Energy

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265-
6-30-84 JS(1)

DR-0138-4

DOE/ID/12303-2
(DE84010357)

FLUIDIZED BED WASTE HEAT RECOVERY SYSTEM

Annual Report for the Period October 1, 1981—March 31, 1983

By
H. W. Williams
K. E. Unmack

Work Performed Under Contract No. FC07-81ID12303

Aerojet Energy Conversion Company
Sacramento, California

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ANNUAL REPORT

**For the Period
1 October 1981 - 31 March 1983**

H.W. Williams

K. E. Unmack

AEROJET ENERGY CONVERSION COMPANY

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Prepared for the

U.S. Depart of Energy

Energy Conservation Branch

Under Cooperative Agreement DE-FC07-81ID12303

ABSTRACT

The technical progress made during the first 18 months of the Fluid Bed Waste Heat Recovery Program to develop an advanced self-cleaning waste heat boiler is reported. During this initial period significant engineering study activity centered around evaluation of two Kaiser facilities as host sites; a Brick Kiln and an Aluminum Melting Furnace. When Kaiser support was suspended because of business conditions; a host site agreement was made with ALCOA for an aluminum melting furnace at the Massena, N.Y. facility in July 1982. Subsequent to that, a specification was prepared documenting the test Fluid Bed Waste Heat Recovery requirements consistent with the ALCOA host site requirements. The advanced fluid bed waste heat boiler is currently being designed for field testing on the aluminum furnace exhaust. A study was prepared to evaluate performance and development requirements for operation at higher inlet temperatures.

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1.0 SUMMARY

A waste heat recovery program was initiated by Aerojet, prior to the beginning of this DOE cooperative agreement, with efforts to find a suitable host site for a Fluid Bed Waste Heat Recovery System. The host site at that point was to be furnished by the Kaiser Aluminum and Chemical Corporation from among their many energy intensive facilities. That, most studied at the beginning, was a brick kiln at the Moss Landing, California brick plant. At the formalization of the cooperative agreement, the Kaiser interest shifted to the Ravenswood, Virginia aluminum plant. Corporate plans changed, however, and a search was made among other similar large aluminum facilities. The studies conducted by Kaiser and Aerojet personnel will be of great value in the conduct of the project.

An agreement was reached in July 1982 with the Aluminum Company of America regarding the Massena operations in New York. Since that agreement, a specification has been published which characterizes the waste stream and includes ALCOA, DOE and Aerojet design requirements. Installation of the test unit has been engineered in preliminary form by ALCOA in close liaison with Aerojet and details are being established.

A subcontract has been awarded by Aerojet to the Johnston Boiler Company of Ferrysburg, Michigan for the design and fabrication of the fluid bed heat exchanger. Initial thermal analyses are complete and a preliminary arrangement layout has been started.

Materials corrosion tests were conducted by Oak Ridge National Laboratory on samples of fluid bed heat exchanger materials under the range of temperatures expected. Samples included carbon steel, stainless steels and Incoloy. Test atmospheres included hydrogen chloride and chlorine corrosive species.

A study was completed of the research and development which would be necessary to raise the gas inlet temperature rating of the heat exchanger above 1100°F. This study has been formalized and submitted in a topical report and discussions are ongoing regarding an activity (Task VI) added to the present contract to conduct high temperature R&D work.

2.0 INTRODUCTION

2.1 PROGRAM OBJECTIVE

The objective of the Fluid Bed Waste Heat Recovery Program is to evaluate the energy conservation potential of a heat recovery system in an industrial application. The heat recovery system will capture waste heat from an aluminum furnace to produce steam. Production of this steam will then reduce the demand load on an existing steam boiler and thus conserve fuel.

The waste heat recovery system will be evaluated on its technical and economic attractiveness. The technical feature will be judged based on exposure to a dirty industrial gas without corresponding problems related to fouling and corrosion. Economic evaluation will be based upon Return-on-Investment.

2.2 PROGRAM OVERVIEW

The program consists of design, construction and testing a Fluidized Bed Waste Heat Recovery System (FBWHRS) and evaluating the performance of that FBWHRS at a host site.

Aluminum Company of America
Massena Operations
P.O. Box 150
Massena, NY 13662

The FBWHRS incorporates a unique shallow fluid bed heat exchanger which was originally developed by Stone-Platt Fluidfire in England. This unique shallow bed features a minimum pressure drop and has not previously been utilized in the USA. Existing installations are operating, however, in England, Norway and Japan.

The FBWHRS is being designed specifically to permit evaluation of this advanced system and to meet the ALCOA requirements. It will be installed at the Massena plant, to utilize the waste heat from an 83-ton capacity melter furnace as ducted to the heat exchanger. As seen in Figure 2-1, the 2000°F flue gas will be diluted with air to a heat exchanger inlet capability of 1100°F; exchange of that gas through two fluidized beds in parallel will produce over 8000 lb/hr of saturated steam at 175 psig. The overall program schedule, shown in Figure 2-2, is seen to include evaluation testing to be complete at ALCOA in March 1985.

Figure 2.1. Fluidized Bed Waste Heat Recovery System

2.3 BACKGROUND

This program is established by a waste heat recovery cooperative agreement between the U.S. Department of Energy and Aerojet Energy Conversion Company with support of the Aluminum Company of America.

The program is contracted by the DOE Office of Industrial Programs through the DOE Energy Conservation Branch of the Idaho Operations Office with a goal of demonstrating an effective energy conservation potential in an industrial environment through utilization of a waste heat stream.

This program is aimed at recovering energy lost in energy intensive industries, such as shown on Table 2.1. As a portion of the energy totals shown on Table 2.1, there is a significant amount of energy, shown on Table 2.2, which is now wasted.

TABLE 2.1
Industrial Energy Use Profile
(10^{12} Btu/Yr)

SIC	Industry	Fossil Electric (Purchased)		Total	High Temperature Furnace Thermal Process	Boiler Steam/ Hot Water
20	Food	740	115	855	315	417
22	Textile Mill	210	85	295	47	172
26	Paper & Pulp	1130	120	1250	532	590
28	Chemicals	2160	340	2500	310	655
29	Petroleum	3160	80	3240	1785	1210
32	Stone, Clay & Glass	1100	415	1515	780	370
33	Primary Metals	1920	415	2335	1555	465
34	Fabricated Metals	185	68	253	198	15
35	Non-Electrical Machinery	210	76	286	140	85
37	Transportation Equipment	255	94	349	230	35

TABLE 2.2

Energy Wasted by U.S. Industry

SIC	Industry	Waste Heat Available (10 ¹² Btu)	%
20	Food	994	9
22	Textiles	229	2
26	Pulp and Paper	1,032	10
28	Chemicals	895	8
29	Petroleum	3,067	29
32	Stone, Clay and Glass	1,114	10
33	Primary Metals	1,950	18
34	Fabricated Metals	234	2
35	Non-electric Machinery	243	2
37	Transportation Equipment	265	2
	Other	853	8
	Totals	10,877	100

Source: Brown, H.L., et al., Industrial Waste Energy Data Base
Technology Evaluation: Executive Summary, Drexel
University/Mathematica, Inc., DOE Report No. C00/2862-31
(Jan. 1977).

Waste heat, as shown on Table 2.2, is of course recoverable by many types of heat exchangers. The uniqueness of the fluid bed heat exchanger, in comparison to all other types, rests on three overall advantages, as follows:

1. The heat transfer rate between the gas, bed particles and tube material is some 4 to 5 times that of the conventional gas to extended surface metal heat exchanger, thus necessitating less heat transfer surface for the same steam production.
2. Because of the shallow bed design and high heat transfer rate, the heat transfer takes place in one row of tubes. This one row can be divided into parallel beds, as described later, and separated by gas spaces allowing easy access for inspection and maintenance.

