gases to maintain the 1100°F gas-preheat temperature. The mixture temperature is controlled by varying the fraction of the gas that by-passes the RFR. The mixed gases pass through the recirculating blower and then to the heating chamber.

The heating chamber is a round chamber that is raised and lowered with its own lift mechanism. The chamber has a hood which is supported from the inside roof of the preheat chamber. The hood is connected to the inlet duct of the preheater chamber through a high temperature expansion joint. The hood rests on top of the scrap bucket and is sealed with a seal which was selected from Phase II testing.

The preheater chamber has an inlet and outlet duct off the top of the chamber. These ducts are equipped with water seals to allow the chamber to be raised and lowered. Additional ductwork connects the chamber ducts with the RFR.

The ductwork connecting the preheating chamber, the RFR and the recirculation fan is designed with isolation valves and bypass lines to isolate the preheater chamber when scrap buckets are being charged or discharged. This bypass ductwork is used to maintain RFR operations during bucket changes.

There are control valves and a bypass line around the RFR to temper the gases flowing into the scrap bucket. The ducts are internally insulated and have high temperature expansion joints.

The scrap preheating furnace is controlled using three temperature control loops, an oxygen control loop, and a pressure control loop. The temperature loops control the gases entering the heating chamber, the RFR auxiliary fuel flow, and the cold air infiltration at the exhaust fan. The oxygen controller maintains the oxygen level in the exhaust from the RFR, and the pressure controller maintains the draft level in the heating chamber.

## 3.0 CRITICAL COMPONENT EVALUATION

A series of evaluations were performed to assist in the system design. The critical components are the heating chamber seals, the recirculating hot fan, and emission controls. The evaluations included laboratory testing and engineering studies. The following evaluation were performed:

1. Laboratory testing of materials and configurations for the seal between the hood and the top of the scrap bucket.

2. Measurement of the pressure drop of gas flowing through typical buckets of scrap.

3. Evaluation of location for the recirculating fan.

4. Measurement of air emissions from heating scrap in a pilot furnace.

5. Evaluation of the method for transferring scrap buckets into and out of the heating chamber.

The following is a summary of the evaluations and their impact of the furnace design.

### 3.1 HOOD/BUCKET SEAL EVALUATION

When the bucket is placed in the heating chamber, the hood is lowered onto the top of the bucket (see Figure 2). The hood is the hot gas inlet into the scrap bucket and heating chamber. The hood/bucket seal forces the hot gases to pass directly through the bucket. The rim, or top of the bucket, is 3/4" thick and contains dents and minor deformations. Hot gas leakage through this seal reduces the amount of gas flowing through the bucket. Therefore, the recirculating fan must be large enough to supply the desired flow through the bucket with a certain leakage rate.

The objective of this evaluation was to select a design and material for the seal and to approximate the expected leakage rate. A series of potential seal designs were compared and five were selected for testing. Testing was done on a small scale hood and a simulated bucket. The preferred configuration was integrated into the hood design.

### 3.1.1 Testing

The five seal designs selected for testing are shown in Figure 3. The leakage rate was measured for each, and two designs were selected for more complete testing. The tests were performed using a small scale hood and bucket. The top of the bucket was the same thickness as a full sized bucket. The tests were performed following the matrix in Table 1. Each design was cycled for the desired times and the leakage rate was determined by measuring the air flow into the hood at a given static pressure in the hood. A cycle was performed by lifting the hood off the bucket rotating the hood slightly and the lowering the hood to remake the seal. The seal was compressed with a force proportional to that expected in the full sized system.

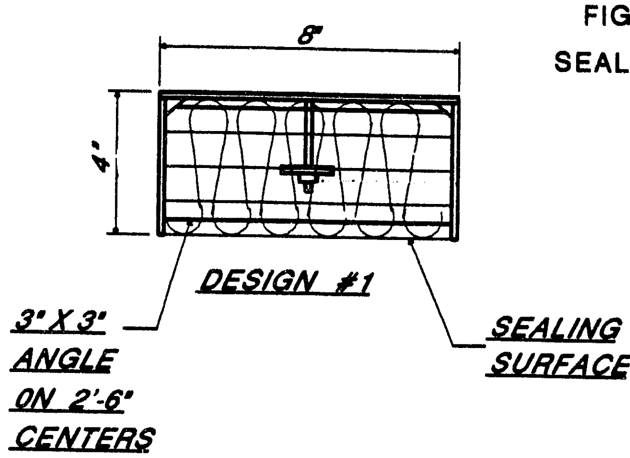
### 3.1.2 Results and Impact

The seal materials consisted of fibrous ceramics in different configurations. Designs 1 and 2 were modules of ceramic fiber blanket compacted for strength. Design 1 had metal retaining angles while Design 2 did not. Designs 2, 3 and 4 used fiber encased in woven ceramic fabric tube. These tubes are more flexible so support rods were added on approximately 2'-6" centers in Design 4. Design 5 used a dense ceramic roping with support rods. The initial leakage rates are given in Table 2.

Designs 2 and 5 were selected for further testing because they had low leakage rates and good durability. They were first tested for 1000 cycles with a higher compressive pressure. The top of the simulated bucket was then covered with sharp pieces of metal and the seals were tested for another 200 cycles. Finally the seal materials were heated to 1100°F and retested for another 200 cycles. The leakage rates of the seals after completion of the entire test series is shown in Figure 4. It is expressed as SCFH leakage per foot of seal length which can be scaled to a layer diameter seal.

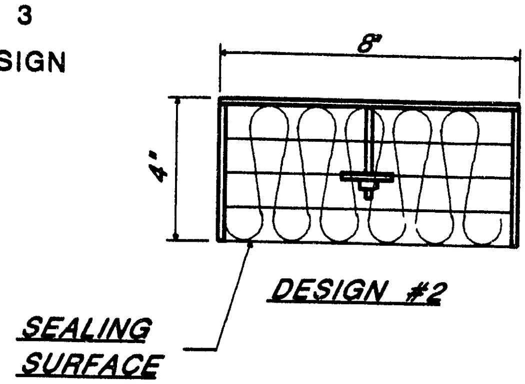
Careful examination of the seal material at the conclusion of the tests showed that the Kaowool modules of Design 2 had degraded. The binders were decomposed and the fiber was brittle. The ceramic rope of seal Design 5 was still

# FIGURE 3
## SEAL DESIGN



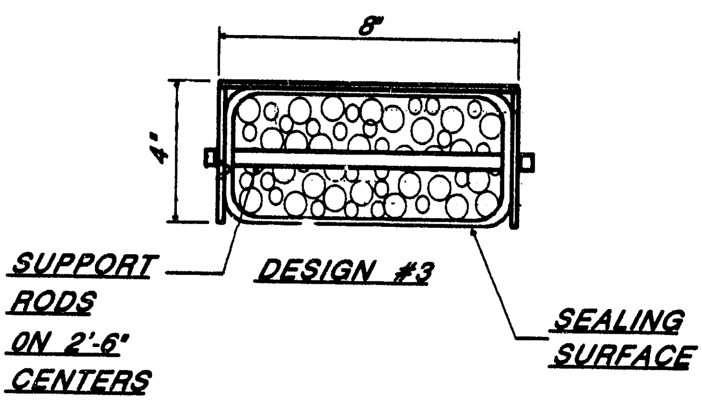

DESIGN #1

SEAL TYPE: THERMAL CERAMICS KAOWOOL MODULES WITH SUPPORT ANGLE ON 2'-6" CENTERS
MATERIAL: CERAMIC FIBER
DENSITY: 15 LBS/CU. FT.



