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Coal Reburning for Cost-Effective NO_x Compliance

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by

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ABSTRACT

This paper presents the application of micronized coal reburning to a cyclone-fired boiler in order to meet RACT emissions requirements in New York State. Discussed in the paper are reburning technology, the use of a coal micronizer, and the application of the technology to an Eastman Kodak unit. The program is designed to demonstrate the economical reduction of NO_x emissions without adverse impact to the boiler.

INTRODUCTION

The Eastman Kodak Company's Kodak Park Site is one of the nation's largest industrial parks, spanning an area in excess of 1,300 acres. Over 200 buildings on the site produce thousands of different photographic and chemical products. Supporting production are two power plants containing a total of 14 boilers. An agreement between Kodak and the New York State Department of Environmental Conservation (NYSDEC) states that Kodak will install coal or natural gas reburning systems on all four of its cyclone boilers. Kodak has recently completed installation of a natural gas reburning system on #43, Boiler which is located on the western side of the Kodak Park Site facility. The upgrades of the three remaining boilers (#15, #41, and #42) are planned for the 1996 through 1998 time frame. #15 Boiler is located apart from the other three cyclone boilers, approximately three miles from #43 Boiler. The original schedule for upgrades was #43 by 1996, #41 and #42 by 1997, and #15 by 1998.

In September 1996, New York State Electric and Gas (NYSEG) presented Kodak with an alternative: NYSEG and Kodak could work together with the United States Department of Energy (DOE) to complete the upgrade of #15 Boiler if Kodak would use micronized coal as the reburn fuel instead of natural gas. This proposal was attractive to Kodak for three reasons: (1) there is no natural gas main pipeline in the eastern Kodak Park Site; (2) natural gas is currently more than twice the cost of coal; and (3) DOE would co-fund the cost of installing the new system. The project will enable Kodak to meet the terms and conditions of the Kodak/NYSDEC agreement in a more economical and timely fashion.

Eastman Kodak #15 Boiler

Kodak's #15 Boiler, installed in 1956, is a cyclone-fired unit located at Kodak Park in Rochester, New York (see Figure 1). Supplied by Babcock & Wilcox Co., the unit contains two cyclone furnaces on the front wall firing crushed Eastern Bituminous coal. It typically operates at steam generation rates between 300,000 to 400,000 lb/hr; peak generation rate is 440,000 lb/hr. The cyclone furnaces operate at a very high heat release rate, creating molten slag which is captured on the cyclone walls and flows to a slag tap at the bottom of the furnace. Particulate control is maintained by an electrostatic precipitator.

In February 1996, EER performed a baseline test and measured NO_x emissions at 1.21

lb/10^6 Btu for full load and 0.92 lb/10^6 Btu for low load. Baseline CO emissions were 56 ppm and 34 ppm at full and low loads, respectively. The results correlated closely with Kodak's belief that the baseline NO_x emissions are 1.25 lb/10^6 Btu and baseline CO is less than 100 ppm.

Coal Reburning Technology for NO_x Control

Coal Reburning is a NO_X control technology whereby NO_X is reduced by reaction with hydrocarbon fuel fragments [1]. A typical application of coal reburning to a coal-fired boiler is illustrated in Figure 2. No physical changes to the main burners (cyclone furnaces in this case) are required. The burners are simply turned down and operated with the lowest excess air commensurate with acceptable lower furnace performance considering such factors as flame stability, carbon loss, and ash deposition.

The technology involves reducing the levels of coal and combustion air in the burner area and injecting reburn fuel (micronized coal) above the burners followed by the injection of overfire air (OFA) above the reburn zone. This three-zone process creates a reducing area in the boiler furnace within which NO_x created in the primary zone is reduced to elemental nitrogen and other less harmful nitrogen species. Each zone has a unique stoichiometric ratio (ratio of total air in the zone to that theoretically required for complete combustion) as determined by the flows of coal, burner air, reburn fuel, and OFA. The descriptions of the zones are as follows:

- *Primary (burner) Zone:* Coal is fired at a rate corresponding to 75 to 90 percent of the total heat input. NO_x created in this zone is slightly lower than normal operation due to the lower heat release and the reduced excess air level.

- *Reburn Zone:* Reburn fuel (micronized coal) is injected above the main burners through wall ports. The reburn fuel consumes the available oxygen and produces hydrocarbon fragments (CH, CH_2, etc.) which react with NO_X from the lower furnace and reduce it to elemental nitrogen, N_2. Optimum NO_X reduction performance is typically achieved when the reburn zone is operated at about 90% of stoichiometric ratio, which is slightly fuel rich (reducing) [2]. NO_X reduction can be adjusted by varying the reburn fuel injection rate, typically over the range of 10-25% of total boiler heat input. To minimize the reburn fuel required to achieve fuel rich conditions in the reburn zone, EER's design utilizes injectors rather than burners, which would have introduced additional air [3].