2.3 (continued)

3. The continual motion of the bed particles around the finned tubes in the bed prevents the build-up of any fouling on the tubes. Fouling will occur on the underside of the gas distributor plates supporting the bed, which being flat are easier to clean than finned tubes.

Over and above these advantages, the shallow bed FBWHRS offers a significantly lower pressure drop, which translates directly into lower operating cost in comparison with any other type.

Based upon these advantages, fluid bed heat exchangers have been used industrially since 1974 in other countries, totaling some 24 units in England and Japan. The fluid bed heat exchanger installed in a marine vessel, used by Shell Oil in Norwegian waters has been successfully operated since mid-1977 and is shown in Figure 2-3.

The FBWHRS described in this report will utilize a proven technology but extend it into a higher risk area.

Marine fluidized bed waste heat boiler

Diagrammatic arrangement of fluidized bed waste heat boiler

Arrangement of cleaning system for distributor plates

Specifications

Fuel	2000 Sec Oil
Gas Flow	8500 lb/hr
Secondary Fluid	428°F Steam
Gas Temp	608°F
Heat Recovery	8.5×10^6 Btu/hr

Figure 2.3. Fjord Shell Installation

3.0 SITE SELECTION (Task I-1)

3.1 TASK OBJECTIVE

The objective of this task was to select a host site for the fluid bed test unit which met the criteria of this cooperative agreement. The criteria required an industrial application wherein the waste stream was sufficiently dirty to foul a normal heat exchanger. This waste stream was to have a temperature potential up to 1800°F and sufficient energy for at least 8 million Btu/hr steam production. The site should also have steam use requirements such that the economic attractiveness of waste heat recovery could be adequately demonstrated.

3.2 TASK PROGRESS

The major time span in this program has been taken by the site selection activity. This activity started in 1980, before the cooperative agreement, with a review of industrial energy use as described in Section 2.3. This review led to a determination that the Kaiser corporate family represented an ideal matrix of potential host sites. The initial Kaiser site selected was the brick kiln at Moss Landing, California. As discussed in the next section, the business plans of this facility changed and interest shifted to the aluminum plant at Ravenswood, Virginia. Kaiser participation with this facility ultimately changed, however, and a review of many other host sites began. This review ended with a selection of the ALCOA Massena operations as an ideal site and an agreement was signed on 30 July 1982. This agreement is Reference 3.1. The sections will discuss in more detail the studies of these various sites.

3.3 KAISER HOST SITE STUDIES

3.3.1 Moss Landing

The Kaiser Moss Landing brick plant is one of three Kaiser plants using kilns in California and eight in the United States. There are nine kilns in California alone which could potentially use fluid bed waste heat recovery systems. The brick plant is located on the California coast about 15 miles north of Monterey. It is wholly-owned by Kaiser and is immediately adjacent to Pacific Gas & Electric Company's Moss Landing utility power plant to the north and a Kaiser seawater magnesia plant to the south.

3.3.1 (continued)

Steam raised by the fluid bed waste heat recovery system could have been utilized in several ways. Pacific Gas & Electric Company has a policy of buying industrially generated electricity and steam, when practical, and could use the steam to heat large oil tanks adjacent to the brick plant. This would save oil used to generate steam. Also, the magnesia plant's package boiler load run could have been taken over, thereby saving natural gas. There are also natural gas fired dryers in the brick plant adjacent to the kilns which could use steam for heating drying air to about 350°F.

The overall brick plant site is shown in Figure 3-1, while the selected kiln #3 is shown in Figure 3-2. Visits to the site and discussions with Kaiser representatives showed the kiln specifications to be as shown in Table 3.1 and the operating conditions to be as shown in Table 3.2.

Preliminary analysis and conceptual design of a fluid bed heat exchanger was begun with Stone Fluidfire. The analysis showed the application to be similar to past uses of fluid bed units, as shown in Table 3.3; an overall description of the proposed unit is shown in Table 3.4.

Further detail design of the heat exchanger section was performed by Granco Construction for Stone Fluidfire in England; a preliminary arrangement drawing is shown in Figure 3-3. The basic approach for the steam circuit, utilizing an economiser, evaporator and superheater tube sections is shown in Figure 3-4.

Early in 1981, Kaiser elected to discontinue the use of the Moss Landing brick kiln as a host site for the fluid bed test unit. The reason for this was a projection of burner operational changes which would significantly reduce the amount of waste heat. Kaiser corporate interest in the waste heat program remained high and study was transferred to the Kaiser aluminum facility at Ravenswood.

Brick Plant

Figure 3.1. Kaiser Brick Plant Layout

Figure 3.2. Kaiser Moss Landing Brick Plant

3.3.1 (continued)

TABLE 3.1

Brick Kiln No. 3 Specifications

Kiln Type - Tunnel Kiln with 3 Sections (Preheat, Fire, Cooling)
Fuel - Natural Gas
Fuel Rate - 23,000 CFH
Brick Production - 90 Tons/Day
Energy Consumption - 6.1×10^6 Btu/Ton Bricks
Exhaust Gas Temperature - Up to 1800°F

TABLE 3.2

Brick Kiln No. 3 Operating Conditions

	High Fire	Nominal	Low Fire
Preheated Air Intake, SCFH	220,000	220,000	220,000
Natural Gas, SCFH	23,000	23,000	10,000
Firing Zone Temperature, °F	3,250	3,200	2,700
Exhaust Temperature, °F	1,200	1,100	800
Cooling Air Input, SCFH	358,000	358,000	358,000
Net Exhaust Temperature	730	730	550
Net Exhaust Flow, SCFH	600,000	600,000	600,000

3.3.1 (continued)

TABLE 3.3

Fluidized Bed Waste Heat Boiler Application

Parameter	Shell International	Existing		Proposed
		Brick Tunnel Kiln	Aluminum Melting Furnace	Kaiser Tunnel Kiln No. 3
Gas flow (lb/hr)	165,000	2100	800	39,135
Gas temperature in (°F)	608	1200	1850	1,800 (1)
Gas temperature out (°F)	460	375	500	450
Gas superficial velocity in bed (FPS)	4 - 5	4	5	3 - 5
Steam pressure (psig)	160	—	—	150
Steam flow (lb/hr)	5,400	356°F (2)	482°F (2)	steam (400°F)
Size (L,W,H) (ft)	13, 8, 13	4, 3, 4	4, 3, 4	9, 4, 6
Energy saved (10 ⁶ Btu/hr)	7.0	0.40	0.28	6.2
Years experience	3	6	5	—

(1) With damper adjustable to operate at 1200°F max.

(2) Low pressure hot water.

TABLE 3.4

Fluidized Bed HX Description

Heat Exchanger Type - Double pass fluidized bed.

Approximate Overall Dimensions - 8-1/2 ft. long x 8-1/2 ft. wide
x 11 ft. high (not including ID fan).

Heat Recovery - Approximately 5,000,000 Btu/hour.

Generated Steam Flow - 5,000 lbs/hour

Exhaust Gas Exit Temperature - 381°F

Approximate Operating Pressure Drop Through Unit - 8-16" W.G.

Figure 3.3. Kaiser Kiln 3 Preliminary Arrangement

Figure 3.4. Fluidized Bed Waste Heat Recovery Superheated Steam Unit

3.3.2 Ravenswood

The Kaiser plant at Ravenswood, West Virginia is the world's largest integrated aluminum facility and is located on 3000 acres. Two application options at this plant were studied at first: the DC-1 melting furnace and the walking beam furnace. Sketches showing the installation of a waste heat boiler in each of these furnaces are shown in Figures 3-5 and 3-6. A study of the economics of the waste heat boiler in each of these furnaces yielded the data shown in Table 3.5. The DC-1 melter was shown to have a shorter payback period and so further studies were concentrated on this installation.

