

Energy and
Environmental
Research Corporation

XC NEHER

April 16, 1996

Mr. Robert Rock
Eastman Kodak Company
Kodak Park Site
Utilities Division - Bldg. 31
Rochester, NY 14652-3709

Dear Mr. Rock:

EER has completed its evaluation of the applicability of micronized coal reburning to Kodak Park Boiler No. 15. This evaluation has included:

- Characterization of the reburn potential of the Kodak coal in EER's Boiler Simulator Facility (BSF).
- Isothermal flow model studies of the furnace aerodynamics to develop reburning fuel and overfire air injector designs.
- Mathematical modeling of the impacts of reburning on boiler performance and emissions.

We have concluded that the target objective of 50 percent NO_x control can be achieved without unacceptable impacts on other aspects of boiler operation and performance. We are prepared at this time to proceed to the detailed engineering design phase.

The coal reburning design utilizes simultaneous operation of two Fuller micromills, which will provide 25% reburning heat input at full load (400,000 lb/hr steam flow) and 30% at maximum load (440,000 lb/hr steam flow). The required mill pressure is provided by two flue gas booster fans, the gas being tempered with a water spray. The flue gas is extracted from the electrostatic precipitator outlet duct eliminating the need for a multiclone. The four micronizer outlets (two from each unit) are joined in a common header/splitter which then distributes the flow to each of the eight injection nozzles. The coal injectors are located on the rear wall of the boiler at elevation 226'-0".

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Overfire air is extracted from the secondary air ducts and routed to four injection nozzles located on the front wall of the boiler at elevation 247'-9". A common header arrangement may be used for nozzle flow distribution. The dual-concentric nozzles produce two air streams which can be controlled for good mixing and operational flexibility.

Attached for your use are the specific process design parameters. A copy of the process design report that describes the development of these parameters will be submitted to you on Thursday of this week. A more comprehensive report that includes the results of the flow model testing, performance analysis and combustion testing will be submitted by April 30. Please contact me if you have any questions. Thank you.

Sincerely,



Donald A. Engelhardt
Project Manager

cc: TMS/File 8882.3200
Lon Harvey - Parsons
DKH/DM

**Energy and Environmental Research Corporation
Micronized Coal Reburning Project for Eastman Kodak Company
Process Design Parameters**

System Configuration

Recirculated flue gas source	After ESP
Transport FGR fan	At micronizer inlet
Tempering method	Water spray
Micromills	2 in service
Assumed micronizer outlet temperature	170 degrees F
Transport line configuration	See note 1
Overfire air source	Secondary air duct

Reburning Injectors

Quantity	8
Elevation	226'-0"
Location	Rear wall
Configuration	Injectors are symmetrical about boiler centerline; first injector 16.5" from sidewall tube centerline; remaining three injectors spaced at 30".
Injector Size	5" pipe
Maximum coal flow	12,000 lb/hr
Minimum coal flow	2,500 lb/hr
Transport flow	32,000 lb/hr
Velocity head at injector inlet	18 in. H ₂ O (see note 2)

Overfire Air Injectors

Quantity	4
Elevation	247'-9"
Location	Front wall
Configuration	Injectors are symmetrical about boiler centerline; first injector 30" from sidewall tube centerline; second injector spaced at 58.5".
Maximum flow rate	140,000 lb/hr
Injector size	12.5" O.D.
Velocity head at injector inlet	30 in. H ₂ O (see note 2)

Note 1: All micronizer outlet lines will feed a common header that will be used to distribute the flow among the eight nozzles.

Note 2: The velocity head does not include the furnace pressure.

Micronized Coal Reburning Demonstration on Kodak Park Boiler No. 15

Reburning System Process Design Specifications

1.0 Introduction

This document summarizes process design specifications developed for a coal reburning system for Boiler No. 15 at the Kodak Industrial Park in Rochester, New York. Boiler No. 15 has been selected as the host site for a demonstration of the use of micronized coal reburning for NO_x emissions control under the U.S. Department of Energy's Clean Coal Technology Program. One of the objectives of the project is to demonstrate the applicability of micronized coal reburning to a cyclone fired boiler.

Reburning is a NO_x control technology which is applicable to a wide range of boiler designs and firing configurations. The reburning process relies on introducing fuel and air into the boiler in three stages or zones. This staging is implemented in a fashion which results in the use of a portion of the fuel to form a "reburning" zone where NO_x is reduced. Unlike conventional fuel staging processes which require operation of a portion of the combustion system at extremely fuel rich conditions, reburning is highly effective at conditions which are only slightly fuel rich.

Reburning is a particularly attractive technology for application to cyclone fired boilers, since the design and operation of these boilers is not amenable to the use of other combustion modification NO_x control technologies, such as air staging or low-NO_x burners. Post-combustion control methods, such as selective noncatalytic reduction (SNCR), can be applied to cyclone fired boilers, but poor access to optimum temperature regions and high upper furnace quench rates limit emissions control performance and can cause high levels of ammonia slip.

The application of reburning to a particular boiler requires careful consideration of the furnace flow field characteristics and the boiler design in the development of the reburning system specifications. To optimize the emissions control performance of the reburning system, and to minimize any negative impacts of retrofitting reburning to the boiler, it is necessary to develop a reburning system design which achieves rapid and uniform mixing of the reburning fuel and overfire air streams, but minimizes the extent of modifications to the boiler heat release and heat absorption profiles. To achieve these goals, EER has developed a methodology which uses various experimental and analytical tools to develop the necessary injector specifications and operating characteristics for a

reburning system with the objective of attaining optimum emissions control performance while maintaining boiler operation and performance at close to normal levels. This design methodology has been applied to the Kodak boiler, and the results are the subject of this document.

This document is divided into five sections. The following section provides a brief overview of reburning technology, and of the parameters expected to control the performance of the process as applied to the Kodak boiler. Section 3 describes EER's design approach selected for application of coal reburning to Boiler No. 15. Section 4 summarizes the key results of EER's process design studies, and presents the proposed reburning system design.

2.0 Reburning Technology

Reburning is a combustion modification technology which removes NO_x from combustion products by using fuel as a reducing agent. The fundamental principle of reburning—that fuel fragments can react with NO to form molecular nitrogen—was first demonstrated as a viable NO_x control technique over twenty years ago. This control technique is particularly effective at controlling NO_x emissions, and can generally be easily retrofit to utility boilers. To implement the process on a large utility boiler, fuel is injected above the main combustion zone to provide a slightly fuel rich environment or "reburning zone" which reduces nitrogen oxides formed in the primary combustion zone to molecular nitrogen. Following the reburning zone, additional combustion air is added to the boiler to oxidize carbon monoxide and any remaining fuel fragments exiting the reburning zone. The primary advantages of reburning over other available NO_x control technologies are that:

- (1) Reburning provides high levels of NO_x control. To date, EER's demonstrations of reburning on three coal-fired utility boilers have shown typical NO_x control levels of 60 percent, with 70 percent control achievable under optimal conditions.
- (2) Reburning can be implemented without significant impacts on boiler performance. Although reburning implementation can impact the distribution of heat absorption in the boiler, these effects are generally small in comparison to variations due to normal changes in boiler operation (e.g., fouling).

- (3) Reburning produces no measurable by-product emissions. Unlike other additive NO_x control processes such as urea or ammonia injection, reburning does not result in the release of other pollutants such as ammonia or nitrous oxide.
- (4) Reburning is fuel flexible and can be applied to gas-, oil-, or coal-fired boilers. These fuels can also be used as the reburning fuel in the process itself.
- (5) Reburning can be applied to all types of fossil fuel fired boilers. EER has demonstrated reburning on a 150 MW wall-fired boiler, a 70 MW tangentially fired boiler, and a 33 MW cyclone fired boiler. EER has completed the development of designs for a fuel oil reburning system for a package boiler, and a multifuel reburning system for a 300 MW opposed-wall fired wet-bottom boiler. Results from these systems are expected in the 1996-97 time frame.

EER's approach to the implementation of reburning on a utility boiler requires dividing the combustion air and fuel into multiple zones which stage the fuel and air addition to the furnace. Figure 1 shows an illustration of the typical approach for applying reburning to a utility boiler. As shown in this figure, application of the basic reburning process to a utility boiler conceptually divides the furnace into the three zones which are described below.

Primary Combustion Zone: The heat release in this zone normally accounts for 80 to 85 percent of the total heat input to the combustion system. The main fuel is burned under fuel-lean conditions resulting in high levels of NO_x emissions.

Reburning Zone: The reburning fuel, which accounts for the other 15 to 20 percent of the fuel heat input, is injected downstream of the primary zone in sufficient quantity to form a slightly fuel rich zone where NO_x from the primary zone is reduced. In the reburning zone, hydrocarbon radicals, such as CH, generated during breakdown of the reburning fuel react with NO molecules from the primary zone to form other nitrogenous species such as hydrogen cyanide, HCN. The HCN then decays through several reaction intermediates, NCO → NH → N, and ultimately reaches N₂ via the reverse Zeldovich reaction:



Burnout Zone: In the third and final zone, additional combustion air is added to oxidize carbon monoxide and any remaining fuel fragments, and to produce overall fuel-lean conditions. The

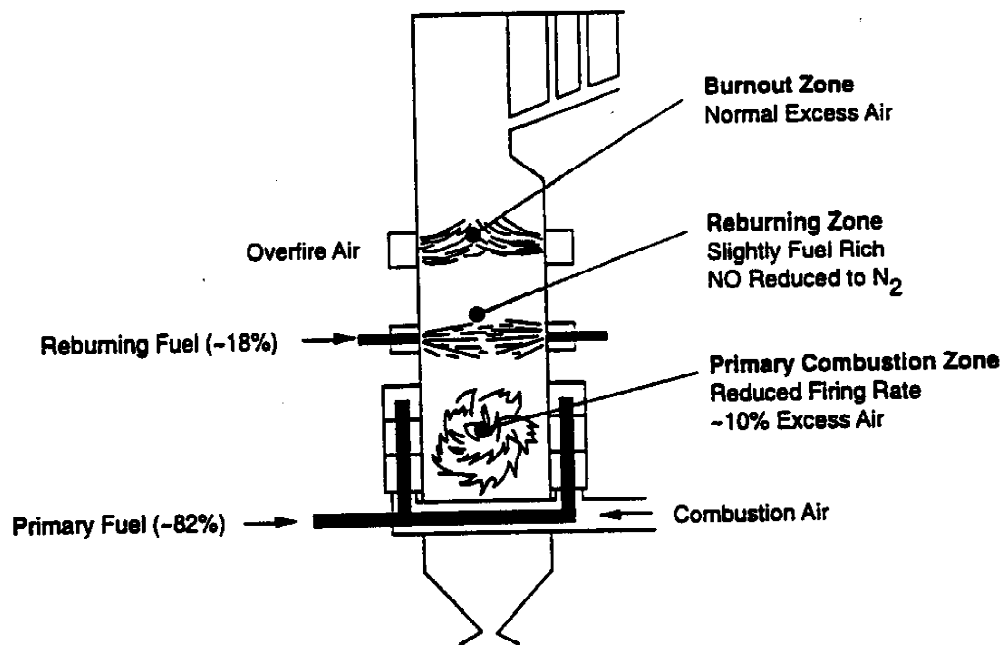


Figure 1. Application of reburning technology to a utility boiler.

remaining reduced nitrogen species are generally oxidized to NO, or reduced to N₂, depending upon specific conditions at the point of overfire air introduction.

2.1 Controlling Process Parameters

Since the early 1980's, EER has extensively evaluated the reburning process at bench, pilot and full scale to identify the parameters which control process performance. The results of small-scale studies have shown that the most critical parameters which impact reburning performance are: primary NO_x level; reburning zone temperature and residence time; reburning zone stoichiometry; and mixing of the reburning fuel and the overfire air with the bulk furnace gases. EER's full-scale demonstrations of the technology have confirmed the influence of these parameters. Understanding how these parameters influence reburning performance is the first step in the successful application of the technology. Therefore, the importance of zone stoichiometries, residence times and temperatures, and mixing is discussed below.

Operating Stoichiometries: The most important stoichiometry in the process is that of the reburning zone. The impact of this parameter on the NO_x emissions achievable with various reburning fuels is shown in Figure 2. Here, the reburning zone stoichiometric ratio is defined as the ratio of the total air supplied to the primary and reburning zones to the total stoichiometric air requirements of the primary and reburning fuels. As shown in this figure, overall NO_x reductions are highest when the reburning zone stoichiometry is in the region of 0.90. To minimize the amount of reburning fuel needed to reach the optimum stoichiometry, the primary combustion zone should be operated as close to stoichiometric as possible. For coal-fired boilers, operation of the primary combustion zone with an excess air level of ten percent or less is preferred to bring the reburning fuel requirements to between 18 and 20 percent of the fuel heat input to the furnace, and to maintain the nominal coal flame combustion characteristics. Lower stoichiometries in the primary combustion zone can be used provided that combustion stability and carbon burnout are not sacrificed. In the burnout zone, overfire air is added to bring the overall furnace combustion system to its normal operating stoichiometry. When applying reburning, it is desirable to minimize the overall excess air level in order to improve the thermal efficiency of the unit. This reduction can be accomplished if the reburning system is designed to provide effective mixing of the overfire air, and if acceptable to the boiler thermal cycle operation.

