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DOE/ET/12307-1142
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**DESIGN, CONSTRUCTION, OPERATION AND EVALUATION OF A
PROTOTYPE CULM COMBUSTION BOILER/HEATER UNIT**

Quarterly Technical Progress Report for Period October 1—December 21, 1981

January 1982

Work Performed Under Contract No. AC21-78ET12307

Curtiss-Wright Corporation
Wood-Ridge, New Jersey

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

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DESIGN, CONSTRUCTION, OPERATION AND EVALUATION
OF A PROTOTYPE CULM COMBUSTION BOILER/HEATER UNIT

QUARTERLY TECHNICAL PROGRESS REPORT

FOR THE PERIOD OCTOBER 1 TO DECEMBER 21, 1981

By

Curtiss Wright Corporation
Wood Ridge, New Jersey

January 1982

Prepared for

United States Department of Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

Under Contract No. DE-AC21-78ET12307

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ABSTRACT

This report provides a summary of the work performed on the Prototype Culm Combustion Boiler/Heater Unit, Phase I - Engineering Design and Analysis, Phase II - Prototype Plant Construction and Phase III - Start-Up and Operation during the period October 1, 1981 through December 31, 1981. The objectives of the program as well as the technical progress and problem areas encountered during the reporting period are presented.

Seven shakedown tests were run. Start-up and shakedown testing was completed.

Four parametric tests were run. Performance data are presented with the exception of boiler efficiency which will be reported once chemical analyses are completed.

Total boiler operation time through the end of this quarter - 1225 hours, 50 minutes; operating time on culm and culm/limestone - 682 hours, 43 minutes.

Inspection revealed no problems with boiler tube wear.

Sulfur capture greater than 94% was demonstrated (design is 88%).

A turndown of better than 4 to 1 was shown (design is 2.5 to 1).

Computer control of most of the loops has been successful and manual control was also demonstrated.

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SECTION 1.0
DESCRIPTION OF PROJECT

1.1 INTRODUCTION

Mining of over five billion tons of anthracite coal for the last 150 years in Pennsylvania has deposited some 900 million cubic yards of anthracite refuse above ground, disfiguring the landscape, polluting the total environment and contributing to generally depressed conditions. This refuse, conversely, could prove a resource capable of reducing the chronically high unemployment and enhancing the ecology of the area. Anthracite refuse is made up of breaker refuse (culm) silt, mine refuse and tunnel rock. Culm, containing appreciable amounts of coal, is essentially a low quality fuel. Burning of the culm in a fluidized bed combustor boiler is considered to be a feasible, cost-effective way of utilizing this fuel in an environmentally acceptable manner and attracting industry to an area sorely in need of economic stimulus.

Fluidized bed technology has been used commercially in the fields of mining and metallurgy since the 1940's and more recently in chemical processing, heat-treating, and combustion systems. The fluidized bed combustor (FBC) is essentially a furnace which can burn a variety of fuels including coal. It consists of a vessel containing a bed of active particles such as coal, and inert particles such as coal ash, rock, and limestone. When combustion air is blown into the bed through a grate-like distributor, the particles are lifted and suspended by the air. The result is a homogenous, turbulent motion of particles and gas which in appearance resembles a boiling liquid. During combustion of the coal, the FBC is very attractive from the standpoint of both combustion efficiency and heating surfaces immersed in the bed. The addition of a sulfur retaining sorbent, such as limestone, makes it also possible to limit the sulfur oxide release to the atmosphere with environmentally acceptable levels.

At any given time, the solid material in the FBC contains only one to two percent combustible material, the balance being inert solids. Because of this, the FBC can burn materials of very low heating value, such as anthracite culm.

This, and the ability to control temperatures to capture sulfur within the bed, are the major advantages of the FBC over other more conventional combustion systems for the burning of culm.

Experimental combustion tests on a wide variety of anthracite culm samples have been successfully completed on a bench scale FBC at Morgantown Energy Technology Center (METC) of the U.S. Department of Energy (DOE). These tests led to the involvement of DOE in a program to stimulate and advance the use of the anthracite culm combustion process for steam generation/process heat application and to demonstrate the commercial viability of anthracite culm-fueled, fluidized bed combustor/steam boilers.

