DOE/PC/91160--T9

# DEVELOPMENT AND TESTING OF A HIGH EFFICIENCY ADVANCED COAL COMBUSTOR PHASE III INDUSTRIAL BOILER RETROFIT

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## Executive Summary

The objective of this project is to retrofit a burner capable of firing microfine coal to a standard gas/oil designed industrial boiler to assess the technical and economic viability of displacing premium fuels with microfine coal. This report documents the technical aspects of this project during the fifteenth quarter (April '95 through June '95) of the program.

The overall program has consisted of five major tasks:

1.0 A review of current state-of-the-art coal firing system components.
2.0 Design and experimental testing of a prototype HEACC (High Efficiency Advanced Coal Combustor) burner.
3.0 Installation and testing of a prototype HEACC system in a commercial retrofit application.
4.0 Economics evaluation of the HEACC concept for retrofit applications.
5.0 Long term demonstration under commercial user demand conditions.

Task 1 through Task 4 were previously completed. Based on all the results obtained to date the ABB/Penn State team and DOE/PETC have decided to conduct a 1000 hr demonstration test (Task 5). Importantly, a decision was made to employ a new burner for the demonstration. The new burner is based on the concept called "Radially Stratified Flame Core (RSFC)", developed by MIT and licensed by ABB.

Work under Task 5 of this program was started during this reporting period. Activities at Penn State focused on completing the modifications to the coal storage and handling facilities. The coal feed system was modified by replacing the existing surge bin and screw feeder with a new hopper and weigh-belt feeder. These modifications were made in conjunction with this and another DOE program (DE-FC22-92PC92162) at Penn State.

Activities at ABB CE focused on completing the design /fabrication of the new (RSFC) microfine coal burner (using ABB CE's funding). The decision to go with the RSFC-based burner in place of the HEACC burner was based on the expectation that improved NOx reduction and carbon conversion would be obtained. Experience at MIT with the RSFC burner being fired at 5 million BTU/hr on coal showed excellent performance. Results indicated that RSFC-based burner has the potential to produce lower NOx and higher carbon conversion efficiencies than the HEACC burner.

Two low ash (~3 to 4%) coals, Middle Kittaning and Kentucky, were selected for the demonstration phase (Task5) testing. The rationale for this selection was to get the same or similar coals (Brookville and Kentucky) that were used during Task 3 -400 hr testing. Since the Brookville Seam has been closed and it is not available, we have selected Middle Kittaning coal which is very similar type and it is also from Pennsylvania. An arrangement was made for acquiring coal (~300 tons of Middle Kittaning ~3.5% ash) for the initial demonstration phase testing.

A technical paper "Microfine Coal Firing Results from a Retrofit Gas/Oil-Designed Package Boiler" (Attachment I) was prepared for the Eleventh Annual Coal

Preparation, Utilization and Environmental Control Contractors Review Meeting, held in Pittsburgh, during July 12-14, 1995.

During the next quarter we plan to complete installing a new soot blower in the convective pass which extends to convective pass entrance; installing the burner and quarl; characterizing the burner on natural gas and micronized coal; shaking down the new coal handling system; and firing micronized coal. After verification of the expected, improved performance (i.e., lower NOx and higher combustion efficiency) of the new burner compared to the HEACC, the finalized demonstration test plan will be prepared, and the long term (1000 hr) demonstration test phase (Task 5) will begin.

## 1.0 Introduction

The objective of this project is to retrofit a burner capable of firing microfine coal to a standard gas/oil designed industrial boiler to assess the technical and economic viability of displacing premium fuels with microfine coal. A complete microfine pulverized coal milling and firing system will be retrofitted to an existing 15,000 lb/hr package boiler located in the East Campus Steam Plant of the Pennsylvania State University.

Following a brief burner confirmation test at ABB/CE's Power Plant Laboratories, the complete retrofit milling and firing system at Penn State will be run for a total of 400 hours on microfine coal to obtain performance and economic data for comparison against a base fuel (natural gas) case. Pending acceptable technical and economic results, a 1000 hour test will then be run under normal user demands to evaluate the system's capability to perform acceptably under field conditions. It is expected that a successful outcome of this program will help facilitate the acceptance of clean coal technology by American industry. The technical approach chosen for this program, namely direct firing of dry microfine pulverized, low ash coal is the fastest track technology available to displace significant quantities of oil and natural gas in industrial equipment.

## 2.0 Task 1 Design, Fabricate and Integrate Components

Complete

## 3.0 Task 2 Preliminary System Tests at ABB Combustion Engineering

Complete

## 4.0 Task 3 Proof-of-Concept-Tests at Penn State

Complete

## 5.0 Task 4 Economic Evaluation and Commercialization Plan

No work was scheduled or performed during this quarter.

## 6.0 Task 5 Site Demonstration

### 6.1 Summary of Quarterly Activities

Task 5 work was started during this reporting period. Activities at Penn State focused on completing modifications to the coal storage and handling facilities. The modifications were made in conjunction with this and another DOE program (DE-FC22-92PC92162) at Penn State. The coal feed system, shown in Figure 1, was modified by replacing the existing surge bin and screw feeder with new hopper and weigh-belt feeder. The system was modified because of severe coal handling problems encountered during the Task 3 testing that was conducted during the winter months of December 1993 to March 1994. Because of the relatively small quantities of low ash coal required for the testing, coal was cleaned in a bench mode by heavy media cyclones and stored in a local coal yard. During testing in the winter, snow and ice were included in the shipments. The wet or ice-laden coal (often with moisture contents in excess of 12%) tended to bridge and rathole in the hoppers, especially the surge bin. This required constant operator attention and corrective action and resulted in erratic coal feed. This inconsistent coal feed, coupled with the variability introduced by varying coal size and moisture content, made it difficult to maintain a constant feed to the burner. The moisture content was inconsistent because of non-uniform drying in the heated building and by an air sparge system that was installed on the surge bin.