Furnace Temperatures: The furnace gas temperature at which the reburning fuel is injected has an impact on the process efficiency, with higher temperatures preferred. Typically, this requirement

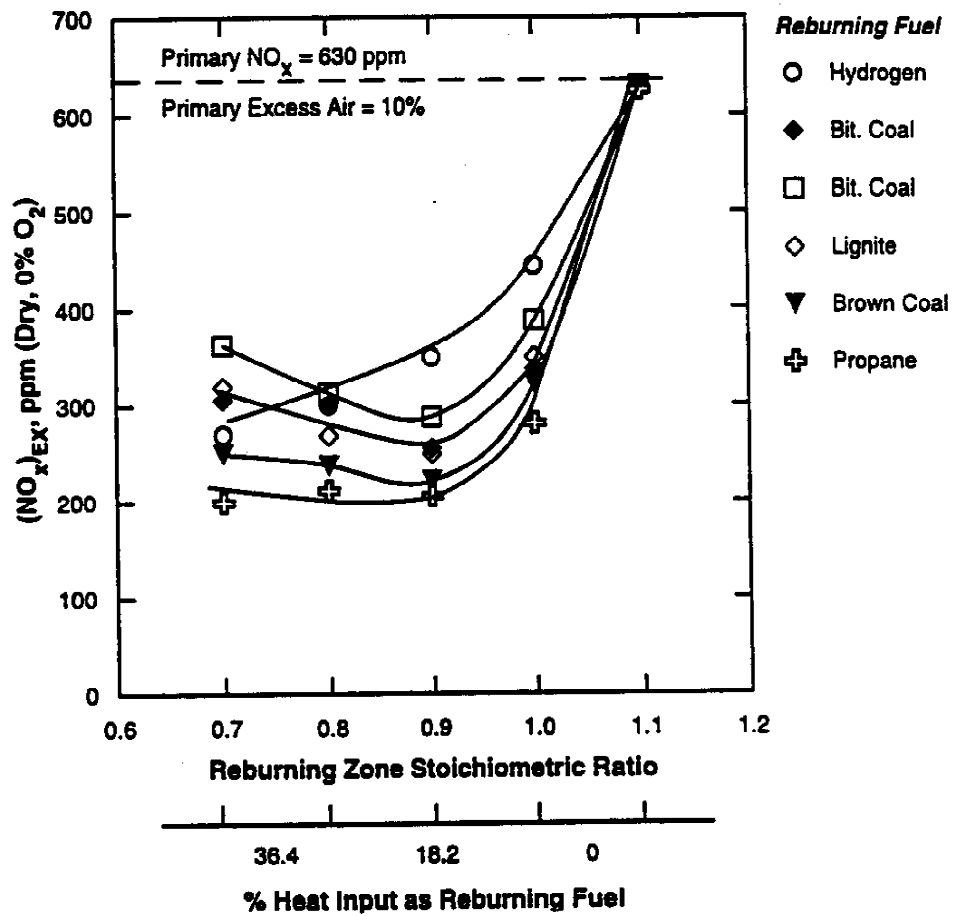


Figure 2. Impact of reburning zone stoichiometry and reburning fuel type on reburning performance.

suggests that the reburning fuel should be injected as close to the primary zone as possible. However, the reburning fuel must be injected at a distance above the primary zone sufficient to allow burnout of the volatile hydrocarbons in the primary flame and reduction of the oxygen concentration entering the reburning zone. The temperature at which the burnout air is injected does not directly influence the efficiency of the reburning process for most gaseous and liquid reburning fuels, but it is important that the temperature is high enough to allow oxidation of carbon monoxide and hydrocarbon fragments from the reburning zone to occur readily.

Zone Residence Times: Sufficient residence time must be available in the primary combustion zone to allow combustion of the primary fuel to proceed near completion. However, the residence time of the reburning zone is the most critical to the process. Sufficient residence time in the reburning zone should be available to allow mixing and reaction of the reburning fuel with the residual oxygen and the products from the primary combustion zone. For most combustion systems, small-scale studies have shown that the reburning zone residence time should be between 300 to 500 milliseconds. Finally, sufficient residence time must be provided in the burnout zone to permit oxidation of the carbon monoxide and hydrocarbon fragments from the reburning zone.

Mixing: Pilot-scale studies of the reburning process have also shown the importance of effective mixing in both the reburning and burnout zones. Effective mixing of the reburning fuel optimizes the process efficiency by making the most efficient use of the available furnace residence time, while effective mixing of the overfire air reduces carbon monoxide emissions and unburned carbon or soot. For most combustion systems, good mixing is important to minimize operational impacts while maximizing NO_x reductions. In order to ensure that the reburning fuel is mixed effectively in the furnace, the use of recycled flue gas to boost the nozzle velocity has been employed in full-scale demonstrations. Although recent results indicate that the use of flue gas is not necessary for natural gas reburning provided that the reburning fuel nozzle is designed to provide good mixing of the reburning fuel, the use of coal as a reburning fuel requires the use of a transport medium for the coal. Pilot-scale coal reburning tests conducted by EER indicate that the oxygen content of the carrier gas can impact the emissions control performance achievable with coal reburning, in addition to requiring the use of more reburning fuel to achieve a target reburning zone stoichiometry.

2.2 Coal Reburning Performance

During the process design studies, EER conducted a pilot-scale combustion rig study to evaluate the effectiveness of using the bituminous coal fired by Kodak as a reburning fuel. The primary

objectives of these tests were to assess the impacts of fuel-specific parameters on the effectiveness of the Kodak nominal coal as a reburning fuel, and to characterize the impacts of reburning process parameters on the NO_x reductions achievable with coal reburning at conditions typical of Boiler No. 15. This testing was necessary since it is not possible to predict the NO_x control performance achievable with a specific coal based upon simple coal properties and analyses. These tests were conducted at EER's Test Site in El Toro, California, which is equipped with a number of facilities developed for evaluation and scale up of the reburning process.

The tests were conducted using EER's Boiler Simulator Furnace (BSF) which is shown in Figure 3. The BSF consists of a down-fired refractory lined combustion tunnel followed by a horizontal convective-pass simulator. The combustion tunnel is designed to simulate the time-temperature characteristics of the flue gases in a typical utility boiler furnace. Cooling panels and rods can be inserted through ports in the walls of the furnace in order to adjust the thermal profile to simulate a specific furnace. The ports also provide access for the insertion of injectors for the reburning fuel and overfire air. This facility has been used in previous investigations of the reburning process.

For these experiments, the main burner was fired on natural gas or coal. For natural gas firing, ammonia was premixed with the combustion air to provide a controlled initial NO_x level. The reburning fuel was Pittsburgh seam bituminous coal provided by Kodak. The reburning coal was injected into the furnace through an injector designed to provide rapid dispersion of the coal into the flue gas from the main burner. The transport for the coal was either air or nitrogen (to simulate recycled flue gas). The range of conditions investigated in the study represented the range of conditions expected for the Kodak boiler. The main burner was fired at an excess air level ten percent. The reburning fuel was injected at rates between 10 to 35 percent of the total furnace heat input, and at a temperature of 2,600°F. The reburning zone residence time was varied from 400 to 600 milliseconds. The initial NO_x level was varied between 700 to 1,000 ppm (dry, corrected to 0% O_2).

The impacts of various process parameters on the effectiveness of the bituminous coal fired by Kodak in the reburning process are shown in Figures 4 to 6. The influence of reburning zone stoichiometry and reburning transport medium on the performance of coal reburning is shown in Figure 4. Here, the data are reported as the fraction of heat input with the reburning fuel. For conditions with ten percent excess air in the primary zone, a reburning zone stoichiometric ratio of 0.9 corresponds to a reburn fuel usage of approximately 18 percent, when nitrogen is used as the transport. The use of air as a transport requires a higher percentage of reburn fuel usage to reach the

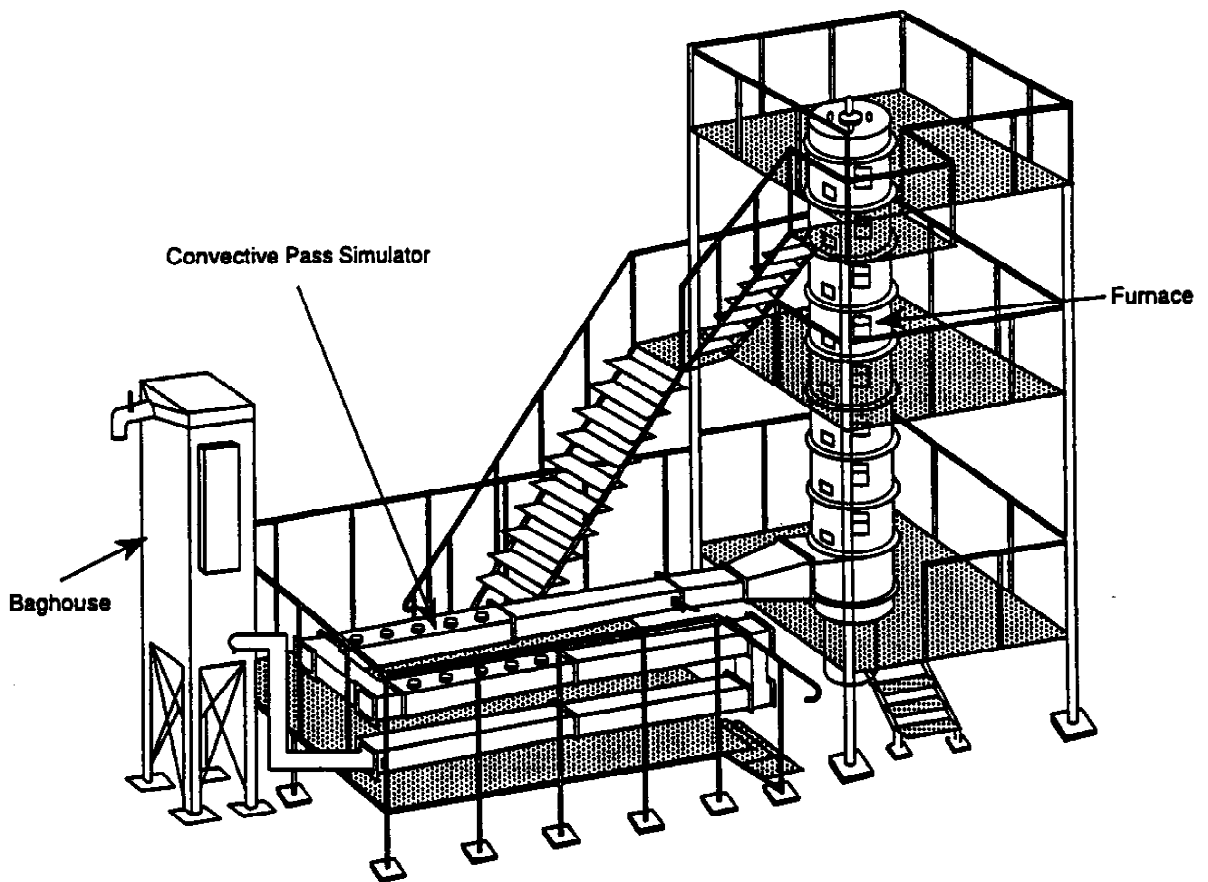


Figure 3. Schematic of pilot-scale test facility.

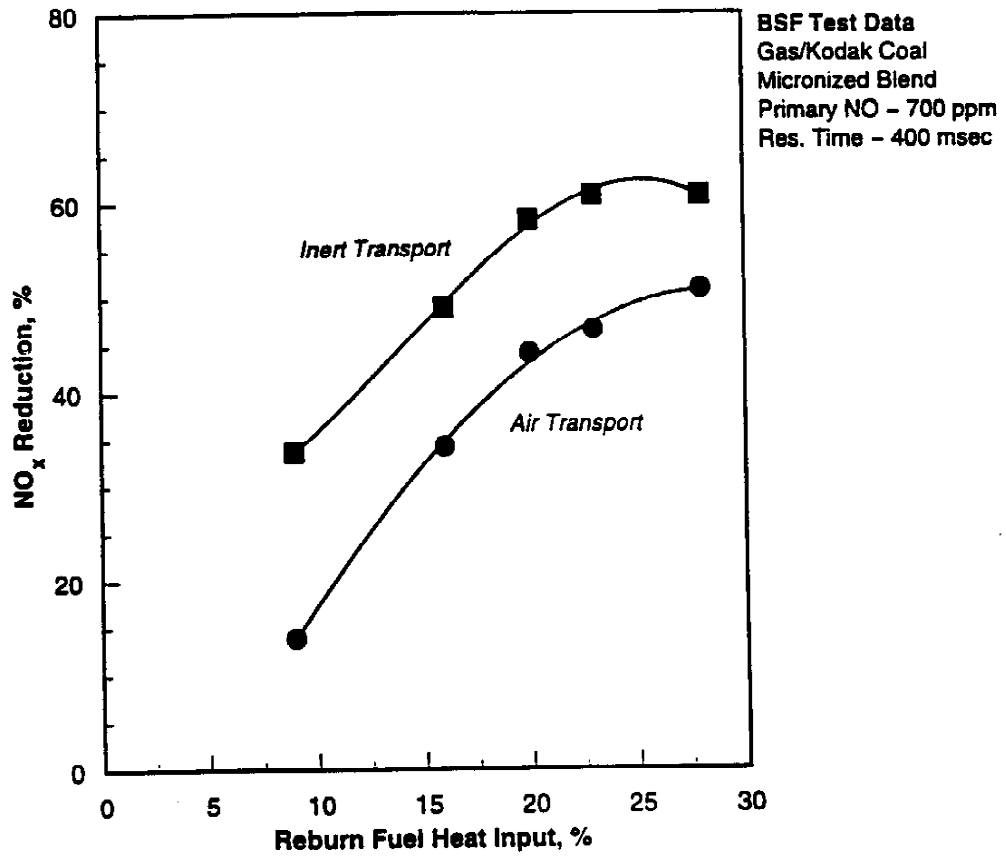


Figure 4. NO_x control performance achieved with Kodak coal using air or simulated FGR for transport.

same reburn zone stoichiometry in comparison to the use of an inert transport. For the use of inert transport medium, the data show that increasing the quantity of reburning fuel used improves NO_x control up to about 25 percent reburn fuel addition. Increasing the reburning fuel above this level does not result in an increase in performance. For the use of air as a transport medium, a slight increase in performance is achieved when the reburn fuel heat input is increased above 25 percent. However, previous studies have shown that the performance improvement decreases when the amount of reburn fuel is increased above 30 percent.

Kinetic studies of reburning chemistry have shown that an optimum in reburn zone stoichiometry, or reburn fuel usage, exists due to the generation of peak concentrations of CH radicals at a stoichiometric ratio near 0.9. Increasing the amount of reburning fuel added to the reburning zone does not result in an increase in radical concentrations above these peak levels. Hence, no further benefit of increased reburn fuel usage is observed. For fuels containing bound-nitrogen species, such as coal, further increases in the quantity of reburn fuel used above the optimum level can have a negative impact of reburn performance, since the additional fuel nitrogen added to the reburn zone does not have an opportunity to be processed under favorable conditions.

As discussed later in this report, the reburning zone residence time is a key consideration for application of coal reburning to Kodak Boiler No. 15. The size of the furnace and available access for the location of reburn fuel and overfire air injectors limit the residence time which can be achieved in the furnace. Based upon the injection elevations identified for the Kodak boiler, a nominal bulk residence time of nearly 500 milliseconds is expected. The impact of reburning zone residence time on coal reburning is shown in Figure 5. Increasing the reburning zone residence time from 400 to 600 milliseconds did not have a significant impact on the NO_x control performance achievable with the bituminous coal fired by Kodak. However, reductions in the furnace residence time would be expected to have a negative impact of reburn performance.

The impact of the initial NO_x level entering the reburning zone is shown in Figure 6. This figure shows the NO_x reductions achieved as a function of the primary NO_x level for coal reburning with both air and inert transport media. In general, the performance of coal reburning appears to decrease as the initial NO_x level is decreased below 600 ppm. At NO_x emissions levels, typical of the Kodak boiler operation (i.e., 700 to 900 ppm), the effects of primary NO_x level on reburning effectiveness are expected to be minor.