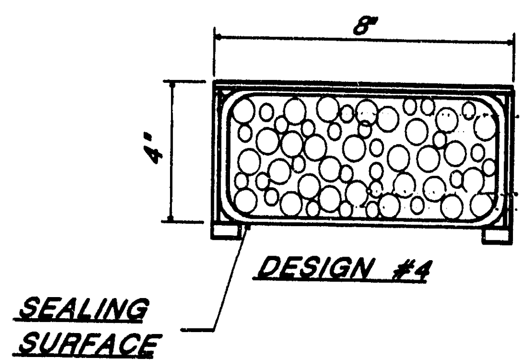

DESIGN #2

SEAL TYPE: THERMAL CERAMICS KAOWOOL MODULES
MATERIAL: CERAMIC FIBER
DENSITY: 15 LBS/CU. FT.



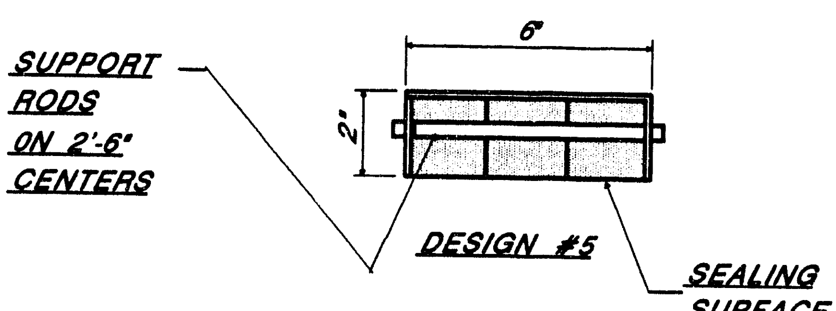

DESIGN #3

SEAL TYPE: THERMAL CERAMICS SOCK SEAL WITH SUPPORT RODS ON 2'-6" CENTERS
MATERIAL: WIRE REINFORCED CERAMIC FIBER FABRIC COVERING W/LOOSE CERAMIC FIBER INTERIOR
DENSITY: INTERIOR FIBER, 9 LBS/CU.FT.




DESIGN #4

SEAL TYPE: THERMAL CERAMICS SOCK SEAL
MATERIAL: WIRE REINFORCED CERAMIC FIBER FABRIC COVERING W/LOOSE CERAMIC FIBER INTERIOR
DENSITY: INTERIOR FIBER, 9 LBS/CU.FT.




DESIGN #5

SEAL TYPE: CERAMIC FIBER ROPE SEAL WITH SUPPORT RODS
MATERIAL: CERAMIC FIBER SQUARE ROPE PACKING
DENSITY: 27 LBS/CU.FT.

FIGURE 4

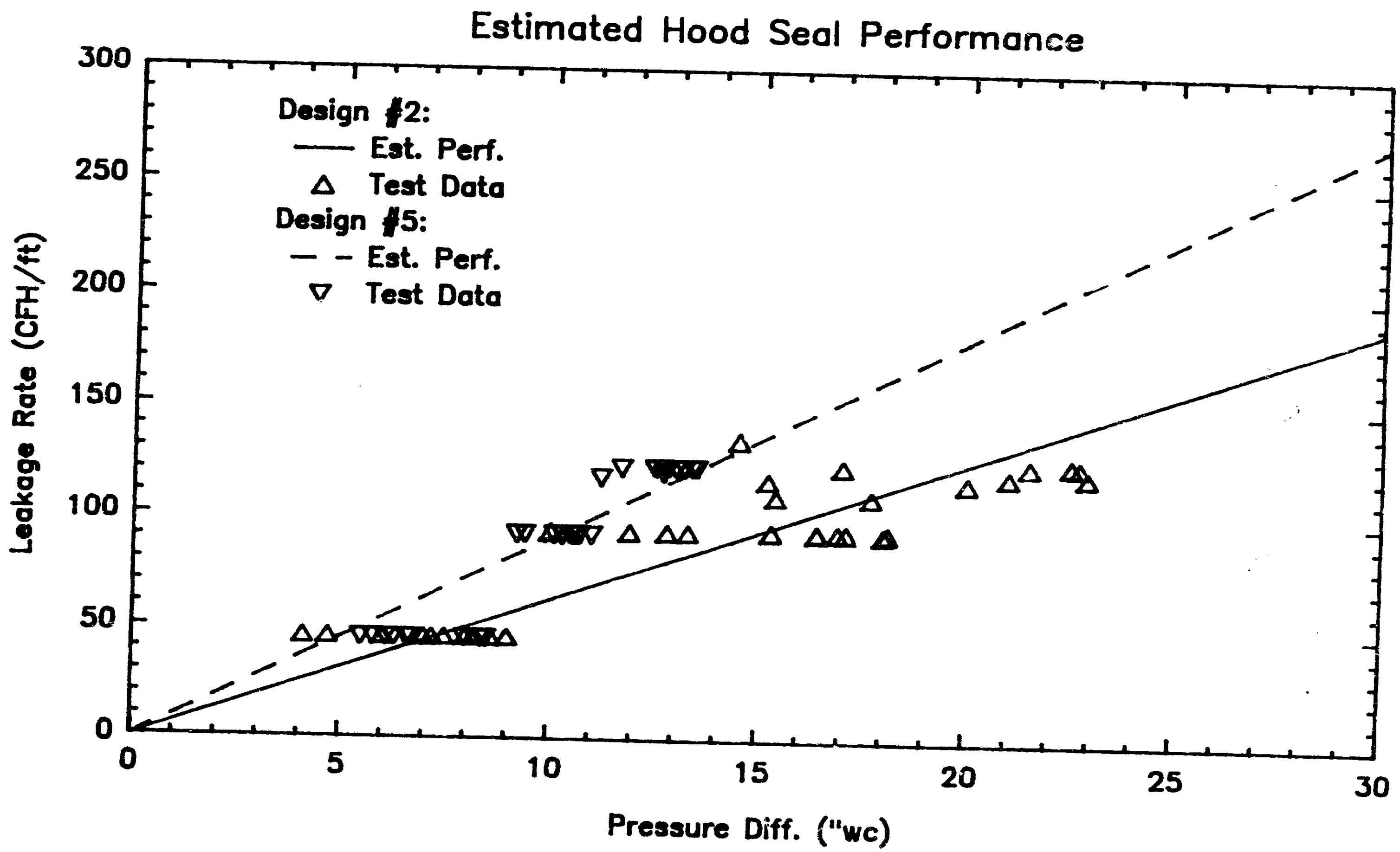

Estimated Hood Seal Performance
Design #2:
Est. Perf.
Test Data
Design #5:
Est. Perf.
Test Data
Leakage Rate (CFH/ft)
Pressure Diff. ("wc)
0
50
100
150
200
250
300
0
5
10
15
20
25
30

**TABLE 1**

**TEXT MATRIX FOR HOOD BUCKET SEAL TESTS**

| | Hood Pressure | Hood Weight (lbs) | Cycles | Bucket Top Surface |
|---|---|---|---|---|
| TEST 1 | 15" W.C. | 900 | 200 | Smooth |
| TEST 2 | Variable | 3600 | 1000 | Smooth |
| TEST 3 | Variable | 3600 | 200 | Roughened with metal pieces |
| TEST 4 (AFTER HEATING) | Variable | 3600 | 200 | Smooth |

**TABLE 2**

**LEAKAGE RATE WITH 15" W.C. STATIC PRESSURE**

| SEAL DESIGN NUMBER | LEAKAGE RATE SCFM/FOOT OF SEAL |
|---|---|
| 1 | 5.13 |
| 2 | 4.98 |
| 3 | 27.15 |
| 4 | 12.63 |
| 5 | 5.40 |

resilient and could be compressed without damaging the fiber. Therefore, Design 5 was selected for the preheater seal. At the expected 26" w.c. pressure differential, we estimate the seal leakage to be 8000 SCFH, which is 2.2% of the total recycle gas flow and considered acceptable.