Since most of the coal feed problems occurred in the surge bin, the design of this component was evaluated and it was found that the bin outlet dimensions and hopper sidewall angle needed to be modified to improve coal handling. The original surge bin had a circular opening with a bin angle of 60°. A pyramidal bin with a length to width discharge outlet of 3:1 and angle of 70° was designed and installed. An isometric view of the new hopper is shown in Figure 2. The new surge bin is constructed of stainless steel to eliminate scaling. In addition, the screw feeder was replaced with a weigh-belt feeder to eliminate fuel feed rate oscillations. Figure 3 is a schematic diagram of the new coal storage and handling system. Figure 4 is a schematic diagram of the micronized coal-fired boiler system with the new coal storage and handling system.

Activities at ABB CE focused on completing the design /fabrication of the new (RSFC) microfine coal burner (using ABB CE's funding). The decision to go with the RSFC-based burner in place of the HEACC burner was based on the expectation that improved NOx reduction and carbon conversion would be obtained. Experience at MIT with the RSFC burner being fired at 5 million BTU/hr on coal showed excellent performance. Results indicated that RSFC-based burner has the potential to produce lower NOx and higher carbon conversion efficiencies than the HEACC burner.

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## 6.2 Next Quarter's Plan -

Complete installation of a new soot blower in the convective pass which extends to convective pass entrance; install the burner and quarl; characterize the burner on natural gas micronized coal; shake down the new coal handling system; and fire micronized coal. After verifying the expected improved performance (i.e., lower NOx and higher combustion efficiency) of the new burner compared to the HEACC, prepare the finalized test plan, and begin the long term demonstration test phase (Task 5).

## 7.0 Task 6 Decommission Site

No work was scheduled or performed during this quarter.

## 8.0 Task 7 Project Management

During this reporting period, work included the preparation of required technical, schedular and financial monthly and quarterly reports. A technical paper "Microfine Coal Firing Results from a Retrofit Gas/Oil-Designed Package Boiler" (Attachment I) was prepared for the Eleventh Annual Coal Preparation, Utilization and Environmental Control Contractors Review Meeting, held in Pittsburgh, during July 12-14, 1995.