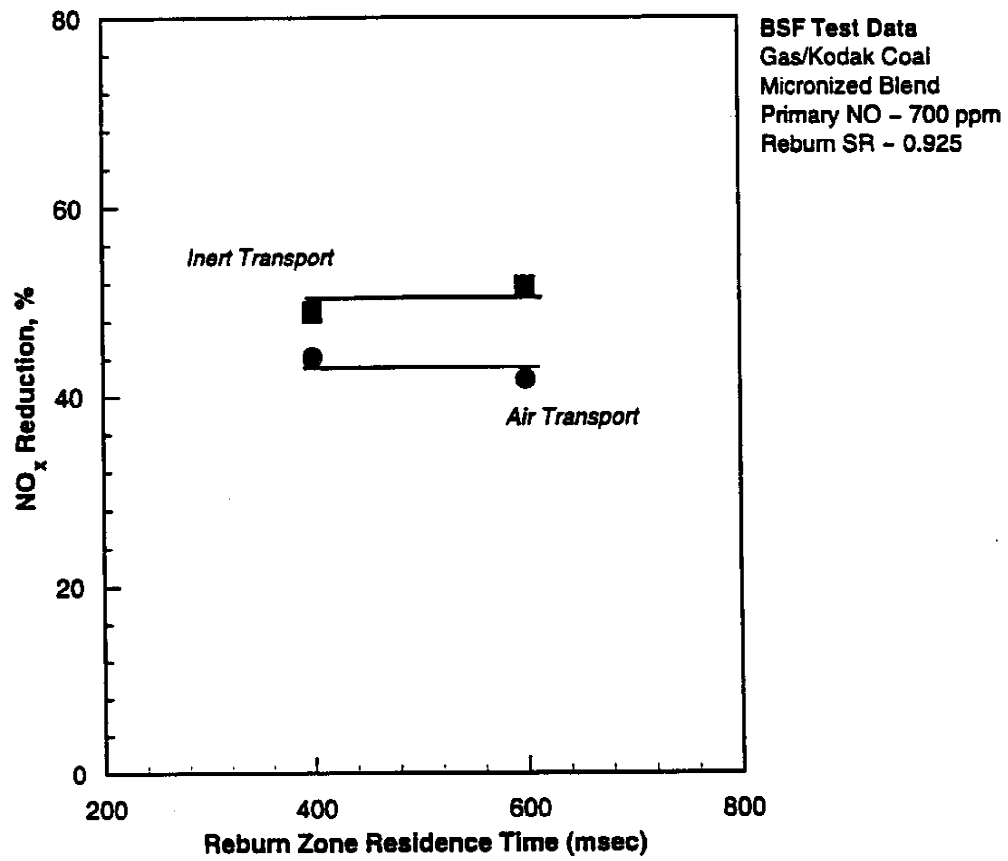


Figure 5. Impact of increasing residence time on coal reburn performance.

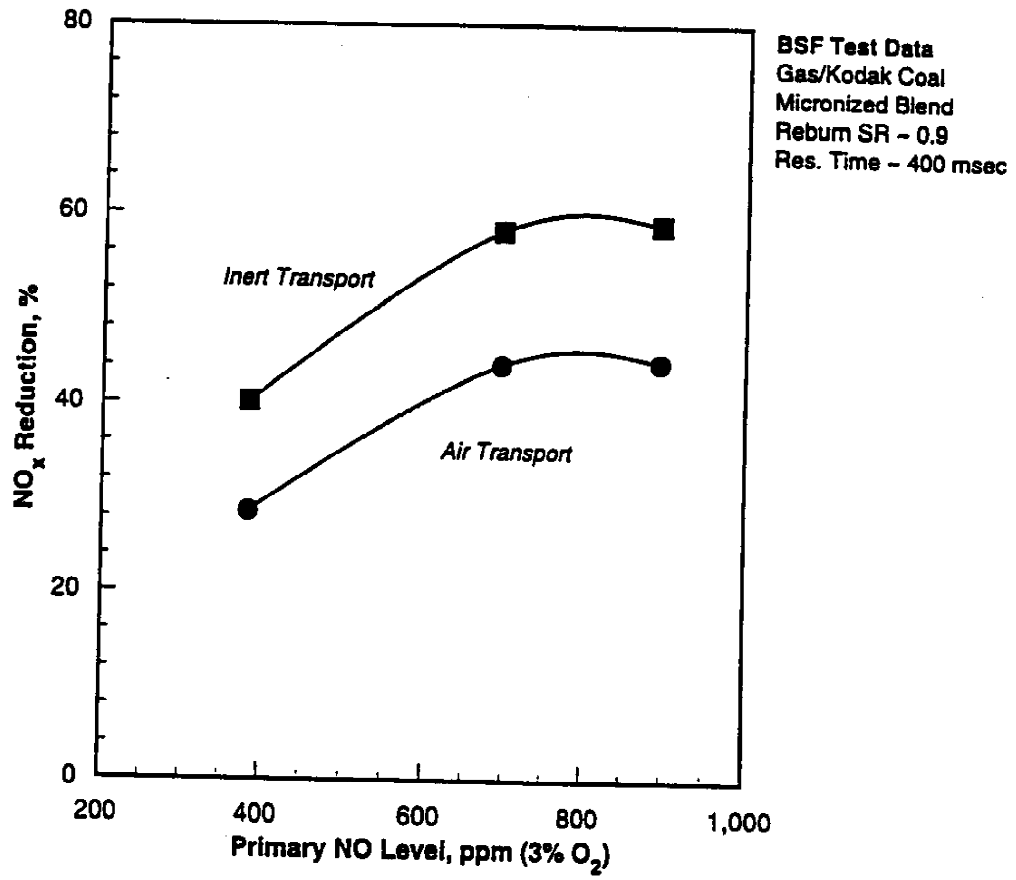


Figure 6. Impact of primary NO_x level on coal reburn performance.

In summary, the results of these experiments indicate that the bituminous coal fired by Kodak can be used as an effective reburning fuel at the conditions typical of Boiler No. 15. Comparison of the results of this study against EER's database on reburning fuels indicates that the trends obtained with the bituminous coal fired by Kodak are similar to those which might be expected for a fuel with similar characteristics. Comparison of the performance of the bituminous coal fired by Kodak to other lignitic, subbituminous, and bituminous coals, and to natural gas, tested on the pilot-scale facility as similar conditions, as shown in Figure 7, indicates that the bituminous coal fired by Kodak is only a moderate reburning performer. This comparison suggests that the use of reburning coals more reactive than the current coal could result in further reductions in NO_x emissions. At initial NO_x levels and bulk residence times representative of the Kodak furnace, NO_x reductions of approximately 60 percent were achievable when using simulated FGR as a transport fuel, while 50 percent control was achievable using air as a transport. Achieving these levels of control at full scale will be dependent upon the extent to which effective mixing of the reburning fuel can be achieved, and the extent to which the furnace flow field characteristics impact the reburning zone residence time.

3.0 Design Approach

The pilot-scale tests discussed in the preceding section have confirmed the overall viability of using the bituminous coal fired by Kodak as a reburning fuel. The data indicate that high levels of NO_x reduction can be achieved provided that adequate residence time is provided in the reburning zone. EER's recommended approach for applying coal reburning to the Kodak boiler involves injection of the reburning fuel at an elevation in the furnace just above the exit height of the cyclones, and injection of overfire air at a distance downstream of the reburning fuel injection elevation selected to provide sufficient residence time in the furnace for the reburning zone, while providing adequate time for overfire air mixing prior to entrance of the flue gas into the generating bank. The proposed reburning fuel and overfire air injection elevations are shown in Figure 8. The bulk residence time between the reburning fuel and overfire air injection elevations is estimated to be approximately 500 milliseconds. However, as discussed in Section 4, the general flow field in the boiler is extremely complex, and the effective residence time in the reburning zone is estimated to be less than half of this value.

The elevations shown in Figure 8 are relatively free from obstructions; however, the proposed overfire air elevation is close to the platform at Elevation 245'. Movement of the overfire air

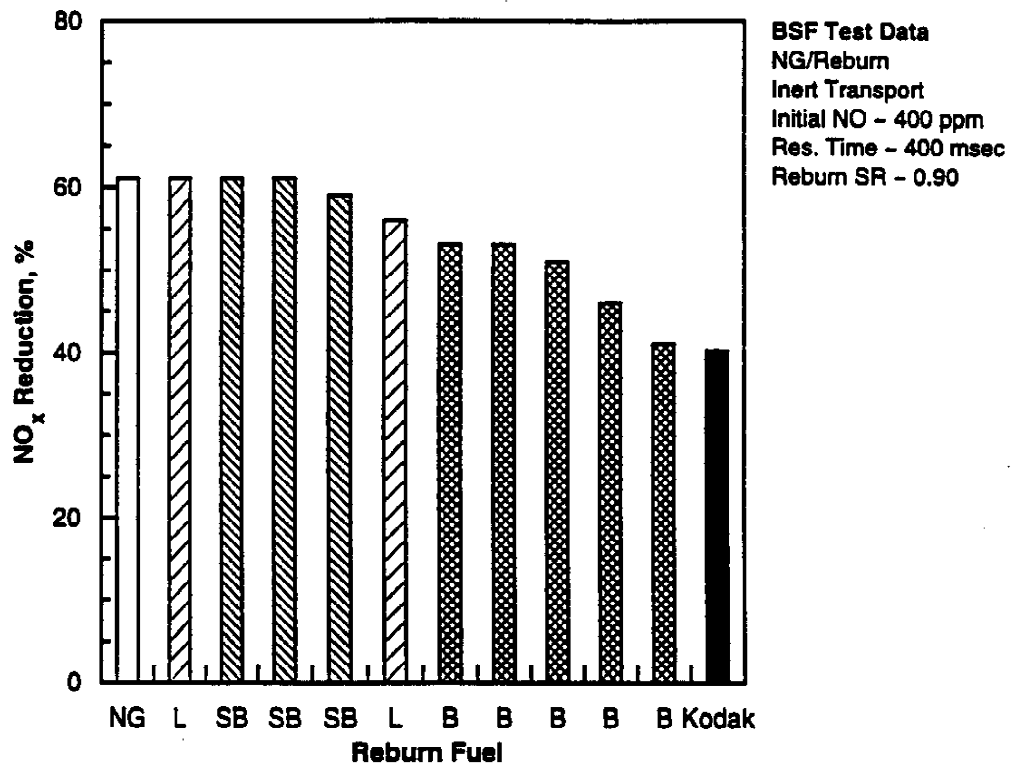


Figure 7. Comparison of NO_x control performance of Kodak coal to other coals and natural gas.

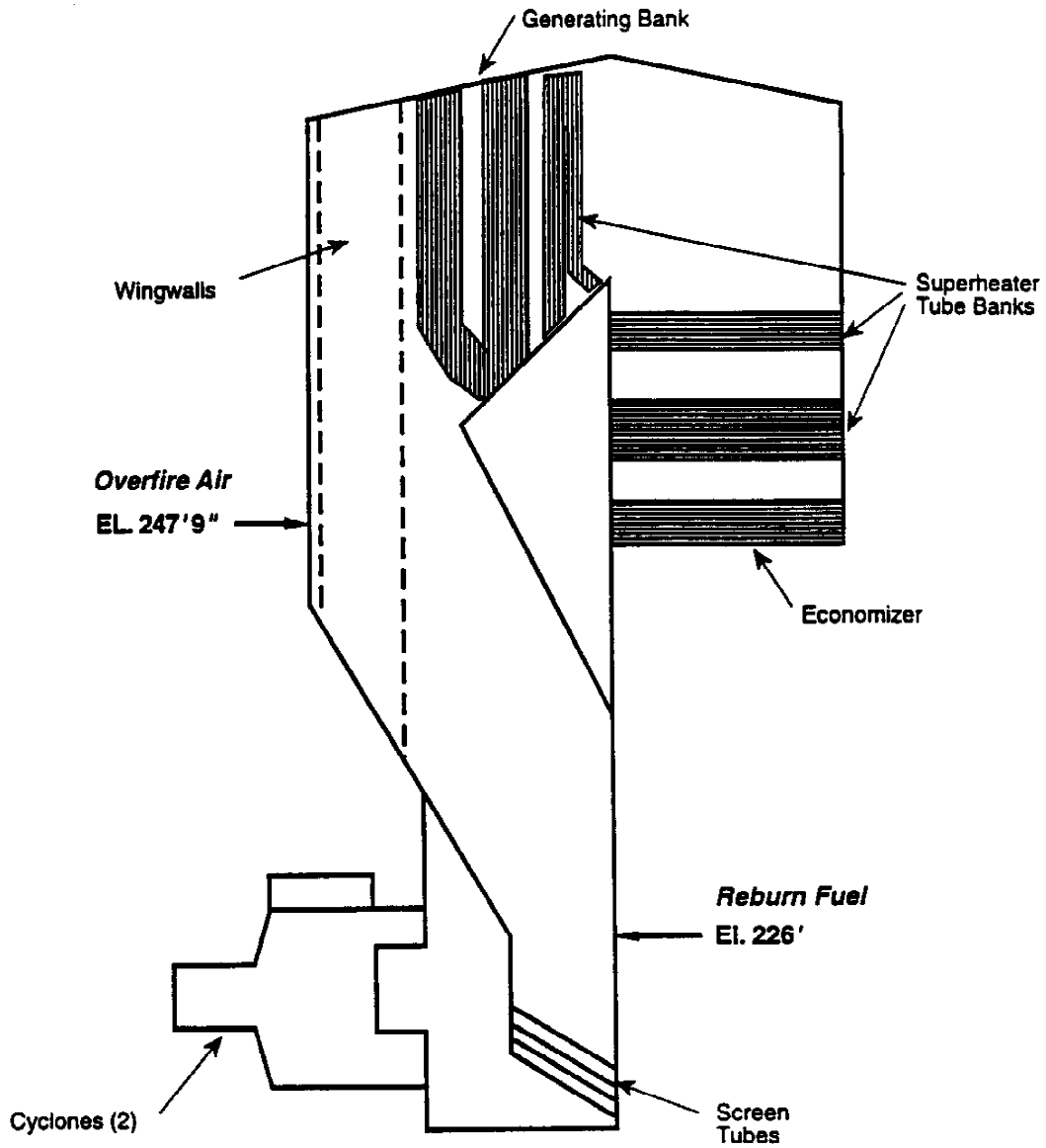


Figure 8. Proposed reburn fuel and overfire air injection elevations for Kodak Boiler No. 15.

elevation lower in the furnace will decrease the available residence time in the reburning zone resulting in a reduction in NO_x control, while a higher elevation will increase the reburning zone residence time and NO_x control, but at the potential expense of an increase in carbon monoxide emissions and unburned carbon. Therefore, EER does not recommend relocating the overfire air elevation at this time.