Further study showed that the proposed waste heat recovery boiler (WHRB) would be installed on the lower level of the casting house roof and adjacent to DC-1 stack. A short exhaust duct would run from the DC-1 stack to the WHRB. An induced draft fan on the WHRB would draw the exhaust through the boiler tubes via the short exhaust duct bypass when DC-1 is on high fire. Cooled exhaust gas is then vented upward out from the I.D. fan on the WHRB. When not on high fire, the I.D. fan is off and the DC-1 exhausts out the existing stack.

The steam output line on the WHRB would be connected to the existing Fab. Plant line by a short insulated run of less than 30 feet.

Boiler feedwater for the WHRB would be drawn from the existing treatment plant and piped via the existing condensate return pipeline. Connections would be modified at the WHRB and the boiler house as required.

Kaiser plans for this facility changed in March 1982, however, and a search was initiated among other aluminum plants.

3.4 ALCOA

Visits were made to a number of potential host sites during the period of March through July 1982. Analyses were made of the pertinent technical and economic criteria as well as the potential backing of plant and corporate management.

Based on the criteria noted above, plus the fast response of its management, the ALCOA Massena operation was selected and a host site agreement was signed at the end of July 1982.

Figure 3.5. DC-1 Melter Installation

Figure 3.6. Walking Beam Furnace Installation

TABLE 3.5

Waste Heat Boiler Comparison
Kaiser, Ravenswood

		Walking Beam	Furnace	Melter
		One Side	Both Sides	DC-1
1.	Installation	Floor	Floor	Roof edge
2.	Max heat recovery (mm Btu/hr)	4.64 @ 15 cycles/mo	9.28 @ 15 cycles/mo	9.63
3.	Peak steam flow (lb/hr)	4000	8000	8300
4.	Gas duct	52 ft.	300 ft.	52 ft.
5.	Steam pipe	54 ft.	54 ft.	22 ft.
6.	Profits			
	A. Revenue			
	1983	\$120,221	\$240,442	\$398,000
	1985	\$189,823	\$379,646	\$502,000
	B. Maintenance	\$15M	\$18M	\$15M
	C. Startup	\$15M	\$20M	\$20M
	D. 1983 profit after taxes	\$79,000	\$174,000	\$227,000
7.	Payback	2.0 yrs.	1.3 yrs.	1.0 yrs.
8.	Particulate scrubbing	Future potential for No. 6 oil		Yes
9.	SO ₂ scrubbing for No. 6 oil	Future potential		

4.0 TEST UNIT REQUIREMENTS (Task I-2 and I-3)

4.1 TASK OBJECTIVE

The objective of this task is to obtain detail information concerning the host site and to document this information into specifics which can be utilized to guide the analysis, design and fabrication of the test unit.

This detail information was gained by coordination with ALCOA representatives and it includes a characterization of the waste stream as well as the test unit interfaces and controls. This information is documented in a procurement specification (Reference 4.1).

4.2 WASTE HEAT STREAM CHARACTERISTICS

The operating characteristics of the ALCOA melting furnace No. 34 are that waste heat is available for producing steam only when the melting furnace is being fired. The furnace is fired on a cyclic schedule with a high fire period, followed by a low fire period, followed by a non-firing period. The durations of these periods for the two modes of furnace operation are shown on Table 4.1.

TABLE 4.1
Aluminum Furnace Firing Schedule

Furnace Mode	Relative Frequency (%)	Duration (hr)			Total Cycle
		High Fire	Low Fire	Non-Firing	
Scrap plus Molten	80	2-1/2	1	1	4-1/2
Molten	20	1	2	1	4

The waste heat from the furnace is cooled by the site with the addition of diluent air as shown in Figure 4-1; the flow conditions of the waste heat are documented on Table 4.2.

4.2 (continued)

Figure 4.1. Schematic - Flue Gas Cooling

TABLE 4.2

Flow Conditions

Quantity and Unit	Measurement Locations	Flow Conditions		
		Min.	Mean	Max.
<u>HIGH FIRE</u>				
Energy rate (Btu/hr)	Furnace		34 x 10 ⁶	
Duration (%)		50	50	< 1
Volumetric	Flue	6,230	6,230	6,230
flow rate (SCFM)	Diluent	3,470	6,870	10,270
	FBHX	9,700	13,100	16,500
Temperature	Flue	1,700	2,000	2,300
(°F)	Diluent	70	70	70
	FBHX	1,050	1,100	1,150
<u>LOW FIRE</u>				
Energy rate (Btu/hr)	Furnace		21 x 10 ⁶	
Duration (%)		15	60	15
Volumetric	Flue	3,700	3,700	3,700
flow rate (SCFM)	Diluent	4,908	4,326	3,914
	FBHX	8,608	8,026	7,614
Temperature	Flue	1,600	1,800	2,000
(°F)	Diluent	70	70	70
	FBHX	800	950	1,100

4.2.1 Fuel Oil Characteristics

The furnace is fired with No. 6 fuel oil; some characteristics of this oil are specified in Table 4.3 below.

TABLE 4.3
No. 6 Fuel Oil Specifications

	Control		Typical
	Min.	Max.	
Gravity, API @ 60°F	10.5	20.0	16.0
Flash Pt, PM CC (Deg. F)	150	350	180
Visc SSF @ 122°F (in)	131	200	196
Sulphur ASTM (%)		2.8	2.7
BS & W		1.0	0.4
Ash (%)		.10	.06
Pour Point ASTM (°F)		60	45
Btu/gal			151,200
Vanadium (ppm)			49.0
Additive: Arol Chemical Prod. 456 SV			

4.2.2 Flue Gas Constituents

The chemical constituents of the flue gas are as shown in Table 4.4.

TABLE 4.4

Flue Gas Constituents

Gas Composition, vol %	
N ₂	74.4
CO ₂	11.9
H ₂ O	11.8
O ₂	1.8
SO ₂	.16
SO ₃	TBD
Cl	Trace
AlCl	Trace
HCl	Trace
Particulate Composition, wt %	
NaCl	TBD
KCl	TBD
Al ₂ O ₃	TBD
V ₂ O ₅	TBD
Al ₂ SO ₄	TBD
KO ₂	TBD

4.3 INTERFACES

The physical interfaces of the test unit are partially dictated by the general layout of the ALCOA building. This general layout is shown in Figure 4-2. This general layout results in the test unit being comprised of two units on a balcony and three in the blockhouse. In more detail, the furnace is shown in Figure 4-3, while the general plan and elevation views of the units on the balcony are shown in Figures 4-4 and 4-5.

A detail designation of the individual mechanical, electrical and fluid interfaces of these five items of equipment comprising the test unit are found in Figures 4-6 and Table 4.5. For further detail information on the fluid bed heat exchanger unit, a cut-away is shown in Figure 4-7.