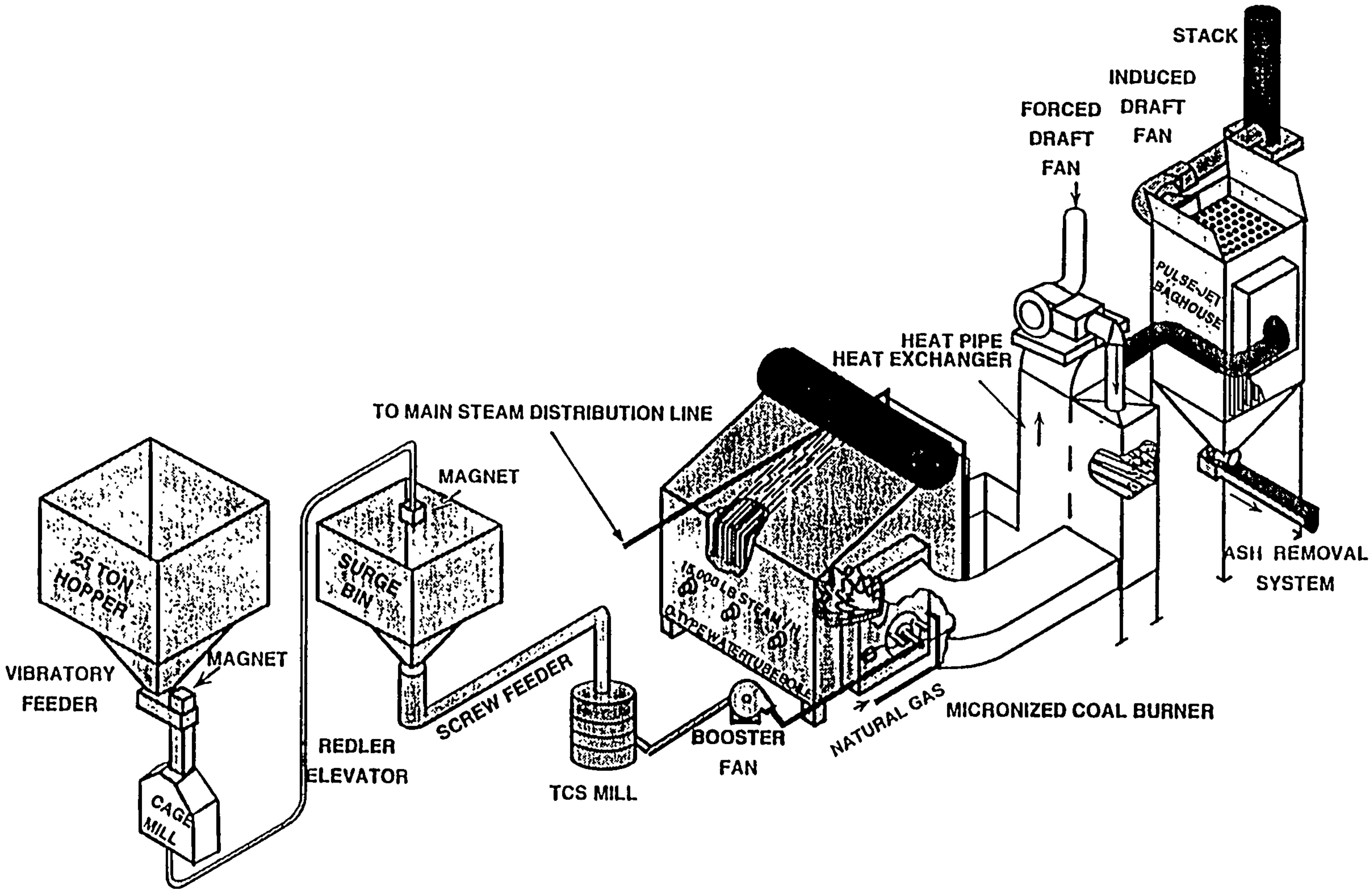


Figure 1. MICRONIZED COAL-FIRED BOILER SYSTEM

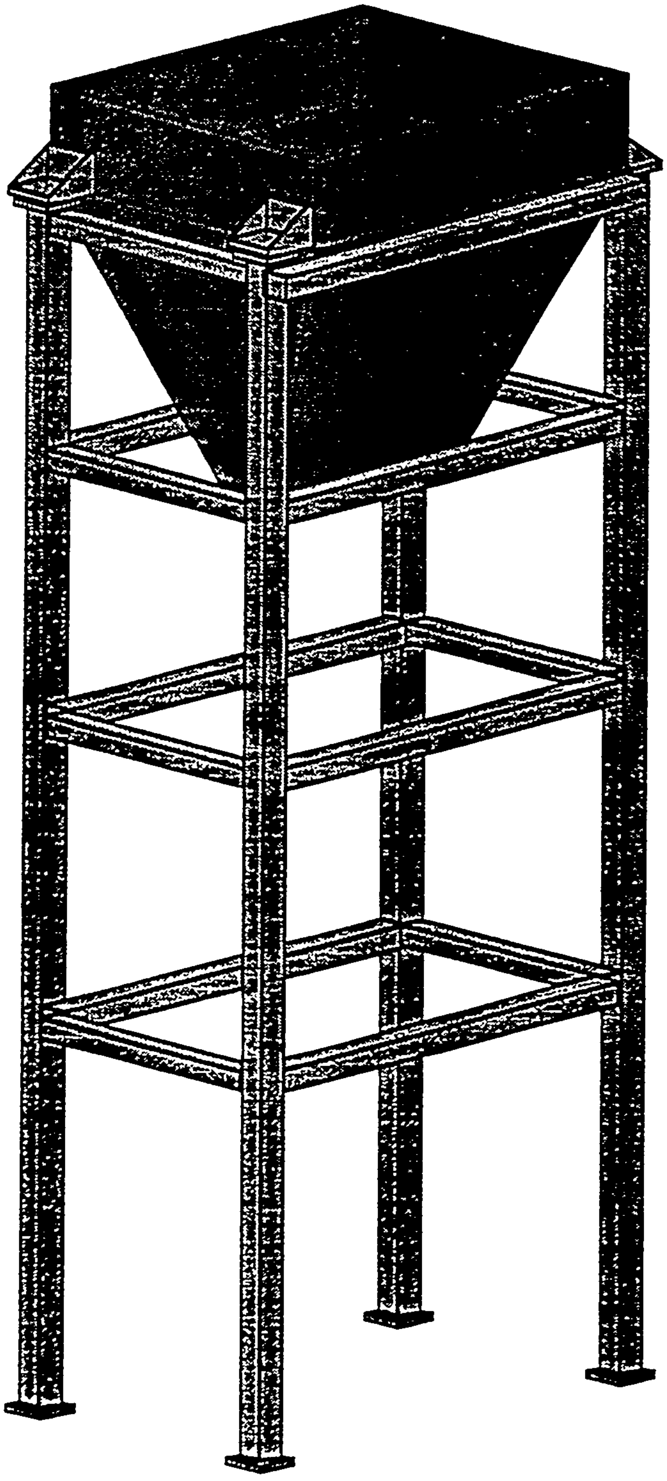

Figure 2. ISOMETRIC VIEW OF NEW HOPPER

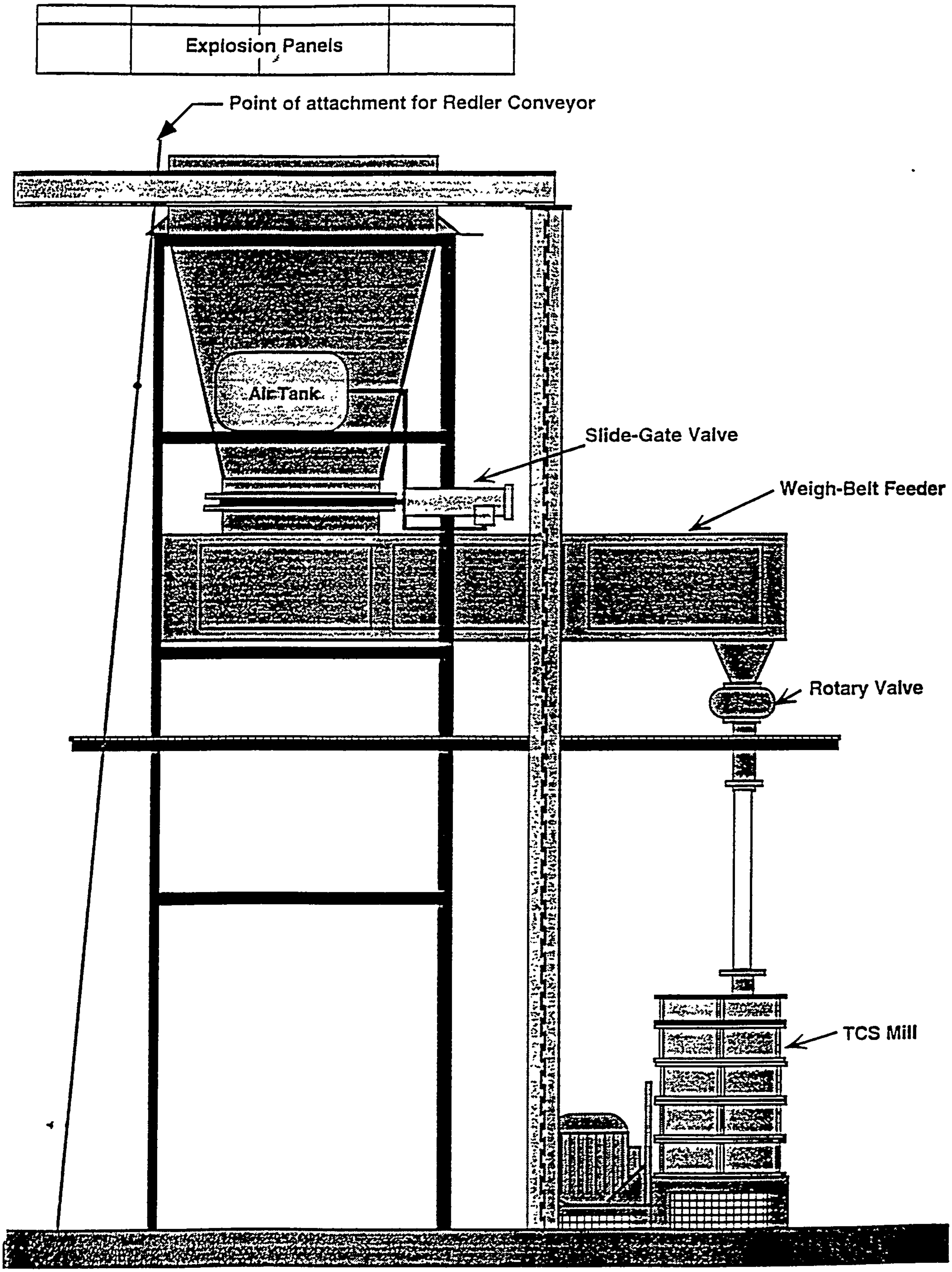


Figure 3. SCHEMATIC DIAGRAM OF NEW COAL HANDLING SYSTEM

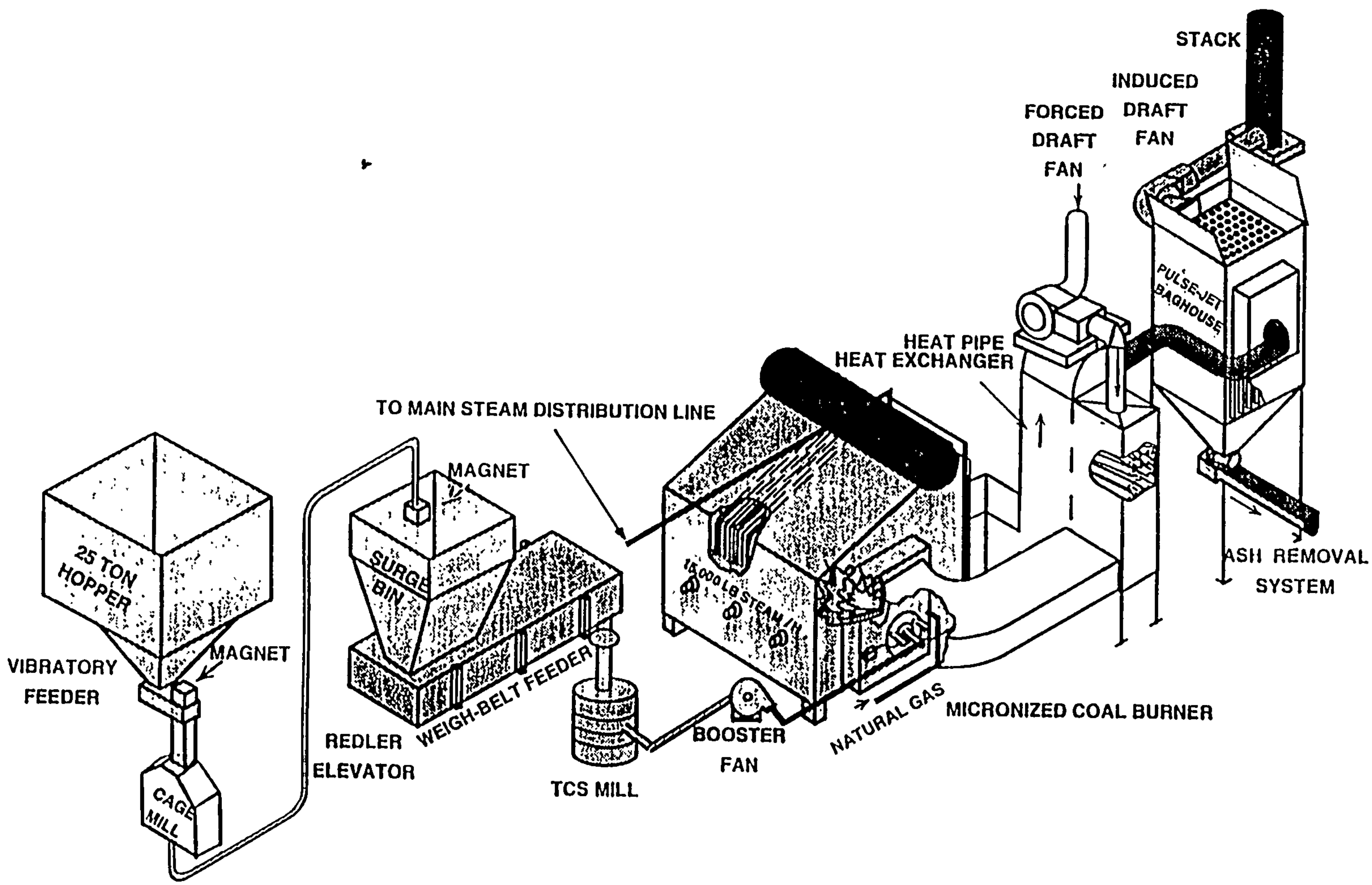


Figure 4. MICRONIZED COAL-FIRED BOILER SYSTEM WITH COAL HANDLING MODIFICATIONS

ATTACHMENT - I

# MICROFINE COAL FIRING RESULTS FROM A RETROFIT GAS/OIL-DESIGNED INDUSTRIAL BOILER

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## INTRODUCTION/ BACKGROUND

Under U.S. Department of Energy, Pittsburgh Energy Technology Center (PETC) support, the development of a High Efficiency Advanced Coal Combustor (HEACC) has been in progress since 1987 at the ABB Power Plant Laboratories (Rini, et al.. 1987, 1988). The initial work on this concept produced an advanced coal firing system that was capable of firing both water-based and dry pulverized coal in an industrial boiler environment (Rini, et al., 1990).

Economics may one day dictate that it makes sense to replace oil or natural gas with coal in boilers that were originally designed to burn these fuels. In recognition of this future possibility, the U.S. Department of Energy, Pittsburgh Energy Technology Center (PETC) has continued to support this program led by ABB Power Plant Laboratories and the Fuels Research Center of Penn State University to develop the HEACC concept. The objective of the current program is to demonstrate the technical and economic feasibility of retrofitting a gas/oil designed boiler to burn micronized coal. In support of this overall objective, the following specific areas were targeted:

- A coal handling/preparation system that can meet the technical requirements for retrofitting microfine coal on a boiler designed for burning oil or natural gas.
- Maintaining boiler thermal performance in accordance with specifications when burning oil or natural gas.
- Maintaining NOx emissions at or below 0.6 lb/MBtu (~450 ppm)