- *Burnout (exit) Zone:* The oxygen required to burn out the combustibles from the reburn zone is provided by injecting air through overfire air ports positioned above the reburn zone. These ports are similar to conventional overfire air ports except that they are positioned higher in the furnace so as to maximize the residence time for NO_X reduction occurring in the reburn zone. OFA is typically 20 percent of the total air flow. OFA flow rate and injection parameters are optimized to minimize CO emissions and unburned carbon-in-fly ash.

The concept of NO_X reduction via reactions with hydrocarbon fuels has been recognized for some time [4]. The work has progressed from analysis and pilot-scale tests [2] through several full-scale demonstrations including three installations on coal-fired utility boilers as part of the U.S. Department of Energy's Clean Coal Technology Program [5] and a commercial installation at New York State Electric and Gas' Greenidge Plant [6].

Goals of Micronized Coal Reburning Demonstration

The objective of the coal reburning demonstration is to evaluate the applicability of the technology to full-scale cyclone-fired boilers for reduction of NO_x emissions. The project goals are:

- Reduce NO_x emissions at full load from the current established baseline of 1.25 $lb/10^6$ Btu
  to 0.60 $lb/10^6$ Btu.
- Maintain CO emissions at or below 100 ppm.
- Minimize the impact on boiler efficiency.
- Reduce NO_x without serious impact to cyclone operation, boiler performance or other emissions streams.
- Demonstrate a technically and economically feasible retrofit technology.
- Demonstrate the advantages of micronized coal reburning over conventional coal reburning.

Several derived benefits can be realized with coal reburning. From an economic standpoint, coal reburning is less expensive to install and costs less to operate than selective catalytic reduction. With micronized coal as the reburn fuel, the utilization of the fuel is enhanced. This results in reduced carbon-in-ash, when compared to conventional coal reburning, and also reduces particulate loading to the ESP. These benefits outweigh the additional power requirements associated with operation of the micronizers and FGR.

PROCESS DESIGN

The application of reburning to a particular boiler requires careful consideration of the furnace flow field characteristics and the boiler design when developing reburning system specifications. To optimize the emissions control performance and to minimize any negative impacts of the retrofit, it is necessary to develop a design that achieves rapid and uniform mixing of the reburn fuel and overfire air streams, but minimizes the extent of modifications to the boiler heat release and heat absorption profiles.

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 that control process performance. The results of these studies have shown that the most critical parameters are primary NO_x level, reburn zone temperature and residence time, reburn zone stoichiometric ratio, and mixing of the reburn fuel and overfire air with the bulk furnace gases.

Reburn Zone Stoichiometric Ratio: The impact of this parameter on the NO_x emissions achievable with various reburn fuels is shown in Figure 3 [7]. As shown in the figure, overall NO_x reductions are highest when the ratio is approximately 0.9. To minimize the amount of reburn fuel needed to reach the optimum ratio, the primary combustion zone is operated as close to stoichiometric as possible. It should be noted, however, that with cyclone-fired boilers reducing the stoichiometric ratio in the primary zone will disrupt the slagging characteristics of the cyclone. Therefore, the fuel-to-air ratio in this area remains relatively unchanged.

Furnace Temperatures and Residence Times: As defined above, the reburn zone is that area of the boiler situated between the reburn fuel injectors and overfire air injectors. The amount of time required for the flue gas to pass through this area is referred to as the residence time. The locations of injectors are selected using the following criteria:

- High temperatures in the reburn zone are preferred in order to maximize the rate of NO_x reduction. This suggests that the reburn fuel be injected just downstream of the primary zone.
- The temperature in the burnout zone must be high enough to allow oxidation of carbon monoxide and hydrocarbon fragments from the reburn zone to occur readily.
- The residence time must be of sufficient duration for the reactions to occur. EER has evaluated a number of reburning systems and concluded that a residence time of 0.2 to 0.5 seconds will achieve high efficiency NO_x reduction.

Mixing: Pilot-scale studies of the reburning process have shown the importance of effective mixing in both the reburn and burnout zones [8]. Effective mixing of the reburn fuel optimizes the process efficiency by making the most efficient use of the available furnace residence time. Effective mixing of the overfire air reduces carbon monoxide emissions and unburned carbon or soot.