Figure 4.3 Fluid Bed Heat Exchanger-ALCOA Furnace

Figure 4.4. Fluidized Bed Heat Exchanger

Figure 4.5. Elevation View Fluidized Bed Heat Exchanger

FURNISHED BY:

○ Supplier

□ Site

Figure 4.6. Interface Control

4.3 (continued)

TABLE 4.5

Interface Description

Nomenclature	Description
A Flange	SITE duct to FBHX inlet.
B Flange	FBHX outlet to SITE duct.
C Miscellaneous	Water, steam, power, control and instrumentation lines, as required.
D Miscellaneous Electrical	SITE supplied power, control and instrumentation lines from Balcony to Blockhouse.
E Balcony	SITE Balcony for FBHX and auxiliary equipment unit.
F Feed Water	SITE feed water supply to auxiliary equipment unit.
G Steam Supply	FBWHRS steam supply to SITE piping.
H Blowdown Drain	Auxiliary equipment unit to SITE drain.
I Main Electrical Power	SITE 460V, 3 ϕ , 60 Hz, TBD amp supply to auxiliary equipment unit.
J Oxygen Dosing	SITE oxygen dosing for water control.
K Condensate	Auxiliary equipment unit to SITE condensate.
L System Drain	Auxiliary equipment unit to SITE drain for freeze protection.
M Main Electrical Power	SITE 460V, 3 ϕ , 60 Hz, TBD amps supply to motor starter console unit.
N Miscellaneous Electrical	Electrical power, control & instrumentation, as required.
O Electrical Data	Instrumentation, as required.
P Data - Phone	SITE Modem phone data line to AECC.
Q Electrical Power	SITE 120V, 60Hz electrical power.
R Blockhouse	SITE Blockhouse room for electrical equipment.

Figure 4.7. Fluid Bed Heat Recovery Boiler

4.4 INSTRUMENTATION AND CONTROLS

4.4.1 Controls

The exact configuration of the controls will be determined during the detail design phase. At this point, it is considered that there are four control loops, as follows:

<u>Controlled Element</u>	<u>Signal Parameter for Control</u>
Flue Damper D 1	Stack Pressure PC 1
Diluent Air Damper D 5	FBHX Inlet Temperature TC 1
Feed Water Flow Control Valve V 1	Drum Level Control LC 1
FBHX Flow Dampers D 6 D 7	Drum Steam Pressure PC 2

These four loops are shown in Figure 4-8. It is noted that the first two of these control loops are furnished by the site, while the last two are part of the test unit.

Figure 4.8. Controls Diagram

4.4.2 Instrumentation

The exact configuration of the instrumentation required to control the operation of the FBWHRS shall be determined during the detail design. In Table 4.6 the parameters listed for control shall be considered during this design phase; the parameters listed for data are specific requirements for a data acquisition system.

TABLE 4.6
Controls and Instrumentation

Parameter	Control	Data	Quantity
Distributor plate ΔP	X	X	2
Bed ΔP	X	X	2
Fan temperature protection	X	X	1
Inlet gas temperature and shutdown trip	X	X	2
Cleaning brush position indicator		X	2
Damper position indicator		X	1
Exit gas temperature		X	1
Distributor plate temperature		X	2
Bed temperature		X	2
Inlet plenum chamber pressure		X	2
Plenum metal temperature		X	2
Fin temperature		X	2
Freeboard metal temperature on casing		X	2
Boiler water flow (modulating controller) with high and low level alarm	X	X	1
Steam pressure and shutdown trip	X	X	1
Deaerator level control	X	X	1
O ₂ sensor	X	X	1
Conductivity sensor	X	X	1
Steam temperature		X	1
Steam flow meter		X	1
Drum level control	X	X	1

4.4.3 Safety

A complete set of safety equipment will be provided with the FBWHRS to detect and prevent operation at conditions beyond the scope of design. If any of the necessary operating requirements violate the preset limits, an alarm will sound, the fan will automatically shut off and the fluidized bed will collapse, thus stopping heat flow through the system. In the case of gas inlet temperature, redundant over-limit controls shall be provided for system shutdown. The safety equipment will include the components shown in Table 4.7.

TABLE 4.7

Safety Equipment

FBHX over-temperature protection.
Water flow failure sensor.
Steam pressure gauge and controller.
Two steam main stop/bleed valves on steam drum outlet and steam supply to deaerator.
Steam pressure relief valve.
Steam trap.
Feedwater check valve.
Water by-pass regulator.
Continuous blowdown valve.
Hot gas damper and temperature control.
Return duct automatic control.
Steam pressure operator.
Furnace pressure control.
Dilution blower air pressure.
Furnace On/Off control.
Furnace temperature control.

5.0 TEST UNIT ANALYSIS, DESIGN AND FABRICATION (Task I-4)

5.1 TASK OBJECTIVES

The object of this task is to perform the detail analysis, design and fabrication of a test unit which will fulfill the requirements as discussed in the previous section. The sequence of this task is approximately as shown in Figure 5-1. It is seen that the thermal analysis is followed by the design of various components. There is a provision for a design review prior to fabrication and after fabrication there is a provision for testing prior to delivery.

5.2 ANALYSIS

The analysis is used to determine the thermal operating points of the test unit. The thermal characteristics of the waste stream, as documented in the specification, are used to determine the design of the steam tube bundle so as to remove a maximum amount of the available energy. This analysis utilizes programs which have been derived from theoretical principals as well as experimental data. A printout of one of these programs is shown on Table 5.1.

Figure 5.1. Analysis, Design, Fabrication Sequence

TABLE 5.1
TYPICAL TEST UNIT ANALYSIS

WASTE GAS FLOW RATE - SCFM	SCFM = 14117.0
MOLECULAR WEIGHT AVERAGE OF WASTE GAS	XM = 29.1000
GAS INLET TEMPERATURE - DEG. F.	TIN = 1100.00
EXHAUST GAS TEMPERATURE - DEG. F.	TX = 546.129
GAS DENSITY AT STP - LBM. PER. CU. FT.	DENSTP = 0.751774E-01
MASS FLOW RATE OF GAS - LBM. PER. SEC.	FG = 17.6880
INLET GAS CP - BTU. PER. LBM. DEG. F.	CPIN = 0.285500
EXHAUST GAS CP - BTU. PER. LBM. DEG. F.	CPX = 0.271627
AVERAGE CP - BTU. PER. LBM. DEG. F.	CPAVG = 0.278563
POTENTIAL THERMAL DUTY - BTU. PER. H.	Q = 0.982457E+07
INSULATION HEAT LOSS - BTU. PER. H.	QINS = 491229.
NET STEAM GENERATION - LBM. P. H.	STENET = 7980.00
BLOWDOWN, DEAERATION LOSSES FRACTION	B = 0.000000
DISTRIBUTOR INLET PRESSURE - IN. W. G.	P1 = -2.42461
DISTRIBUTOR PRESSURE DROP - IN. W. G.	DELTAD = 4.38648
DISTRIBUTOR OUTLET PRESSURE - IN. W. G.	P2 = -6.81113
BED PRESSURE DROP - IN. W. G.	DELTAB = 6.53273
BLOWER INLET PRESSURE - IN. W. G.	P3 = -13.3439
ADIABATIC FLOW POWER REQUIRED - KW.	POWI = 41.2528
IN-BED HEAT EXCHANGER & TRANSFER	
STEAM GENERATION THERMAL DUTY - BTU/H	QSTEAM = 0.933660E+07
STEAM DELIVERY TEMPERATURE - DEG. F.	TSTEAM = 377.500
FIN METAL CONDUCTIVITY - BTU/H. FT. F	XKFIN = 42.0000
BOILER TUBE INSIDE DIAMETER - IN.	DI = 0.869000
BOILER TUBE OUTSIDE DIAMETER - IN.	OD = 1.12500
TOTAL BOILER TUBES LENGTH - FT.	XLUBE = 619.649
BED CROSS-SECTIONAL AREA, IN ² .	AT = 26768.8
IN-BED GAS VOLUME FLOW RATE, CFS.	VFLOWB = 446.085
SUPERFICIAL VELOCITY - FPS.	UO = 2.39967
MINIMUM FLOW AREA, TUBES PLANE, IN ² .	AMIN = 15429.3
VELOCITY AT MINIMUM FLOW AREA, FPS.	UAMIN = 4.16327
BOILING TRANSFER SURFACE AREA - SQ. FT.	AC = 140.973
BOILER TUBE FIN BASE THICKNESS - IN.	DELFIN = 0.100000
FIN-TO-FIN SPACING - IN.	PERFIN = 0.250000
NONFINNED AREA BED SIDE - SQ. FT.	AHDO = 109.501
FIN TIP DIAMETER - IN.	DF = 2.12500
FINNED AREA BED SIDE - SQ. FT.	AHFIND = 1192.35
FINNED AND NONFINNED AREA - SQ. FT.	AH = 1301.85
RADIAL FIN HEIGHT - IN.	XLFIN = 0.500000
CENTER-TO-CENTER TUBES DIMENSION, IN.	CTUBEC = 2.25000
FIN TIP-TO-FIN TIP SEPARATION, IN.	XTIP = 0.125000
VOLUME OF EXCHANGER TUBE/FINS, CU. IN.	VOLXR = 14983.4
WEIGHT OF BED MATERIAL, LBM.	WGIBM = 2422.35
BED-TO-FIN COEFFICIENT - BTU/H. FT ² . F	H = 65.0011
FIN EFFECTIVENESS PARAMETER, PER IN.	XMFIN = 1.60605
STEAM SIDE COEFFICIENT - BTU/H. FT ² . F	HC = 2700.00
FIN TEMPERATURE EFFECTIVENESS	ETAFIN = 0.829020
SURFACE TEMPERATURE EFFECTIVENESS	ETAD = 0.843402
BOILER TUBE WALL THICKNESS, IN.	THICK = 0.128000
WALL CONDUCTION AREA - SQ. FT.	AW = 182.502
OVERALL CONDUCTANCE BTU/H. FT ² . F	UI = 42.6026
BED SURFACE AREA - SQ. FT.	HAHEA = 112905
UAS TO BED COEFFICIENT, BTU/H. FT ² . F	HP = 64.8276
STEAM SIDE WALL TEMPERATURE, F	TSBW = 402.030
FIN BASE TEMPERATURE, F	TFINB = 415.022
FIN TIP TEMPERATURE, F	TFINT = 437.390
FLUIDIZED BED TEMPERATURE, F	TBED = 544.853
FREEDMAN GAS-TO-BED DIFFERENTIAL, F	DELTAT = 1.27560

