THE IMPACT OF FURNACE SORBENT INJECTION ON BOILER PERFORMANCE

by
ROBERT A. LISAUSKAS
Manager, Research Projects
and
RALPH K. MONGEON
Manager, Program Development
RILEY STOKER CORPORATION
WORCESTER, MASSACHUSETTS

Presented to
THE 1985 JOINT POWER GENERATION CONFERENCE
Milwaukee, Wisconsin
OCTOBER 20-24, 1985

RST-46

RILEY RILEY
STOKER
POST OFFICE BOX 547
WORCESTER, MASSACHUSETTS 01613

THE IMPACT OF FURNACE SORBENT INJECTION ON BOILER PERFORMANCE

by
ROBERT A. LISAUSKAS, Manager, Research Projects
and
RALPH K. MONGEON, Manager, Program Development
RILEY RESEARCH CENTER
RILEY STOKER CORPORATION
WORCESTER, MASSACHUSETTS

ABSTRACT

Furnace sorbent injection presents a low-cost alternative to the use of wet scrubbers for the removal of SO_2 from power boiler flue gases. Recent laboratory and pilot scale studies have produced SO_2 captures of over 50%. Full-scale field evaluations, sponsored by both the U.S. EPA and the Electric Power Research Institute, are currently in the planning stages.

This paper presents an overview of considerations related to furnace sorbent injection technology from the boiler manufacturers' point of view. It provides an interface between on-going development work and the field evaluations, and will focus on the various design and operational concerns associated with new and existing steam generating units.

INTRODUCTION

Although there is considerable scientific debate concerning the relationship between emissions and acid deposition, the thrust of all proposed acid rain legislation has been on the reduction of sulfur emissions from new and existing coal-fired power plants. The prospect of more stringent emission standards has provided a strong incentive to develop alternatives to flue gas desulfurization based on wet scrubbing. As a result, an extensive amount of research and develop ment is currently being pursued in the area of dry sorbent injection for sulfur dioxide (SO_2) control. This technology is particularly attractive for retrofit to older boilers due to its lower first cost as compared to conventional flue gas desulfurization processes. Dry sorbent injection also offers the opportunity for incremental SO_2 control on new unit designs.

A renewed interest took place in dry sorbent SO_2 control during the mid-1970's due in large part to developments in West Germany and pilot-scale research conducted by the U.S. Environmental Protection Agency (EPA). The West German developments were based on the installation of dry sorbent injection systems, as incremental SO_2 control measures, on two brown coal-fired boilers.

As a result of its pilot scale studies using sorbent injection through a distributed mixing burner, the EPA initiated its Limestone Injection with Multistage Burners (LIMB) program for simultaneous NO_x/SO_2 control. The LIMB concept was originally based on the theory that the conditions created by second generation low NO_x burners might also enhance the capture of sulfur with calcium-based sorbents. The lower peak flame temperatures and the extended fuel-rich conditions in the low NO_x flame could contribute to sorbent SO_2 removal. The EPA LIMB program objective has been to achieve 50 to 60% reduction in SO_2 in retrofit applications with practical levels of sorbent injection[1].

A large number of laboratory and field test programs are currently underway by various organizations in North America, Europe, and Japan. These programs are investigating a variety of process methodologies, and sorbent types in addition to limestone. Recent work has shown that reducing zone capture does not seem possible in full-scale boilers, and that the most favorable sulfur capture conditions occur in the post-flame region of the boiler. Another key factor in obtaining high capture rates is the ability of the process to achieve and maintain high sorbent reactivity.

In spite of the high level of on-going research and development in this area, there are still a great many unknowns concerning the effect of dry sorbent injection on combustion systems and boilers. This paper focuses on the impact of this technology on boiler design and performance from a boiler manufacturer's point of view.

FURNACE SORBENT INJECTION

SO_2 reduction through dry sorbent injection encompasses a number of furnace and post-furnace injection options. In this paper, we will discuss furnace sorbent injection, or the injection of calcium-based materials directly into the furnace cavity of a coal-fired boiler. There are a number of commercial calcium-based sorbent candidates for this process. These include limestone ($CaCO_3$), dolomite ($CaCO_3.MgCO_3$) and their derivatives, hydrated lime ($Ca(OH)_2$), dolomitic hydroxide ($Ca(OH)_2.Mg(OH)_2$) and quick lime (CaO). These compounds may be injected through burner passages into the main flame zone, or above the burners into the post-flame region.

Sulfur capture by furnace sorbent injection involves several process steps during which the sorbent particles are rapidly heated, activated, partially deactivated, reacted with gas phase sulfur species (e.g., SO_2, H_2S, or COS), and regenerated. Sorbent activation occurs as the particles are heated forming porous particles with high surface area. This process takes place in the furnace through particle fragmentation and rapid calcination. During calcination, reactive CaO forms as carbon dioxide and water vapor are driven from the sorbent crystal structure. The calcination of limestone, or calcium carbonate ($CaCO_3$), is described by the following reaction:

$$CaCO_3 \rightarrow CaO + CO_2$$

The calcination of limestone is an endothermic reaction requiring approximately 800 Btu per pound of pure calcium carbonate.

Calcination rates are a function of the type of sorbent and its initial surface area. The calcination of limestone is relatively fast at temperatures of 1800°F or greater. Laboratory studies have found that 80% calcination occurs within 0.5 seconds or less at this temperature[2]. Calcination rates for hydrated compounds are even more rapid. However, as the peak calcination temperature continues to increase, sorbent grain growth and sintering can occur. Sorbent particles become deactivated as their porosity and internal surface area decrease.

Under oxidizing conditions, sulfation or sulfur capture is described by the following general reaction:

$$CaO + SO_2 + \frac{1}{2}O_2 \rightleftarrows CaSO_4$$

The formation of calcium sulfate ($CaSO_4$) is an exothermic reaction releasing approximately 4000 Btu per pound of calcium oxide reacted. Sulfation rates are controlled by the diffusion of SO_2 through the porous sorbent particle. Below 1600°F, reaction rates are low and little SO_2 removal occurs.

The degree of sulfation becomes self limiting as the reaction of SO_2 and CaO proceeds. A product layer of $CaSO_4$ forms on the surface of the oxide increasing the solid diffusion resistance. Also, since the specific volume of $CaSO_4$ is significantly greater than CaO, the porous structure of the particle eventually becomes plugged with sulfate. Maximum calcium utilization, therefore, is on the order of 60%. Since MgCO does not sulfate, dolomitic compounds are not limited by pore plugging.