- Achieving combustion efficiencies of 98% or higher
- Calculating economic payback periods as a function of key variables

The overall program has consisted of five major tasks:

1.0 A review of current state-of-the-art coal firing system components.
2.0 Design and experimental testing of a prototype HEACC burner.
3.0 Installation and testing of a HEACC system in a commercial retrofit application.
4.0 Economic evaluation of the HEACC concept for retrofit applications.
5.0 Long term demonstration under commercial user demand conditions

This paper will summarize the latest key experimental results (Task 3) and the economic evaluation (Task 4) of the HEACC concept for retrofit applications.

## BURNER INSTALLATION AND TESTING IN AN INDUSTRIAL BOILER

The overall objective of this program has been to assess the technical and economic viability of displacing premium fuels with micro-fine coal by retrofitting the previously developed High Efficiency Advanced Coal Combustor (HEACC) to a gas/oil designed industrial boiler. This paper summarizes the work involving the retrofit of a complete micro-fine pulverized coal milling and firing system to an existing 15,000 lb/hr package boiler located in the East Steam Plant of Penn State University. Combustion performance-related objectives included steady state operation on 100% coal while achieving a carbon conversion efficiency of 98%, without increasing NOx emissions above 0.6 lb/MBtu (~450 ppm). The testing was also designed to show that consistent, reliable operation of entire coal storage/handling and pulverization system could be achieved. Reliable operation of the coal preparation system in concert with satisfactory burner performance would serve as a prerequisite to the demonstration phase of the project.

