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DOE/MC/26308-3647
(DE94004067)

**CE IGCC Repowering Project
Bins and Lockhoppers**

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**Topical Report
January 1, 1992 - February 28, 1993**

October 1993

Work Performed Under Contract No.: DE-FC21-90MC26308

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Combustion Engineering, Inc.
Windsor, Connecticut

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Topical Report

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Introduction

CE is participating in a coal gasification combined cycle repowering project that will provide a nominal 65 MW of electricity to City, Water, Light and Power (CWL&P) in Springfield, Illinois. The IGCC system will consist of CE's air-blown pressurized entrained flow two-stage gasifier; an advanced hot gas cleanup system; a combustion turbine adapted to use low-BTU gas; and all necessary coal handling equipment.

The coal feed system will utilize a unique high pressure lockhopper system to allow dry delivery of pulverized coal to the gasifier. A similar high pressure, high temperature lockhopper system will also be used to recycle char from the product gas stream back to the gasifier to maximize carbon utilization. This Topical Report describes the current state of design for the bins and lockhoppers to be used for the coal and char feed system.

The project is currently in the second budget period of five. The major activities during this budget period are:

- Establishment of approved for design (AFD) engineering package.
- Development of a detailed cost estimate.
- Resolution of project business issues.
- CWL&P renewal and replacement activities
- Application for environmental air permits.

Bin and Lockhopper Topical Report

1.0 Summary of Results

In 1992 the detailed design of the coal and char lockhopper and bin system began and as of February 1993 is approximately 40% complete. Many inside and outside resources were used to develop practical design from the previous conceptual and test work. The emphasis during this period has been on simplicity and reliability. The results of this work include: selection of coal and char pressurizing, fluidizing, and transport media, development of control sequence, piping and instrumentation diagrams, sizing and arrangement of receiving bins, lockhoppers and feed bins, development of bin material options, system arrangement drawings, material handling valve selection, and development of a pneumatic coal feed test program.

2.0 Description of Coal and Char Bin and Lockhopper System

2.1 Coal Bin and Lockhopper System

A pulverized coal receiving bin continuously receives and stores pulverized coal from the coal milling system for the intermittent feeding of the coal lockhoppers. A pantleg chute allows coal to flow by gravity to one of two coal lockhoppers. A pair of material handling valves in each pantleg control the flow of pulverized coal into each of the two lockhoppers. The lockhoppers intermittently receive, pressurize and feed the pulverized coal to their associated pulverized coal bins. There is one lockhopper for each feed bin. Each lockhopper feeds its associated feed bin intermittently and on demand by gravity thru a pair of material handling valves. After dumping its coal to its feed bin, the lockhopper de-pressurizes to receive another charge from the receiving bin. Each pulverized coal feed bin continuously feeds the coal at high pressure through its flow control valves into the coal transport line(s). Displacement gas is continuously metered into the feed bin to fluidize the coal and displace coal volume as each coal flow control valve meters the flow of coal to its pickup tee's and controls the firing rate of the gasifier. Transport gas is continuously supplied into the pickup tee to enable pneumatic transport of the pulverized coal to the gasifier coal nozzles.

2.2 Char Bin and Lockhopper System

A char receiving bin continuously receives char by gravity and stores char from the char cyclone and char bagfilters for the intermittent feeding of the char lockhoppers. A pantleg chute allows char to flow by gravity to one of two char lockhoppers. A pair of material handling valves in each pantleg direct the flow of char into each of the two lockhoppers. The lockhoppers intermittently receive, pressurize and feed the char to a single char feed bin. Each lockhopper feeds the feed bin alternately and intermittently on demand by gravity thru a pair of material handling valves. After dumping its char to the feed bin, the lockhopper de-pressurizes to receive another charge from the receiving bin. Each char feed bin continuously feeds the char at high pressure through its flow control valves into the char transport line. Displacement gas is continuously metered into the feed bin to fluidize the char and displace char volume as the char

flow control valve meters the flow of char to its pickup tee. Transport gas is continuously supplied into the pickup tee to enable pneumatic transport of the char to the char nozzles on the gasifier.