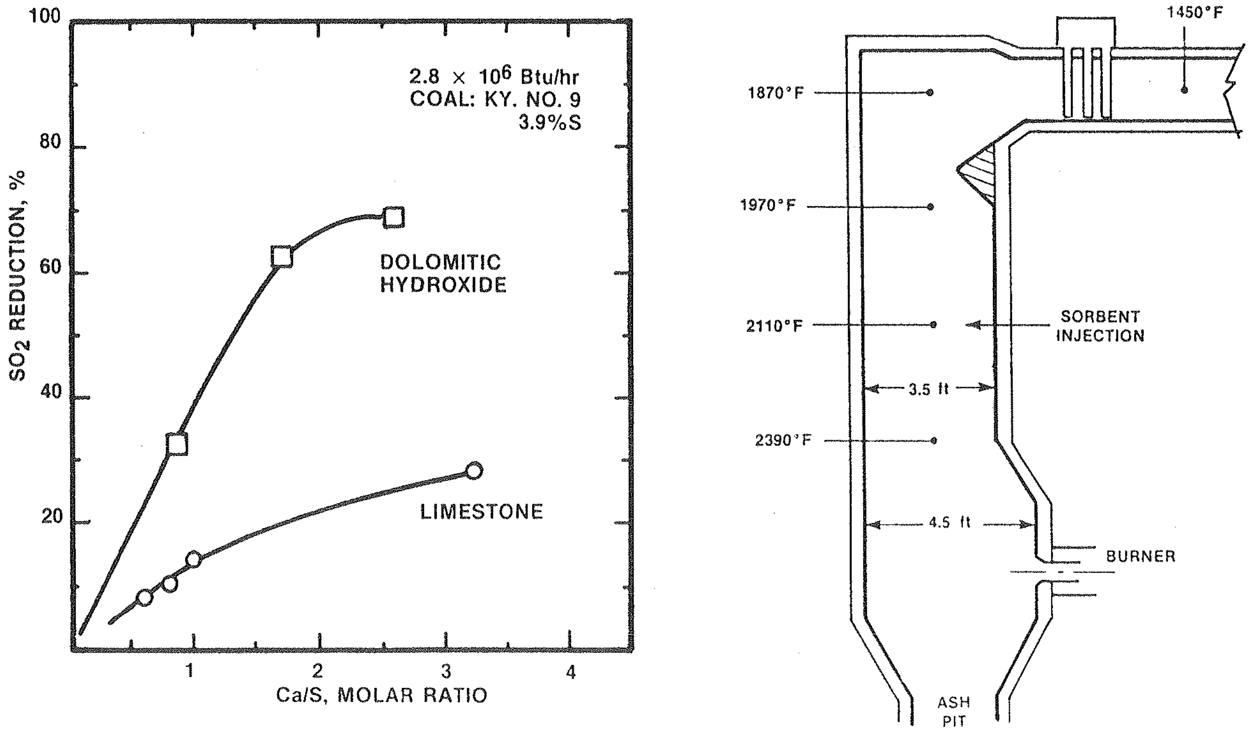
The sulfation reaction is also reversible. Spent sorbent particles may decompose and regenerate gaseous sulfur species. The stability of $CaSO_4$ is a function of the gas phase composition, as well as temperature. Under conditions existing in the first part of a pulverized coal flame, the onset of $CaSO_4$ instability can occur as low as 1850°F[3].

The principal parameters controlling SO_2 removal through these sorbent injection process steps are sorbent type, injection rate or Ca/S ratio, and thermal history of the sorbent particles. Furnace sorbent injection appears to be most effective in the temperature region between 2300 to 1600°F[4]. The performance of two basic commercial sorbent types is shown in Figure 1a. SO_2 removal characteristics for both limestone and dolomitic hydroxide were obtained in a 3 x 10^6 Btu/hr pilot-scale combustion facility at the Riley Research Center. The temperature profile and sorbent injection location for these characterization tests on Kentucky No. 9 bituminous coal (3.9% sulfur) are given in Figure 1b. Quench rates in the sulfation reaction window were on the order of 300°F/sec. This condition is typical of many full scale utility furnaces.

The difference in SO_2 removal characteristics for both of these sorbents is substantial. SO_2 reduction in excess of 65% at a Ca/S molar ratio of 2 was achieved with a pressure hydrated dolomitic lime. The effectiveness of limestone was much less at about 20% reduction at Ca/S = 2.

In full scale applications, the effectiveness of furnace sorbent injection will also be strongly influenced by the mixing and dispersion of the sorbent with the furnace gases. Rapid mixing and dispersion will be required to match pilot scale results.

In the following sections recent full scale experiences and the potential impact of this technology on a number of boiler risk areas will be reviewed.



(a) SULFUR CAPURE

(b) RILEY RESEARCH PILOT SCALE FURNACE

Figure 1 Comparison of sorbents tested in a Riley Research pilot scale furnace. Sorbent injection at 2100°F, 2.8 × 10^6 Btu/hr, Kentucky No. 9 Coal

FULL SCALE EXPERIENCE

Furnace sorbent injection is not a new technology. Limestone injection has been used to reduce low temperature corrosion and high temperature fouling in the convection passes of steam generators[5]. Its use was not wide spread and, while it may have helped, it was an expensive process making it undesirable.

During the late 1960s and early 1970s furnace sorbent injection was tried for SO_2 removal in units mostly equipped with conventional, high turbulence burners. Removal efficiencies varied from 15 to 50% with the mean at approximately 20%[6,7]. The experimental conditions under which the widest spread in removal efficiencies are reported were conducted in boilers having considerably different thermal and residence time characteristics.

Tests were run on horizontally fired, vertically fired, and tangentially fired units during this period. Limestone was generally introduced into the furnace with the fuel, although injection above the burners was also tried on some of the units. A representative list of the most noteworthy full scale demonstrations is contained in Table I. Included in this table is the sulfur content of the coal, the sorbent utilized, the capture efficiency, and some of the problems encountered within the steam generating unit. The low SO_2 captures resulted from "dead burning" of the sorbent (thermal deactivation).

Much of this "dead burning" resulted from of the sorbent being injected with the fuel in the high temperature combustion zones. A general boiler problem was hard fouling deposits and plugging of convection sections within the boilers. Some of the tests are described in greater detail in the following paragraphs.