The HEACC burner was previously tested (Task 2) in the Industrial Scale Burner Facility (ISBF) located at Combustion Engineering's ABB Power Plant Laboratories (PPL) in Windsor, Connecticut. A key objective of the 100 hour burner validation tests at PPL was to fine-tune the burner operating characteristics and demonstrate operation over the range of conditions expected for the field boiler tests. All performance goals were successfully achieved during these ISBF tests. The testing at PPL demonstrated the technical validity of the design improvements incorporated into the second generation HEACC. This burner was then installed as part of a complete coal handling and firing system in Penn State's commercial boiler for a 400 hour proof-of-concept test program (Task 3).

A schematic of the micronized coal preparation/firing system at Penn State is shown in Figure 1. As can be seen, the cleaned coal comes on site and is stored in a large hopper. The coal is crushed and sent via a screw feeder to a micronized coal mill (TCS system). The coal is then micronized to ~80% through 325 mesh (~18 microns MMD) in the TCS mill and pneumatically conveyed to the HEACC burner where it is then burned in the boiler. This boiler is an oil/gas designed Tampella Keeler Model DS-15; a package D-type watertube boiler capable of producing 15,000 lb/hr of saturated steam at 300 psig. It represents a typical gas/oil - designed system with a furnace volumetric heat release of 50,000 Btu/hr $ft^3$, standard for this class of boiler. Furthermore, its design is similar to that of many other manufacturers' (including Combustion Engineering) models.

## EXPERIMENTAL TESTING RESULTS

### A) OVERVIEW

During the long term test period, the boiler system was operated over a range of operating conditions. Specifically, the boiler was tested over a variety of load ranges, excess air, combustion air damper settings and burner swirl levels. Two coals Brookville Seam and Kentucky were used. Their analyses are summarized in Table 1. During the test period, boiler performance data, emissions data, electric parasitic power and house compressed air consumption data, as well as other data required for the technical and economical analysis of the system were obtained.