## 3.2 RECIRCULATING FAN PRESSURE EVALUATION

The recirculating fan provides the pressure to move the hot gases through the bucket to heat the scrap. The gas flow rate was determined by heat transfer simulation, but the required pressure rise in the fan depends upon the pressure drop through the bucket. In this evaluation, the pressure drop was measured in eight different buckets of scrap at Washington steel.

### 3.2.1 Testing

The bucket pressure drop is the sum of the drop from flow through the bottom of the bucket plus the drop from flow through the scrap material. There will be two types of scrap charges in the buckets. The first type has turnings from machine tools (small sized) on the bottom with larger pieces of loose scrap on top of it, referred to as mixed scrap. This bucket is normally full. The second type contains 2' to 3' square bails of stainless steel scrap. This load is more open and therefore has a smaller pressure drop than the first charge bucket. Eight buckets were measured with four air flow rates ranging from 13,000 lb/hr to 75,000 lb/hr. The test matrix and results are shown in Table 3.

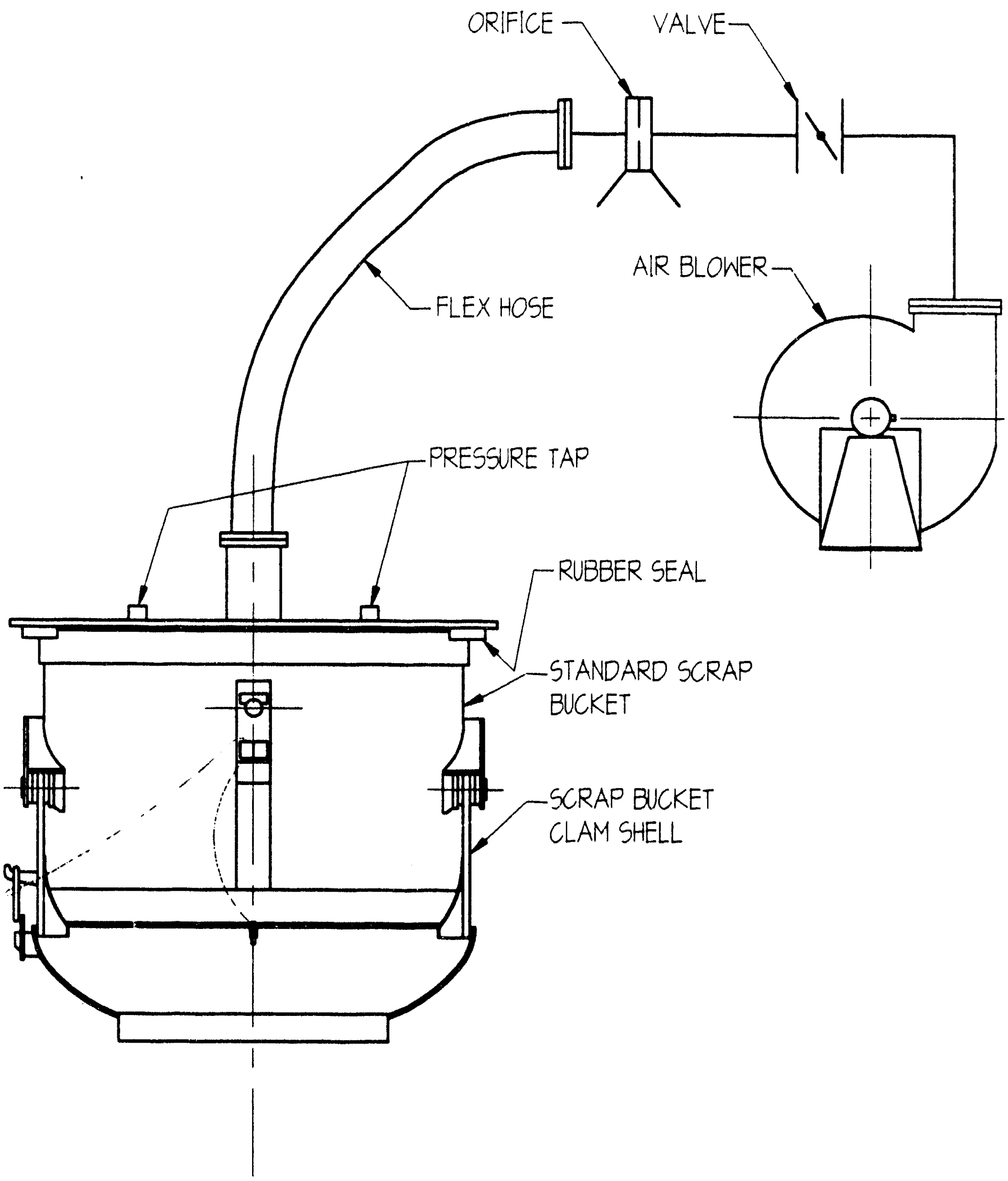
The tests were made at Washington Steel melt shop in Houston, PA. The eight buckets were loaded with the scrap that was later melted in the arc furnace. A cover was fabricated, to seal the top of the buckets. Air was blown through the bucket using a large blower. Figure 5 is a schematic of the test apparatus. Figure 6 shows a photograph of the cover being placed on the bucket and some of the loose scrap that was loaded into the buckets.