5.3 DESIGN

The design of the test unit is currently in process; some of the constraints and background activity are described in this section.

5.3.1 Materials

The baseline materials are as shown in Table 5.2 below.

TABLE 5.2
Baseline Materials

Distributor Plate	RA 330 (Incoloy 800)
Brush System	Stainless Type 304
Distributor Plate Support	Low Carbon Steel
Housing Insulation	Castable Fiberglass

These materials have been selected by the supplier, based on past experience. RA 330 is also characterized as Incoloy 800 and is made up of 19% chromium and 35% nickel.

5.3.1.1 ORNL Tests

Significant materials testing was performed for this program by ORNL during the past year. The results of this testing are documented in Reference 5.1. This testing consisted of exposing four alloys (each alloy of two conditions) to a synthetic flue gas at temperatures of 240 to 665°C for durations from 500 to 3000 hours. Corrosion rates were measured and then projected into an actual use basis. The composition of the synthetic flue gas is shown in Table 5.3.

The final result of the corrosion measurements are summarized in Table 5.4. It is seen that insignificant corrosion rates (<5 mils/year) are predicted for the distributor plate material Incoloy 800. Although the above tests were obtained in a chlorine atmosphere which is indicative of fluxing procedures utilized in the Kaiser Ravenswood plant for purification, it will be very useful for the current design.

5.3.1.1 (continued)

TABLE 5.3
Composition of Synthetic Flue Gases

	Flowrate <u>1</u> / cm ³ /min.	Concentration vol %
N ₂	4700	79
O ₂	1020	17
CO ₂	120	2
H ₂ O	120	2
Cl ₂	0.4	0.0067
HCl	0.4	0.0067
<u>1/</u> Measured at approx. 25°C except H ₂ O, which was not directly metered.		

TABLE 5.4

Summary of Corrosion Results for Candidate Materials Exposed to Synthetic Flue Gases

Material	Condition	Temperature °C	Depth of Corrosion (μm) for Cumulative Exposure Times (h) of			Corrosion Rate (nm/h) for Cumulative Exposure Times (h) of			Corrosion Rate Projected from 3000 h Exposure	
			500	1500	3000	500	1500	3000	mm/y	in./y
Plain-cannon steel	As-received	240	0	10	30	0	7	10	0.076	0.003
		430	3	36	61	6	24	20	0.178	0.007
		560	38	56	155	76	37	52	0.457	0.018
Plain-cannon steel	Annealed	240	0	10	15	0	7	5	0.051	0.002
		430	5	18	46	10	12	15	0.127	0.005
		560	41	107	201	82	71	67	0.584	0.023
Type 405 stainless steel	As-received	220	0	0	10	0	0	3	0.025	0.001
		340	0	0	13	0	0	4	0.025	0.001
		475	0	0	8	0	0	3	0.025	0.001
		560	5	8	28	10	5	9	0.076	0.003
Type 405 stainless steel	Annealed	220	0	0	23	0	0	8	0.076	0.003
		340	0	0	20	0	0	7	0.051	0.002
		475	0	0	18	0	0	6	0.051	0.002
		560	0	13	20	0	9	7	0.051	0.002
Type 316 stainless steel	As-received	625	48	51	64	96	34	21	0.178	0.007
		660	43	53	66	86	35	22	0.203	0.008
Type 316 stainless steel	Annealed	625	48	51	74	96	34	25	0.229	0.009
		660	33	36	56	66	24	19	0.178	0.007
Incoloy 800	As-received	605	10	20	46	20	13	15	0.127	0.005
		640	15	25	46	30	17	15	0.127	0.005
		665	10	36	38	20	24	13	0.102	0.004
Incoloy 800	Annealed	605	15	23	33	30	15	11	0.102	0.004
		640	18	18	28	36	12	9	0.076	0.003
		665	20	25	30	40	17	10	0.076	0.003

5.3.2 Code

The design of the steam system is guided by the ASME Boiler and Pressure Code, as follows:

Stamp - The system will bear the ASME code stamp and will be provided with a certificate of compliance to Section I of this code, and will be registered with the National Board of Boiler and Pressure Vessel Inspectors.

Steam - Metal in contact with the process steam will be in accordance with Sections I and II of the ASME Boiler and Pressure Vessel Code.

Piping - All piping will be in accordance with the requirements of ANSI/ASME B31.1.

Welding - Welds will be in accordance with the ASME Boiler and Pressure Vessel Code, as follows:

Steam System	Section I, Power Boilers, Part PW Section VIII Vessels ANSI/ASME B31.1
Qualifications	Section IX
Materials	Section II, Part C

5.3.3 Electrical

The design of the electrical equipment is guided by the applicable IEEE and NEMA standards as well as the ALCOA standards documented in Reference 5.2. Some detail requirements are as follows:

5.3.3.1 Power

The system shall accept 460V, 60 Hz, 3-phase power. All motors shall be Reliance Electric, Type XT, or approved equal and shall be totally enclosed and fan-cooled, with epoxy-insulated windings. All remote operators for valve and dampers shall be electrically operated and shall be by H. Beck & Sons, Inc. Where required by Code, local disconnects shall be provided with all electrical equipment.