The TVA boiler, located at the Shawnee Station, noted in Table I is wall-fired with temperatures in the burner zone typically greater than 3000°F and, depending on load, the temperature of the products of combustion dropped to approximately 1400°F in 1 to 1.5 seconds. Injecting the sorbent with the coal resulted in low SO_2 efficiencies. Limestone was also injected at various locations above the burner where the gas temperature region was approximately 2000°F. From this location to the 1400°F zone the maximum residence

Test	Coal	Sorbent	Capture Efficiency	Handling	Boiler
STEAG Kellerman (1967)	1.5% S German	Limestone Lime Calcined limestone Hydrated limestone Hydrated dolomite	30% at 1.8		
Wisconsin Electric Power Port Washington	2.8% S WV	Dolomite	40-50% at 1-15	No problem	Hard fouling deposits could not be soot blown
Detroit Edison St. Clair (1967)	3.3% S OH	Dolomite	15-29%		No corrosion No slagging
Kansas Power & Light Lawrence (1969)	3% S	Limestone	30% at 1.2:1		1st, super heater economizer plugging
TVA Shawnee (1973)	2.6% S	Limestone	10-30%		Hard fouling deposits, long term reheater slagging
Saskatchewan Power Corporation Boundary Dam (1976)	0.3% S Lignite	Ca CO_3	43 at 1.9		Reduced slagging & fouling
Otter Tail Power Co. Hoot Lake (1981)	0.8% S Lignite	Limestone	22 at 1.8 44 at 5.5	Poor co-grinding of limestone increased power consumption by 10%, fine limestone difficult to feed	Fouling rate X2 in super heater but deposit softer

Table I Results of sorbent injection into boilers[5]

Test	Coal	Sorbent	Capture Efficiency	Handling	Boiler
RWE Fortuna II (1980)	0.3% S Brown coal	Ca $(OH)_2$ Ca (OH_3) Dolomite Ca_O	50-75 at 2.5		No change in slagging/ fouling
Osterreichische Draudraft Voitsberg II (1981)	0.5-1.3% S Brown coal	Ca $(OH)_2$	25% at 2		No change in slagging/ fouling
Steinmuller (1981) Weiher II	1% S	Ca $(OH)_2$			Increased fouling but can be soot blown
Penelec (1982) Homer City /3	1% S	Limestone	12-20% at 2-3	Feed system over load, damaged feeder belt, good limestone pulveriazation	Increased slagging near nose, difficult to remove pre-heater deposits, sticky economizer deposits
Penelec (1983) Homer City /3		Limestone	< 15% at 1.5 13-27 at 1-2	Mill feeder plugging	Preheater plugging corrosion, erosion high Δ P, feeder overload
Otter Tail Power Co. Hoot Lake (1984)	< 1% S	Pressure Hydrated Limestone	50% at 2 80% at 7	Deposits increased but easily removed	

Table I (Continued) Results of sorbent injection into boilers

time was less than 0.5 seconds. The sorbent removal efficiencies for either injection location, with the fuel or in the lower gas temperature regions, were relatively low.

The Detroit Edison unit is tangentially fired which provides a longer flame length than the circular, wall-fired, high turbulence burner. The test work was conducted with the sorbent being injected either with the coal or in the upper row of burners only. SO_2 removal efficiencies varied from 15 to 29%. The Wisconsin Electric Power unit is arch fired. The burner fires downward with lean O_2 levels and additional combustion air is added from the side walls at discrete locations. Similar to the tangentially fired unit, the combustion process would provide a more favorable temperature/time history for the sorbent. During these tests, the sorbent was injected with the fuel and high (40 to 50%) SO_2 removal efficiencies were achieved.

These programs were abandoned but, with the advent of low NO_x burner technology, were revived around 1979. Low NO_x burner technology stages the combustion process, producing lower flame and gas temperatures in the lower portions of the furnace. The U.S. EPA conducted pilot scale tests around 1979 which indicated that SO_2 removal efficiencies of 70% might be possible with sorbent injection through low NO_x burners at reasonable calcium to sulfur molar ratios. In 1980, the EPA initiated its LIMB program to identify the process variables that resulted in the high capture observed in the pilot scale studies. The program's objective was to develop LIMB and low NO_x burner technology for both retrofit and new applications.

Recent sorbent injection testing has been performed at several scales, styles of firing, and various fuels. The Otter Tail Power Company unit is tangentially fired with a North Dakota lignite. The sorbent used was a pressure hydrated midwestern lime. SO_2 captures of approximately 50% were demonstrated at a calcium to sulfur ratio of two with no adverse impact on the boiler. SO_2 capture of 80% was achieved when the calcium to sulfur ratio was increased to seven. Previous tests with limestone required three times the amount of sorbent to achieve 50% removal. The fouling rate was noted to increase although this may have been due to the sodium levels in the fuel and not specifically to the sorbent. The deposits were easily removed using normal sootblowing procedures[9].

The Steinmueller program, conducted at the Weiher boiler in West Germany, was initially directed at assessing potential operational problems during sorbent injection. Two of the 24 burners were set up for sorbent injec-

a. The results indicated that the combustion, heat transfer, and slagging processes were not adversely af-
ted. Calcium utilization with hydrated lime was found to be 22% at full load and 35 to 57% at half load.
e unit was recently retrofitted to accommodate sorbent injection into all of the burners but has encountered
me regulatory problems dealing with the disposal of fly ash and the fate of this project is currently uncertain.

Additional utility scale evaluations of furnace sorbent injection which are currently being planned include:

- The EPA demonstration of LIMB technology at the Ohio Edison Edgewater Station
- The furnace sorbent injection program at the Homer City Station of Pennsylvania Electric Company
- A 300 MW front fired unit in West Germany
- A 150 MW unit in Denmark
- A United States/Canadian project at Gagetown, New Brunswick
- A proposed program sponsored by the Electric Power Research Institute (EPRI) and Public Service of Indiana at the Wabash River Station.

Most of the past studies have focused on optimizing or investigating SO_2 removal capabilities, with the impact on system operation and performance assuming a somewhat secondary role. The proposed EPRI program is a departure from the previous activities in assigning at least equal priority to the integration issues.

SORBENT FEED SYSTEM

One of the major impacts of furnace sorbent injection to either new or existing units is the sorbent feed system. This system can encompass the unloading, storage, pulverization, pulverized sorbent storage and transport equipment required to take the sorbent from the storage bins and bring it to the furnace. Based on high sulfur coal, this sorbent flow rate could be the equivalent of 20% of the fuel fired in the unit. Although optimum sorbent selection criteria, including grind size, are the subject of continuing research, it is expected that a highly reactive, finely ground sorbent will be required. Sorbent is typically ground to approximately 20 micron mean size. This is equivalent to over 90% passing through a 325 mesh screen.

The bulk of the sorbent will be transported to the power plants by truck or by rail. It should be stored in a pile with a roof over it to prevent unnecessary moisture contamination. Depending on the as delivered size and moisture content of the sorbent, it may then require crushing to intermediate size and drying prior to final fine grinding. There are many candidate mills for pulverization including ball, roller, high speed hammer, attrition, and pin mills. Grinding power to produce a finely ground product such as 20 micron mean size will be high. Agglomeration of finely ground sorbent accompanied by its adherence to inner mill surfaces and consequent reduced mill efficiency is a known problem. If an extremely fine sorbent is necessary, it may be appropriate to consider other grinding techniques. A typical sorbent preparation and injection system schematic is shown in Figure 2.