**TABLE 3**

**TEST MATRIX AND RESULTS**

| Bucket # Empty/Loaded | Bucket Pressure to Cause Air Leakage of 13,000 lbs/hr. ("wc) | Bucket Pressure to Cause Air Leakage of 38,000 lbs/hr. ("wc) | Bucket Pressure to Cause Air Leakage of 56,000 lbs/hr. ("wc) | Bucket Pressure to Cause Air Leakage of 75,000 lbs/hr. ("wc) | Comments Scrap Type & How Far Bucket Was Filled |
|---|---|---|---|---|---|
| #1 empty | 0.20 | 1.30 | 2.3 | 4.25 | Baled |
| #1 loaded | 0.15 | 0.40 | 1.00 | 1.60 | 36,120 lbs. |
| #2 empty | 0.10 | 0.58 | 0.98 | 1.65 | |
| #2 loaded | 2.90 | 11.70 | - | - | Mixed 58,320 lbs. |
| #3 empty | 0.08 | 0.43 | 0.70 | 1.18 | Baled |
| #3 loaded | 0.20 | 0.45 | 1.23 | 2.45 | 36,400 lbs. |
| #4 empty | 0.03 | 0.13 | 0.35 | 0.63 | Mixed |
| #4 loaded | 1.80 | 8.00 | 14.10 | | 53,160 lbs. |
| #5 empty | | 1.3 | 1.80 | 3.35 | Mixed |
| #5 loaded | 3.90 | 11.30 | | | 70,780 lbs. |
| #6 empty | 0.50 | 0.70 | 1.65 | 2.65 | Mixed |
| #6 loaded | 3.10 | 8.85 | 11.90 | | 70,700 lbs. |
| #7 empty | - | - | - | - | |
| #7 loaded | 0.10 | 0.43 | 0.6 | 1.08 | Baled 46,220 lbs. |
| #8 empty | 0.10 | 0.75 | | 1.85 | Mixed |
| #8 loaded | 2.80 | 7.50 | 14.40 | | 61,800 lbs. |

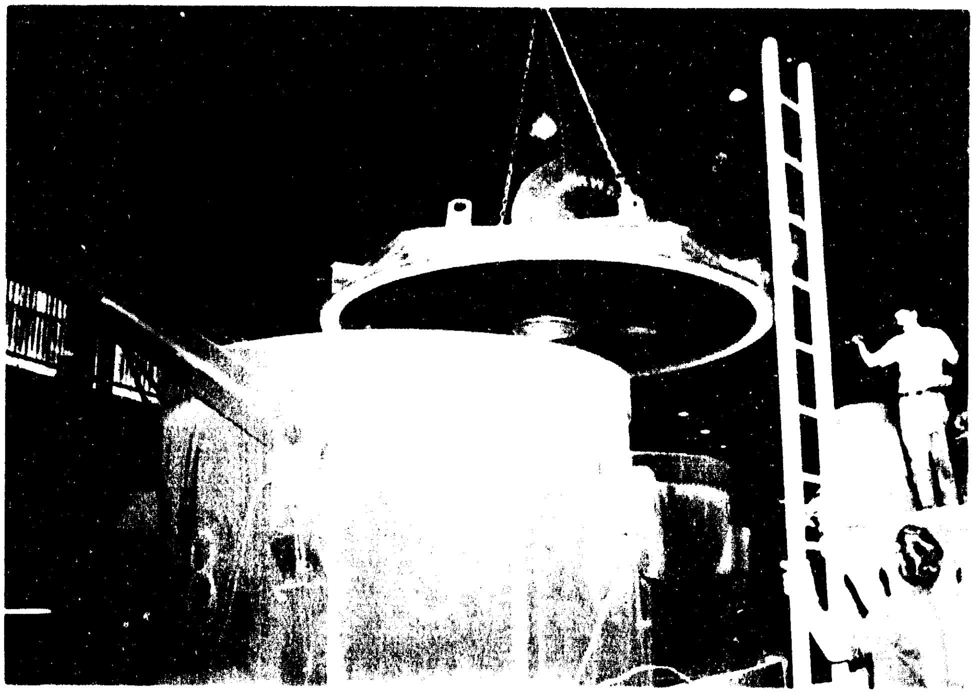
FIGURE 5




**SCHEMATIC OF SCRAP BUCKET**

**PRESSURE DROP TEST**

**FIGURE 6**



COVER BEING POSITIONED ON BUCKET

TYPICAL SCRAP CHARGE

### 3.2.2 Results and Impact

Figure 7 shows the anticipated pressure drop with both types of charges as a function of the gas flow rate. An operating point for 25,000 lb/hr gas flow rate at 1100°F having a pressure drop of 25"wc was determined for the system. The bailed scrap has a much lower pressure drop so the corresponding flow rate will be higher. Bail heating will be more dependent upon the thermal conductivity of that bail than the gas flow rate.

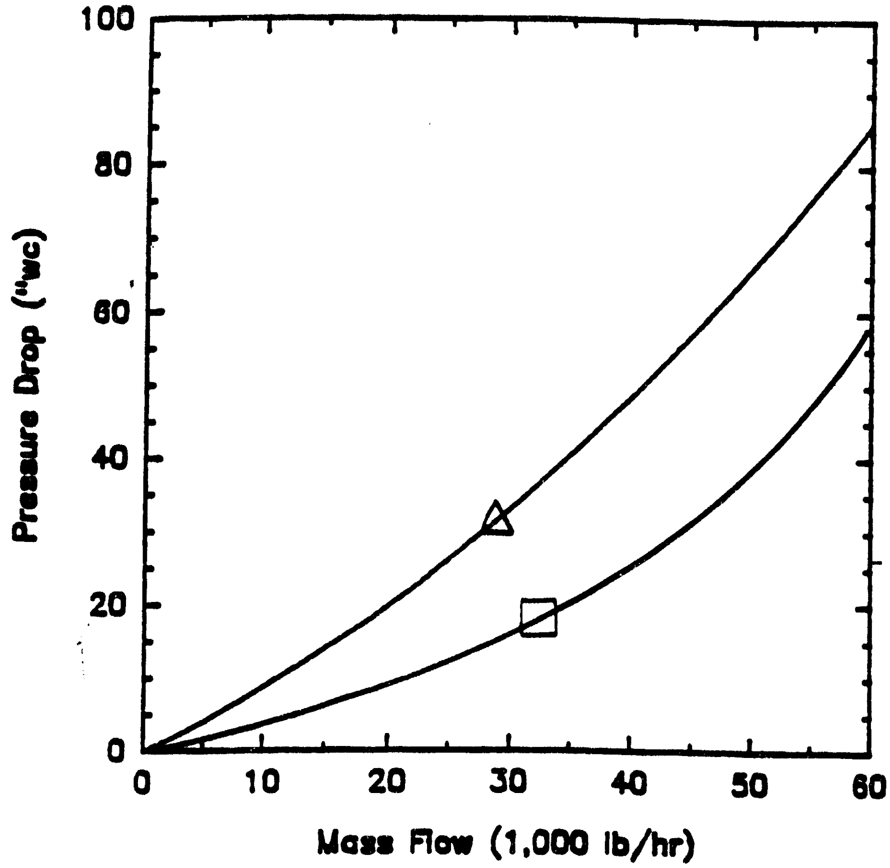
## 3.3 RECIRCULATING FAN LOCATION EVALUATION

The fan recirculates hot gases through the bucket, through the RFR and back to the bucket. The gas temperature varies throughout the cycle which effects the fan requirements. The gas temperature leaving the bucket is cold at the start of the cycle and increases as the scrap is heated. There could be situations where the gas temperature leaving the bucket is nearly equal to that entering the bucket (scrap at maximum temperature).

### 3.3.1 Testing

Two primary locations were considered for the fan as shown in Figure 8. Each location was evaluated through an engineering study and vendor consultations concerning the thermal capabilities of their fan designs.