5.3.3.2 Motor Control Center Unit

The motor control center shall be a free-standing NEMA 1 gasketed unit as manufactured by Square D Company, or approved equal. The motor starter shall be three

5.3.3.2 (continued)

pole NEMA rated size 1, or larger, with a fusible switch. Each starter shall be provided with thermal overload protection in each of the three phases. Proper sized UL approved aluminum wire terminals shall be provided for load connections. Control terminal blocks shall be provided for 120 volt circuits. Terminal blocks shall have tri-plated, brass, washer-head or binder-head screws and tin plated brass contact straps. The motor control center shall be provided with an incoming line fusible switch.

5.3.3.3 Operator Control Panel

The operator control panel shall be of enclosed NEMA 12 construction and installed on the Auxiliary Equipment Unit. The operator control panel shall provide all controls necessary for operation of the FBWHRS, including the following items:

- On/Off and Selector Switches
- Status Lights
- Control Loop Access Module
- Alarm Annunciator
- Essential Indicating Instruments

The panel mounted devices shall be suitable for the factory floor environment. Switches and indicator lights shall be industrial oil-tight, Cutler-Hammer, or approved equal.

5.3.3.4 Electrical Control Unit

The electrical control unit shall be mounted in a NEMA 1 gasketed enclosure. Cooling fans with inlet and outlet air filters may be used if required. The electrical control unit shall be based on a Texas Instruments PM 550 programmable process controller to provide the following functions:

- a. System logic control, including automatic startup, operation and shutdown as initiated by signals from the furnace. Provides control signals to operate solenoid valves, motor starters, etc. Receives signals from limit switches, auxiliary relays and the operator control panel.
- b. Process control for all control loops required by the FBWHRS, including boiler drum level control and hot gas flow control.

5.3.3.4 (continued)

- c. Instrument interface and signal processing. Receives and processes signals from field instruments. Provides output to the logic controller, annunciator panel and data acquisition system.**
- d. Data acquisition - receives, records and computes data as required for high speed logging and shift reporting. Provides commands for printing. Provides for a modem data transmittal link to AECC.**

5.3.3.5 Data Printing Unit

The data printing unit shall consist of a Texas Instrument Omni 810 as mounted in a free-standing console. The unit shall print automatically, on command, or in response to any alarm.

5.3.3.6 Instrument Transmitters

Instrument transmitters shall be provided for all control and data requirements listed in Table VIII. All instrument transmitters shall be of the industrial type. All instrument transmitters shall provide an electrical output signal of 4 to 20 MA unless approved otherwise. Instrument accuracy shall be $\pm 0.5\%$ of full scale.

5.4 REVIEWS

Design Reviews of both the concept and the final details are held as shown in Figure 5-1. The final details shall include the following:

- a. General arrangement drawings consisting of a composite outline of the unit. These drawings shall show all basic dimensions, clearances and tolerances. A piping and instrumentation drawing and an equipment list showing all system components, controls and instrumentation shall be provided, in addition to electrical schematics showing power and control circuits.**
- b. Fabrication drawings showing assembly and component details, cross sections of the unit and materials of construction. Details of the replacement parts, including overall dimensions for the distributor plate, and brushes shall be provided.**
- c. Drawings required for each replacement part in the unit. Each replacement part shall be separately identified by part number.**

5.4 (continued)

- d. Engineering calculations of FBWHRS performance, heat loss, pressure schedules, electrical load, material corrosion and erosion, control system logic, failure analysis, etc.
- e. Design details and drawings of proprietary items will be available for AECC review at the supplier's plant.

5.5 FABRICATION

The fabrication of the test unit will take place as shown in Figure 5-1. After completion of the fabrication, tests shall be performed on the main assembly unit at the supplier's facility, to verify features of the design.

Uniformity - The main assembly unit shall be operated at ambient temperature at both high fire and low fire flow rates. The uniformity of fluidization shall be judged both visually and by photographs. Ten photographs shall be made at each flow. The bed height shall be measured at both flows and after flowing.

Elutriation - The function of the elutriation screen shall be demonstrated at high fire flow rate.

Brushes - The distribution plate brushes shall be operated through a full cleaning cycle.

6.0 TEST UNIT INSTALLATION AND EVALUATION (Tasks II and III)

6.1 TASK OBJECTIVE

The objective of this task is to install the test unit at the ALCOA Massena facility, check it out, and then operate it for a period of time to evaluate its economic potential. Beyond this economic assessment, inspections will be performed during the evaluation period to quantify certain risk parameters.

6.2 INSTALLATION

The test unit will be accepted at the suppliers facility and then shipped to ALCOA. The installation will be performed by ALCOA with engineering assistance available from the supplier and Aerojet. After completion of the installation, the test unit shall undergo a shakedown test.

6.3 SHAKEDOWN TEST

The details of the shakedown test are currently being planned. The objective of the shakedown test will be as follows:

Train - Train personnel, sufficient for 3 shift coverage, to operate and maintain the FBWHRs during the evaluation test and beyond.

Safety - Identify detail safety procedures and precautions to be followed during the evaluation test and beyond.

Reliability - Assure the reliable operation of the system during the evaluation test.

Control - Evaluate the settings and assure the satisfactory operation of all control signals for the evaluation test and beyond.

Shutdown - Evaluate the settings and assure the satisfactory operation of all shutdown parameters for the evaluation test and beyond.

Data Acquisition System - Evaluate and assure the satisfactory operation of the Data Acquisition System to properly report all data during the evaluation test.

For information, the control and data parameters are shown in Table 6.1.

6.3 (continued)

TABLE 6.1
Control and Data Parameters

Parameter	Control	Data	Designation
<u>FBWHRS</u>			
Distributor plate ΔP	X	X	DPDU DPDL
Bed ΔP	X	X	DPBU DPBL
Fan temperature protection	X	X	TF
Inlet gas temperature and shutdown trip	X	X	TC1U TC1L
Cleaning brush position indicator		X	IBU IBL
Damper position indicator		X	IDU IDL
Exit gas temperature		X	TEG
Distributor plate temperature		X	TPU TPL
Bed temperature		X	TBU TBL
Inlet plenum chamber pressure		X	PCU PCL
Plenum metal temperature		X	TPU TPL
Fin temperature		X	TFU TFL
Freeboard metal temperature on casing		X	TCU TCL
Boiler water flow (modulating controller) with high and low level alarm	X	X	FMW
Steam pressure and shutdown trip	X	X	PC2
Deaerator level control	X	X	LC2
O ₂ sensor	X	X	O2
Conductivity sensor	X	X	CS
Steam temperature		X	TS
Steam flow meter		X	FMS
Drum level control	X	X	LC1
<u>ALCOA</u>			
High fire signal	X	X	HI
Low fire signal	X	X	LO
Off signal	X	X	OFF
Flue gas temperature		X	TFG
Flue gas pressure	X	X	PC1

6.4 EVALUATION TEST

The objective of this test is to determine the economic and technical acceptability of the FBWHRS. The economic acceptability will be by assessing the ROI, while the technical is by measuring pertinent risk areas.

6.4.1 Economic Acceptability

The economic acceptability of the FBWHRS shall be assessed by AECC by determining the Return on Investment (ROI) by the book value method. This shall be accomplished just prior to the system evaluation test by using the data from Table 6.2, as follows:

1. Outflow = total installed cost (A + B)
2. Inflow = annual savings (C x D x E - projected value of F)
3. Operating and maintenance expenses (K)
4. Net annual savings (2 - 3)
5. Depreciation (L)
6. Advantage prior to taxes (4 - 5)
7. Tax (M x 6)
8. Regular investment credit (N x 1)
9. Energy investment credit (P x 1)
10. Net tax (7 - 8 - 9)
11. Advantage after tax (6 - 10) or (4 - 5 - 7 + 8 + 9)
12. Cash flow (retained cash payback) = 11 + 5
13. ROI (11 / 1)

6.4.2 ROI Update

The ROI of the FBWHRS shall be again determined after the system evaluation test by recalculation. The recalculation shall utilize actual data, as extrapolated to a one-year period and corrected for the lower load demand in summer. The actual data to be used, from Table 6.2, shall include Items F, G, H, I and J.