1.2 OBJECTIVES

The overall technical objective of this program is boiler system development of anthracite culm technology using the fluidized bed combustion process that burns culm directly in an environmentally acceptable manner and is applicable to representative culm reserves.

The specific objectives of this program are to:

1. Identify and conduct evaluations to determine steam generation/process heat applications in which the fluidized bed combustion process, using anthracite culm as the fuel source, is technically, economically, and environmentally feasible.
2. Design, build, operate, test and demonstrate a prototype boiler to establish the commercial practicality of burning anthracite culm.
3. Obtain sufficient data from prototype operations for the commercial application of steam generation using anthracite culm as a primary fuel.
4. Establish design criteria for burning of anthracite culm in fluidized bed combustors in a safe and efficient manner.

1.3 SCOPE OF WORK

The scope of the work for this program is to engineer, design, procure, construct, test, operate and evaluate an atmospheric fluidized bed steam generating plant using culm as the primary fuel. This plant will be erected in the Shamokin Area Industrial Park located at Paxinos in Ralpho Township, Pennsylvania. The unit will be sized to deliver 20,000 pph of steam at 150 psig which will be utilized by Cellu Products Company for the reprocessing of paper. Culm will be obtained from the Swift colliery, located on the outskirts of Shamokin, Pennsylvania.

Experience gained in the design and operation of prototype anthracite culm combustion units will lead to improvement of the concept; provide the technical and economic information needed to determine commercial applicability for steam generation/process heat application, and ultimately advance the acceptance and use of alternate fossil fuels, such as anthracite culm, in the commercial sector.

All work will be performed in accordance with three distinct phases as follows:

Phase I - Engineering, Design and Analysis

The first phase of this project is divided into four tasks. These are concerned with the preliminary design of a prototype boiler using anthracite culm as the fuel, the evaluation of larger sized boilers of approximately 100,000 pph of steam, the investigation of the environmental impact of such systems, the final design of the prototype unit and the management and reporting functions.

Phase II - Prototype Plant Construction

The second phase is divided into four tasks. These are concerned with the pre-construction activity, construction and installation of the plant, check-out and acceptance of the plant, and the management and reporting functions.

Phase III - Start-Up and Operation

The third phase is also divided into four tasks, which are concerned with the start-up and shakedown of the plant; operation of the plant, including initial and extended testing; systems evaluation and management and reporting functions.

1.4 REPORT CONTENT

In accordance with the DOE "Uniform Contractor Reporting Guidelines", this Technical Progress Report summarizes the work performed on Phase I - Engineering Design and Analysis, Phase II - Prototype Plant Construction and Phase III - Start-Up and Operation during the period from October 1, 1981 through December 31, 1981. Emphasized are the technical results achieved, the technical problems encountered, and requirements for corrective action where necessary.

The text of the report follows the Phase and Task Definition specified in the contract.

1.5 PROGRAM STATUS

Figure 1 shows the current status of the overall program.

SHAMOKEN PROTOTYPE CULM COMBUSTION BOILER/HEATER UNIT
PROGRAM SCHEDULE

SECTION 2.0
TECHNICAL PROGRESS

Phase I - Engineering Design and Analysis

2.1 TASK 1 - PROGRAM PLAN

Completed.

2.2 TASK 2 - PRELIMINARY ENGINEERING

2.2.1 Components and System Engineering Studies

Completed.

2.2.2 Combustion Studies

Completed.

2.2.3 Environmental Assessment

The revised Environmental Assessment Report requested by DOE as authorized by Contract Modification A010 was submitted to DOE on November 17, 1981.

2.3 TASK 3 - FINAL DESIGN

2.3.1 Drawing Preparation

Completed.

2.3.2 Prepare Bid Package

Completed.

2.3.3 Advanced Procurement

Completed.