3.0 Methodology

Numerous system studies were conducted to provide the bin and lockhopper systems a sound theoretical basis for designs, to determine potential safety hazards and appropriate code application, to develop empirical data for component design, and to ensure constructability and reliability. The outside resources used include:

- F. Zenz - Solids Flow

- J. R. Johanson, Inc. - Bin and Lockhopper Design

- T. Hamilton Consulting - NFPA Code

- Lummus Crest, Inc. - Safety, Constructability, and Materials

Considerable in house resources were also used for system studies. Of particular note is the Kreisinger Development Laboratory (KDL) for pneumatic conveying and metallurgy, and Resource Recovery Systems for operating considerations and material handling expertise.

System reliability is a prime consideration for the gasifier at this stage of the project design when the gasifier general arrangements, major component arrangements and P&ID's are being done. Design personnel with start-up and power plant operating experience are being used to access all components and their interfaces for reliable operation. Minor but important revisions have been made and continue to be made to provide the most simple and reliable systems possible for the chosen design.

During this phase of the project the design of the bin and lockhopper systems are being integrated with the design of the entire gasifier island. A 3 dimensional computer aided design system, PASCE, was used to assist this effort. Safety, environmental, construction, operation, and maintenance issues are being considered in the selection and arrangement of all system components. References for critical components in similar applications are being checked out to learn what the end user's experience has been. In order to ensure successful operation of the bin and lockhopper system, a full scale test program has been developed to test the critical functions of the bin and lockhopper system. A series of internal and external design reviews are ongoing to ensure objectivity and thoroughness.

4.0 Discussion of Specific Design Aspects

4.1 Pressurizing, Fluidizing, and Transport Gas Selection

Prior to refining the coal feed system lockhopper and feed bin sizes and cycle times, a study was performed to evaluate pressurizing, fluidizing, and conveying gas option for the coal feed system. Air, nitrogen, steam, carbon dioxide, and flue gas were considered. The early study looked at the economic, operating, and technical aspects of each gas. It concluded that steam was the best

option from cost and functional point of view. Carbon dioxide and flue gas were rejected because of technical problems and poor economics. Nitrogen appeared feasible but with higher capital and operating costs than steam. Air also appeared more costly and may not be allowable for pressurizing due to NFPA considerations.

However, the use of steam would require the use of a fluidized bed steam coil between the coal bag filter discharge and the coal receiving bin inlet to bring the coal temperature up to 500°F to prevent condensation in the receiving bin and lockhoppers. As the system design progressed the coal heater became an object of increasing concern for technical, economic, and operating reasons. Also, due to significant reductions in the lockhopper and feed bin sizes the amount of gas to drive the system had decreased appreciably. Consequently an updated economic evaluation and reliability study was done to compare nitrogen and steam. The new economic study showed steam to have significantly higher capital cost but lower operating costs. Although the nitrogen operating costs are higher, they are not prohibitive, and the development of commercial membrane type separation systems allows simple on site nitrogen generation at predictable prices. A check of references showed that facilities using high pressure pneumatic coal transport with nitrogen has been proven and operated reliably on two gasifier projects (200 TPD) and in a large coke making operation at a major steel mill. A similar precedent for steam is very limited and not encouraging. The current coal feed design will use nitrogen for pressurizing, fluidizing, and transport. Steam and air will continue to be studied for use as a pressurizing and/or conveying medium for coal as a future option. Proprietary Appendix I

includes a coal feed system nitrogen usage chart and a spreadsheet comparing the economics of steam, nitrogen, and a combination of nitrogen air for use in the coal feed system.

Because the char feed system will operate at very high temperature, superheated steam was selected as the pressurizing, fluidizing, and transport media. There will be no requirement to heat up the char to prevent condensation. However, the use of steam does require that the char bins and lockhoppers be pre-heated for cold start ups and that every effort be made to preclude steam leaks at valves and connection points. During extended shutdowns it will be necessary to discharge the contents of the char bins and lockhoppers prior to allowing their internal temperatures to drop to the saturation point. In this case char will be discharged into the gasifier slag tank for quenching and removal to the slag storage area.

4.2 Control Sequence

Refer to Figure 1 for a basic presentation of the bin and lockhopper sequence at design capacities (46,985 lb/hr for coal, 57,000 lb/hr for char). A ten minute sequence was selected for the coal and char feed system to optimize the combination of valve cycles, vessel size, and stack up height. The ten minute storage volume in the lockhoppers and ten minute working volume in the feed bins allows the use of vessels less than 12ft in diameter. This permits complete vessel fabrication in the shop and keeps stack up heights within the height limitations for building steel dictated by the air permit and building economics. The material handling and vent valves will cycle a maximum of six times an hour or approximately 50,000 times a year.