Design Approach

The final design was established on the basis of small-scale flow modeling, thermal heat transfer computer analysis, and operation of a pilot-scale micronizer using EER's Boiler Simulator Furnace. The reburn fuel and overfire air injection elevations were selected to provide the maximum amount of residence time possible in the reburn zone in order to maximize the NO_x control performance. This approach involved injection of the reburn fuel at an elevation in the furnace just above the exit of the cyclones and injection of overfire air at a distance downstream of the coal injectors that would provide for a maximum bulk residence time (Figure 4).

The reburn fuel is pneumatically transported to the boiler using recycled flue gas (FGR) as the carrier medium. The fuel is then introduced into the boiler through injectors that are designed to rapidly mix the small quantity of the reburn fuel with the furnace gases. FGR is particularly suited as a carrier gas in lieu of air since it consists of a very low level of O_2. Note that any O_2 introduced as carrier gas must be consumed by additional reburn fuel. The use of FGR minimizes this fuel requirement.

SYSTEM DESCRIPTION

Coal Micronizer

Preparation of the reburning fuel is performed using a MicroMill system supplied by Fuller Mineral Process Inc. The MicroMill is a patented centrifugal-pneumatic mill that works on the principle of particle-to-particle attrition. Coal is conveyed with a hot air stream into the cone area, creating a vortex of air and coal particles. As the diameter of the cone section of the mill becomes larger, the air to coal velocity decreases. The coal assumes a position in the cone based on each particle's size and weight. Particles of similar size will form bands of material with the larger particles at the bottom of the cone. Smaller particles will move through these bands and enter the vortex created by the rotating blades in the rotational impact zone of the mill. As these smaller particles collide with the larger particles, size reduction occurs. When a particle's size is small enough to attain the required velocity, it passes through the blades located in the scroll section of the mill and exits the mill to a static classifier.

A static classifier is used for final particle size distribution. Oversized material falls through a rotary air lock and back into the feed airstream of the mill. Stripping air provided to the classifier can be adjusted to fine tune the classifier collection efficiency allowing larger or smaller particles to pass to the boiler.

The MicroMill system can fit in approximately a 13-foot by 9-foot area and is only about 12 feet high. The mill's overall size and weight made it an ideal choice for Kodak's tight space limitations and its modular construction makes it easy to perform maintenance. The mill is designed with wear resistant materials in areas contacting the feed being processed to minimize maintenance. When maintenance is required, the cone can be unbolted, lowered on the pivot pin, and rotated for access to the rotor, wear liners, and replaceable blades.

The MicroMill is supported by Fuller's extensive research and development facilities, which include a full-scale MF3018 MicroMill for product testing and demonstration. The Kodak feed materials were tested on this unit to determine expected capacity, fineness, and power consumption. In the lab, a capacity of three tons per hour at 86% passing 44μ was obtained. The limiting factor in the laboratory was motor HP. The motor for the project was increased from 150 horsepower to 200 horsepower; thus higher capacities are expected in the field. Power consumption expected for the mill is about 37.3 KW/ton of material processed. In addition, the fineness required for the application is 80% passing 44μ, which will further increase the capacity of the system. Flexibility has been designed into the system to provide a higher fineness product or greater capacity at a lower fineness.

The two-mill system for the Kodak project includes:

Mill and motor
Classifier
Recycle and feed rotary airlock
Blow-through tee and feed piping
Classifier and mill air control valves.
Air flow meter

The mill is equipped with a water-cooled bearing jacket, vibration sensor, bearing RTD's, and a proximity switch. The bearing jacket will allow the use of Kodak's uncooled flue gas as a transport medium. By utilizing the water-cooled jacket, the need for expensive flue gas cooling equipment was eliminated.

Coal Transportation and Injection

The coal transportation system is shown in Figure 5. The slipstream for flue gas is extracted from the boiler just downstream of the precipitator and is boosted by a single fan to feed both coal micronizers. FGR is used to transport coal to the boiler and also boost its injection momentum to ensure that the reburn fuel is mixed effectively in the furnace.

Two coal micronizers with classifiers are used in the system. Each micronizer is supplied coal from a bunker through a screw feeder. The FGR system assists in the micronizing process and in operation of the classifiers. The mills are capable of operating singly or as a pair, although, due to capacity limitations, both may be required to produce the targeted NO_x reduction.

The micronized coal exiting the two mills is merged into a single 18-inch pipe for transportation to the boiler. The line is then divided into eight 6-inch segments by a coal flow splitter supplied by EER. The splitter is designed to apportion the coal into equal segments without incurring any pressure drop. Upstream of the splitter is a coal rope breaker (RopeMaster®) supplied by Rolls-Royce/International Combustion, which will enhance the splitter's effectiveness. Downstream of the splitter are eight FlowMastEER® dampers designed by EER that are used to perform final adjustments to the coal flow balance. The dampers can also be used to create flow biasing.