SECTION 3.0
TECHNICAL PROGRESS

Phase II - Prototype Plant Construction

3.1 TASK 1 - PRECONSTRUCTION ACTIVITY

The following was accomplished against the requirements of Contract Modification M011:

1. The exhaust gas visual emission/opacity monitoring system, procured from Data Test in accordance with Specification E-90140, Rev. A, was delivered to the prototype plant site. It is expected that this system will be installed and checked out during the next reporting period.
2. The magnetic tape storage facility as an addition to the AFBB Process Computer is on order from Fisher Controls Co. in accordance with Specification E-90155, Rev. B. This equipment is scheduled for delivery in January 1982.

3.2 TASK 2 - CONSTRUCTION AND INSTALLATION

Completed.

3.3 TASK 3 -CHECK-OUT AND ACCEPTANCE

Completed.

SECTION 4.0
TECHNICAL PROGRESS

Phase III - Start-Up and Operation

The Start-Up and Testing Schedule is shown in Figure 2.

Total boiler operation time through the end of this quarter is summarized below:

<u>Operation Method</u>	<u>Time-Hour-Min.</u>
Culm and Limestone	305:21
Culm	377:22
Soft Coal, Culm and Limestone	10:10
Soft Coal and Culm	116:03
Oil, Soft Coal and Culm	24:58
Oil and Culm	2:49
Soft Coal	31:47
Oil and Soft Coal	149:16
Oil	<u>208:04</u>
Total	1225:50

A Summary of Prototype Plant Operation for this reporting period is shown in Table 1.

4.1 TASK 1 - START-UP AND SHAKEDOWN

4.1.1 Training Program

Completed.

4.1.2 Test Plan

Completed.

	1981					1982												1983												
	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
START-UP AND SHAKE DOWN																														
INITIAL (PARAMETRIC) TESTING																														
EXTENDED TESTING																														
	COMPLETE 9/83																													

Figure 2
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TABLE 1

SUMMARY OF OPERATION - OCTOBER-DECEMBER 1981

<u>Period</u>	<u>Accomplishments</u>	<u>Comments</u>
October 5-13	1. Ran Shakedown Tests	1. Plant capacity limited by culm preparation equipment.
October 14-19	1. Boiler Inspection and Maintenance	1. Boiler tubes looked good. 2. Replaced pressure relief valve. 3. Installed larger bags in ash-fill bin vent. 4. Worked on gas duct expansion joints.
October 20-30	1. Continuous Operation 2. Dedication Ceremony 3. Ran Parametric Test 1	1. Culm screen broke on October 30. Plant shut down.
October 31 - November 15	1. Inspection and Maintenance	1. Boiler tubes looked good. 2. Replaced broken 4-mesh screen. 3. Removed the coarse material from bed. 4. Replaced cracked duct expansion joints. 5. Reworked some refractory in boiler. 6. Modified ash cooler.
November 16 - December 3	1. Ran Sporadically	1. Still purging system of oversized culm. 2. Replaced 4-mesh screen with 3-mesh screen on November 7. 3. Culm feeder tachometer control broke. Plant shut down December 4.
December 4 - December 6	1. Maintenance	1. Replaced tachometer.
December 7-18	1. Ran Parametric Tests 2-4	1. Gas analyzer malfunction. 2. Computer system failed. Ran manually. 3. Culm preparation equipment could not maintain capacity.
December 19-31	1. Inspection and Maintenance	1. Boiler tubes looked good. 2. Fixed gas analyzer. 3. Tested slotted culm screen. 4. Modified air ducting to heat feed bins and culm screen.

4.1.3 Shakedown Tests

4.1.3.1 Operation

Seven shakedown tests were run during the period from October 5th to 13th (Table 2) to check out the equipment and controls at varying operating conditions. It was found that to operate at full load conditions with this 71% ash culm, the rotary screw speed under the primary cyclone had to be increased; the baghouse door needed better sealing to accommodate the pressure drop at higher capacity without leaking; and the capacity of the ash bin vent had to be increased by using longer filter bags. Full boiler capacity was limited by the culm preparation equipment since the screening operation could not keep up with the culm feed rate requirements.