FIGURE 1
BIN AND LOCKHOPPER SEQUENCE
FOR COAL AND CHAR FEED AT DESIGN CAPACITY

10 MINUTE REPEATING CYCLE

The valves selected for material handling and vent service can provide a one year service life with this amount of cycling. When the gasifier runs at less than full load or the coal system is firing multiple elevations simultaneously, the number of valve cycles will go down significantly.

In both the cases of the coal and char feed systems the lockhoppers will fill in approximately 2 minutes, pressurize in approximately 5 minutes, dump in approximately 2 minutes, and vent in approximately 1 minute. Both pressurizing and venting require the associated valves and piping to accommodate sonic flow of the pressurizing media. Flow rate versus time and pressure was calculated for the ten minute cycle, and valves have been selected and arranged to accommodate sonic and sub-sonic conditions while providing as much operating flexibility as possible.

4.3 Bin and Lockhopper Design

Section 4.2 explains why the lockhopper and feed bins are sized with ten minute working volumes. The coal receiving bin is sized for a 40 minute storage volume to allow the feed system to accommodate brief interruptions in coal feed from the coal mill system and load swings without starving the coal feed system. The char feed bin requires only a ten minute working volume because its recirculation duty precludes flow interruptions that can be remedied on line.

J. R. Johanson, Inc. was employed to develop the parameters for coal and char receiving bin, lockhopper, and feed bin design and operation. Johanson tested coal and char samples to determine bulk and fluidized densities, critical arching and ratholing dimensions, hopper angles, and fluidizing characteristics. From these results and the use of their mass flow system models, specific design criteria was developed for the bin configurations, pipe sizes, fluidizing methodology, pressurizing and fluidizing flows, flow control and bin materials. A series of recommendations were issued by J. R. Johanson based on this work. Their most relevant reports to date are included in Appendix II. Early reports by J. R. Johanson recommended and assumed the use of his "Diamond Back" mass flow hopper configurations. After discussion of the costs versus benefits of a diamond back configuration for high pressure thick walled vessels this recommendation was dropped in favor of conical hoppers. Further testing by J., R. Johanson showed that a 74° from horizontal cone angle would be sufficient for both coal and char vessels if certain steels and finishes were used to minimize friction. Also note that J. R. Johanson's bin sizes are based on 15 minute working storage volumes. Appropriate adjustments have been made in the number and position of pressurizing/fluidizing assemblies and their flow rates to accommodate the 10 minute sequence described in section 4.2. At this time, it is planned to use the pressurizing, fluidizing arrangement recommended by J. R. Johanson that consists of a series of pressurizing/fluidizing ring headers located inside the bins and lockhoppers at different elevations. Design details are in the process of being developed from the conceptual sketches shown in J. R. Johanson's reports. Some feasible and alternate options have been developed. The pressurizing/fluidizing assembly details are critical to bin and lockhoppers function and reliability. This area will continue to receive further scrutiny and testing.

The possibility of independently controlling double or triple material flows at the feed bin discharge was investigated with the assistance of J. R. Johanson, Inc. To date, a proven operation using this concept has not been found by Johanson or ABB. The instrumentation necessary to reliably support such an operation has not yet been developed. As a result, ABB has elected to design the demonstration plant with single discharge from the feed bins with provisions for the future use of dual discharge. Single discharge controlled flow is a proven concept and is in common use in commercial positive pressure pneumatic conveying systems. ABB plans to test any new instruments that show true promise in being able to reliably and accurately measure solids flow in a pneumatic transport line.

The elimination of steam as a pressurizing, fluidizing, and transport media in the coal feed system allows the use of carbon steel vessels with little or no insulation or heat tracing. Investigation is continuing for the final selection of cone finish and/or liner material for low temperature operation. The design pressure for the coal lockhopper and feed bins is 450 psia at 300°F. Approximate high pressure coal vessel thickness is 1.5 inches. The coal receiving bin operates at near atmospheric pressure and will be designed for 50 psig per NFPA 8503.

The char vessels will be designed for 450 psia at 1000°F. At this time it is planned to evaluate two methods of fabrication. One is to construct the vessels of a stainless steel alloy with thick external insulation. Vessel thickness would be approximately 3½" with this method. The vessels would be very heavy and hot spots would be difficult to monitor and detect. The other method is to construct the vessels of carbon steel with internal layers of insulating refractory. The refractory may or may not be contained with a thin walled stainless steel liner. This design requires no external insulation and permits easy detection of hot spots. The outer shell would be exposed to temperatures less than 400°F and require a thickness of approximately 1½ inches of carbon steel. About 4½ inches of light weight refractory would be required for internal insulation. Tank penetrations are more difficult to design for with this method.