Eight micronized coal injectors are installed, six on the rear wall and one on each side wall near the rear wall. The injectors utilize the considerable momentum provided by the FGR transport gas plus additional design features to enhance coal penetration. Each injector is equipped with a variable swirl device to control the mixing characteristics of each fuel jet as it enters the furnace. Adjustments will be made during initial start-up to optimize the injector effectiveness. The coal injectors were designed by EER specifically for this project.

Overfire Air System

Located on the front wall are four overfire air injectors. These injectors utilize EER's Second Generation dual-concentric overfire air design. This is EER's second application of this concept [9]. The injectors are designed to provide good jet penetration as well as good lateral dispersion across the boiler depth and width. Each injector is equipped with an integral damper to maintain the desired injection velocity as load changes and a swirler which, when adjusted, provides for optimum mixing in the burnout zone.

Controls

Kodak installed a new Coen burner management system and replaced the complete boiler control system with a Westinghouse WDPF distributed digital control system. The new controls operate both the existing equipment and the micronized coal reburning system. All normal start/stop/modulate operator actions occur in the control room. Critical operations are interlocked to prevent inadvertent operation of equipment when such operation may present an operating hazard or other undesirable condition. The controls are designed to shut down the reburning system while maintaining operation of the boiler. Kodak's insurance carrier, Factory Mutual, has approved this control arrangement. Previous to this project, EER reburning retrofits were approved by Factory Mutual and Hartford Steam.

Operation

During operation of the reburning system, the total fuel to the boiler is the sum of the fuel to the cyclones plus the fuel to the reburn injectors. Any change in the amount of reburn fuel must be balanced by an converse change in the fuel to the cyclones. During normal operation, the boiler generates steam at rates between 300,000 and 400,000 lb/hr. The lower limit of 300,000 lb/hr is based on the amount of bottom ash required to prevent slag freezing. The range of reburn fuel injection is based on the following two factors:

- The minimum reburn fuel injection rate is based on a lower operational limit of the coal preparation equipment (coal feeder, micronizer, classifier, etc.).

- The maximum reburn fuel injection rate is that amount required to raise the boiler from the cyclone minimum operating level (300,000 lb/hr steam) to the boiler maximum operating level (400,000 lb/hr steam). Note that the minimum cyclone operating level may be lower than 300,000 lb/hr during reburning since reburn fuel ash also contributes to the bottom ash total. The maximum amount of reburn fuel that can be injected is estimated to be 25% of the total heat input.

At boiler full load with maximum operation of reburning, load can be reduced by lowering the injection rate of the reburn fuel. The load on the cyclones would remain the same. This capability is described in Figure 6.

SUMMARY

The coal reburning installation at Eastman Kodak Company will permit Kodak to meet RACT emissions requirements in New York State. The project, conducted under the auspices of the U.S. Department of Energy's Clean Coal Technology Program, is designed to demonstrate the economic advantages of using coal micronizer technology versus conventional coal reburning. Testing of the system will verify the target goals of NO_x emissions reduction and determine the full range of operation, including turndown capabilities. The testing will also be used to develop a database of technical information that can be applied to similar boilers.

Coal reburning is less expensive to install and costs less to operate than selective catalytic reduction (SCR). Using coal as the reburn fuel results in economical reburn fuel selection, decreased primary mill capacity, no additional chemical/catalyst cost, and no ammonia slip normally associated with SNCR. With the micronizer technology feature, the utilization of the reburn fuel is enhanced. This results in reduced carbon-in-ash when compared to conventional coal reburning and also reduces particulate loading to the ESP.

This paper has focused on reburning technology, a description of the project and its inherent benefits including. Future papers will present the results of extensive testing.