During the latter part of October, the boiler was operated for its first extended period. This was an eleven day run from October 20th to the 30th with steam production generally ranging from 25 to 50% of rated capacity. The initial parametric test point was run during this period. This running period was terminated when the culm screen broke, allowing oversized culm (1.5 inches) to get into the feed, boiler and ash handling systems.

4.1.3.2 Maintenance

1. The water seal pressure relief device was replaced with a valved system.
2. Longer bags were put in the ash bin vent bag filter.
3. The primary cyclone rotary valve motor shorted and required re-winding.

TABLE 2
SHAKEDOWN TESTS

<u>Test Number</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>
Bed Zones Fluidized	1	1	1,2	1,2,3	1,2,3	1	1
Bed Temperature, °F	1687	1628	1608	1669	1655	1644	1433
Fluidization Velocity, Ft/Sec	3.5	3.5	3.6	3.8	3.7	5.4	4.8
Bed Height, Inches	40	48	53	48	57	56	47
Steam Rate, Lb/Hr	10,200	10,900	15,900	16,900	19,000	18,200	11,200

4. There has been a general problem of failure of the rubber expansion joints, primarily in the fluidizing air ducts. Replacement joints were procured and installed. The vendor concluded that the problem was with their design and quality control. They agreed to supply a special set of expansion joints for the plant based on hot and cold joint installation dimensions.
5. A leak apparently caused by the erosive effects of the ash developed at one of the bends in the pneumatic ash handling system. This elbow has been replaced with a spare elbow of the same material.
6. A new 4-mesh culm screen was installed to replace the failed screen. The cause of failure is under review with the screen supplier.
7. Due to the problems in removing bottom ash from the boiler through the ash cooler system to maintain bed height, the ash cooler was modified to add a new air duct to the zone next to the boiler and add a dam in the windbox for better fluidization, (See Figure 3). The 4" x 4" hole size in bottom of SS divider plate was increased to 7" x 8", a slide valve was added to the bottom of ash cooler Fluoseal, and pipe nipples and ball valves were added on each of the zone drain port flanges.
8. When boiler internals, were inspected, refractory spalling and abrasion were found on the rear and front walls of the boiler in the free-board zone. The rear wall of the boiler is defined as the wall with the culm and limestone feed chutes. The refractory supplier was brought in to assess the spalling/abrasion problem. It was determined that the silicon carbide on the rear wall was vulnerable to thermal shock and spalled off. The refractory which abraded out of the front wall may not have been a suitable material or may have been improperly cured due to cold weather when the refractory was installed. However, further study and test experience is needed to accurately assess the problem. The area of the front refractory wall, which experienced the abrasion was repaired with three different castables

Figure 3
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(J. H. France Hydrecon Tab Cast, AR-19 and 186-ES) to determine which one is most abrasion resistant. Silicon carbide castable which spalled off the rear wall was replaced by J. H. France Hydrecon 186-ES castable.

4.2 TASK 2 - OPERATION

4.2.1 Parametric Tests

4.2.1.1 Operation

After the above described maintenance work was completed, the culm feed bin was cleaned and the oversize bed material was removed. Further running from November 16 to December 3 was sporadic since oversize culm was coming through the system from the crushed culm silo. This coarse material was eventually purged from the system, permitting smooth operation in December.

During the first week of December, agglomeration and clinker formation of bed material were detected. It was then decided to run with only Zone 1 for the tests during the month simulating turndown conditions. At a slumped condition for Zones 2 and 3, some air always leaked through the closed valves and entered these two zones. It was suspected that the air leakage might have contributed to bed agglomeration. To completely stop the air leakage and to see its effects on bed agglomeration, blank flanges were inserted in the air ducts of Zones 2 and 3. In addition, a revised start-up procedure was used as an additional corrective action for the prevention of clinker formation. Parametric Test Points 2-4 were run during the next two-week period.