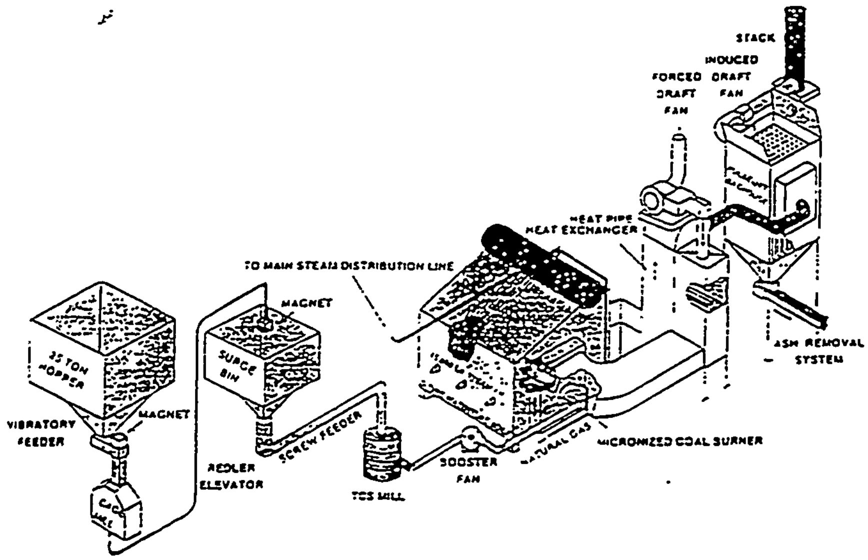


**Figure 1 Micronized Coal Combustion System at Penn State**

The initial burner tests included a shakedown series of runs using natural gas firing (Jennings, et al., 1994a, 1994b). At the conclusion of baseline natural gas firing, the boiler operation was directed towards hardware optimization (e.g., coal handling/preparation, burner settings) and testing with 100% coal firing. During this phase of the work, a major objective was to obtain consistent, repeatable 100% coal fired runs. This goal, along with minor modifications to the system (discussed in the next section) to increase boiler and carbon conversion efficiency resulted in several short term tests. Subsequently, the chosen hardware configuration was then used during the long term (~400 hr) test program (Task 3).

**Table 1 Selected Analyses of the Brookville and Kentucky Coals**

| | Brookville Seam | Kentucky |
|---|---|---|
| Proximate, wt% | | |
| Moisture | 8.2 | 6.8 |
| Volatile Matter | 33.1 | 33.3 |
| Fixed Carbon | 55.8 | 55.4 |
| Ash | 2.9 | 4.5 |
| HHV, Btu/lb | 13,260 | 13,010 |
| Ash Fusion Temp, °F | | |
| IDT | 2,820 | 2,803 |
| ST | +3,000 | +3,000 |
| FT | +3,000 | +3,000 |

B) SYSTEM CHARACTERIZATION/MODIFICATIONS

A key objective of the proof of concept testing was to determine the operating characteristics of the complete, integrated system in contrast to the operation of the individual components. Although all of the system components installed at the demonstration boiler host site were proven in either commercial operation or prior testing, the complete system from micro-fine coal production to steam production at this scale had not been previously demonstrated/proven.

The testing at Penn State indicated areas that should be carefully engineered in a commercial design. Furthermore, it was anticipated that if any problems occurred, they would likely be related to the burner (the least developed system component). However, the coal handling/feeding sub-system as it related to boiler system operability proved to be a critical component during initial testing. Some of the key system modifications and operational problems relating to the Penn State boiler are discussed below.

TCS Mill

The TCS mill and booster fan operated well without constant supervision. Initial system testing, however, revealed a coal settling problem in the mill outlet duct. This problem was corrected by a specially designed diffuser/transition section fitted to the mill exit. In addition, a detailed experimental study was carried out to characterize the effect of mill air flow rate and mill speed, on coal particle size distribution (PSD) and top size for the two coals tested. This was done as part of an effort to determine the milling conditions necessary to reduce the coal PSD and top size in order to achieve maximum coal combustion efficiency. In addition, the results were used to evaluate the feasibility for external classification to reduce the coal top size. The mill speed was a most important parameter to obtain the desired coal PSD. The results from these tests were used to optimize the mill settings for coal fineness during the experimental test program. Table 2 presents typical optimized mill operating conditions.

**Table 2 Mill Performance Summary**

- Typical mill air flow rate: 370-400 acfm
- Typical coal feed rate: 16.5- 18.5 lb/min

| Particle Size (microns) | Brookville Seam Coal | Kentucky Coal |
|---|---|---|
| Top Size | 190-300 | 250-275 |
| $D_{80}$ | 50-70 | 50-70 |
| $D_{50}$ | 25-30 | 25-30 |

Furnace Modifications

The furnace geometry was slightly altered during the test program by installing a ceramic wall at the exit of the radiant section of the boiler. The basic idea was to improve carbon burnout by making better use of the entire boiler volume through changing the gas patterns and temperature profile in the boiler. This was done because analytical (CFD) modeling showed that the flame was skewed from the burner to the furnace outlet and that the entire furnace volume was not being effectively used (Model results were subsequently verified by suction pyrometry).

Boiler System Operability

During the initial testing period, a number of operational problems involving the coal handling and boiler system were encountered. They were primarily related to the weather (cold, snow), the coal (particle size, moisture content), the burner/boiler system (unstable/ low u.v. flame scanner signal), or mechanical difficulties (feedwater pump, steam valves). With the exception of the coal handling problems caused by high moisture, these problems were all addressed and solved during the shakedown test series. The coal moisture problems will be fully addressed prior to beginning the 1000 hour demonstration test (Task 5).

C) SUMMARY OF EXPERIMENTAL RESULTS

Under the 400 hour test program, Brookville Seam and Kentucky coals were evaluated, the furnace geometry was modified by installing a ceramic wall, two coal guns (the RO-II with and without a coal deflector/accelerator and the I -Jet) were tested, and the operating conditions and without a coal deflector/accelerator and the I -Jet) were tested, and the operating conditions (excess air and firing rate) were varied. During the course of the long term coal only tests, no support fuel was required and the burner operated with excellent ignition stability. A typical summary of the microfine coal firing (both coals) is given in Table 3.