In applying the coal reburning process to the Kodak boiler, the design of the reburning fuel and overfire air injectors must provide rapid mixing of the reburning fuel and overfire air in order to maximize emissions control and to minimize carbon dioxide emissions and unburned carbon. In full-scale applications of reburning technology to date, some means of enhancing the mixing and distribution of the reburning fuel has been needed. This requirement is driven by the need to rapidly mix the relatively small quantity of reburning fuel with a much larger quantity of flue gas over the large cross section typical of most boiler furnaces. The use of recycled flue gas or FGR has been the preferred means of improving reburning fuel mixing. FGR can have a negative impact on boiler performance, although the impacts of recycled flue gas on boiler performance depends on a number of factors such as the extent to which the heat absorption profile is modified by reburning and the quantity of FGR used for controlling reburning fuel mixing. For the use of coal as a reburning fuel, a means of transporting the coal to the boiler is also needed. This transport can be FGR or air. However, as shown by the results of the pilot-scale tests, the use of air as a transport medium has a negative impact on NO_x reduction performance, and requires the use of additional reburning fuel to reach optimum reburning zone stoichiometries.

Since only front wall injection of the overfire air is feasible on the Kodak boiler, the overfire air system must be designed to provide good jet penetration as well as good lateral dispersion across the boiler depth and width. These goals must be accomplished using a relatively small quantity of overfire air, and in the face of a relatively high cross stream velocity. In addition, the overfire air system must be designed to provide some flexibility to respond to changing boiler conditions. EER's approach to the design of an effective overfire air system uses a double-concentric nozzle which produces two air streams which can be controlled for good mixing and operational flexibility. The design developed for the Kodak boiler was used successfully in EER's second generation gas reburning system installed at Public Service of Colorado's Cherokee Station.

Kodak has indicated that Boiler No. 15 typically operates at steam generation rates between 300,000 to 400,000 lb/hr. The boiler can also be operated at a peak steam generation rate of 440,000 lb/hr. At

steam loads below 300,000 lb/hr, slag freezing can occur. In addition, Kodak has indicated that it would be desirable to operate the reburning system over as wide a range of boiler operation as possible. The relationship between boiler load and coal flow to the cyclones is illustrated in Figure 9 for various assumed levels of reburn fuel heat input. As indicated in this figure, the minimum coal flow to the cyclones, corresponding to a steam generation rate of 300,000 lb/hr, is approximately 26,000 lb/hr. At this load, no reburning fuel could be injected since it would require operation of the cyclones below the minimum coal flow rate necessary to maintain acceptable slag tapping. Boiler load can be increased from this level by adding fuel through the reburning system. At a steam generation rate of 335,000 lb/hr, it would be possible to operate the coal reburn system to provide approximately ten percent of the total boiler heat input. As load is increased above this level, the level of coal reburning could be increased to higher levels, and hence, higher levels of NO_x control could be achieved. At the nominal boiler full load of 400,000 lb/hr, approximately twenty percent of the total boiler heat input could be supplied by the reburning system. Up to thirty percent of the boiler heat input could be supplied by the reburning system at the boiler maximum continuous rating.

Assuming that the minimum allowable coal flow to the cyclones is approximately 26,000 pounds per hour with the current coal fired at the plant, it is possible to construct a curve of the maximum level of reburning which can be sustained as a function of load. The resulting curve is shown in Figure 10. This figure also shows the level of reburning which can be achieved using a single Fuller micromill with a capacity of 8,000 pounds per hour. At boiler loads up to approximately 375,000 pounds per hour of steam, the level of reburning which can be achieved with a single micromill is equivalent to the maximum level which can be applied without encountering slag tapping problems. At boiler loads above 375,000 pounds per hour, the maximum level of reburning which can be achieved with one mill in operation is between 20 to 22 percent. EER understands that Fuller will guarantee the performance of the mill only to 8,000 pounds per hour. Given that the guaranteed capacity of the mill will limit the reburn system operation to substantially less than the maximum level of reburning which could be utilized at loads above 375,000 pounds per hour, EER recommends that the reburn system be designed to provide coal from both of the mills to the reburning fuel nozzles. Operation with two mills in service will ensure that Kodak has sufficient flexibility to achieve the highest levels of NO_x control possible by maximizing the reburn fuel usage, and should provide sufficient margin in the system design should operation of the cyclones at lower than normal excess air levels not be possible. However, a critical aspect of this design is the approach for accommodating operation with only one mill in service, for times when one mill is under repair.

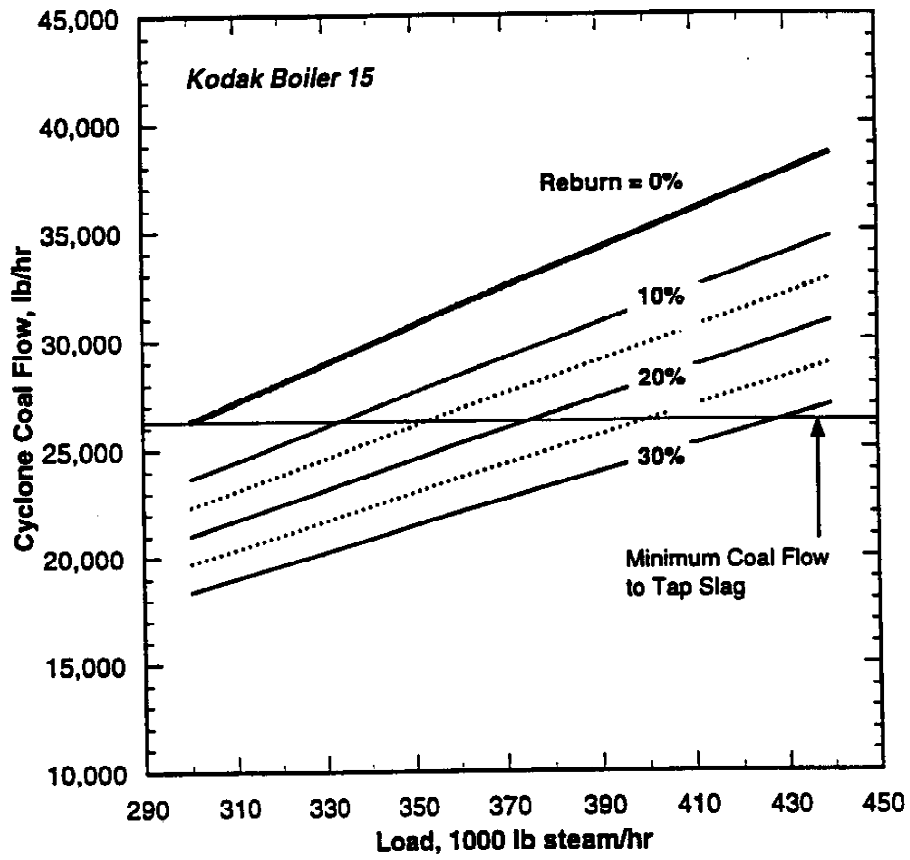


Figure 9. Cyclone coal flow rate verses load and reburn system operation.

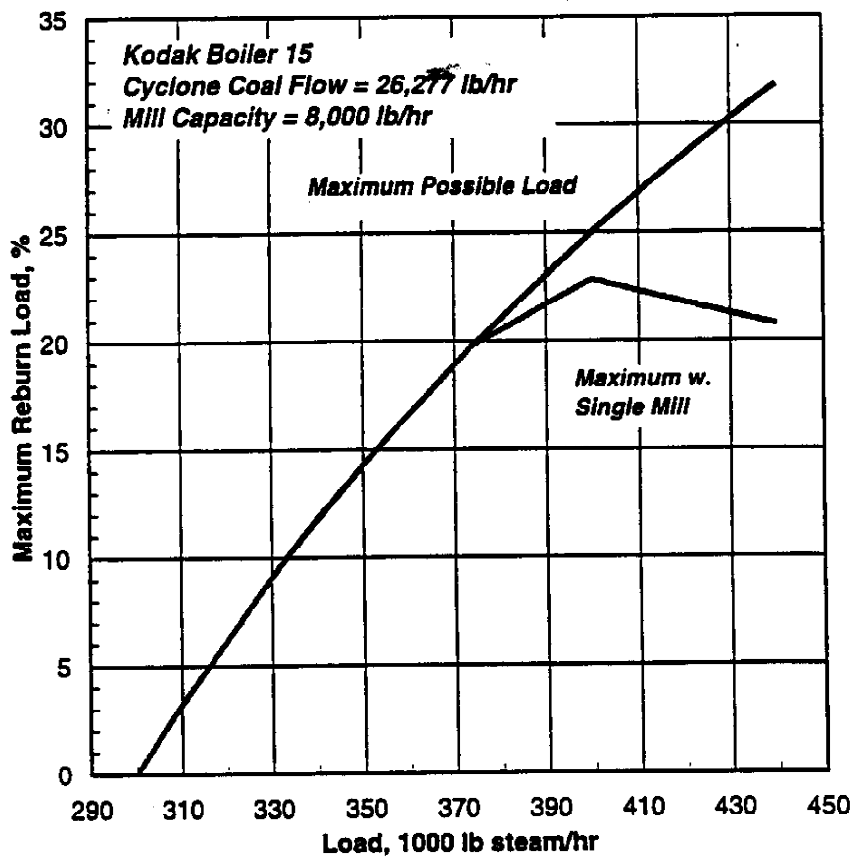


Figure 10. Maximum level of reburn system operation achievable while maintaining minimum coal flow to cyclones.

Although adequate mixing of the reburning fuel could be achieved with either air or recycled flue gas as the transport medium, the limited levels of reburning fuel which can be added to the boiler over the boiler load range, and the need for relatively high levels of control imply that only FGR should be considered for use as an injection and transport medium. In discussions with Fuller, Fuller has indicated that the use of FGR should not have an impact on mill operating performance provided that the mill outlet temperature can be controlled. Therefore, EER recommends that this option be used for application of coal reburning to Kodak boiler 15. The results of the process design studies discussed in the following section indicate that effective reburning fuel mixing can be achieved at FGR levels between five to ten percent. In the process design studies, EER has assumed that clean flue gas will be taken from the outlet of the electrostatic precipitator, and that a water quench system will be used to cool the flue gas to control the mill outlet temperature.

The basis for the coal reburning system design is shown in Table 1. The fuel analysis used in the system design is shown in Table 2. The reburning system design was based on the maximum steam generation rate of 440,000 pounds per hour. Based upon the specifications shown in Table 1, the process flow sheet and material balance for reburning with coal at the maximum load shown in Figure 11 and Table 3 were developed. The operating stoichiometries selected in the process design basis reflect values which are expected to maximize the NO_x reduction achieved with the reburning system while minimizing the impacts of reburning on overall boiler performance. For the primary zone, the cyclone burners will be operated at an excess air level of approximately thirteen percent. This excess air level is consistent with the requirements for normal cyclone operation, but is lower than that typical of the current boiler operation. At the maximum steam flow, the reburning zone will be operated at a stoichiometry of approximately 0.8, which is based upon operation at the maximum reburn coal flow for this load. Operation with this coal flow is consistent with the desire to maximize the NO_x reductions achievable with the reburning system. Finally, the burnout zone will be operated at the boiler normal excess air level of fifteen percent.

Figures 12 and 13 shown proposed curves of cyclone coal flow, reburn fuel flow, and overfire air flow as a function of the boiler steam generation rate. In Figure 12, the amount of coal used in the reburning system corresponds to the maximum allowable value which can be added through the reburning system while still maintaining acceptable slag tapping levels. As shown in Figure 12, EER proposes that boiler load be controlled by increasing the reburning fuel flow rate for boiler loads between 330,000 to 440,000 pounds per hour. At boiler loads below this level, the reburning

TABLE 1. COAL REBURNING SYSTEM PROCESS DESIGN BASIS

Parameter	Units	Value
Load		
Steam Flow	lb/hr	440,000
Zone Stoichiometry		
Primary Zone		1.13
Reburning Zone		0.79
Burnout Zone		1.15
Reburning Fuel	lb/hr	12,000
Transport Type		FGR
Transport Flow	lb gas/lb fuel	1.25
Total FGR Use		6.8%

TABLE 2. COAL ANALYSIS

Parameter	Units	Value
Proximate Analysis:		
Carbon	wt. %	73.38
Hydrogen	wt. %	4.94
Nitrogen	wt. %	1.33
Sulfur	wt. %	2.25
Oxygen	wt. %	4.84
Chlorine	wt. %	0.11
Ash	wt. %	7.15
Moisture	wt. %	6.00
<i>Total</i>		<i>100.00</i>
Higher Heating Value	Btu/lb	13,192

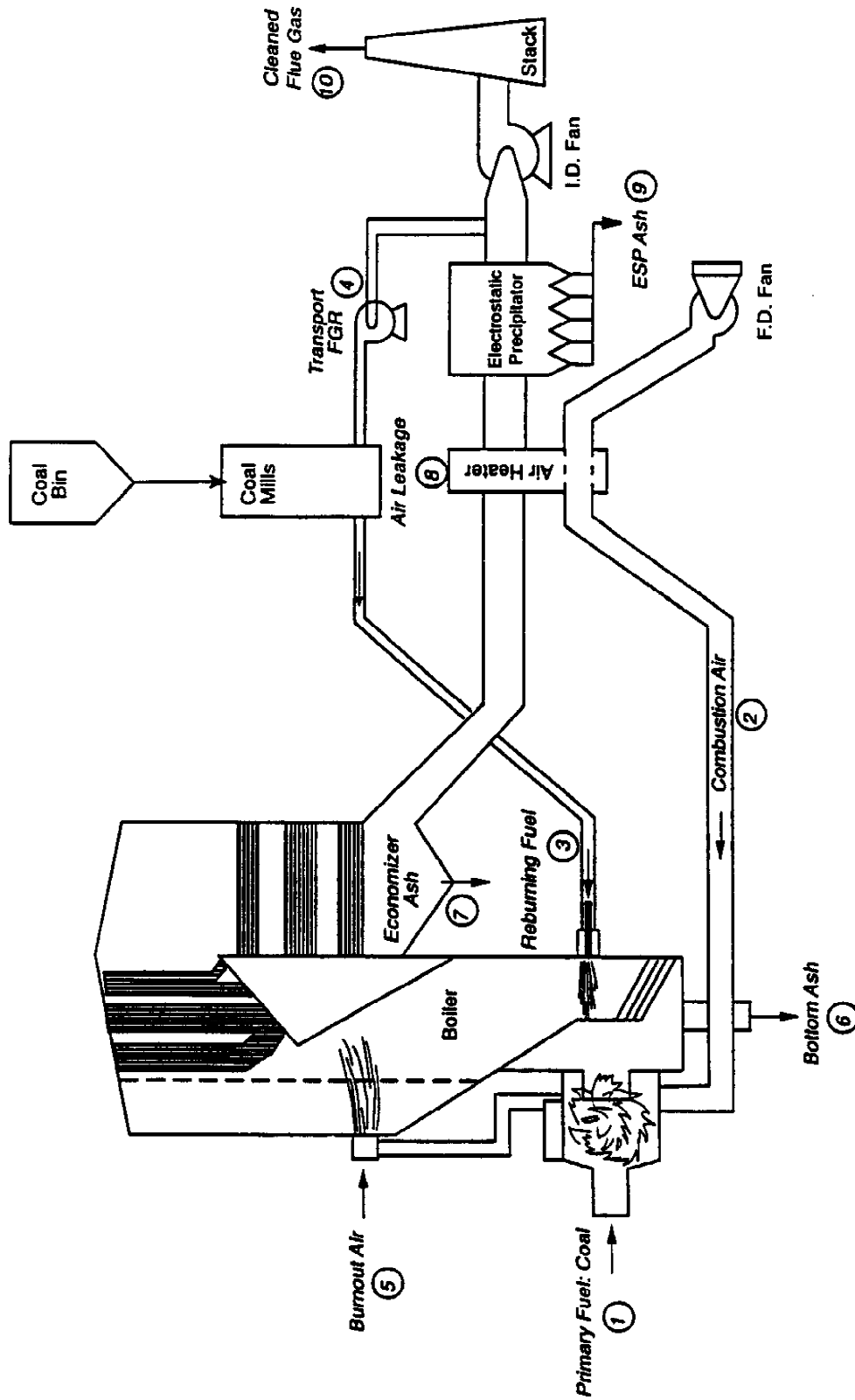


Figure 11. Coal reburning process flow diagram for Kodak Unit 15.