During the week of December 14, 1981, it was observed that the computer started malfunctioning, which led to complete shutdown of the computer on December 15, 1981. It was later learned that a small quantity of dust got into the disc pack and jammed it. The boiler was then operated by the analog controllers only. During the same week it was observed that the culm screening operation could not keep up with the culm demand in the boiler. The screen blinded from wet and frozen culm. The culm feed bin also had a problem with wet fine culm. Paste-like fines stuck to the side of cone section, which often led to complete blockage. These problems forced the plant shutdown on December 18, 1981.

4.2.1.2 Performance

Four parametric tests were run during the quarter. They are summarized in Table 3. For Tests P3 and P4, the gas analyzer was not working properly. During all the tests a sulfur dioxide emission of approximately 100 ppm is targeted, which represents better than 90% sulfur capture with this fuel. The variables being fixed for each test are:

1. Bed Temperature
2. Bed Height
3. Fluidization Velocity
4. SO₂ Emission
5. Zones Fluidized
6. Degree of Recycle

The responses being studied are:

1. Ca/S Ratio
2. Steam Rate
3. Efficiency

Boiler efficiency will be presented once chemical analyses are completed.

4.2.1.3 Maintenance

1. A failure in the process computer disc drive and contributing factors to this failure were analyzed. A loaner drive was obtained for use during the repair period of the disc drive. A new copy of the disc platter was obtained from Fisher, Marshalltown. Disc system, with loaner drive, was placed back into operation.
2. Table 4 is a summary of the corrective actions taken for the culm preparation handling and storage problems encountered which resulted from a combination of moisture in the culm due to rain and snow and the sub-freezing temperatures.

TABLE 3
PARAMETRIC TESTS

<u>Test Number</u>	<u>P1</u>	<u>P2</u>	<u>P3</u>	<u>P4</u>
<u>Date</u>	<u>10-29-81</u>	<u>12-10-81</u>	<u>12-13-81</u>	<u>12-15-81</u>
Zones Fluidized	1	1	1	1
Bed Temperature, °F	1486	1533	1550	1568
Fluidizing Velocity, Ft/Sec	3.5	3.5	5.2	5.2
Bed Height, Inches	36	36	36	58
Steam Rate, Lb/Hr	6300	5500	8200	13700
O ₂ , %	11.9	10.5	--	--
SO ₂ , ppm	80	90	--	--
Ca/S Ratio	5.8	4.8	4.5-5.5*	3.5-4.5*
Sulfur Capture, %	94.3	94.5	--	--
Cyclone Recycle	No	Partial	Partial	Partial

*Ca/S ratios are estimated for these two (2) tests until chemical analyses are performed.

TABLE 4

SHAMOKIN PROTOTYPE PLANT

CULM PREPARATION, HANDLING AND STORAGE PROBLEMS

<u>EQUIPMENT</u>	<u>PROBLEM</u>	<u>CORRECTIVE ACTION</u>	<u>COMPLETION DATE/ STATUS AS OF 12/31/81</u>
1. Hopper	Limited Load	Add extensions to three sides of hopper.	SAIC will obtain quotes from local vendors.
2. Conveyor	*a. Culm clings to under side of belt	a. Install scraper under belt.	Ridgway quote of \$9,000 considered too high. SAIC will obtain quotes from local vendors.
	*b. Tramp Iron Debris Storage area is insufficient	B. Installation of belt scraper will minimize this problem by diverting the culm away from the tramp iron debris storage area.	
3. Crusher	a. Chute to bucket elevator clogs.	a. 1) Enclose crusher support structure. 2) Provide kerosene heaters in this enclosure. 3) Provide access door and cover in chute. 4) Provide S.S. liners. 5) Provide heat to bucket elevator which delivers culm to vibrating screen.	Completed. Completed. Completed. Next shutdown; matl. on order. Completed.
4. Vibrating Screen	a. Blinding & clogging of screen.	a. 1) Install SS ty-Rod screen (equivalent to 3 mesh). Check sample & review with Dorr-Oliver before start-up. 2) Procure 3 mesh SS screen as a back-up 3. Provide heat to vibration screen-line from FD blower and hand control valve.	Completed. Vendor ship date 1/15/82. Completed.