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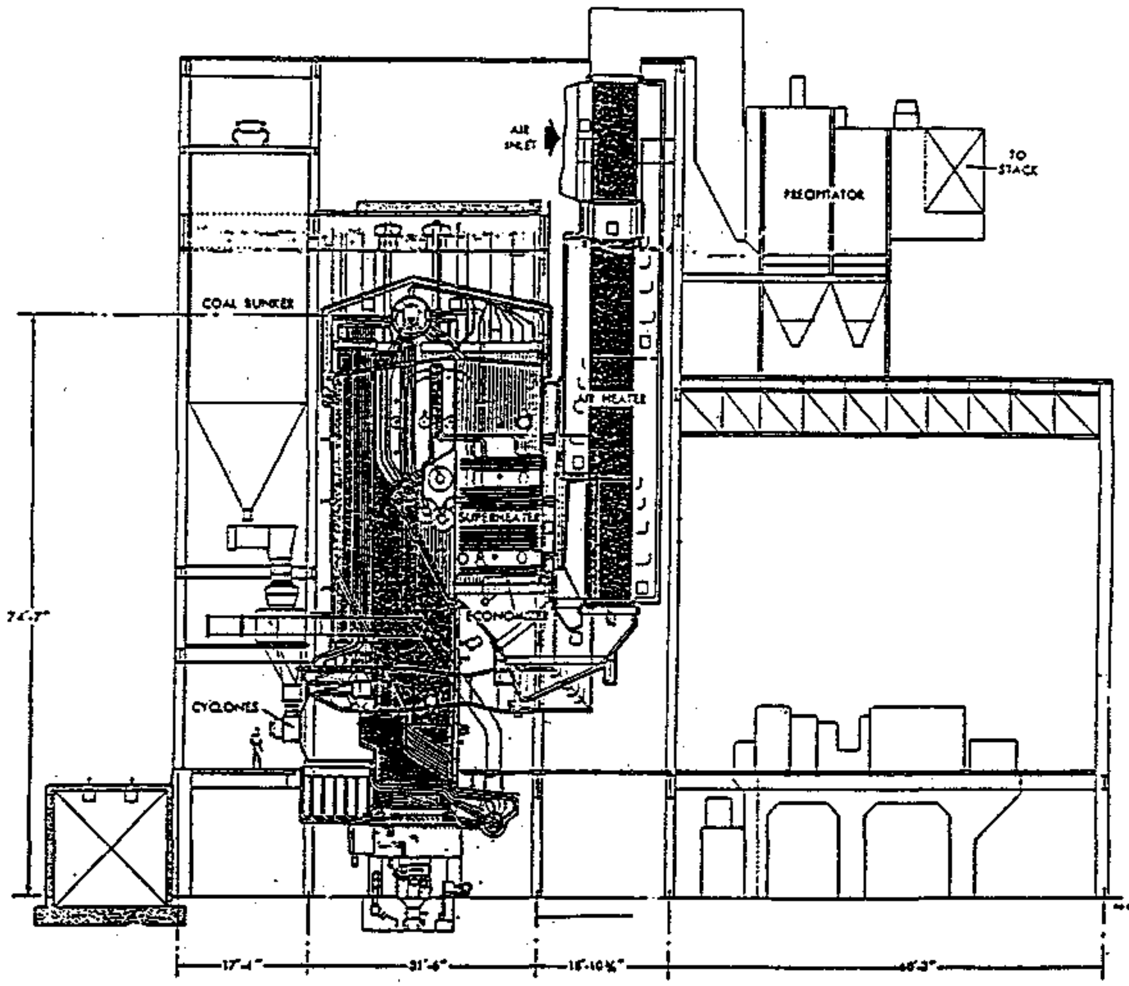

EASTMAN KODAK COMPANY
KODAK PARK WORKS
ROCHESTER, NEW YORK

Figure 1. Kodak #15 Boiler.