6.4.1 (continued)

TABLE 6.2

System Evaluation Test Data Requirements

	ALCOA	AECC	Prior to Test	System Evaluation Test
A. FBWHRS cost		X	X	
B. Installation cost	X		X	
C. Steam usage lb/mo for 12-month period prior to SET	X		X	
D. Fuel/steam generation rate gal fuel/lb steam every month for 12-month period prior to SET	X		X	
E. Fuel cost \$/gal fuel and gal fuel for each purchase over 12-month period prior to SET	X		X	
F. FBWHRS steam production lb/mo for 7-month SET		X		X
G. Steam usage, lb/mo for 7-month SET	X			X
H. Fuel/steam generation rate gal fuel/lb steam for every month during 7-month SET	X			X
I. Fuel cost, \$/gal fuel and gal fuel for each purchase over the 7-month SET	X			X
J. Operating and maintenance cost for FBWHRS during 7-month SET	X			X
K. Projected operating and maintenance cost for FBWHRS	X		X	
L. Depreciation schedule	X		X	
M. State and Federal tax rate on FBWHRS savings	X		X	
N. Regular investment credit	X		X	
P. Energy investment credit	X		X	

6.4.3 Technical Acceptability

There are some aspects of system operation which, at this time, appear to entail certain risk. These aspects are summarized in Table 6.3. This list will be periodically updated and the test plan will be written to require inspections as necessary to either eliminate the area as a concern or to quantify the magnitude of the problem so that plans can be made for a solution.

TABLE 6.3
Risk Assessment

Area	Measurement	Possible Fix
Pressure control interaction between FBHX and PC-1 (Figure 4-7)	PC-1	Connect FBHX and furnace controls
Non-uniform flow distribution in bed	Visual	Ducting changes
Excessive Elutriation	Bed height measurement	Redesign screen, reduce superficial velocity
Distribution plate erosion	Visual & thickness measurement	Change material or add coating
Brush effectivity not as expected	Data review, visual inspection	Evaluate cause first
Corrosion	Detail measurement during periodic inspections	Material changes
Particulate fouling	Data review, visual inspection	Evaluate cause first

7.0 HIGH TEMPERATURE R&D (Task VI)

7.1 TASK OBJECTIVE

The objective of this task is to perform research and development (R&D) which will lead to a higher operating temperature for the test unit at ALCOA. This higher temperature has been shown, in turn, to significantly improve the economics of waste heat utilization.

A proposal (Reference 7.1) was submitted for research and development leading toward an increased operating temperature for the ALCOA system. This proposal followed from a study to determine whether technical problems would be encountered if the inlet temperature were to be increased beyond the current value of 1100°F. The study concluded that there were significant potential problems associated with an increase in temperature, but also that there were meaningful benefits to be gained if the problems could be solved.

The results of this study were documented in Reference 7.2. This report concluded that the risks of pushing beyond 1100°F in the ALCOA testing were high without an orderly program that includes laboratory R&D and an engineered retrofit of the required components. Of particular concern are the fouling, corrosion, and creep strength reduction problems that are imposed on several elements of the heat exchange system. It was also shown that the benefits, as tabulated on Table 7.1, are very significant, particularly at the temperature range of 1600-1800°F. Relative to 1100°F, the heat recovery is increased by 24-29% at 1600 and 1800°F, respectively.

TABLE 7.1

Benefits at 1600°F to 1800°F Relative to 1100°F

Size reduced 29 to 39% (through-flow about same)
Weight reduced 28 to 40%
Installation and acquisition costs reduced 19 to 27%
Heat recovery increased 24 to 29%
User ROI improved by about 33 to 77%
Figure of merit (heat recovery and average cost and size) factors improved 63 to 96%

7.1 (continued)

These benefits are shown in more detail, at three possible new operating temperatures, on Table 7.2 below.

TABLE 7.2
Overall Inlet Temperature Influences

	HX Inlet Temperature			
	1100°F	1400°F	1600°F	1800°F
1. Relative size (RS) & throughflow	1.00	0.82	0.71	0.59
2. Relative weight	1.00	0.83	0.72	0.60
3. Relative heat recovery (RHR)	1.00	1.17	1.24	1.29
4. Relative cost (RC)				
o Unit cost	1.00	0.88	0.81	0.73
o Installation cost	1.00	0.88	0.81	0.73
5. Relative figure-of-merit	1.00	1.38	1.63	1.96
$RM = \frac{RHR}{\frac{RC + RS}{2}}$				
6. Approximate relative ROI	1.00	1.33	1.53	1.77
$ROI = \frac{RHR}{RC}$				
REL				

Assumes furnace gas exhaust 2100°F undiluted and stack minimum 500°F.

It was recommended that there are three main elements that should be incorporated in an R&D plan to resolve the problems. The first is to complete a detailed analysis of the problems which would include analyses of alternative designs.

The second element of the approach would be to conduct bench scale tests to establish a technical understanding of the problems and the impact of the selected design approaches. The bench scale testing must be designed to provide a wide range of conditions

7.1 (continued)

that will fully bound the ALCOA operating condition. The chemistry and thermal conditions must be especially bounded. The solutions obtained from the bench scale testing must be those that are satisfactory under the full range of conditions rather than being successful only for isolated conditions.

Finally, based on the results of the bench scale tests, the best advancements should be retrofitted into the ALCOA test unit and tests conducted with gradually increasing temperature to establish the performance. The problems will be described in detail in the next section.

7.2 HIGH TEMPERATURE PROBLEMS AND RISKS

A study was made of the basic design and the materials for the ALCOA heat exchanger in order to postulate the technical risks associated with operation at inlet temperatures over 1100°F. This study showed, as expected, that there are some risks associated with the 1100°F operation and that these risks increase with temperature. It is pointed out that past experience with the Fjordshell installation is limited to 720°F (Table 7.3), and that the ALCOA use will encounter different particulates than previous installations. A review of the basic components to ascertain possible temperature limitations is shown in Table 7.3.

This study concluded that probably the most significant problem was posed by particulate fouling leading to brushing difficulties. Other problems associated with the current materials were corrosion (plus stress corrosion) and distortion.

7.2 (continued)

TABLE 7.3
Preliminary Yes - No Grid

Component/System	Technology Established?		
	1100°F	1400°F	1800°F
1. <u>Inlet Section</u> (Windbox)	Yes	Yes	Yes
2. <u>Brush System</u>			
A. Structural	No → Yes (bearing)	No (creep strength)	No (creep strength)
B. Brushing ability	Yes (dry)	No (sticky?)	No (sticky?)
3. <u>Distributor Plate</u>			
A. Plate	No → Yes (OK to 1200)	No	No
B. Support strength	Yes	No	No
C. Corrosion	No → Yes (dry particles + Fjordshell 700°F)	No	No
4. <u>Grit Arrestor</u>	Yes	Yes	Yes
5. <u>Fan and Case</u>	Yes	Yes	Yes
6. <u>Heat Exchange Surfaces</u> (higher heat transfer surface packing density must be surveyed)	Yes	Yes	Yes

7.2.1 Particulate Fouling

The potential for particulate fouling is present at any temperature with the current waste stream; it gets greater, of course, at increasing temperatures. The characteristics of the #6 oil used by ALCOA were shown on Table 4.3. This oil leads to chemical constituents in the waste stream, as shown on Table 4.4.