TABLE 3. COAL REBURNING MATERIAL BALANCE FOR MAXIMUM BOILER LOAD (440,000 LBS/HR)

STREAM NUMBER	1	2	3	4	5	6	7	8	9	10
DESCRIPTION	Primary Fuel: Coal	Coal Combustion Air	Reburning Fuel: Coal	Reburning Fuel Transport	Overfire Air	Boiler Bottom Ash	Economizer Hopper Ash	Air Heater Leakage	ESP Ash	Flue Gas to Stack
GAS SIDE:										
Air (lbs/hr)		298,779			138,884			0		
Air (SCFM)		65,008			30,218			0		
Natural Gas (lbs/hr)										
Natural Gas (SCFM)										
Flue Gas (lbs/hr)				32,000						473,445
Flue Gas (SCFM)										94,825
SOLID SIDE:										
Fuel (lbs/hr)	26,539		12,000							
Fuel Inerts (lbs/hr)	1,898		858			1,424	38		1,295	
Total Waste Solids (lbs/hr)	1,898		858			1,424	38		1,295	

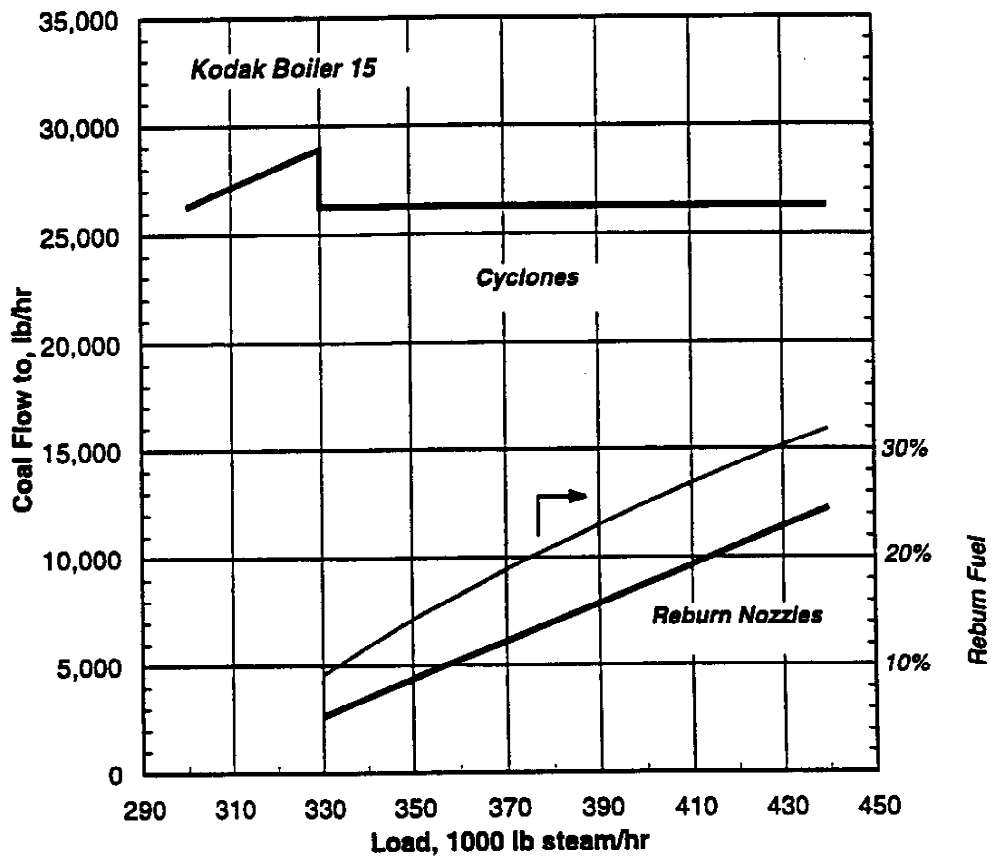


Figure 12. Coal flow rate to cyclones and reburn fuel nozzles over load range, for maximum NO_x control.

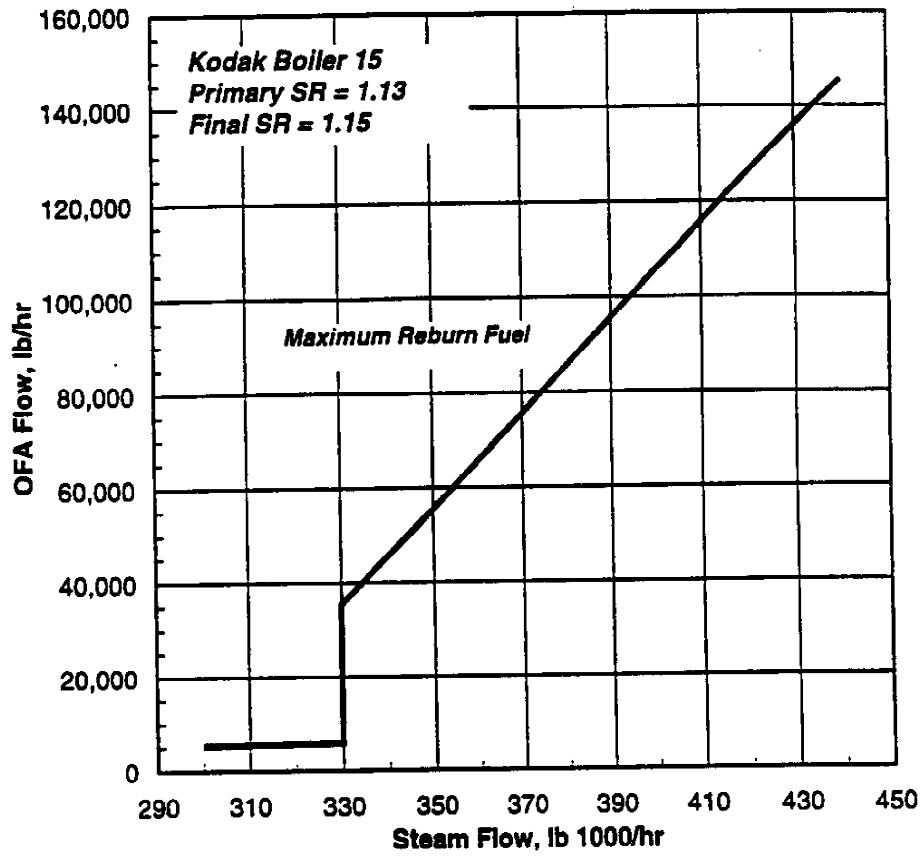


Figure 13. Overfire air flow rate to maintain fifteen percent excess air verses load.

system would be taken out of operation, except for cooling air added through the reburn fuel and overfire air ports.

4.0 Coal Reburning System Process Design

To develop injector specifications which would result in effective mixing of the reburning fuel and overfire air, an isothermal flow model of Boiler No. 15 was constructed. The model is approximately 1:8 scale and provides a detailed simulation of the furnace from the burners through the first horizontal tube bank of the superheater. The wingwalls and lower furnace screen tubes were also simulated in the model. The model was constructed of acrylic to provide a high level of visual access. Following construction of the model, it was connected to one of the test stands in EER's Aerodynamics Modelling Facility, located in Irvine, California.

Flow visualization studies were performed to define the characteristics of the bulk model flow field. Flow visualization was conducted using neutrally buoyant bubble tracers. These tracers were used to identify general furnace flow patterns and flow streaklines. Bubbles were injected through the cyclone burners and followed the burner flow as it developed through the furnace thereby revealing bulk flow features of the furnace flow field such as recirculation, swirl, and turbulence intensity. A general sketch of the model flow field is illustrated in Figure 14. As shown in this figure, the flow passing through the screen tubes in the lower furnace turns upward and flows into the upper furnace. Due to the rapid expansion of the furnace above the cyclones, a large recirculation zone develops in the front portion of the furnace. The flow exiting the lower furnace is highly biased towards the rear wall of the furnace. The nose located on the rear wall constricts the furnace area, and defines the location of the point of closure of the recirculation zone which forms above the cyclone. This results in the generation of an upper furnace velocity distribution at the nose plane which is biased towards the generating bank. The furnace flow then negotiates the turn into the generating bank in the upper furnace.

The bulk flow field characteristics were further quantified by velocity measurements at two cross sections within the model furnace. The two planes selected for analysis consisted of the reburning fuel and overfire air injection elevations. The results of the velocity measurements are shown in Figure 15, which shows the upward component of the velocity measurement normalized to the mean reference value. In general, the flow field is complex, and highly three dimensional. The velocity measurements performed at the reburn fuel injection elevation confirm the general fea-

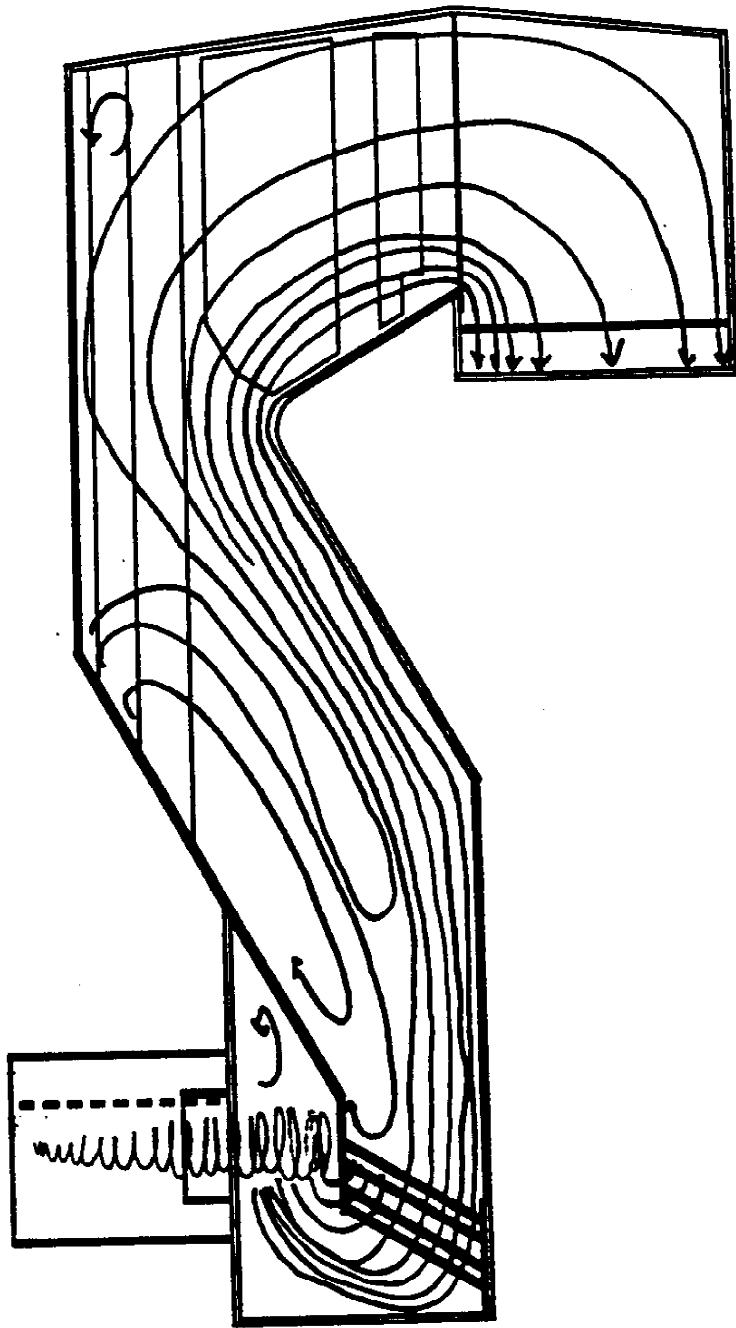
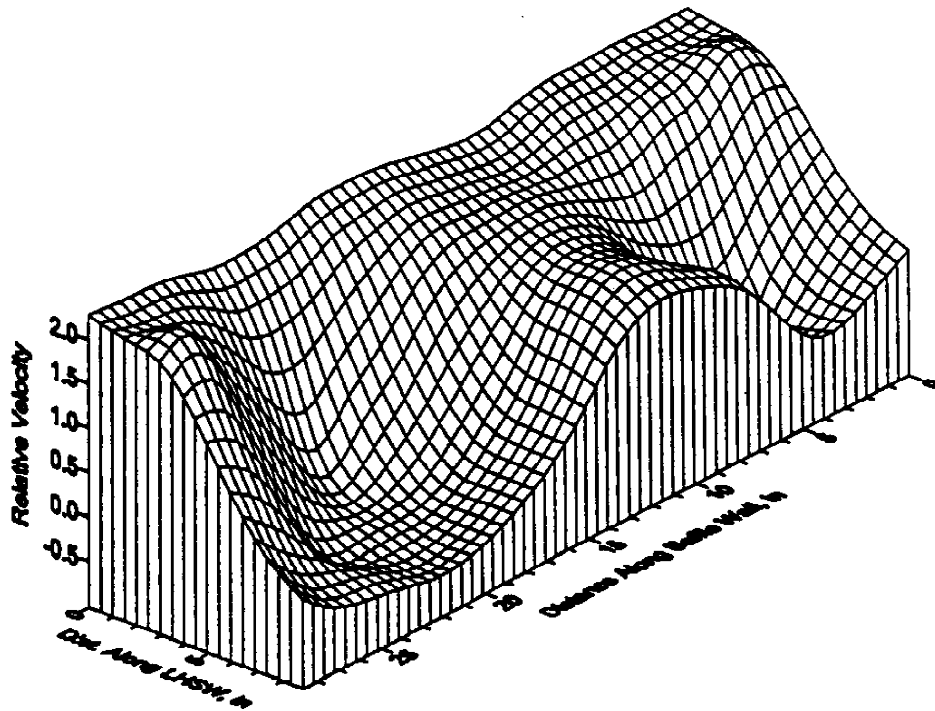
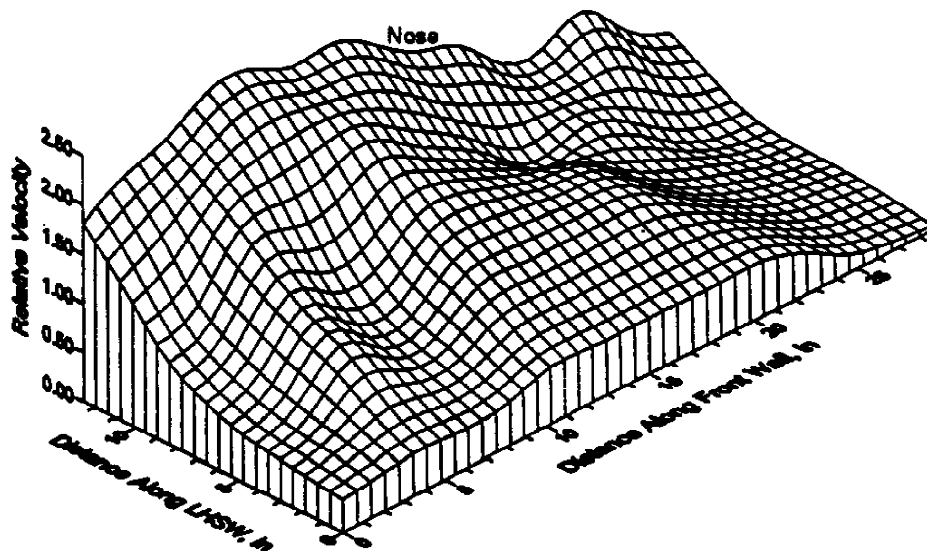