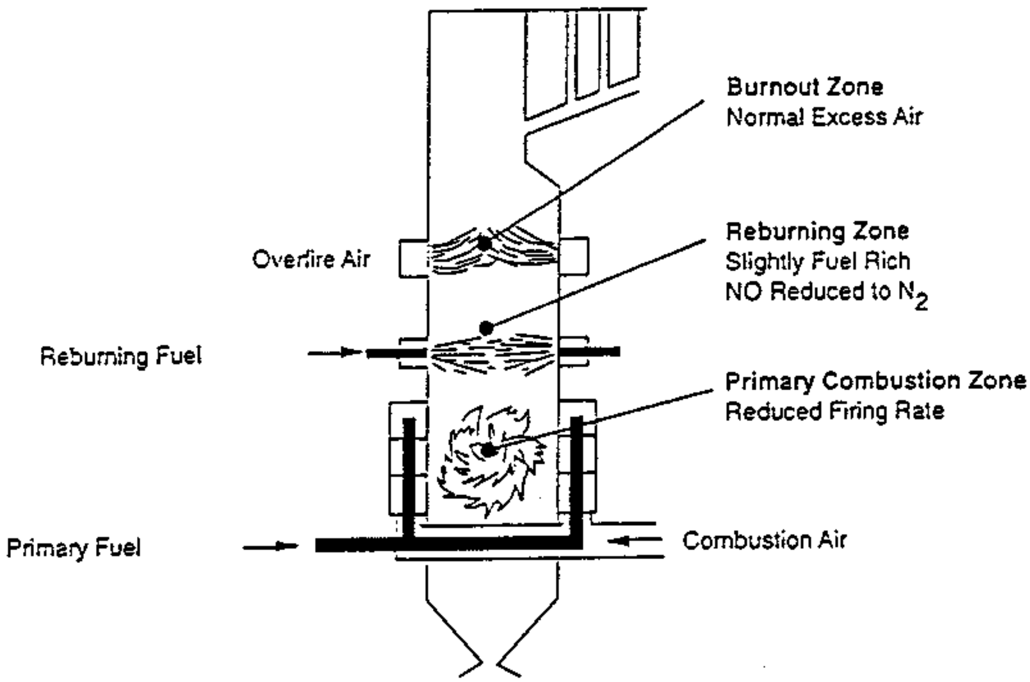

Figure 2. Application of reburning technology to a utility boiler.

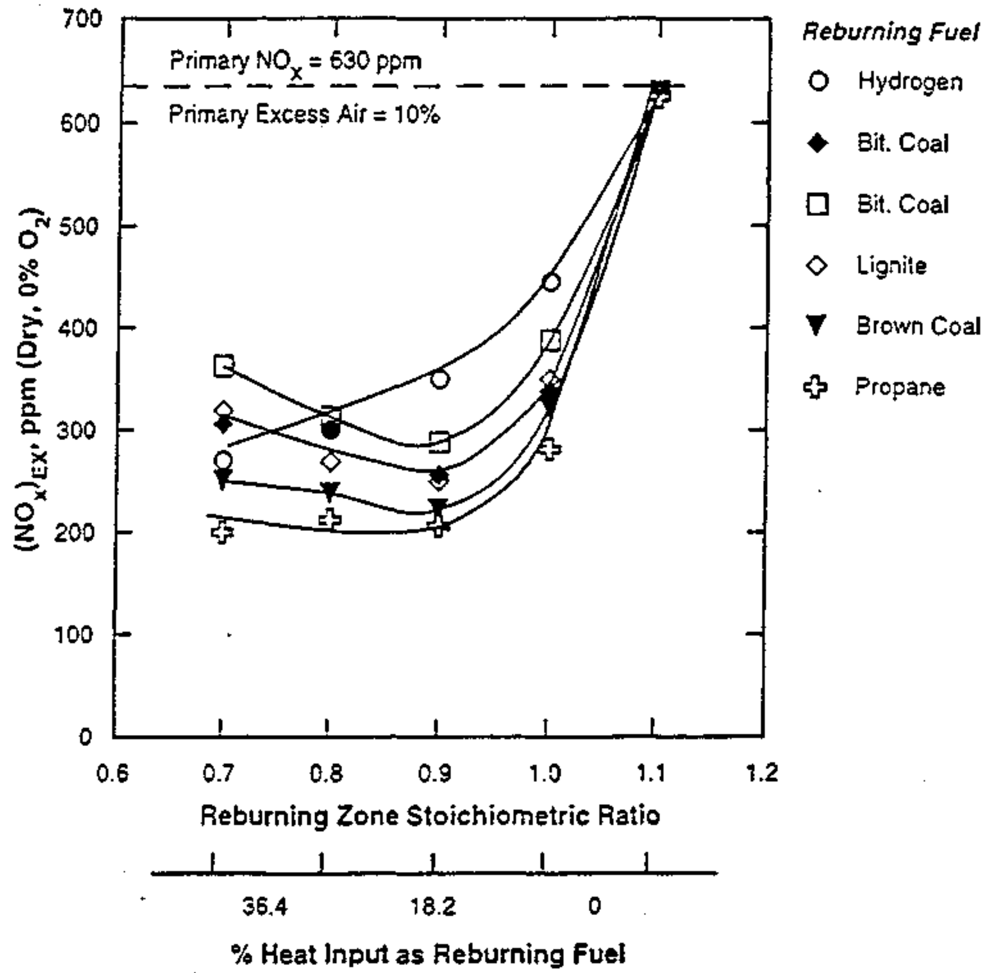

Figure 3. Impact of reburning zone stoichiometric ratio and reburning fuel type on reburning performance.