In configuration A, the fan is located downstream of the heating chamber. The advantage of this location is possible of operating the heating chamber near atmospheric pressure, allowing the RFR to vent naturally. The disadvantage of this configuration is the gases leaving the heating chamber. At the end of a cycle the gas entering the fan could be at the maximum design temperature (1100°F). When the heating chamber is opened, the gas temperature drops to near ambient in approximately one minute. Commercial fans are not capable of withstanding repeated thermal shock of this magnitude. Therefore, the design calls for a "thermal mass" to be located upstream of the fan to protect it. This consists of a chamber filled with firebricks arranged in a checker-work array. The bricks store heat and tend to moderate the gas temperature changes. With the checker-work, the temperature gradient was decreased to a drop of 225°F in one minute. We were not able to find a commercial fan manufacturer that would supply a fan for this service.



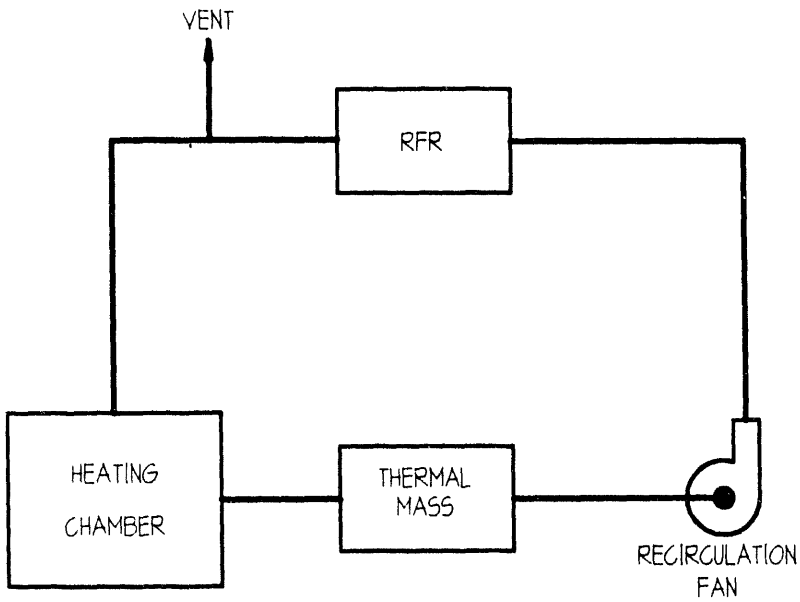

Inlet Temperature = 1100°F
Bucket Diameter = 10'-3"
Scrap Depth = 8'-0"
Mixed Scrap = △
Baled Scrap = □

**FIGURE 7**

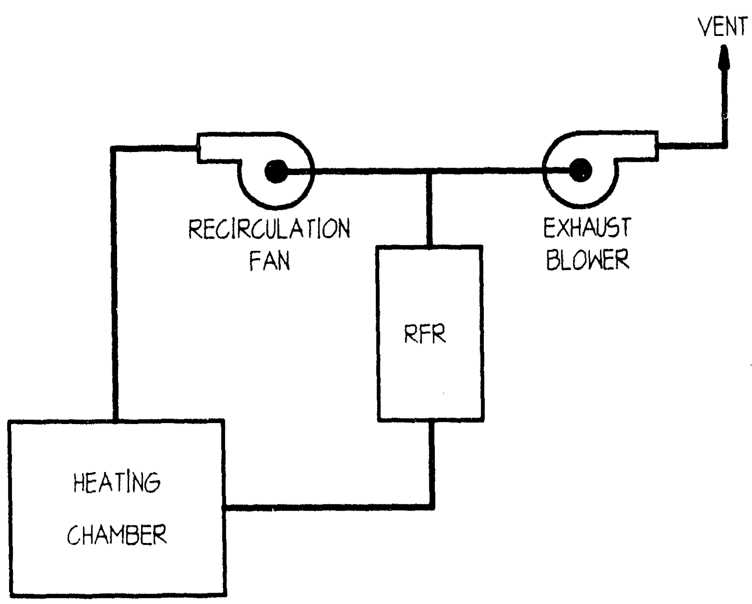
PRESSURE DROP ESTIMATED FROM TEST DATA

**FIGURE 8**

**RECIRCULATION FAN LOCATION CONFIGURATIONS**




**CONFIGURATION "A"**




**CONFIGURATION "B"**

In configuration B, the fan is located upstream of the heating chamber. The advantage of this location is that the inlet gas temperature is controlled, eliminating thermal shock. The disadvantage of this configuration is that an exhaust fan is required to maintain the heating chamber pressure near ambient. A second disadvantage is that the fan limits the maximum gas temperature entering the heating chamber.

### 3.3.2 Results and Impact

Configuration B was selected based upon the availability of a fan. The exhaust fan was added to the flow schematic at the exhaust of the RFR. The gases flowing to the exhaust fan are tempered with cold air, thus lowering the operating requirements of the exhaust fan.

In addition, provision was made for future addition of a natural gas burner between the recirculating fan and the heating chamber. This burner would provide the capability to increase the gas temperature above the fan capability if desired. This causes little change in the overall material balance since the burner natural gas would replace natural gas that would otherwise go to the RFR.

## 3.4 BUCKET HANDLING/HEATING CHAMBER CONFIGURATION EVALUATION

One of the advantages of this scrap preheating furnace is that it fits into the normal material handling flow of the melt shop. Evaluation of material handling with Washington Steel resulted in several changes in the overall configuration. The key items that impacted the evaluation were, use of the preheater for two arc furnaces, the availability of the melt shop crane, and floor space in the melt shop.

### 3.4.1 Testing

This evaluation consisted of a series of engineering studies resulting in an evolution of the system layout into one agreeable to all parties. The original concept was to have a heating chamber with a movable cover that lifted and moved away from the top of the chamber. Buckets were to be lowered into the chamber and the cover then moved back into place. As the concept was discussed in more detail, it was concluded that the crane operator would not be able to lower the bucket without occasionally damaging the side of the heating chamber. Also it was noted that the crane may not be available to remove the bucket as soon as it was ready. The delay impacts the capacity output of the preheater. Finally, there was not enough space in the area originally designated for the preheater.

### 3.4.2 Results and Impact

The resulting heating chamber configuration is illustrated in Figure 9. There are two transfer cars and four car positions. Two buckets are loaded onto two cars and the cars are moved to the outside positions. At this time one car (car A) is at the heating chamber and one (car B) is outside. When the bucket on car A is heated, car A moves inside the building and car B moves into the heating chamber. When the arc furnace is ready for more scrap, the crane picks up the bucket from car A. When the bucket on car B is heated it also moves into the building. When the bucket is removed from car B cold buckets are loaded on to both cars and they return to the outside positions.

The heating chamber is composed of two parts. The fixed top portion lifts as the cars and buckets move into and out of the furnace heating position. There are two lower halves of the chamber affixed to each car. The bottom is shallow allowing the crane operator to lower the bucket onto the car without damaging the chamber sides. There are centering supports on each car to assure that the bucket is placed in the proper position. The entire furnace is located outside the building minimizing the indoor floor space requirement.