The past experience with the current brush design is limited to dry particulates which are only loosely attached to each other and to the distributor plate. A review of those particulates which will have melting points within the temperature range of interest is shown on Table 7.4.

7.2.1 (continued)

TABLE 7.4
ALCOA Melter Particulates

Constituent	(°F) Melting Temp.	Phase Condition at Gas Temp. (°F)			Potential Problem
	1100	1600	1800		
MAJOR CONSTITUENTS					
Aluminum Oxide	3713	Solid	Solid	Solid	No. will brush
Aluminum Sulfate	1418	Solid	Gas	Gas	Probably, above 1200°
Vanadium Pentoxide (various vanadates)	1200 & up (1)	Dry Solid	Sticky Solid	Sticky Solid	Probably, above 1100°
MINOR CONSTITUENTS					
Sodium Sulfate	1623	Solid	Sticky Solid	Liquid	Probably, above 1400°
Potassium Chloride	1429	Solid	Liquid	Liquid	Probably, above 1200°, except only trace amount
Potassium Sulfate	1956	Solid	Solid	Solid (2)	Possibly, above 1700°
Sodium Carbonate	1564	Solid	Liquid	Liquid	Possibly, above 1400°
Potassium Carbonate	1636	Solid	Solid (2)	Gas (3)	Possibly, above 1400°
Potassium Oxide	662	Gas (decomp.)	Gas	Gas	Not likely
Sodium Chloride	1474	Solid	Liquid	Liquid	Probably, above 1300°
Sodium Oxide	2327	Solid	Solid	Solid	No
(1) Melting point examples: Sodium Vanadylvanadate 1160°F; Sodium Metavanadate 1165°F; Sodium Pyrovanadate 1185°F; Sodium Orthovanadate 1560°F.					
(2) Possibly sticky.					
(3) Decomposes rather than melt transition.					

7.2.1 (continued)

A review of the above constituents showed that, based on quantity, the primary problems are expected to be as follows:

Primary Particulate Problems

Vanadium Pentoxide	Sodium Sulphate
Aluminum Sulphate	Potassium Sulphate
Potassium Chloride	Sodium Chloride

7.2.2 Corrosion

The gaseous constituents of the waste stream were shown in Table 4.1; from that it is seen that compounds of sulphur and chlorine are present which could form acid in the presence of water. In addition, the previous section showed the preponderance of vanadates in the particulates; these compounds may be corrosive when in liquid form or may act as a catalyst for changing SO_2 to SO_3 .

The baseline materials for the ALCOA heat exchanger were shown on Table 5.2. These materials could all become problems, as noted in Table 7.5.

TABLE 7.5

Potential Problems

Alkali Sulphate Attack (Low Hot Corrosion)
Vanadium Pentoxide Attack (above 1200°F)
Sulphur Oxides Corrosion
Stress Corrosion Cracking
Structural Life (Time-Temp Effects)
Thermal Fatigue

It is anticipated that the varying temperature of the components, as driven by the melter duty cycle, will make corrosion and stress corrosion, significantly worse. As was seen in Table 4.1, the ALCOA melter operates through varying high fire and low fire time durations followed by off periods. During each off period it is expected that temperatures will be low enough for acids to condense.

7.2.3 Distortion

The third problem anticipated during operation at inlet temperatures above 1100°F is component distortion. The approximate metal temperatures for each of the key components is shown in Table 7.6.

TABLE 7.6
Approximate Maximum Metal Temperatures
Versus Gas Inlet Temperature (°F)

Gas Temperature at Inlet	1100	1400	1600	1800
<u>Distributor Plate</u>				
o Current design (80% surface)	800	1000	1100	1200
o Current design (local)	1000	1300	1500	1700
o Advanced potential (100%)*	800	1000	1100	1200
<u>Brush</u>				
o Short duration peaks	1100	1400	1600	1800
o Balance of time	700	800	900	1000
<u>Brush Bearings</u>				
o Peaks	900	1000	1200	1300
o Balance	600	700	800	900
<u>Distributor Plate Support</u>				
o Current design	900	1200	1400	1600
o Advanced potential*	700	800	900	1000
*With Component Design R&D				

Based on these temperatures and a known marked reduction in yield and creep strength, it is expected that the brushes and the distributor plate supports will require new materials as well as possibly new designs.

Another limitation may be the slot of the distributor plate; laboratory tests have shown that this metal temperature should be kept below approximately 1200°F.

7.3 PLAN

Based on the problems noted in the preceding section, a Research and Development program (R&D) was proposed (Reference 7.1). As shown on Figure 7-1, this program consisted of three phases and was expected to add one year to the current ALCOA evaluation. Further detail scheduling of the activities making up each subtask is shown on Figures 7-2 and 7-3.

The R&D proposed was to include tests at Aerojet of a scale heat exchanger, to determine the limits of, and possible changes to, the current ALCOA design. The scale unit is shown on Figure 7-4; it will interface with existing equipment in the ALRC "A" area facility, as shown on Figure 7-5.

A preliminary plan was made of the bench scale baseline test, Task VI-3. This plan envisages six different test weeks to evaluate temperature limitations and possible changes to the existing components. A test matrix from this preliminary plan is shown in Table 7.7.

Figure 7.1 Fluid Bed Waste Heat Recovery Program Overall Schedules

FBHX R&D ADD-ON
TASK VI

Figure 7.2 FBHX R&D Add-On Task VI

Figure 7.3

FBHX R&D ADD ON TASK VI CONT

Figure 7.4 FBHX Scale Unit

Figure 7.5 Bench Scale Test Setup

TABLE 7.7

TEST MATRIX

Test Series	Test Week	Temperature	Mode	Fuel	Distributor	Brush	Tubes
1100°F	Inspect	1100°F	Steady	ALCOA	Orig	Orig	Orig
	1						
	Inspect	1100°F	Cyclic	ALCOA	Orig	Orig	Orig
	2						
1300°F	Inspect & Determine	1200°F or 1300°F	Steady and/or Cyclic	ALCOA	Orig or Spare	Orig or Spare	Orig or Spare
	3						
	Inspect & Determine	1200°F or 1300°F or 1400°F	Steady and/or Cyclic	ALCOA and/or ALCOA + Ash	Orig or Spare	Orig or Spare	Orig or Spare
	4						
1600°F	Inspect & Determine	1300°F or 1400°F or 1500°F or 1600°F	Steady and/or Cyclic	ALCOA or Standard plus Ash and/or Additives	Spare or New	Spare or New	Spare or New
	5						
	Inspect & Determine	1400°F or 1500°F or 1600°F or 1700°F	Steady and/or Cyclic	ALCOA or Standard plus Ash and/or Additives	New	New	New
	6						
	Inspect & Report						

REFERENCES

- 3.1 Host Site Agreement, signed by the Aluminum Company of America and Aerojet General Corporation on 30 July 1982.
- 4.1 Procurement Specification, AECC-42556E, dated 2 February 1983, Subject: Fluidized Bed Waste Heat Recovery System.
- 5.1 ORNL Report, Corrosion of Fluidized Bed Boiler Materials in Synthetic Flue Gases, JI Federer, Preliminary Copy, 4 February 1983.
- 5.2 ALCOA Engineering Standard 32.4.1, General Specifications for AC Motor Control, Pyrometric and Switchgear Centers, dated February 1975.
- 7.1 AECC letter 8100:3194 to DOE Idaho Operations Office, dated 2 March 1982, Subject: Aerojet Proposal LR888370A for Additional Work Under Cooperative Agreement DE-FC07-81ID12303.
- 7.2 AECC Topical Report DOE/ID/12303-1, dated December 1982, Subject: High Temperature Fluid-Bed Heat Recovery for Aluminum Melting Furnace.