After pulverization, the sorbent would be stored in one or more day silos and would be pneumatically injected into the furnace through a pneumatic transport system. This system is expected to be dilute phase with fairly high injection velocities to promote adequate penetration and dispersion within the furnace. Special care would have to be taken with the design of equipment handling the finely ground sorbent because of its agglomeration tendencies. For example, silos should be of mass flow design with slot bottoms to prevent bridging. If necessary, heat might be required to prevent condensation within the silo or the feed system. Similar to pulverized coal, the sorbent could be injected into the furnace directly from the pulverizers if there is adequate redundancy to maintain system flow requirements with mills off the line for maintenance.

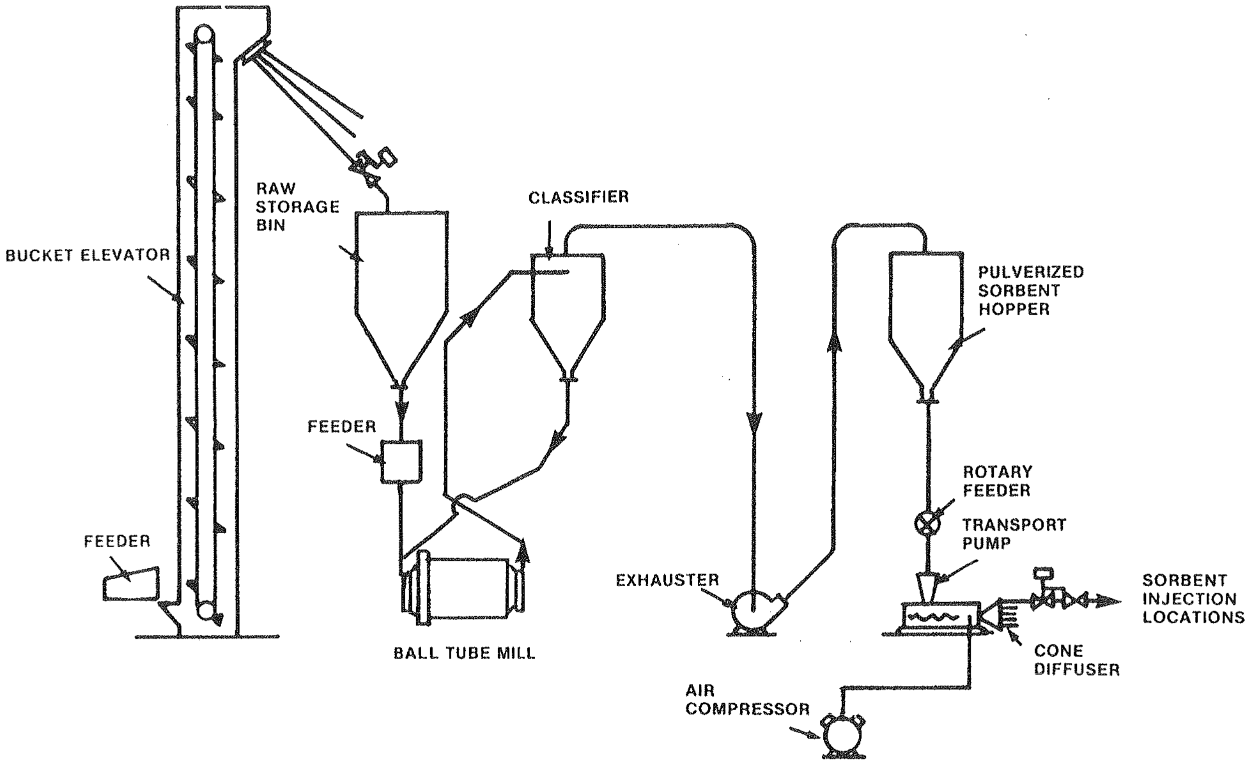


Figure 2 Sorbent preparation and injection schematic

SORBENT INJECTION SYSTEM

Rapid sorbent mixing and dispersion may be the key to success in the application of furnace sorbent injection to full-scale boilers. Once injected into the furnace, the calcination and sulfation of pulverized sorbent occurs rapidly. Certain sorbents may require injection into the cooler regions of the upper furnace. This will bring the injection point closer to the boiler screen tube section. The quench rate in this region is very rapid as the upward furnace flow turns and accelerates toward the convective cooling surfaces. Effective sorbent dispersion and mixing will be crucial in these situations.

The achievement of rapid sorbent mixing requires decisions on a number of injection parameters. These include the number of injection points, the shape of the injector nozzle, transport medium to sorbent mass ratio, and injector locations. An understanding of flow distribution within the furnace is also important. Recirculation zones in the upper furnace may carry sorbent particles back down in the flame zone where sintering of unreacted sorbent and regeneration of $CaSO_4$ to ($CaO + SO_2$) can take place. The presence and location of furnace recirculation zones can vary due to furnace dimensions, firing configuration, (single or opposed-wall) and the location of furnace arches.

The mixing characteristics and penetration of an expanding sorbent jet are controlled by the following design parameters:

- Density of the particle laden jet.
- Size of the jet.
- The relative momentum flux between the sorbent jet and furnace crossflow.
- Physical forces influencing dynamic system including inertia, viscosity and gravity (i.e., Reynolds number and Froude number).

The effects of jet diameter and injection velocity on sorbent jet penetration and centerline trajectories are shown in Figure 3. These calculations were made using an empirical correlation for single jet behavior in a crossflow[10]. The particle laden jet has been treated as a single phase stream with a mean density to account for both the solid particles and transport air. The assumption is also made that no slip exists between the solid and gas phase. These assumptions appear to be valid for small sorbent particles 20 microns in diameter or less. The analysis shown in Figure 3 is useful in understanding the influence of sorbent jet parameters on dispersion and mixing.