Figure 14. Sketch of general flow field features observed in isothermal flow model of Boiler No. 15.



(a). Velocity profiles at reburning fuel injection elevation (226°).



(b). Velocity profiles at nose elevation.

Figure 15. Velocity profiles measured in isothermal flow model.

tures shown in the flow field sketch. High velocities near the rear wall, and a recirculation zone near the screen tubes. High velocities were also measured along the rear wall at the overfire air elevation.

The large recirculation zone which forms in the furnace is expected to have a negative impact on reburn performance. First, since the recirculation zone forces the main upward flow to occupy a substantially smaller area than the furnace cross section, the residence time of the bulk gases in the reburning zone is substantially reduced. Second, flow visualization of the overfire air jets indicate that there is a tendency of overfire air to be entrained into the recirculation zone, and to be recirculated to the lower furnace. Entrainment of overfire air into the reburning zone will increase the effective reburning zone stoichiometry. Both of these factors indicate that the reburning fuel injection system should be designed to provide extremely rapid mixing of the reburning fuel. This requirement points to the need for using multiple small-diameter, high-velocity injectors for the reburning fuel injection system.

Following characterization of the model flow field, preliminary designs for the reburning fuel and overfire air were screened using smoke tracers. Smoke was added to the simulated reburning fuel and overfire air jets to evaluate the jet penetration characteristics. The results of these studies indicated that reburning fuel jet velocities in the range of 250 to 300 feet per second are necessary to ensure that the reburning fuel jets achieve sufficient penetration into the flow field. In addition, overfire air jet velocities between 450 to 500 feet per second are needed to ensure that the overfire air jets penetrate into the high velocity flow near the rear wall of the boiler.

Once the ideal jet penetration characteristics had been established, the mixing performance of various reburn fuel and overfire air injection systems were quantitatively analyzed using dispersion measurement techniques. In this technique, tracer dispersion measurements are taken in a cross-sectional plane in the furnace model downstream of the injection elevation to quantify the mixing performance of a specific injection system. The dispersion measurement provides an indication of the local concentration of a tracer gas which is input through the injection system. The tracer gas, which is typically methane, is uniformly mixed in the air prior to injection through the jets into the model. The concentration level at selected points within the measurement plane can be related to the desired reburning zone stoichiometry by analytical means. The well-mixed concentration level is measured in the exhaust duct of the isothermal model where complete mixing is guaranteed. The point dispersion data are compared to the well-mixed condition and are normalized to the design

stoichiometry of the particular furnace region. An ideal injection system will achieve uniform dispersion which will result in a uniform stoichiometry at the measurement plane.

The results of dispersion measurements conducted for the proposed reburning fuel and overfire air injection systems are shown, respectively, in Figures 16 and 17. Figure 16 shows contours of the measured distribution of stoichiometry at a plane located in the reburning zone which corresponds to a residence time of approximately 200 milliseconds. In this figure, uniform mixing of the reburning fuel corresponds to a stoichiometry of 0.9. As indicated by the fact that a significant portion of the dispersion profile is near the target stoichiometry, the distribution of reburning fuel provided by this configuration is relatively uniform. This result is reflected in the coefficient of variation (COV) for this case, which is 0.34. A COV of zero implies uniform reburning fuel distribution. A COV of less than 0.4 is considered adequate for achieving good performance with a reburning system. Figure 17 shows contours of constant stoichiometry measured at the midpoint of the nose. In this figure, uniform mixing of the overfire air corresponds to a stoichiometry of 1.15. The results of this profile indicate that relatively good mixing of the overfire air can be achieved along the rear wall using the coaxial overfire air jet design, but that coverage in the area along the front wall is light. Preliminary measurements in the flow model indicate that the use of swirl in the outer passage can improve coverage in this region.

Based upon these studies, the proposed specifications for the reburning system are summarized in Table 4. The reburning fuel nozzles will utilize a single jet design where the coal transport line diameter is reduced at the nozzle to increase the velocity of the transport FGR and coal. This design minimizes the need for a boost stream. A high pressure FGR fan will be used to supply the transport flue gas stream. The reburning fuel nozzles should be located equally spaced along the rear wall of the furnace. To turndown the reburning fuel system, it is expected that the coal flow from the mill will be reduced, and that the total FGR flow rate to the nozzles will be maintained constant. This approach will permit effective mixing of the reburning fuel to be maintained at reduced reburn fuel flow rates.

The overfire air ports will utilize a coaxial jet design. The inner passage is designed to achieve good penetration of the core overfire air stream over the reburning system required operating range. The outer passage is designed to mix overfire air into the flue gas along the rear wall, and will be used to provide the majority of the overfire air system turndown capability. Figure 18 shows the recommended layout of the overfire air nozzles.

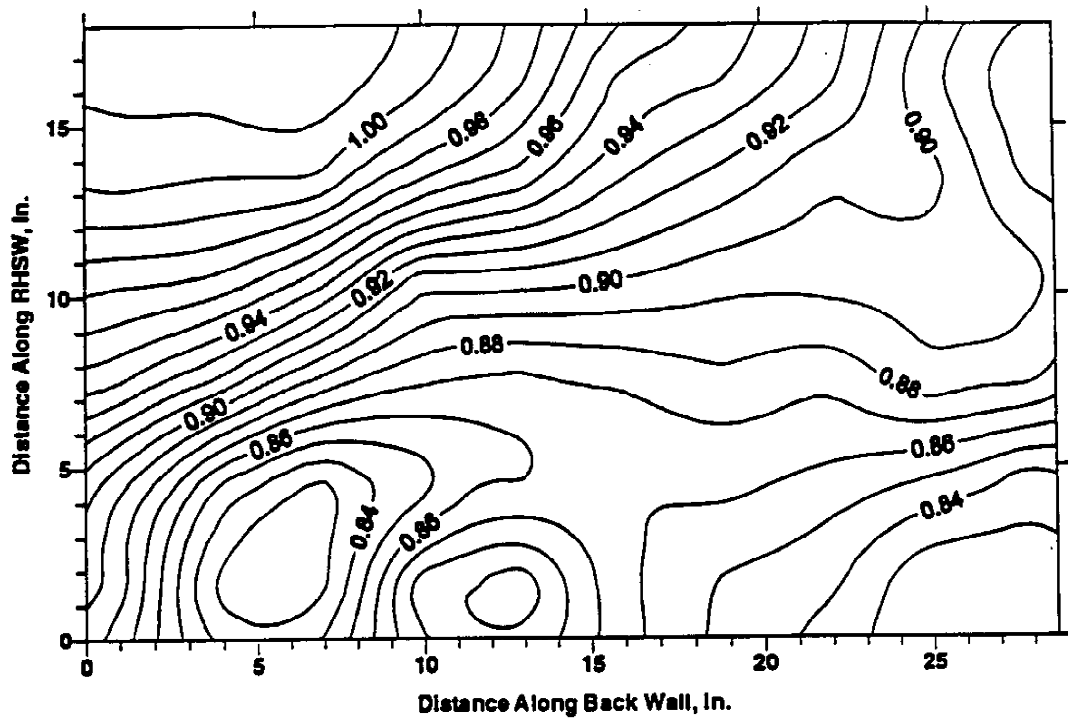


Figure 16. Reburn fuel dispersion for design case at 200 ms.
Reburn zone stoichiometry normalized to 0.90.

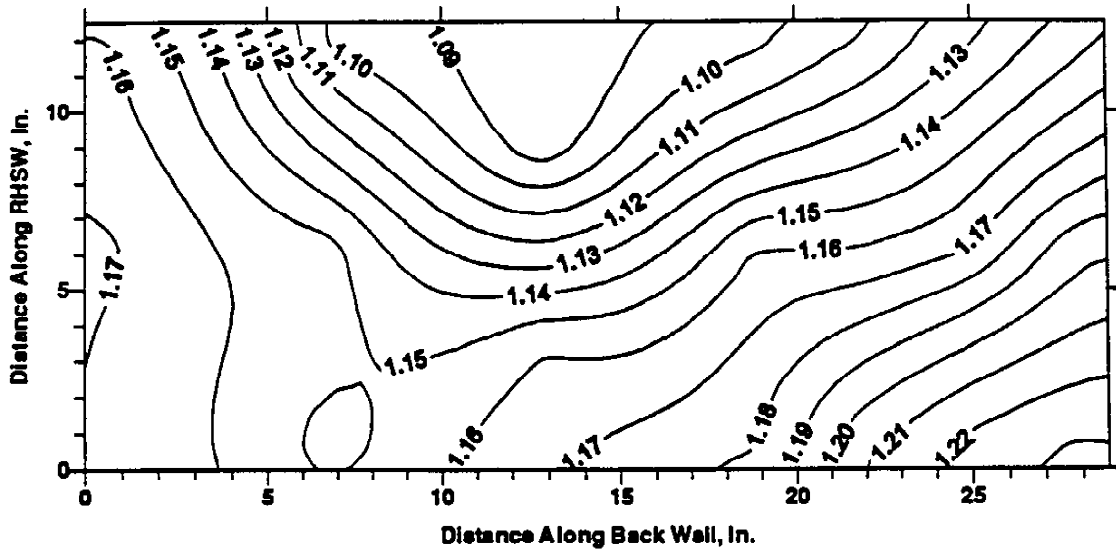


Figure 17. Overfire air dispersion for design case at 260 ms.
Final zone stoichiometry normalized to 1.15.

TABLE 4. REBURNING SYSTEM DESIGN PARAMETERS

Parameter	Units	Value
<i>Reburning Fuel</i>		
Elevation		226'
Number of Nozzles		8
Nozzle Size		
Furnace Outlet ¹	inches	3.6
Pipe Size	inches	5.0
Coal Flow		
Maximum	lb/hr	12,000
Minimum	lb/hr	2,500
Transport Flow	lb/hr	32,000
Velocity Head²		
Nozzle Outlet	in H ₂ O	16.5
<i>Overfire Air</i>		
Elevation		247' 9"
Number of Nozzles		4
Port Size		
Inner Passage		5.19
Outer Passage		11.37
Outer Diameter	inches	12.5
Flow Rate		
Maximum		140,000
Velocity Head³		
Inner Nozzle	in H ₂ O	25
Outer Nozzle	in H ₂ O	21

¹ Equivalent outlet diameter.

² Estimated, does not include loss across injector body.

³ Estimated, does not include loss across OFA assembly.