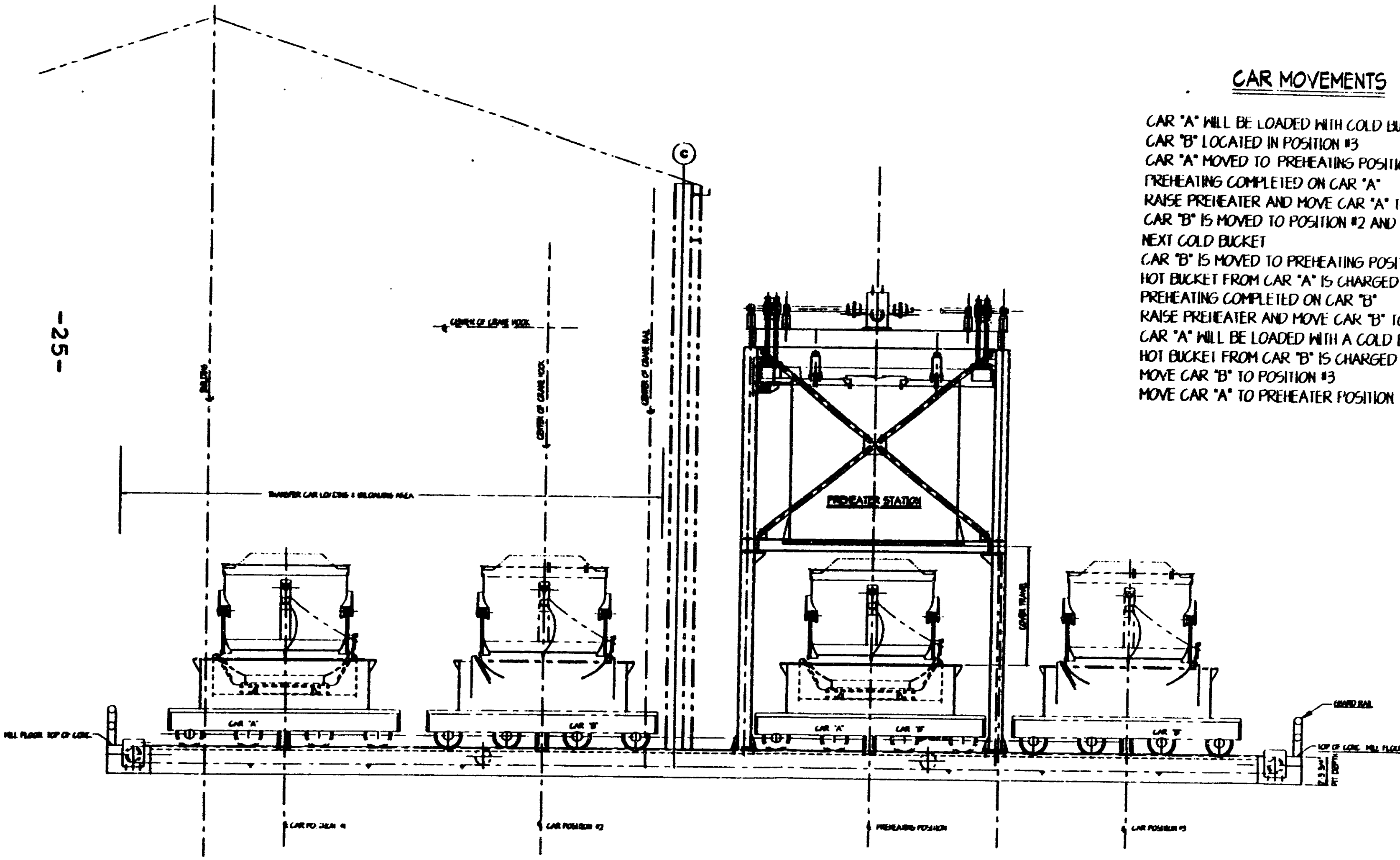
When the top of the heating chamber is lowered over the scrap bucket, it seals to the structure on the car. The gas inlet and outlet are attached to the top section and move with the top of the heating chamber. There is a water-seal in both of these ducts that serve as the connection when the down position. The lifting mechanisms for the top heating chamber section are furnished as part of the preheater.

## 3.5 EMISSIONS EVALUATION

The major portion of this evaluation was to perform tests to estimate the gaseous and particulate emissions from the demonstration preheater. A detailed explanation of the tests can be found in a topical report entitled "Ferrous Scrap Preheating Emission Characterization Test Report" dated October 15, 1992[5]. The following is a summary of that report.

# FIGURE 9

## PREHEATER CAR MOVEMENTS




### CAR MOVEMENTS

CAR "A" WILL BE LOADED WITH COLD BUCKET IN POSITION #1
CAR "B" LOCATED IN POSITION #3
CAR "A" MOVED TO PREHEATING POSITION
PREHEATING COMPLETED ON CAR "A"
RAISE PREHEATER AND MOVE CAR "A" TO POSITION #1
CAR "B" IS MOVED TO POSITION #2 AND IS LOADED WITH NEXT COLD BUCKET
CAR "B" IS MOVED TO PREHEATING POSITION
HOT BUCKET FROM CAR "A" IS CHARGED INTO EAF
PREHEATING COMPLETED ON CAR "B"
RAISE PREHEATER AND MOVE CAR "B" TO POSITION #2
CAR "A" WILL BE LOADED WITH A COLD BUCKET IN POSITION #1
HOT BUCKET FROM CAR "B" IS CHARGED INTO EAF
MOVE CAR "B" TO POSITION #3
MOVE CAR "A" TO PREHEATER POSITION

The scrap preheater, being a fuel fired furnace, has an exhaust gas effluent. There is no normal liquid effluent, but there will be an intermittent water effluent from the self contained cooling water system. This water will be piped to the plant bio treatment facility. There is no normal solid effluent.

### 3.5.1 Testing

The objective of the test was to estimate the emissions of VOC, CO, acid gases, particulate, heavy hydrocarbons, and heavy metals, from a preheating furnace. Tests were performed with steels and stainless steel to provide data for future applications. There were a series of tests using a bench scale furnace as well as a pilot simulation furnace.

The pilot tests were conducted in a system consisting of a heating chamber and a Rich Fume Reactor as shown in Figure 10. This system has been used previously for pyrolytic process testing of waste reclaiming and disposal techniques. The heating chamber, which is shown in Figure 11, is a gas tight direct fired chamber. Scrap materials were placed in the chamber and heated to the desired temperature.

The RFR operation simulated the conditions expected in the final system. A direct simulation was not possible, because the final system will have a high fraction of cool inert gas that will temper the heat of combustion. Water was sprayed into the combustion zone to provide the heat load that the inert gas would otherwise provide. In this way, the RFR operated with little excess oxygen and at a relatively low temperature. The effluent gases were analyzed to determine the combustion efficiency.