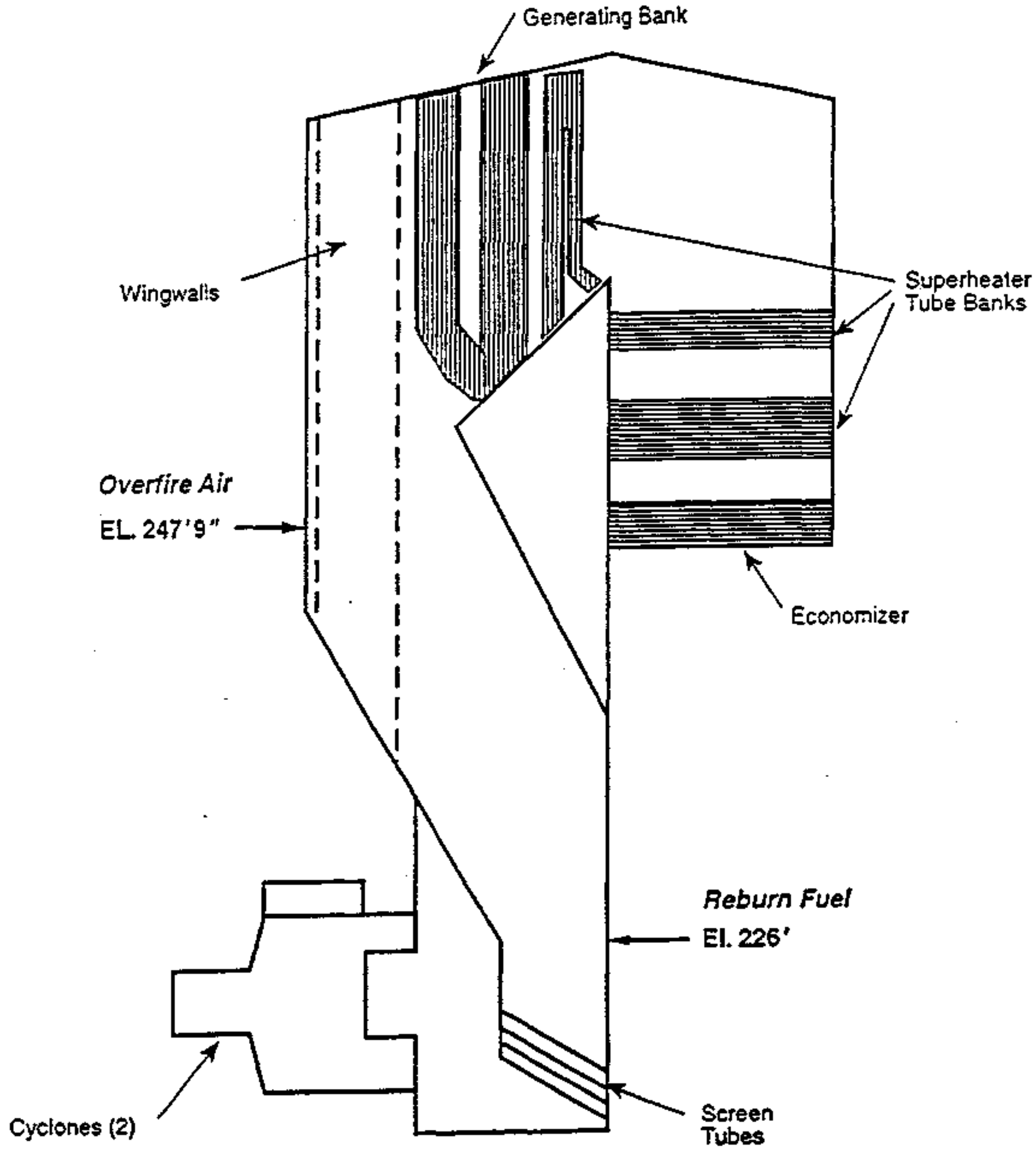

Figure 4. Reburn fuel and overfire air injection elevations for Kodak #15 Boiler.