**Table 3 Microfine Coal Firing Results**

| | |
|---|---|
| Boiler Operation: | |
| Steam Flow Rate (lb/hr) | 13,240 |
| Boiler Efficiency (%) | 84.1 (3% $O_2$) |
| Combustion Performance | |
| Carbon Conversion Efficiency (%) | 95.3 |
| NOx at 3% $O_2$ (ppm) | 413 (0.56 lb/MBtu) |
| Burner Pressure Drop (in $H_2O$) | 8 |

During this test program. key performance variables were monitored in detail: boiler efficiency, combustion efficiency, and NOx emissions. A summary of the results involving these parameters follows.

Boiler Thermal Performance

Boiler thermal performance when firing micro-fine coal was essentially comparable to that achieved when firing natural gas. In fact, because of the greater latent heat loss when burning natural gas (greater formation of water due to higher hydrogen content), firing micro-fine coal actually gave slightly higher boiler efficiencies despite the need to run at higher excess air levels.

During the relatively short operating periods, usually less than 16 hours, ash deposits did not cause significant changes to the boiler thermal performance. It is recognized, however, that longer term operation could result in greater build-up of ash deposits which could impact heat transfer. Because of the relatively short duration of the tests, any build-up of ash deposits would slough off when the boiler was shut down. A better test of the possible impact of ash deposits will occur during the long term demonstration phase of the work (Task 5.0).

NOx Emissions

The NOx emissions target was 0.6 lb NOx per million Btu fired: this translates to about 450 ppm at 3% $O_2$. Testing with 100% microfine coal showed that this target was achieved (in general a NOx emissions value of 0.56 lb NOx per million Btu was routinely met) while meeting nearly all other required conditions. It is acknowledged that the optimum conditions for low NOx will generally exacerbate carbon conversion efficiencies. Indeed, this was the case with the HEACC burner and the challenge was to find a reasonable balance between meeting the NOx target while not aggravating the carbon conversion efficiency.

Combustion Efficiency

The target for combustion efficiency was 98%. The highest combustion efficiency obtained during the test program was slightly over 96%. However. this value was not compatible with meeting the NOx target. and was not able to be routinely repeated. A value of 95% combustion efficiency was able to be routinely achieved. and was compatible with meeting the NOx target.

Considerable effort was spent in trying to determine how combustion efficiency might be improved to meet the target. The challenge to meet the combustion efficiency targert of 98% is. indeed a very difficult one. The bulk boiler residence time is about 0.7 seconds. Further complicating the task is the aspect ratio of the boiler. i.e. the length of the boiler is not very much greater than its height or width (approximatelt 8 ft long x 8 ft high x 6 ft wide). It is aggravates the situation. Burner modifications are being looked at which might increase the particle residence time.

Coal particle size distribution was also evaluated. the premise being that carbon content must be directly proportional to particle size. While the larger particle size fraction of the collected particulate (fly ash) did contain higher carbon contents than the smaller size fractions, the differences were not as great as expected. For example, it would not be possible to dramatically reduce the carbon content of fly ash by eliminating coal particles larger than 150 microns.

## SYSTEM ECONOMICS

This phase of the work involved an economic evaluation of coal firing for existing small industrial boiler installations. In addition to a base case evaluation (the 15,000 lbm/hr natural gas fired Penn State boiler), various economic sensitivity studies which provide insight into the economics for other unit sizes, fuel price scenarios, capacity factors and other variables were carried out. The primary objective of this analysis was to determine how the coal option compares with natural gas firing on an annual basis. With coal firing the capital costs for the retrofit modifications as well as some additional operating and maintenance costs must be justified by the savings in fuel costs. The evaluation summarized here defines the incremental costs and savings on an annual basis as a result of the use of coal as a substitute for natural gas firing. The first year incremental operation and maintenance cost savings and the total retrofit capital requirement were then used to determine a simplified payback period. The details of the data and results have been summarized in a recent publication (Patel, et al., 1995).

### KEY RESULTS FROM THE ECONOMIC EVALUATION

A series of economic comparisons were carried out for the base case and other systems involving different economic input parameters. For these studies a range of differential fuel costs were used, and other sensitivity studies were carried out to determine the effect of unit size, annual operating time, and carbon heat loss on simplified pay back time. Figures 3 to 5 show the results of these sensitivity studies. In addition to differential fuel costs (see Fig. 3), other sensitivity variables studied were shown to have significant effects on payback period. As shown in Fig. 4, increasing unit size is shown to quickly improve the economics. Also, as shown in Fig. 5, changes in the annual operating time from 4000 to 8000 hrs/yr showed significant effects on payback period. Typically industrial boilers have very high capacity factors (the base case for this study used 7000 Hrs/yr (equivalent to an 80 percent capacity factor)). Fig. 8 is of most interest as it shows that variations in carbon heat loss (combustion efficiency) have no significant effect on payback period for the range studied (2 to 6%).

Although this analysis was done relative to natural gas as the base fuel, the results can also be generally applied to oil firing as well. By knowing the differential fuel cost the payback period can be approximated from the attached curves. Although boiler efficiency with oil firing is typically about 5 percent better than with natural gas, the effect on payback period is relatively insignificant as was shown by the results of the carbon heat loss sensitivity study.

## CONCLUSIONS/ RECOMMENDATIONS

The following specific conclusions are based on the results of the coal fired testing at Penn State and the initial economic evaluation of the HEACC system:

- A coal handling/ preparation system can be designed to meet technical requirements for retrofitting micro-fine pulverized coal.