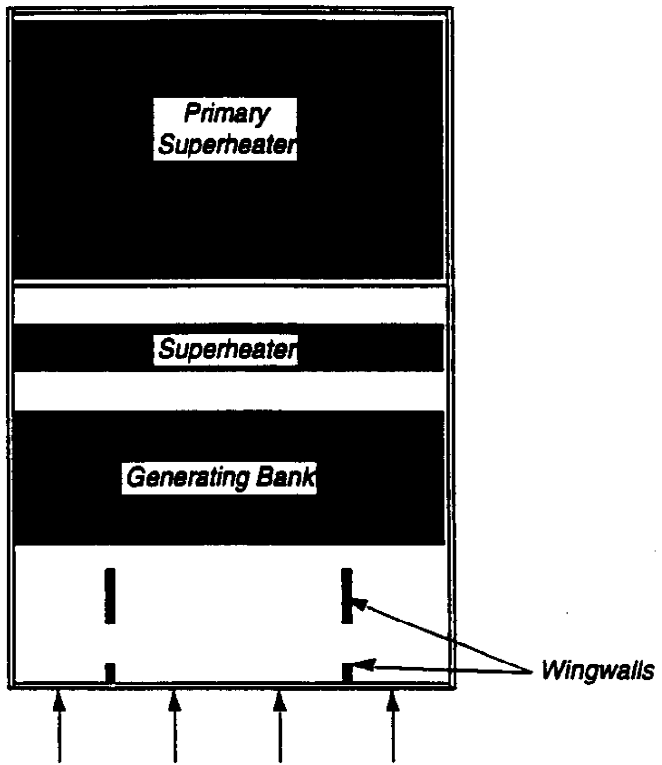
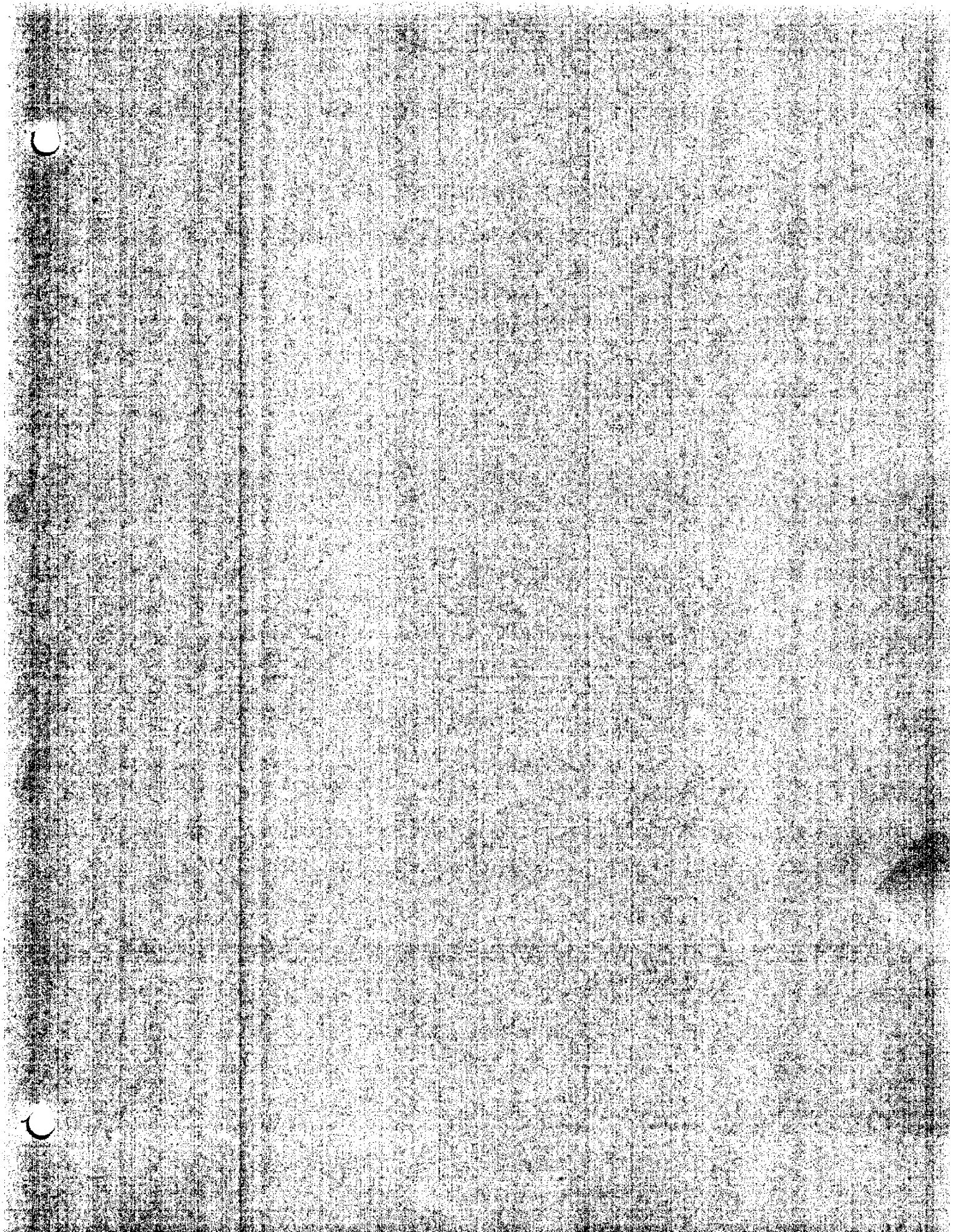
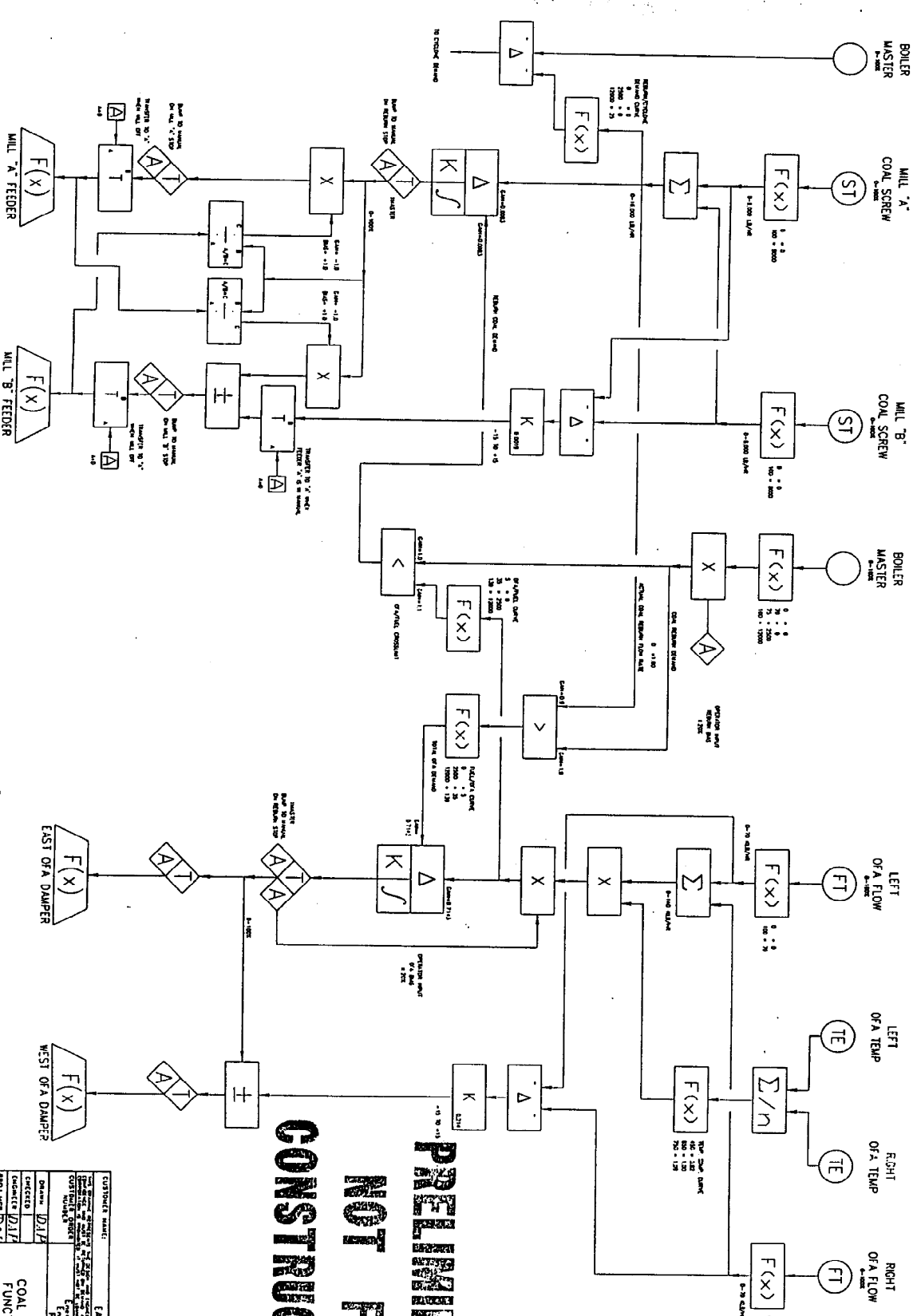


Figure 18. Layout of overfire air ports.



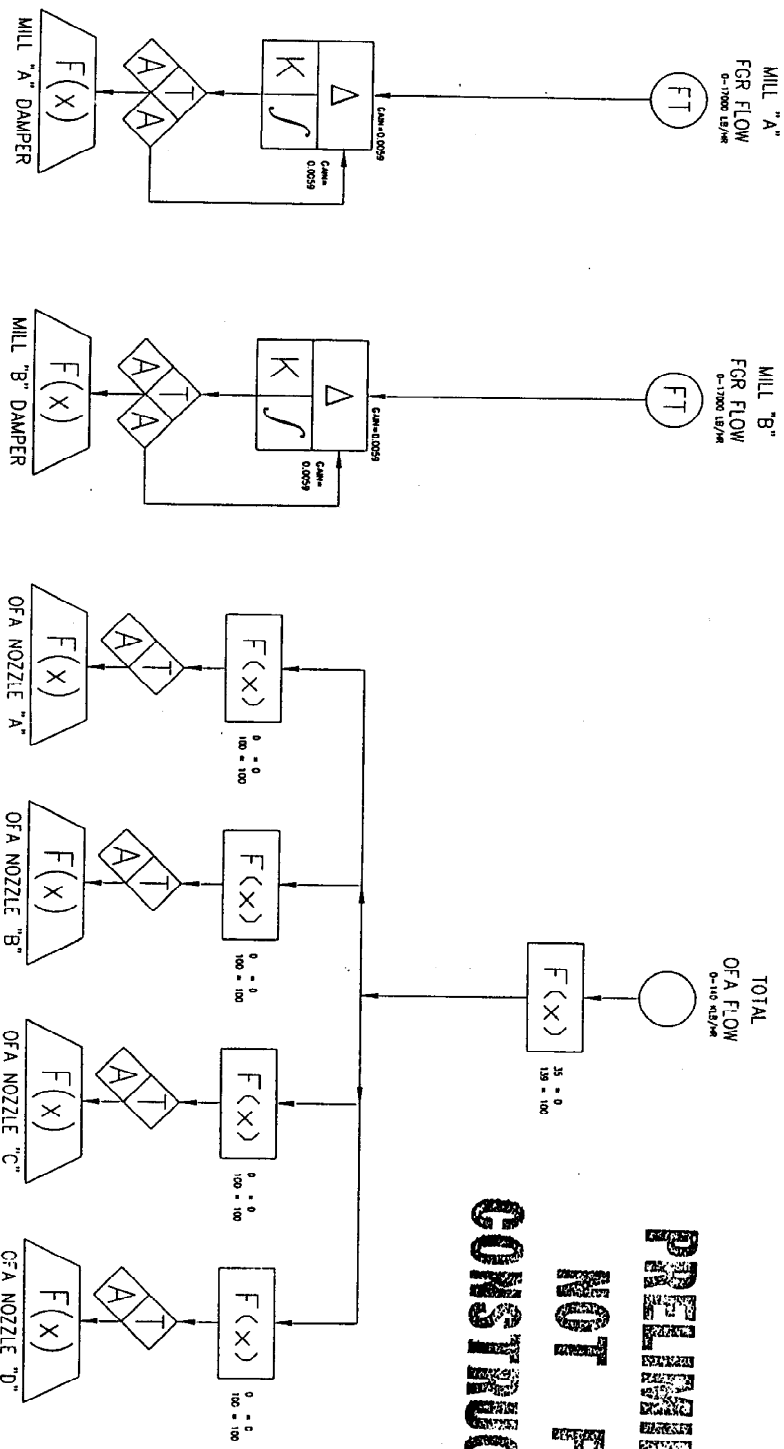
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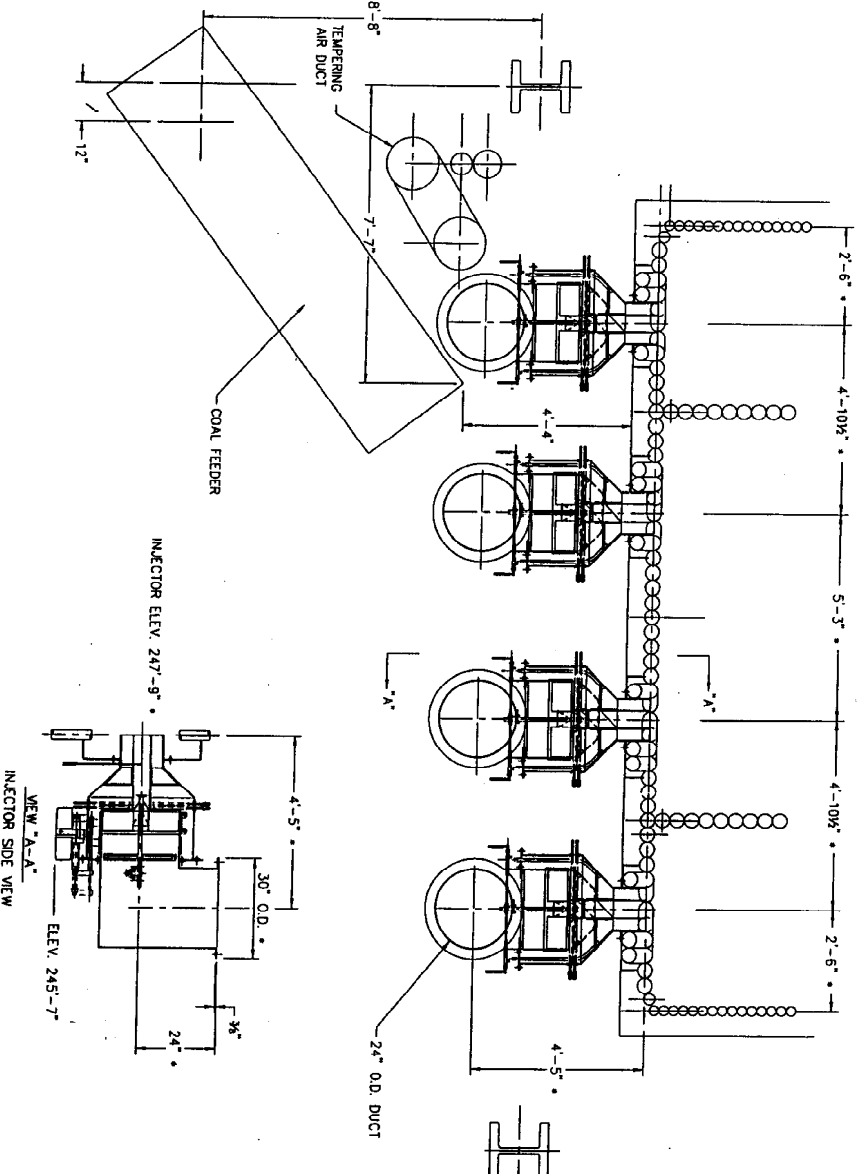
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PROJECT NAME:		COAL REBURN SYSTEM	
DRAWING NO.:		88821-003	
DATE:		1/81	
DESIGNED BY:		D.J.D.	
CHECKED BY:		D.J.D.	
DRAWN BY:		D.J.D.	
SCALE:		NONE	