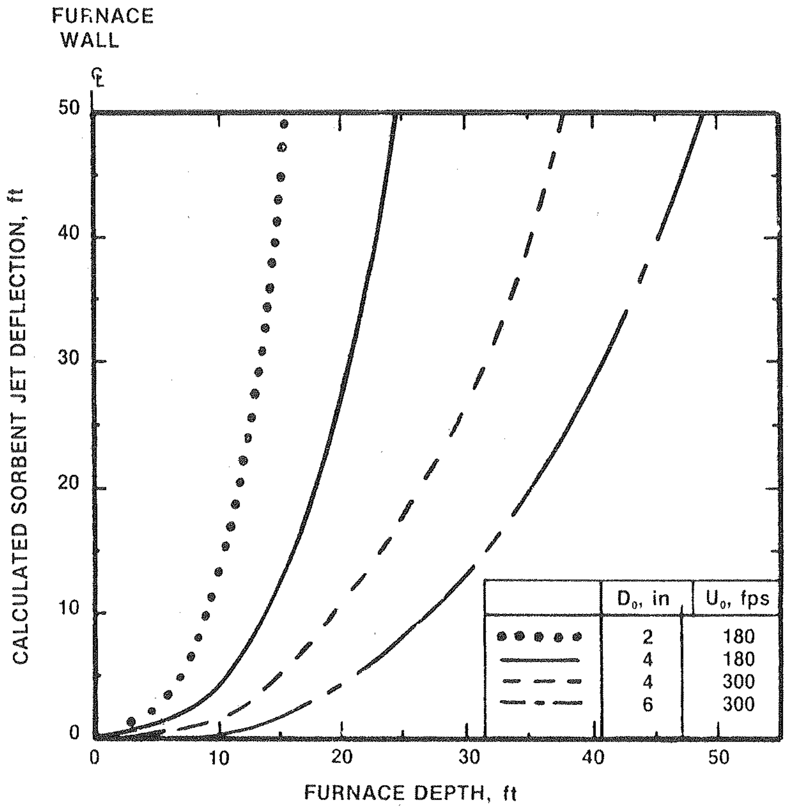


Figure 3 The effect of injection velocity and port diameter on sorbent jet penetration and deflection (Sorbent Injection at 2300°F and furnace velocity of 30 ft/sec)

COAL FIRING SYSTEM

Many earlier full scale demonstrations added the sorbent to the coal before pulverization. A typical coal pulverizing system consists of the unloading, storage, transport, feeder, pulverizer, classifier, and burner systems. The pulverizer system is at the heart of this array. Figure 4 shows the principle components of the coal pulverizing system. It consists of a feeder, crusher dryer, pulverizer, and classifier. As with sorbent, coal pulverizers can consist of many designs including the ball tube mill, vertical spindle mills, and high speed attrition mills.

Aside from reduced SO_2 captures, sorbent introduced with the coal resulted in an increase in mill power consumption, as high as 11%, during the sorbent injection periods. It is likely that many power plants will not have sufficient pulverizer capacity to grind coal/sorbent mixtures. This capacity decrease could be noted in total fuel and sorbent flow or a reduction in the particle size consist leaving the pulverizers.

Furnace sorbent injection can be decoupled from the coal firing system in the sense that, if the sorbent is not introduced through the pulverizer, injection can be controlled independently of the combustion control system. The effect of sorbent injection on the combustion process is somewhat dependent on the injection location. The original LIMB concept was based on the use of second generation low NO_X burners for combined NO_X/SO_2 control. When applied as a retrofit technology, this approach would require the integration of sorbent injection within the burner. The injection of sorbent into the post-flame region will have a much smaller impact on the firing system. There will be less direct influence the higher above the top burner row the sorbent is injected.

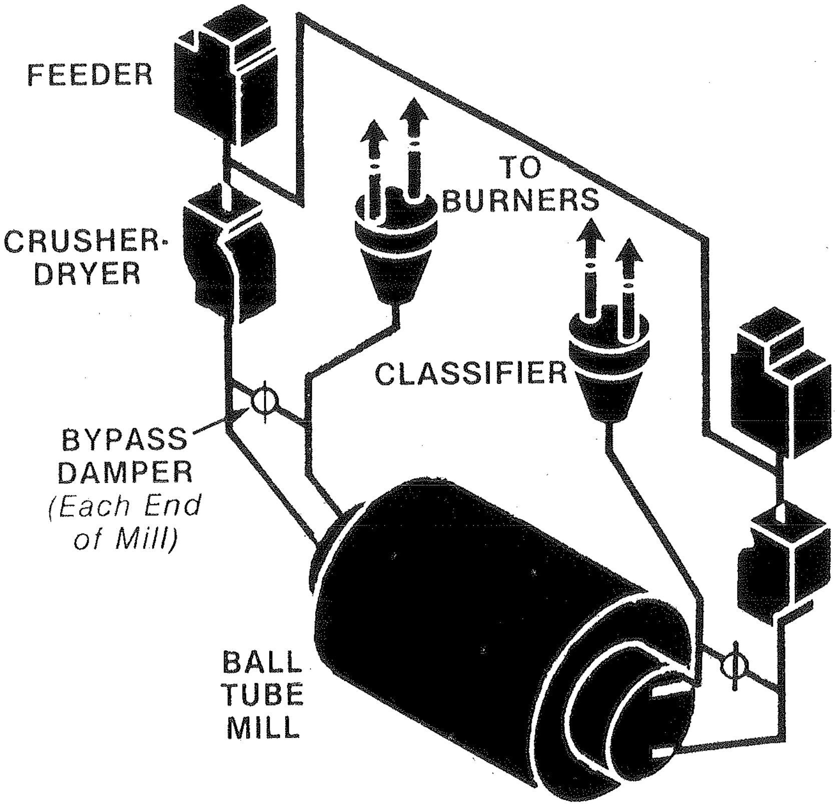


Figure 4 Coal pulverizing system

SLAGGING AND FOULING

There are still many questions to be answered on the influence of furnace sorbent injection on slagging and fouling. It is also not clear whether conventional soot blowing equipment can effectively control the increased deposition which may occur on the convective heat transfer surfaces of a boiler. Pilot scale data from slagging and fouling test rigs has been limited to a relatively few coals. Field tests performed approximately fifteen years ago do not reveal any significant problems due to slagging as a result of furnace sorbent injection. However, this field experience has also been limited, and is based on tests of relatively short duration.

Ash fusibility or melting behavior is one indicator of the tendency of coal ash to slag or foul tube surfaces. The ash fusion characteristics of various furnace flyash samples obtained with and without limestone injection is given in Table II[11]. The softening temperature is the ash fusion temperature most often used to evaluate slagging and fouling. The ash softening temperature drops significantly for the low-sulfur coal with limestone injection, while there is only a small decrease for the high sulfur coal ash.

Another indicator is the difference between the initial deformation temperature and fluid temperature. As this temperature difference narrows the deposits may become more difficult to remove. This temperature difference becomes smaller with limestone addition for both coals listed in Table II.

Item	Low Sulfur Coal (0.7% S)		High Sulfur Coal (3.5% S)	
Ca/S Molar Ratio	0	2.13	0	1.65
SO_2 Reduction, %	0	27	0	27
Ash Fusion Temperatures*, °F				
Initial Deformation	2305	2095	2140	2135
Softening	2400	2175	2210	2150
Hemispherical	2540	2210	2285	2160
Fluid	2640	2385	2385	2185

*Reducing Conditions

Table II Ash fusion results from pilot scale sorbent injection tests (Sorbent type: Limestone)

Fouling, by definition, is the accumulation of deposits in a dry manner which sinters on heat exchange surface in the convection passes of the boiler at temperatures below the fusion temperature of any of the ash constituents. Since nearly all of the sorbent injected for SO_2 removal will be carried over into the convective passes, ash quantities can easily double and often triple when sorbent injection is used in conjunction with high sulfur coal. The fouling deposits can lead to additional problems in the areas of erosion and corrosion of the convection pass superheaters, reheaters, economizers, and air heaters. Areas which can probably be affected are shown in Figure 5.