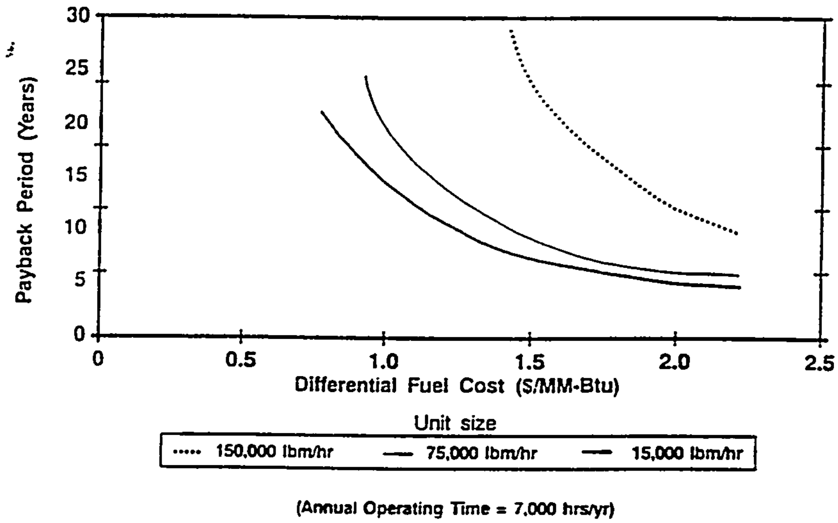


Figure 3 Payback Period as a function of Differential Fuel Cost and Unit Size

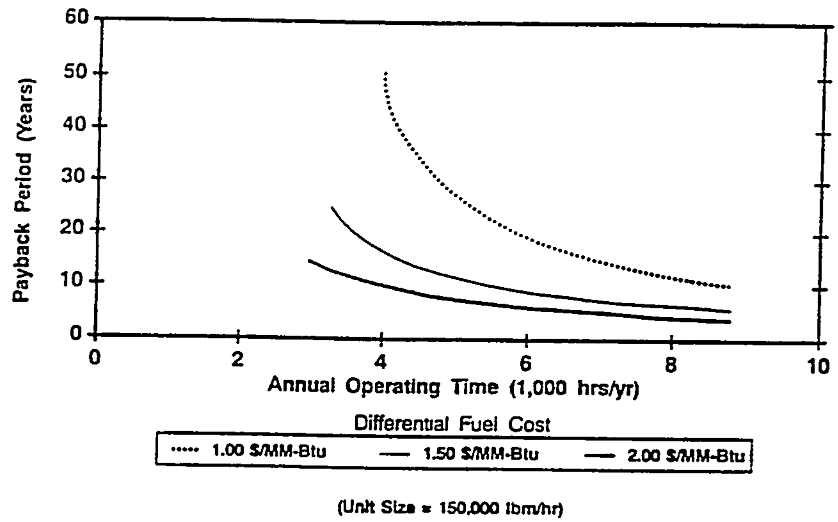


Figure 4 Payback Period as a function of Annual Operating Time

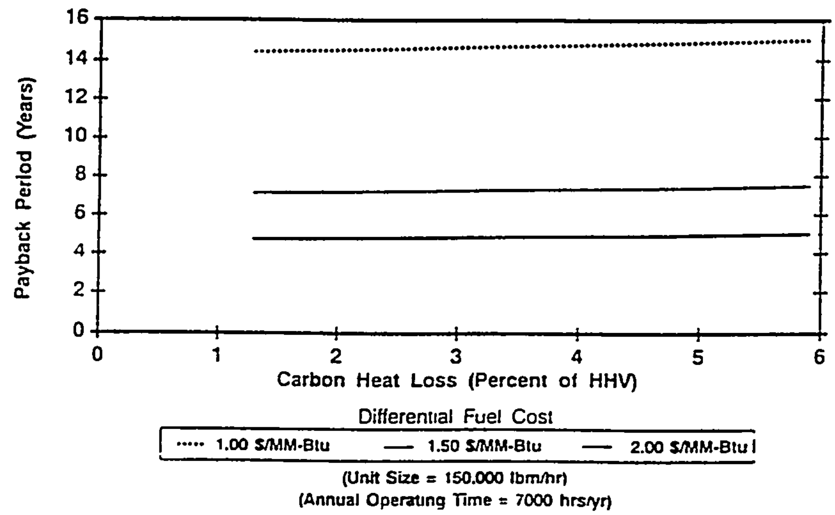


Figure 5 Payback Period as a function of Carbon Heat Loss

- The boiler thermal performance met requirements
- Combustion efficiencies of 95% could be met on a daily average basis, somewhat below the target of 98%
- NOx emissions can meet the target of 0.6 lb/million Btu
- The economic payback was very sensitive to fuel differential cost, unit size, and annual operating hours

As a result of recent long term tests using micronized coal (in another program), Penn State has experienced some convective pass ash deposition problems. To alleviate this problem they are planning to install additional soot blowers. Also, as a result of problems encountered during the 400 hour testing, the following modifications are planned for the Penn State system:

Coal feeding improvements
a) Improved raw coal/ storage and transport
b) Redesign/installation of a surge bin bottom
c) Installation of a gravimetric feeder
Monitoring of ash deposit effects
a) Air sparge/soot blower systems
b) Monitoring effects on heat transfer in the furnace and the convective pass
c) The use of ash deposition probes

In addition, ABB CE plans to modify the burner for more precise aerodynamic control of the fuel and air streams to improve the combustion efficiency and NOx emissions. Based on the results summarized in this paper the ABB/Penn State team and DOE/PETC have decided to conduct a 1000 hr demonstration (Task 5) of this program; it is currently scheduled to begin in July 1995.

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