*There problems are not critical with respect to plant operation.

TABLE 4 (Continued)

<u>EQUIPMENT</u>	<u>PROBLEM</u>	<u>CORRECTIVE ACTION</u>	<u>COMPLETION DATE/ STATUS AS OF 12/31/81</u>
4. Vibrating Screen (Continued)	b. Screen Rupture	b. Screen vendor claims a clogged screen overloads screen and causes failure. Thus, if clogging is corrected, screen rupture problem should be minimized.	
5. Return Chute from Vibrating Screen to Crusher	a. Eroded hole at miter joint. b. Packing/clogging in Return Chute.	a. Install saddle patch. b. 1) Provide new S.S. inlet transition duct to crusher. 2) Install SS liner on upper section, sloping side of chute.	Completed. Next shutdown; Duct on quote. Next shutdown; Duct on quote.
61 6. Storage Silo	a. Freezing and Bridging	a. 1) Install heaters in skirt area. 2) Provide heat to Bucket Elevator which delivers screened culm to silo.	Completed. 1/8/82.
7. Feed Hopper	a. Freezing and Bridging in "V" chutes.	a. 1) Install insulated enclosure around the feed bin. 2) Provide heat to the enclosure-line from FD blower. 3) Provide heat to feed bin bucket elevator-line from FD blower. 4) Provide SS liners in "V" chutes.	Completed. Completed. Completed. Next shutdown; matl. on order.

NOTE: SS Liners to be AISI 304, 2B Finish.

3. The 4-mesh culm screen was replaced with a 3-mesh screen, which did increase the screening capacity sufficiently to handle design throughput at temperatures above freezing. At temperatures below freezing, screen clogging and blinding occurred, having a significant decrease on throughput. In order to reduce blinding, a W. S. Tyler Inc. a stainless steel slotted screen (TY-Rod) was tried. A view of this screen is shown below.

This screen is especially useful for screening materials that tend to clog the openings and blind the screen cloth. The near mesh particles, being held on two sides only, cannot become firmly wedged in the openings and the slight spring action, due to the length between the shoot wires, aids the screen in freeing itself of particles. Use of this screen provided adequate capacity, but not proper material sizing. In addition, heated air was piped from the FD blower discharge to the vibrating screen assembly to raise the screen temperature above freezing. A stainless steel 3-mesh screen will be procured and installed to provide better sliding of the culm through the screen.

4. Gas analysis system instruments and isolators were calibrated. The compatibility with computer was verified. This was done with all instruments, except LOW CO.

5. Culm/limestone feed speed ratio control was brought on line.
6. Culm and limestone feed was placed under bed temperature control. Control action was not stable.
7. A computer alarm was set up in the advent of a coupling failure on the culm feed screw tachometer-generator, so that the operator is advised to take the appropriate action when a loss of culm feed screw RPM is experienced.
8. The defective air dryer was replaced with new unit provided at no cost by the vendor.
9. A supplemental air line was installed from the main FD blower to the boiler Fluoseal and the ash cooler discharge Fluoseal and a new automatic control valve adjacent to the boiler Fluoseal.
10. All other auxiliary equipment was checked.
11. A screen cage was attached to the boiler at the ash discharge outlet to keep oversize material from plugging the ash handling system. This oversize material should eventually break down to smaller particles in the bed. A sketch of this screen cage is shown in Figure 4.

4.2.1.4 Future Work

1. Check out corrective actions taken on equipment problems described above.
2. Continue with the parametric testing.
3. Complete the following instrumentation and control work:
 - a. Recalibrate steam flow instrumentation, and ash cooler distributor plate pressure drop instrumentation.

SCREEN CAGE - BOILER ASH DISCHARGE

Figure 4

- b. Commission combustor bed temperature control for steady-state operation.
- c. Commission Digital Control System for load following or base load operation.
- d. Install and debug Data Recording System.
- e. Install opacity monitor, and program computer for opacity signals.
- f. Recommission fluidizing blower surge control.