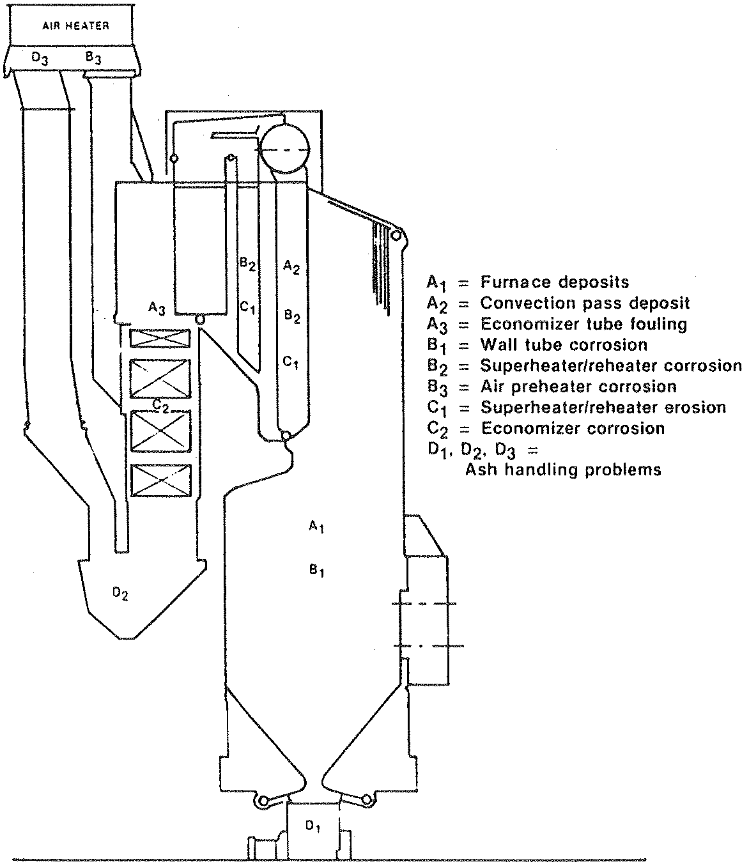


Figure 5 Areas that might be affected by increased ash loading from sorbent injection

The results from field trials and limited pilot scale studies have shown varying influences of sorbent injection on the potential to form difficult fouling deposits. The effect of the sorbent addition on ash sinter strength and ash fusion temperatures has been briefly investigated by others. It was found that the sorbent injection is fuel specific as it relates to ash fusion temperatures. As shown in Table II, the addition of limestone reduces ash fusion temperatures, increasing the tendency of the ash to stick to the tubes, especially in the high temperature regions. In others, the addition of sorbent actually increased the ash fusion temperatures. In most cases, the sintering strength of the ash was reduced allowing the buildups to be more easily removed through conventional means such as soot blowers. The influence of fouling severity and flue gas temperature on boiler convection bank tube spacing is described in Figure 6.

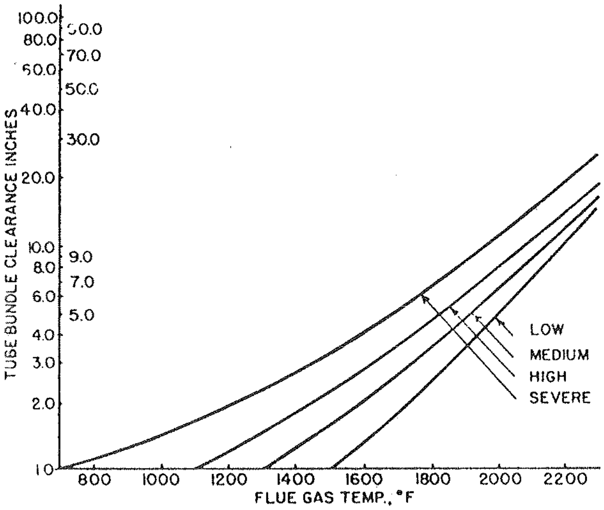


Figure 6 Tube bundle clearance vs. flue gas temperature for different fouling potential coals

The effect of sorbent addition on the particulate loading for a high and low sulfur coal is shown in Table III. The projected loadings are based on calcium utilization rates measured during pilot scale LIMB investigations[11]. Calcium utilization varied from 20 to 35% during these tests. The increase in particulate loading for the 3.5% sulfur coal is significant. Approximately three times the normal loading is reached at a Ca/S = 2.

	Ash Loading, lb/10^6 Btu	
Ca/S Molar Ratio	Low Sulfur Coal (0.7% S, 10.0% Ash)	High Sulfur Coal (3.5% S, 9.4% Ash)
0	8.4	8.5
1	10.0	17.0
2	11.3	24.1
3	12.5	31.0

Table III Effect of sorbent injection on furnace ash loading (Sorbent type: hydrated lime)

Erosion tendencies are increased with a higher loading of particulate in the flue gases. For existing units, this can be troublesome because of the difficulty in altering heat recovery surface spacing and configurations while still maintaining adequate heat transfer surface to perform their required duty. Shields can be installed on tubes but these are only a temporary stop gap and the erosion will continue, making the shields a maintenance item.

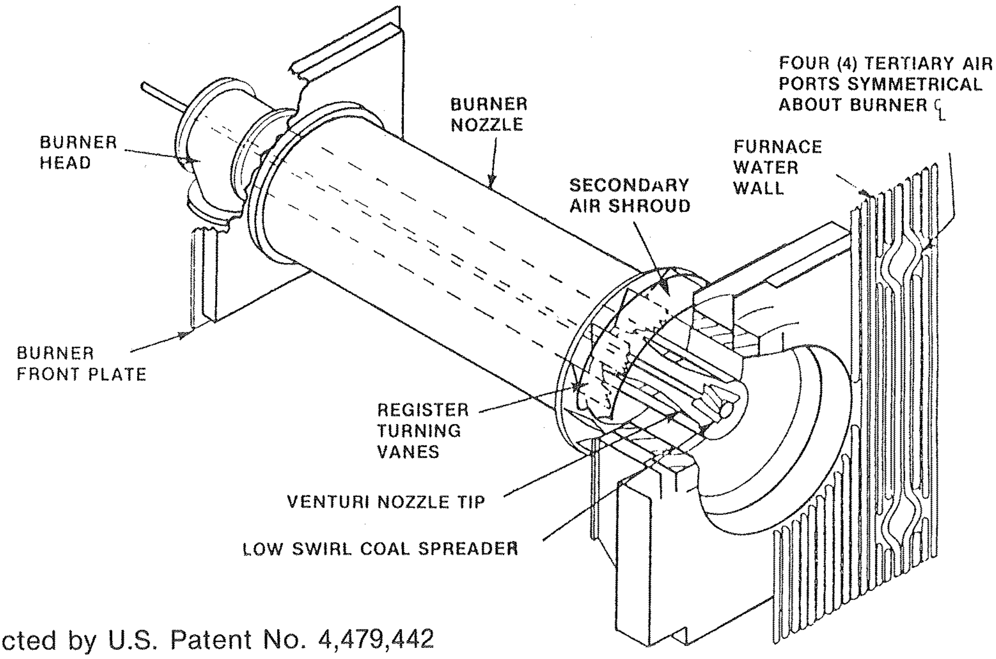
On new units, the designer can incorporate wider clear spacings between tubes or increase depth of the gas passes to bring flue gas velocities down to a safe level. Below 3600 feet per minute, erosion tendencies are generally negligible based on the design of the unit and the turns which the flue gases must make before entering a bank of superheater, reheater, economizer, or other heat recovery tubes. While increased tube spacing will not prevent fouling, it does allow more time between soot blowing cycles so that the gas flow lanes can be kept open.