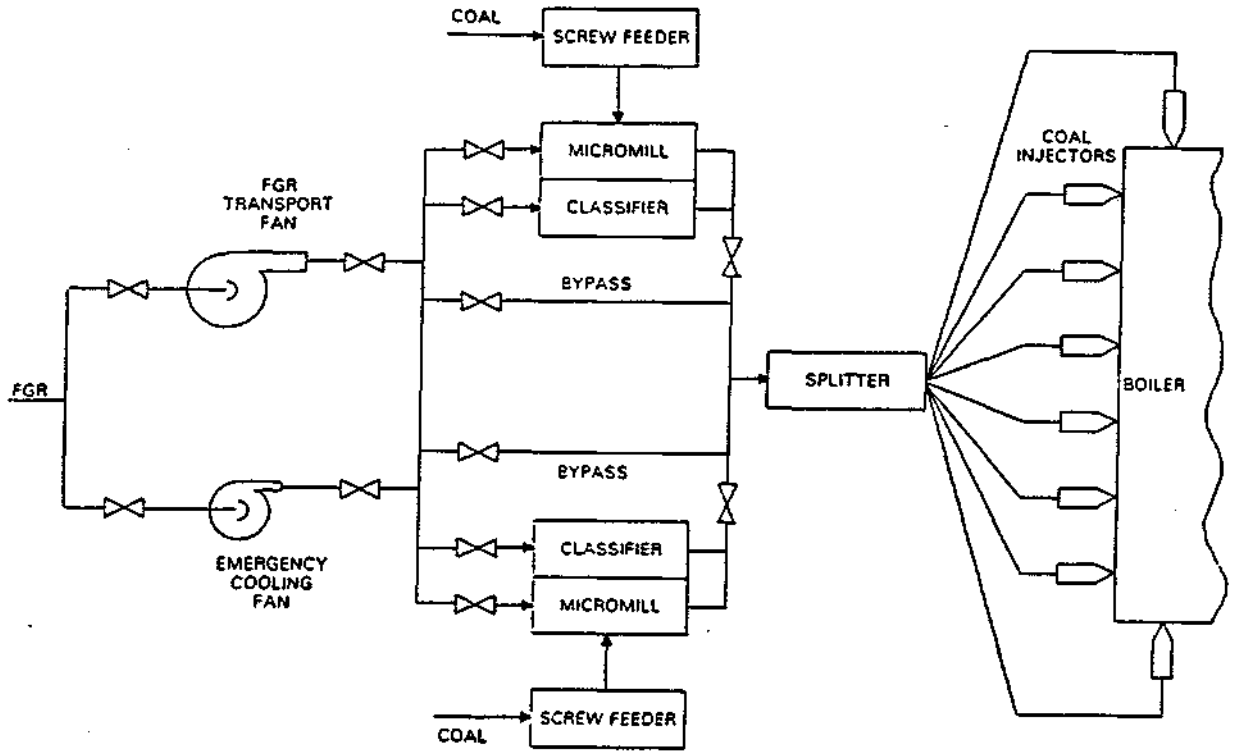

Figure 5. Micronized Coal Feed System

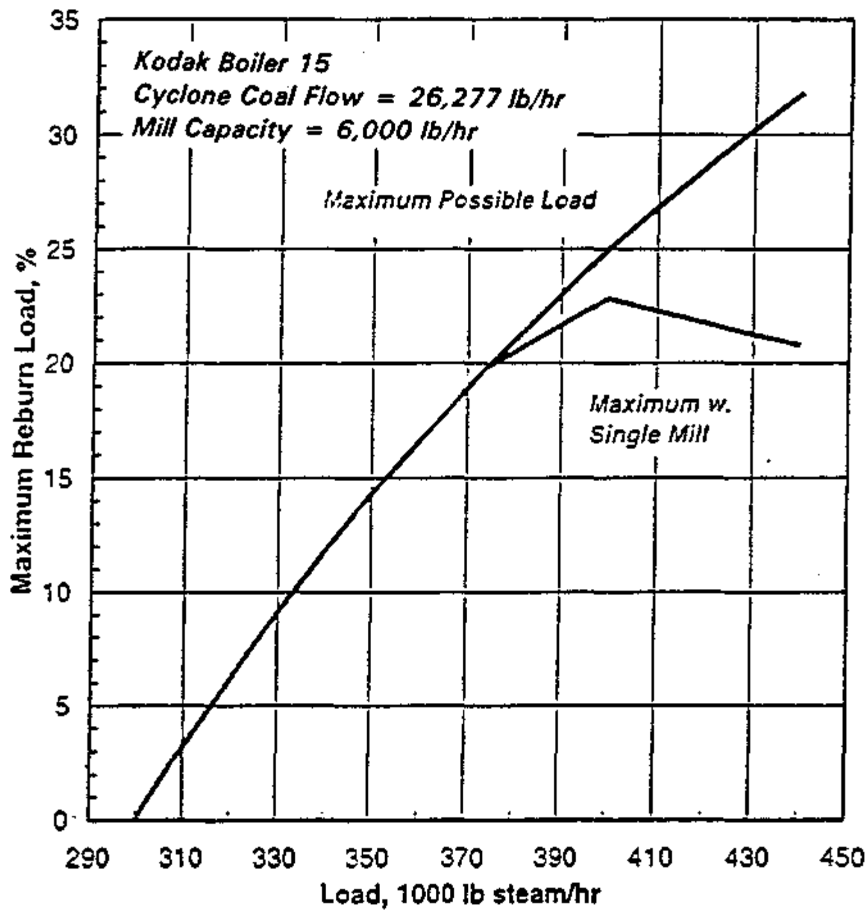

Figure 6. Maximum level of reburning system operation achievable while maintaining minimum coal flow to cyclones.