The burner flue gases were forced through the scrap before exiting the chamber. Note that the air to fuel ratio of the burners was adjusted so that there was less than 2% oxygen in the burner combustion products. The furnace atmosphere and temperature were similar to that expected in a full sized system. The gases passed out of the chamber and into the RFR, where they were heated to 1400°F to 1600°F. In the first half of the test run, the exhaust gases were analyzed for heavy metal content, specifically zinc, lead, cadmium, chrome, and nickel. Tests were made with mixtures of stainless steel, galvanized steel (4.5% zinc), cadmium plated steel (.29% Cd), and lead bearing alloy (.29% Pb)[6]. Between 200 and 400 pounds total of scrap metal was heated during

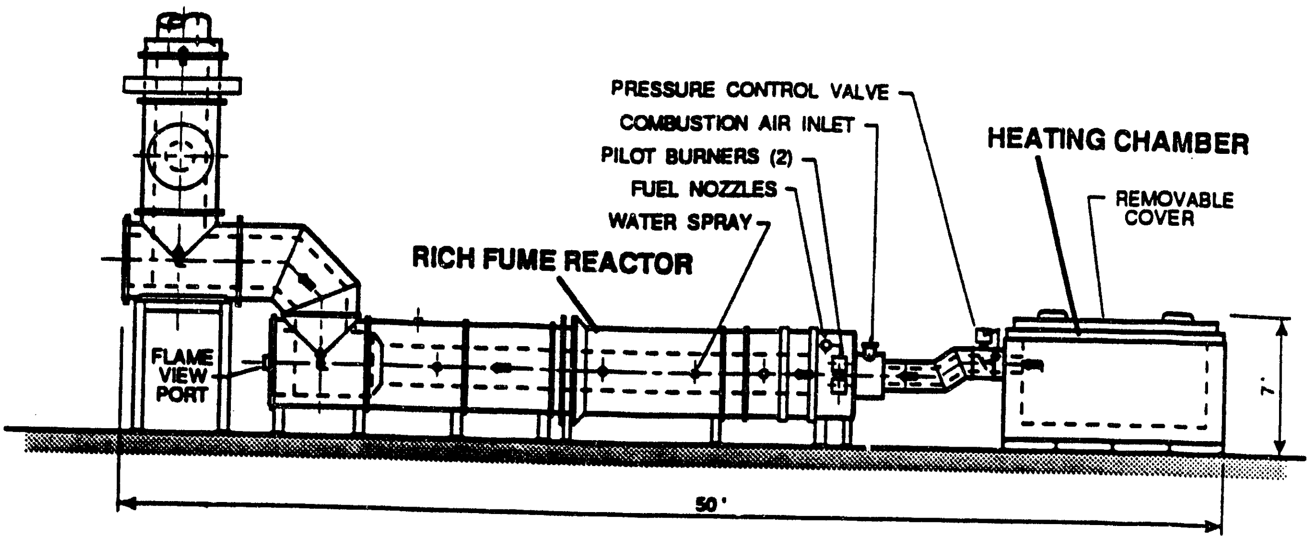



**FIGURE 10 - PILOT TEST FACILITY**

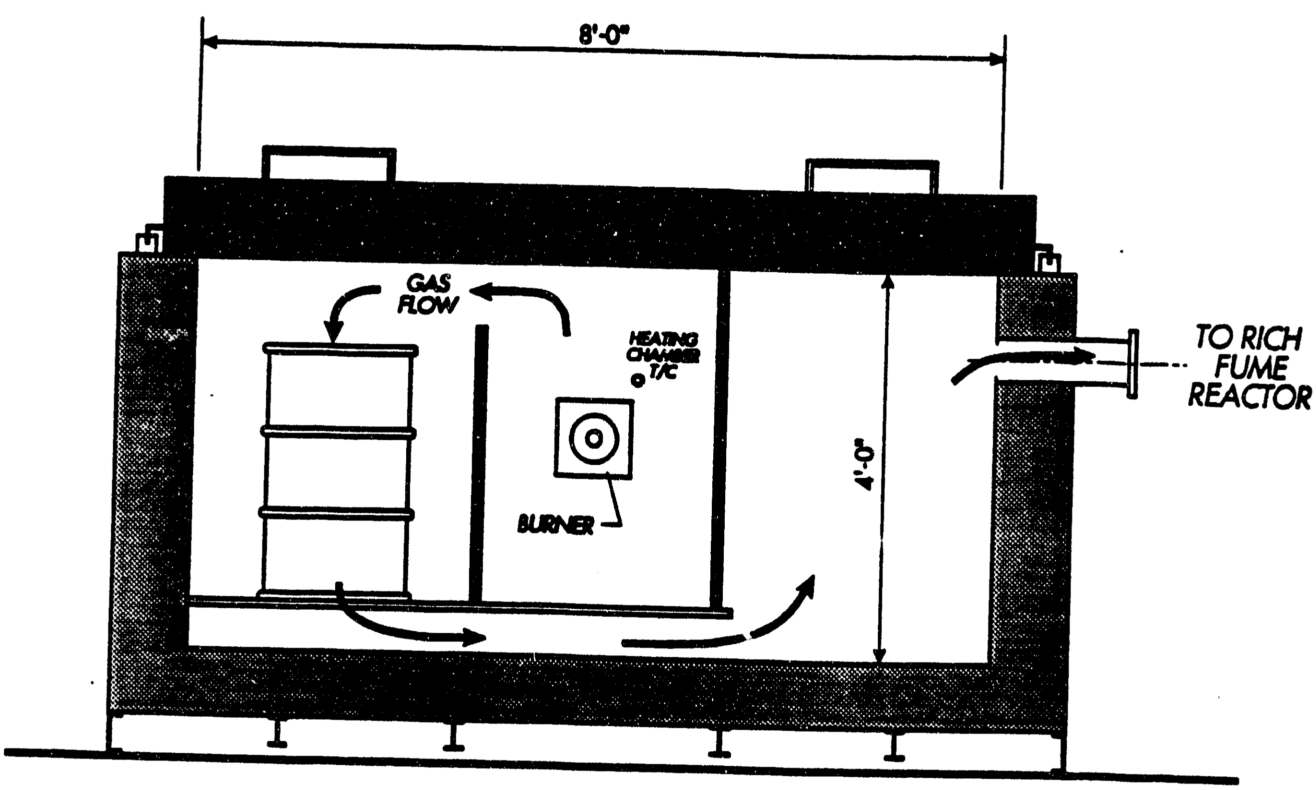



**FIGURE 11 - PILOT HEAT CHAMBER**

each test. Test 1 had only stainless steel, Tests 2, 3, and 4 had approximately equal parts of the four materials. Test 5 had equal parts of the steel based materials but only 5 pounds of stainless steel.

In the second half of the test run, cutting oils were pumped into the furnace. Three cutting oils, listed in Table 4, were selected to represent the range that may be found on scrap. Each of the oils had one critical component for measurement. The petroleum based oil had a high sulfur content, the water soluble oil had chlorine, and the synthetic oil had high organic nitrogen. All of these components can contribute to acid gases in the effluent. The oils were sprayed on to the scrap at a rate equivalent to that expected from preheating scrap with 0.5% oil in the scrap. The flue gases from the heating burners (again adjusted for less than 2% oxygen), and the oil vapors were ducted to the RFR. The oil vapors, formed by heating in the absence of oxygen, consisted of evaporated oils and their thermal pyrolysis products. The test matrix is given in Tables 5 and 6.