A complimentary technology that may substantially decrease the concerns about particulate flows with furnace sorbent injection is coal cleaning. This process, one study of which is now underway at EPRI's Waltz facility, can substantially reduce the ash and sulfur content of the coal fuel. Ash and sulfur removals of 70% and 30% respectively, have been reported. These reductions tend to cancel out the additions to solid waste flows associated with sorbent injection.

The increased particulate loading also has an adverse affect on air preheaters. The tight spacing of preheater baskets can lead to pluggage because of the increased dust loadings. More material is deposited on the plates and bridging between the heat transfer elements is increased. As with the convection passes, part of this pluggage can attributed to a lowering of the ash sintering temperature by the sorbent ash particles.

BOILER OPERATION

Our own pilot scale experience with limestone injection in a 100 x 10^6 Btu/hr multiple stage Low NO_X burner, Figure 7, did not require a change in burner operation[11]. That is, the same burner design, settings, and low NO_X operation were maintained with and without sorbent over a range of coals, loads, and sorbent



Protected by U.S. Patent No. 4,479,442

Figure 7 Controlled combustion venturi burner types. We did not experience a problem with flame scannability even when the sorbent was injected into the main burner zone through tertiary air ports on the burner periphery.

There are, however, a number of potential indirect effects of that sorbent injection can have on overall operation. Increasing excess air, for example, is an operating technique frequently used to adjust for low superheat or reheat temperatures. Should the injection of dry sorbents into the furnace cavity lower final steam temperatures, a higher excess air level may be required.

Furnace sorbent injection can also impact boiler efficiency in a number of ways. One area to consider is the impact of the sorbent transport media. We estimate that 7 to 10% of the total combustion air may be required to transport and inject the sorbent. If cold transport air is used and the same excess air level is maintained, less air will pass through the air preheater. Bypassing air around the air preheater will result in higher stack temperatures and lower boiler efficiency.

HEAT TRANSFER DISTRIBUTION

Understanding the thermal history of flue gases in the radiant furnace and high temperature portions of the convection pass is important for the successful application of furnace sorbent injection in real boilers. The location of peak flame temperatures and the residence time available in the sulfation window are two key factors in the SO_2 capture process. Predicted temperatures for various furnace elevations are shown in Figure 8 for a 100 MWe pulverized coal wall-fired boiler. These temperature predictions were made using a multi-zone radiant furnace heat transfer model[12]. This analysis shows the 2300°F temperature window beginning approximately 17 feet above the top row of burners. For this boiler design a residence time of approximately one second exists within the radiant furnace for sulfur capture. This limited residence time again points out the need for achieving rapid sorbent mixing and dispersion.

The sorbent injection process itself can also influence heat transfer within the boiler system. The increased particulate loading and change in ash chemistry can alter heat transfer characteristics in several ways. Deposit build-ups on the furnace waterwalls and superheater surfaces can impact the radiative flux and furnace efficiency. These deposits have a thermal insulating effect and can alter the wall absorptivity. High loadings of particulate within the furnace volume can also change furnace radiative characteristics through scattering and absorption. The influence of higher particulate loadings, however, is somewhat dependent on the sorbent injection location. The higher the sorbent is injected in the furnace the less likely it is that the SO_2 capture process will significantly affect the overall thermal performance of the radiant furnace.

The effect of higher particulate loading and a thicker ash layer on furnace wall heat flux in a 100 MW boiler is shown in Figure 9. This analysis is based on sorbent injected above the top row of burners. The analysis also accounts for changes in emissivity due to higher particulate loading in the furnace gases in the sorbent injection region. In this case, sorbent injection results in a shift in the furnace wall heat flux distribution. Lower waterwall heat fluxes are predicted for the burner zone and higher fluxes are projected for the sorbent injection region. A shift in the boiler heat transfer distribution can either help or hurt boiler operation and efficiency. For example, reduced heat absorption in the waterwalls and lower furnace efficiency can lead to higher superheater temperatures and the need for more spray attemperation.

If soot blowing measures prove ineffective, the buildup of deposit material in the convective pass can affect heat transfer distribution in a number of ways. Buildup on superheater or reheater tubes may reduce steam temperatures resulting in reduced spray desuperheating requirements or altered flue gas control damper positions. Buildup on the economizer tubes could affect the firing rate required to generate steam. Increased convective pass deposits, therefore, can potentially result in increased boiler exit gas temperature and a corresponding reduction in boiler efficiency.