It will be essential to have a safe and ready means of evacuating the contents of the coal and char vessels in the event of pluggage. An in place hard piped vacuum system is being evaluated in the plant design to provide for 4" diameter vacuum hose attachments in the immediate vicinity of each vessel. A vacuum truck will be used as the power source and receiver for this system. The floor areas immediately under each vessel will be diamond plate to permit easy clean up and containment of spills. Vessel access will be from the top in order to maintain tank wall smoothness and to discourage accidental dumping. This feature and the pressurizing/fluidizing internals of the vessels require a remote means of evacuating vessel contents. This can only be provided by a vacuum system.

4.4 Bin and Lockhopper Arrangement

Proprietary Appendix III contains arrangement drawings of the coal and char feed systems. These arrangements minimize stack up height while eliminating the need for any mechanical conveyors, rotary valves or dump valves. The elimination of such devices not only simplifies

the system and saves capital cost, but eliminates the need for many pressure seals around rotating shafts that will result in continual material leaks and cold spots where steam could condense. All connecting pipes between vessels are restricted to a minimum of 60° from horizontal to ensure free flow between vessels. Fluidizing/purge connections are provided in potential dead legs between vessels and valves to provide an on-line means of initiating stalled flow. High pressure bellows type expansion joints with smooth wall internal liners are used to accommodate expansion between the vessels without providing hide out ledges. The receiving and feed bins are supported on load cells to provide the control system with rate feedback. In addition all vessels will use nuclear level detectors to monitor material levels in the vessels.

A double valve arrangement will be used to isolate the lockhoppers. The upper valve is used primarily to cut thru the material head above it. The lower valve closes just after the upper valve and is used primarily to provide a gas seal. These are 12" valves with oversized pneumatic cylinder actuators that weigh about a ton each. Provisions for expedient removal of these valves are incorporated into the arrangement because of their critical function.

4.5 Material, Vent, and Flow Valve Selection

ANSI 300 LB ball valves with stellite balls, metal seats and oversized actuators are used for material cutting, equalization, and flow control valves. The coal valves use carbon steel bodies and the char valves use stainless steel bodies. This type of valve has a proven track record in pressure system applications with very high solids loadings. Oversized actuators and special seal and seal design are critical to successful application of the ball valve in this service. The ball valves will open and close across low pressure differentials.

ANSI 300 LB Everlast sliding disc type valves are used for material sealing and vent valves. The disc and seats in this valve are stellite and have a good track record for maintaining a tight seal in dirty fluids across high pressure differentials. The coal valves use stainless steel bodies. The Everlast valves require a purge gas connection in the disc cavity to prevent material build up in this area. The Everlast valve has the unique ability to achieve a tighter shut off seal as it wears over a substantial portion of its service life. It also uses an oversize actuator for this service. Appendix IV contains catalogue sheets for the ball and Everlast valves. It is anticipated that these valves will be changed out on a yearly basis for major factory maintenance.

4.6 Coal Feed System Test Program

A test program has been developed to test full scale coal lockhopper and feed bin functions using high pressure air. It is intended to conduct this test prior to fabrication of certain components and construction of the demonstration plant. Because pneumatic systems, and especially unusual pneumatic systems, are not completely predictable from design models, it was decided that a test program would allow the quickest and most certain, if not most cost effective, method of developing a successful coal feed system. The test will be used specifically to finalize hardware details, select an optimum flow regime, and to develop an effective control sequence for

pressurizing and fluidizing the lockhopper, feeding from the feed bin, and transport in the conveying lines. The specification for this program is contained in proprietary Appendix V.

5.0 Future Bin and Lockhopper Work

The following work will be done to complete the design of the bin and lockhopper systems:

- Design of support structures for coal and char vessel stack ups. This will include a detailed stress analysis of interactions between the vessels.
- Detailed design of coal and char vessels with a cost/benefit evaluation of char vessel options.
- Detailed design of pressurizing/fluidizing assemblies.
- Detailed arrangement of vent and equalization lines
- Completion of coal feed test program and incorporation of results into design
- Review of final system design by J. R. Johanson

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