REV. 10/10/80

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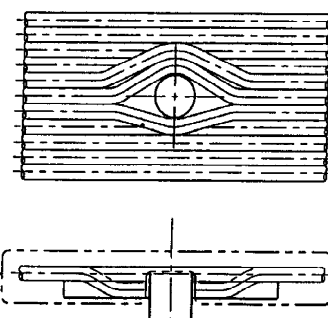


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APPROVED BY:	DJA
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REVISIONS:	
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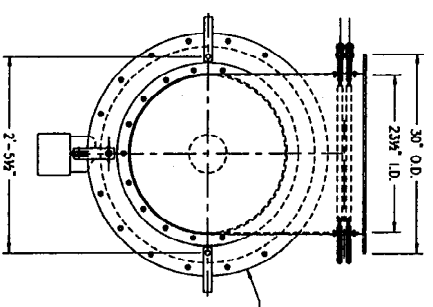
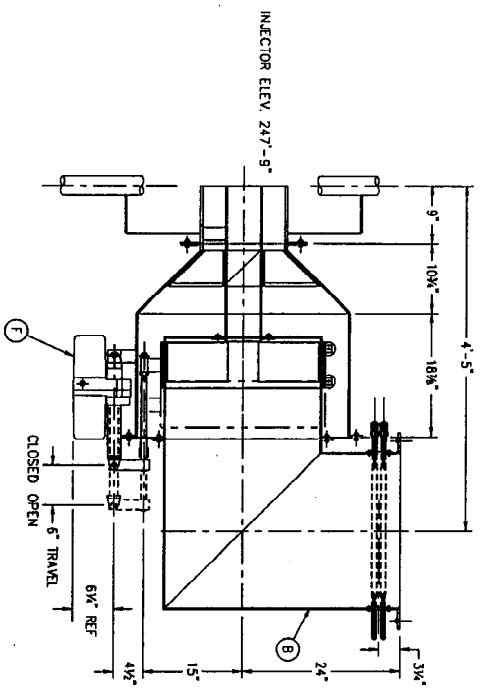
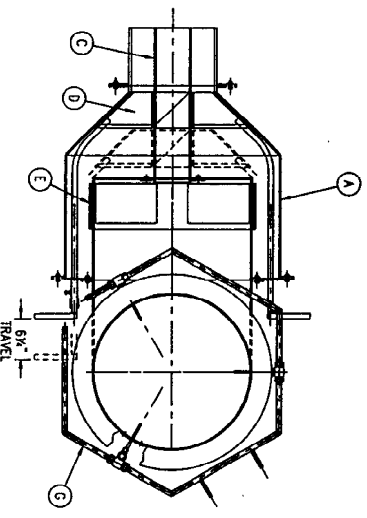
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(VIEWED FROM FURNACE)

BENT TUBES & WALLBOX BY OTHERS
EER TO SPECIFY HOLE DIAMETER AND
BOLT PATTERN FOR MOUNTING INJECTOR.



• THIS DIMENSION CERTIFIED CORRECT BY EER CORPORATION

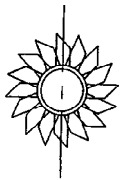
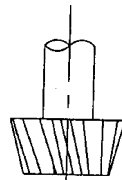
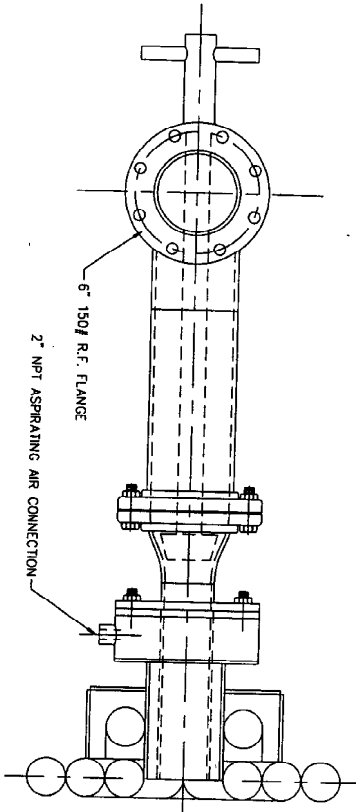
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DRAWING TITLE		G8882D-001-1-0	



ITEM	QTY	DESCRIPTION
A	1	OUTER CHAMBER
B	1	TRANSITION SLEEVE
C	1	INNER SLEEVE
D	1	SWIRLER
E	1	SLIDING SLEEVE DAMPER
F	1	JORDAN DRIVE
G	1	PITOT GRID ASSEMBLY

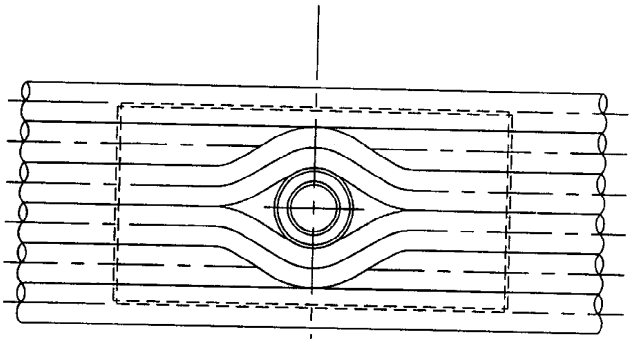
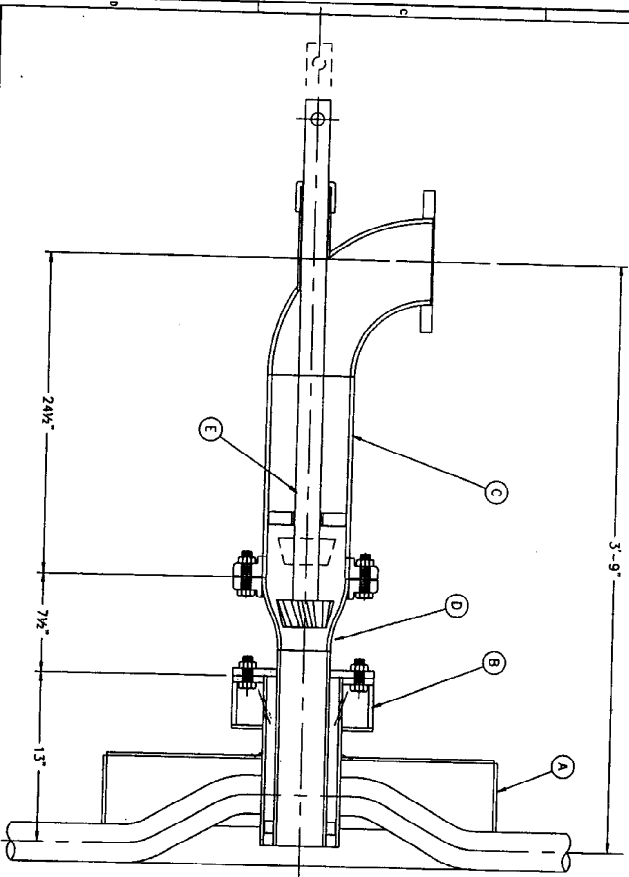
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CONSTRUCTION**

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CHECKED BY: ...	
DATE: 5/10/66	PROJECT NO.: 8882
DATE: 5/10/66	DRAWING NO.: 8882D-001A
DATE: 5/10/66	SCALE: 1/2\"/>



COAL SWIRLER DETAIL

ITEM	QTY	DESCRIPTION
A	1	WALL BOX
B	1	COAL NOZZLE MOUNTING WITH ASPIRATOR
C	1	COAL REBURN INJECTOR BODY
D	1	COAL REBURN INJECTOR NOZZLE
E	1	ADJUSTABLE COAL SWIRLER

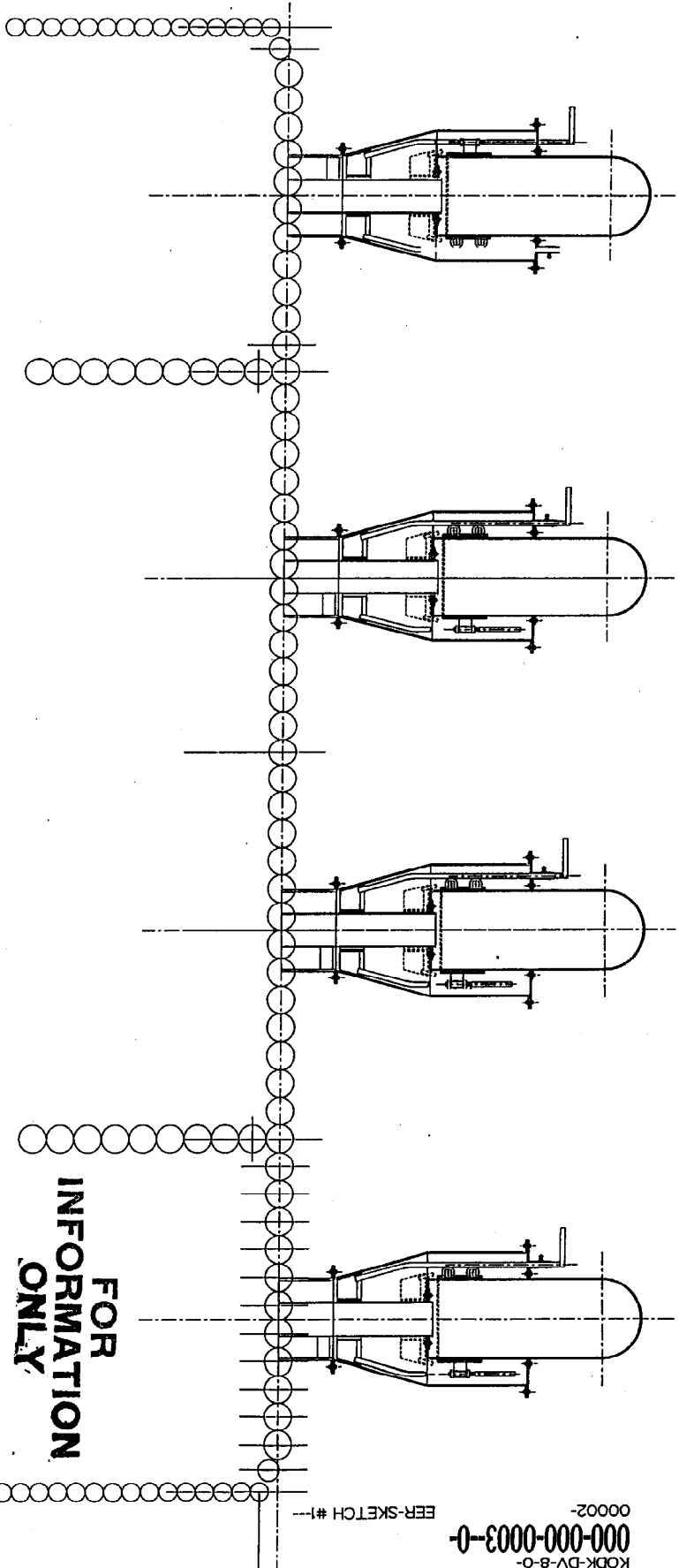


ELEV. 227'-2" (SIDEWALLS)
ELEV. 226'-0" (REARWALL)

PRELIMINARY NOT FOR CONSTRUCTION

KODAK

ENGINEER: [Signature]
 CHECKED: [Signature]
 DATE: 5-12-88
 DRAWING NO: 8882
 PROJECT: COAL INJECTOR PRELIMINARY ASSEMBLY
 SHEET: 2 OF 3
 SCALE: 1/2" = 1'-0"



**FOR
INFORMATION
ONLY**

EER - Sketch #1 5/1/9c

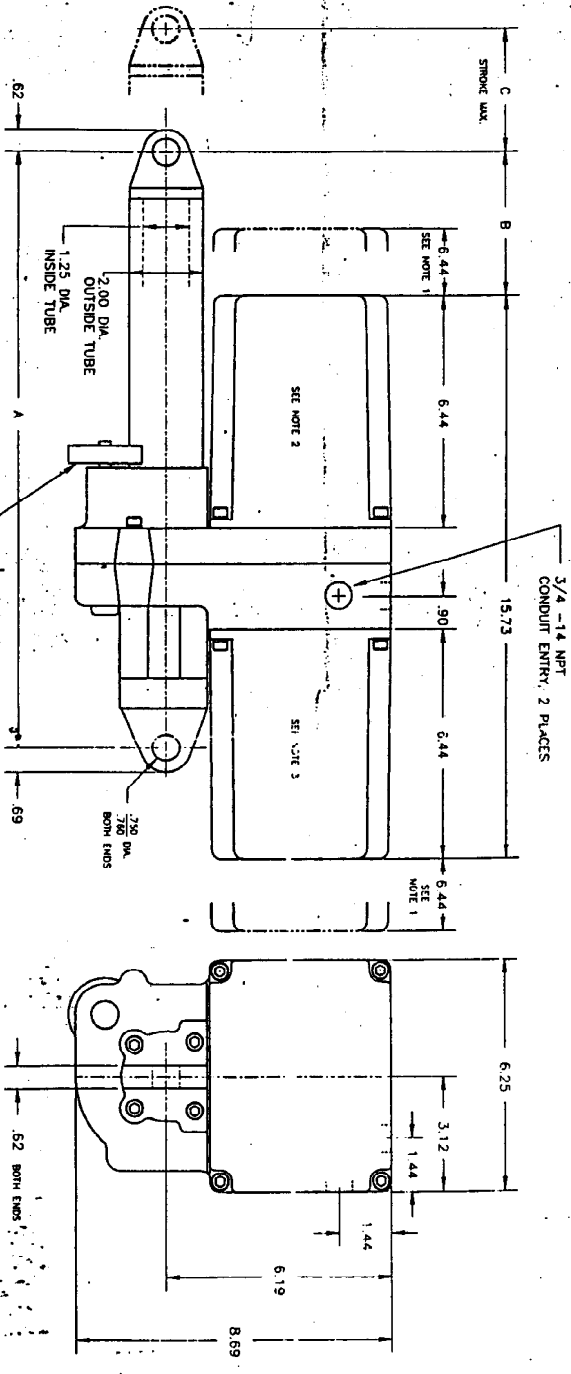
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EER-SKETCH #1



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3	REVISION	10/12/92				4		10/12/92			

DASH #	A	B	C
-001	16.61	4.01	6.0 MAX.
-002	22.61	10.01	12.0 MAX.
-003	28.61	16.01	18.0 MAX.



- NOTES
1. AMOUNT NEEDED FOR COVER REMOVAL
 2. COVER FOR MOTOR, BRAKE AND CAPACITOR
 3. COVER FOR FEEDBACK POTENTIOMETER AND TORQUE LIMIT SWITCHES

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Jordan Controls Inc

WALWAUKEE, WISCONSIN, USA

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PHYSICAL INSTALLATION

10/12/92

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