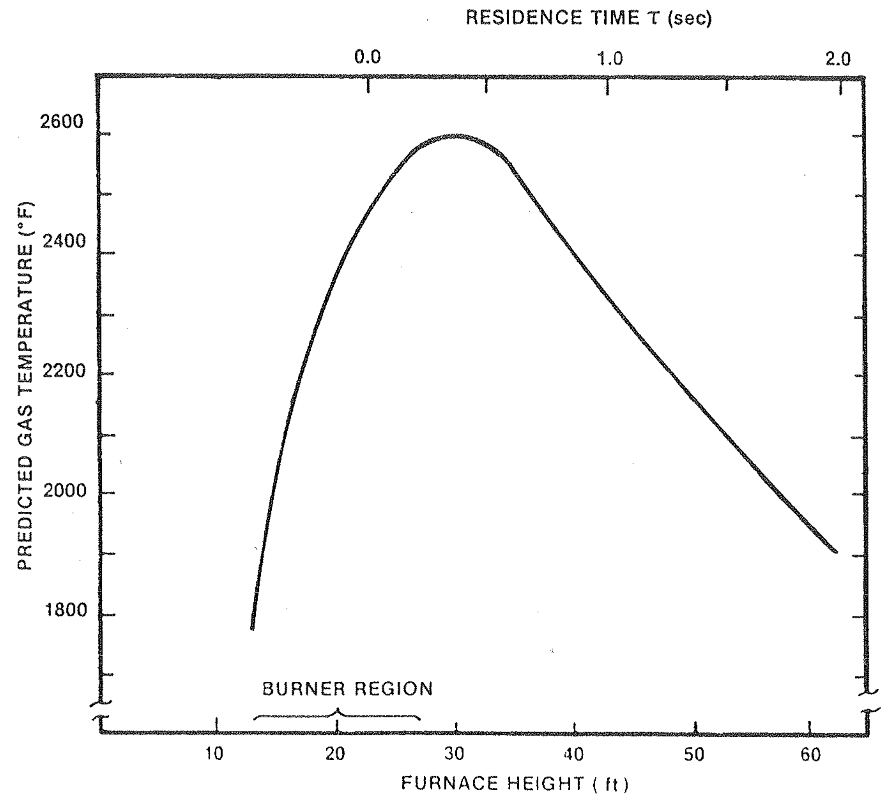


Figure 8 *Predicted furnace thermal profile for a 100 MWe pulverized coal wall-fire boiler*

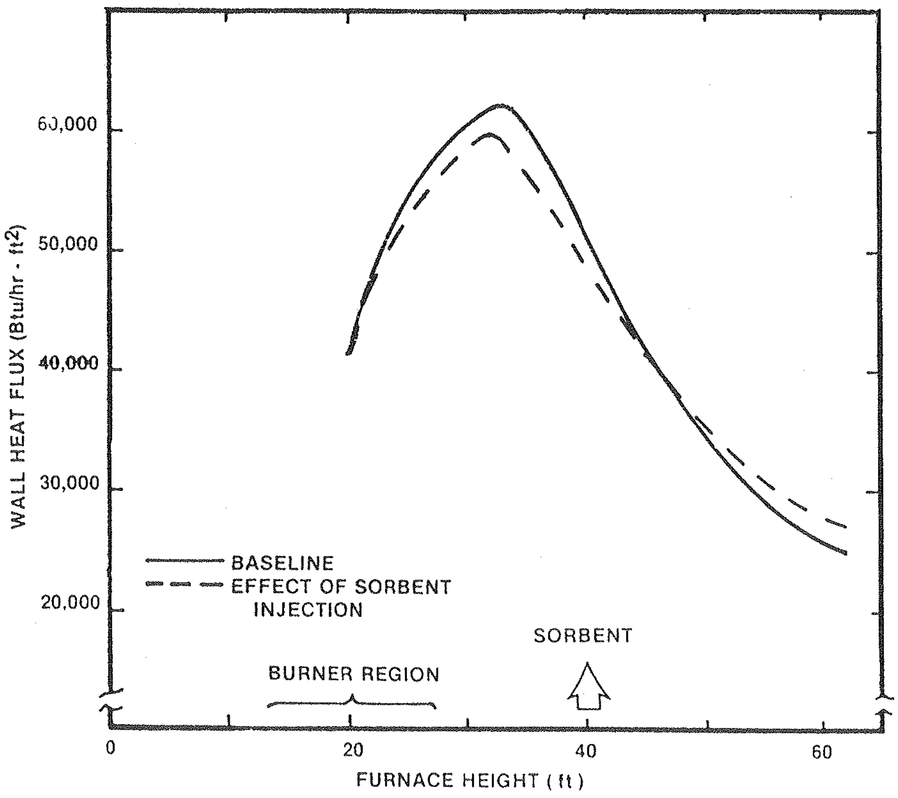


Figure 9 *The predicted effect of sorbent injection on water-wall heat flux due to increased particulate loading and wall deposits*

SUMMARY

As we have discussed, the injection of alkalai materials directly into the furnace cavity can have a number of potential adverse effects on boiler performance. In addition, process by-products consisting of calcium sulfate and unreacted sorbent must be carried out of the furnace by the flue gases and collected with the flyash by the particulate control device. Changes in fly ash resistivity in conjunction with increased particulate loadings present problems for older units with electrostatic precipitators. The generation of solid by-products of different composition can also make waste disposal more of a problem. All of these factors make the total cost impact of this technology unclear at this point.

Total cost will be dependent on the level of control required and eliminating risks. Field tests are needed to demonstrate whether SO_2 reductions achieved in the laboratory can be achieved in full-size utility boilers. They are also required to resolve the critical technical and cost issues necessary for the commercialization of sorbent injection technology.

ACKNOWLEDGMENTS

The authors wish to gratefully acknowledge Ms. C.E. McHale and Dr. C.B. Santanam of the Riley Research staff for their contributions to this paper.

REFERENCES

1. Mongeon, R. K., Mustonen, J. P. and Lachapelle, D. G., "Wall-fired Boiler Design Criteria for Dry Sorbent SO_2 Control with Low NO_x Burners," Presented at the 1st Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies, San Diego, November 1984.

2. Beittel, R. et al, "Studies of Sorbent Calcination and SO_2-Sorbent Reactions in a Pilot-Scale Furnace," Presented at the 1st Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies, San Diego, November 1984.

3. Bortz, S. and Flanert, P., "Recent IFRF Fundamental and Pilot Scale Studies on the Direct Sorbent Injection Process," Presented at the the 1st Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies, San Diego, November 1984.

4. Lachapelle, D. G., "EPA's LIMB Technology Development Program," *Chemical Engineering Progress,* May 1985, pp. 56-62.

5. Attig, R. C. and Sedor, P., "Additive Injection for Sulfur Dioxide Control—A Pilot Plant Study," Report APTD 1176 (NTIS PB 226761), March 1970.

6. Plumley, A. L., Jonakin, J., Martin, J. R., and Singer, J. G., "Removal of SO_2 and Dust from Stack Gases." Presented at Southeastern Electric Exchange, Richmond, Virginia, April 1968.

7. Gartrell, F. E., "Full-scale Desulfurization of Stack Gas by Dry Limestone Injection, Volume I," EPA-650/2-73-019a (NTIS PB 228447), August 1973.

8. Pohl, J. H., Energy and Environmental Research Corporation, August, 1983.

9. Makansi, J., Power Magazine, McGraw-Hill Publishers, June 1985, Page 36.

10. Beer, J. M. and Chigier, N. A., *Combustion Aerodynamics,* Applied Science Publishers, London, 1972, p. 22.

11. Lisauskas, R. A. et al, "Evaluation of a Prototype Burner for Combined NO_x/SO_2 Control," Presented at the AIChE 1985 Spring National Meeting, Houston, March 1985.

12. McHale, C. E. and Lisauskas, R. A., "The Application of the Zone and Monte Carlo Methods to Predict Heat Transfer in Pulverized Coal Fired Utility Boilers," Presented at the ASME Winter Annual Meeting, Boston, November 1983.