**TABLE 4**

**CHARACTERISTICS OF THE OILS USED IN THE TESTS**

| OIL TYPE | % ASH | MAJOR PYROLYSIS PRODUCTS |
|---|---|---|
| Petroleum based 6.4% sulfur | 0.57 | Alkenes ranging from ethylene to decene hydrogen sulfide, and other organo-sulfur compounds. |
| Water Soluble 11% chlorine | 1.30 | Alkenes ranging from ethylene to decene hydrogen chloride. |
| Synthetic oil 3.4% nitrogen | 0.80 | Alcohols, ketones, and nitrogen containing compounds. |

**TABLE 5**

**EMISSION TEST MATRIX**

| TEST NO. | SCRAP MATERIAL | SCRAP TEMPERATURE | REACTOR TEMPERATURE | REACTOR OXYGEN |
|---|---|---|---|---|
| 1 | Stainless | 1300-1400°F | 1400°F | 3.9% |
| 2 | Mixed | 800°F | 1400°F | 1.5% |
| 3 | Mixed | 975°F | 1500°F | 2.0% |
| 4 | Mixed | 50°F | 1600°F | 2.0% |
| 5 | Mixed | 1300°F | 1400°F | ---- |

**TABLE 6**

**WEIGHT OF SCRAP COMPONENTS IN TEST**

| TEST NO. | Pb-ALLOY STEEL | GALVANIZED STEEL | Cd-PLATED STEEL | STAINLESS STEEL |
|---|---|---|---|---|
| 1 | --- | --- | --- | 214 |
| 2 | 133 | 100 | 133.5 | 71 |
| 3 | 133 | 100 | 133 | 71 |
| 4 | 134 | 68 | 133 | 62 |
| 5 | 79 | 100 | 143 | 5 |

### 3.5.2 Results and Impacts

The results of the metal heating tests are shown in Table 7. Of the three heavy metals of interest, zinc, lead, and cadmium, lead was found to be relatively stable with very little present in the exhaust gases. Zinc levels were somewhat higher and show an unusual trend. The lowest zinc levels were found at the highest temperature tested. We feel that this is a result of zinc oxidation. At lower temperatures, the zinc oxidizes more slowly and therefore continues to come off the metal. At higher temperatures, the zinc is converted to zinc oxide which is not volatile.

It should be noted that the proposed maximum temperature for the metal in the preheater is 1100°F, the maximum average temperature is proposed to be 900°F present. The current thinking is to limit the preheat to 500°F to minimize bucket modifications. The data at 1300°F, (Tests 1 and 5) represent conditions above the expected operating range.

The particulate emissions from the stainless steel test were 0.021 grains per dry standard cubic foot (DSCF) corrected to 7% $O_2$. The scrap was supplied by a melt shop, and contained a great deal of dirt. The particulates were mainly dirt from the scrap.

In the test with mixed scrap, the particulate emissions were low (0.001 to 0.004 gr/DSCF) which is less than emission regulations for new sources. The one exception to this was run #5 where the scrap was heated to 1300°F. At this temperature, the cadmium was vaporized and appeared as particulate. The particulate emissions were 0.046 gr/DSFH with 80% of that being cadmium. As noted, the stainless steel scrap does not contain significant cadmium, and the preheater is designed to operate at 1100°F. Therefore, this does not appear to present an operating problem.

The combustion efficiency data for the RFR are shown in Table 8. The tests confirm that it is possible to operate the RFR with less than 2% oxygen in the combustion gases and at temperatures between 1400°F and 1600°F. During these tests the VOC and CO levels were less than 2 ppm, indicating complete combustion. The RFR normally operates with about 50 ppm $NO_x$ in the effluent. There was enough chemically bound nitrogen in the cutting oils to increase the $NO_x$ to about 100 ppm on the average. The sulfur in the oils caused about 50 ppm $SO_x$ in the effluent. The levels of acid gas components

## TABLE 7

## SUMMARY OF PILOT SCALE HEAVY PARTICULATE EMISSIONS (Corrected to 7% $O_2$)

| MATERIAL | METAL TEMPERATURE (°F) | PARTICULATE EMISSIONS (gr/dscf) | HEAVY METAL EMISSIONS ($10^{-4}$ gr/dscf) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Zn | Pb | Cd | Cr | Ni |
| 1. STAINLESS STEEL | 1300-1400 | 0.021 | | | | .72 | 1.5 |
| 2. MIXED SCRAP | 800 | 0.0035 | .28 | .13 | 2.1 | .03 | .03 |
| 3. MIXED SCRAP | 950-1000 | 0.0041 | .34 | .13 | 9.5 | .03 | .01 |
| 4. MIXED SCRAP | 1125-1150 | 0.0013 | .17 | .13 | 10 | .04 | .01 |
| 5. MIXED SCRAP | 1300 | 0.046 | .20 | .37 | 370 | .03 | .03 |

## TABLE 8

## RFR COMBUSTION EFFICIENCY RESULTS OF PILOT SCALE TESTS

| | REACTOR TEMP. (°F) | MEASURED OXYGEN (%) | VOC EMISSIONS PPM | CO EMISSIONS PPM |
|---|---|---|---|---|
| 1. MIXED OILS | 1400 | 3.0 | 1.0 | <0.4 |
| 2. MIXED OILS | 1400 | 1.5 | 0.5 | 2.0 |
| 3. MIXED OILS | 1500 | 2.0 | 2.0 | 0.4 |
| 4. MIXED OILS | 1600 | 2.0 | <0.5 | <0.4 |

in the exhaust gas was less than would be predicted from the amount of sulfur and chlorine in the cutting oils. When the oils were injected into the furnace, there was not oxygen in the furnace. Therefore, the sulfur formed $H_2S$ and HCl. It is believed these gases reacted with the metals in the load, lowering the amount remaining in the exhaust.

The operating limits of the RFR are sufficient to allow its application to scrap preheating without alteration of the operations. More than 99% of the organics were oxidized leaving less than 2 ppm CO and VOC. The RFR can be operated at 1400°F and still achieve the desired results. The acid gas components from the oils tend to react with the metals, lowering the emissions.

The heavy metal emissions were very low. The change in zinc emissions with metal temperature could offer a way to control the zinc in EAF operations. Converting zinc to zinc oxide in the preheater should lower EAF zinc emissions. This may be especially important as the fraction of galvanized scrap increases in the future. The supply of galvanized steel scrap will increase due to the materials popularity for use in auto bodies. This area will likely require further investigation.

Using a simulation of the conditions expected in the final preheater, the test data can be extrapolated into expected emissions for the system. Table 9 lists the concentrations and the mass rates for a system preheating stainless steel to 900°F at a rate of one ton per minute (equivalent to preheating 30 ton bucket of scrap in 30 minutes). These emissions are low enough that it will not be necessary to consider additional abatement equipment for the demonstration site.

The same conclusion can be drawn for preheating steel, with the exception that more investigation will be required to determine whether cadmium will create an emission problem. It is believed that very little cadmium is present in most scrap, so this may not become a significant problem.

Since both the combustion related air emissions and the heavy metal air emissions are below the desired limits, no additional pollution abatement equipment will be required for the demonstration preheater.

**TABLE 9**

**PROJECTED EMISSIONS FOR STAINLESS STEEL PREHEATER**

| COMPONENT | ESTIMATED EMISSION RATE | |
|---|---|---|
| | Concentration | Maxm. Mass Rate (lbs/hr.) |
| Volatile Organic Compounds (VOC) | 2 ppmv | 0.009 |
| Carbon Monoxide | 2 ppmv | 0.0154 |
| Particulate (Total) | 0.0038 grains/dscf | 0.055 |
| A. Chromium | 0.000003 grains/dscf | 0.000044 |
| B. Nickel | 0.000003 grains/dscf | 0.000044 |
| $NO_x$ (Ave) | 102 ppmv | 1.30 |
| $SO_x$ (Ave) | 59 ppmv | 1.01 |
| HCl (Ave) | < 2 ppmv | < 0.02 |

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