WALL-FIRED BOILER DESIGN CRITERIA FOR DRY SORBENT SO_2 CONTROL WITH LOW-NO_x BURNERS

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ABSTRACT

Limestone injection multistage burner (LIMB) technology is being actively investigated as a potentially economical and attractive means of reducing SO_2 and NO_x emissions in coal-fired boilers. Although primary emphasis is on the retrofit potential for existing boilers that are not currently equipped with scrubbers, application to new boilers is being investigated as well.

This paper concentrates on LIMB technology for new and existing coal-fired power stations and also discusses historical and projected design trends which have an effect on it. Advantages and disadvantages of various LIMB methods are discussed, including the effect on steam generator design criteria. A suggested approach is developed, and its ramifications on the boiler and the balance of plant design are discussed.

INTRODUCTION

Injection of dry sorbents into the furnace area of steam generating units is not a new technology. Many years ago, limestone was injected in an attempt to reduce low temperature corrosion and high temperature fouling in the convection passes of steam generators.[1] While it may have helped, it was expensive and its use was not widespread.

More recently, during the late 1960s and early 1970s, limestone injection was evaluated for removal of SO_2 from the products of combustion.[2,3] Removal efficiencies varied from 15 to 50 percent. However, the majority of cases averaged about 20 percent SO_2 removal. 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 a wall-fired unit. Some of the problems encountered

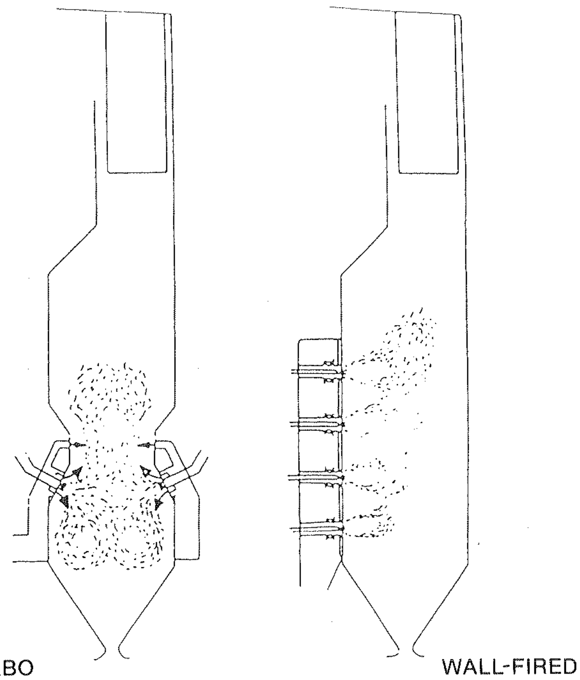


Figure 1 Riley Coal-fired Boiler Designs

included "deadburning" of the sorbent (thermal deactivation) along with fouling of the convective passes and loss in electrostatic precipitator removal efficiency. The 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. U.S. Environmental Protection Agency (EPA) pilot scale tests conducted around 1979 indicated the possibility of 70 percent removal of SO_2 with limestone injection through low-NO_X burners at reasonable Ca/S molar ratios. In 1980, the EPA initiated it's limestone injection multistage burners (LIMB) program to identify the process variables that resulted in the high capture observed in the pilot scale studies. The program's objective is to develop LIMB and low-NO_X burner technology for both retrofit and new applications.

BACKGROUND

Riley Stoker Corporation conducted a survey of its pulverized coal-fired utility boilers greater than 100 MWe sold during the last 25 years. Riley has constructed two basic types of wall-fired boilers during this period: one conforms to the wall-fired configuration for the general boiler industry and the other is a unique type designated the Riley TURBO® furnace. These design types are illustrated in Figure 1 for comparison. Wall-fired units can have burners installed on either or both of the front and rear waterwalls and also on one or more levels. In contrast, the Riley TURBO furnace always has burners installed as opposed pairs and at one elevation. The survey was directed at compiling general design and operational parameters, including but not necessarily limited to:

- Boiler population as a function of start-up year and coal rank
- Operating characteristics
- Boiler design trends including furnace geometry and heat releases
- Slagging and fouling characteristics
- Impact of NO_X control

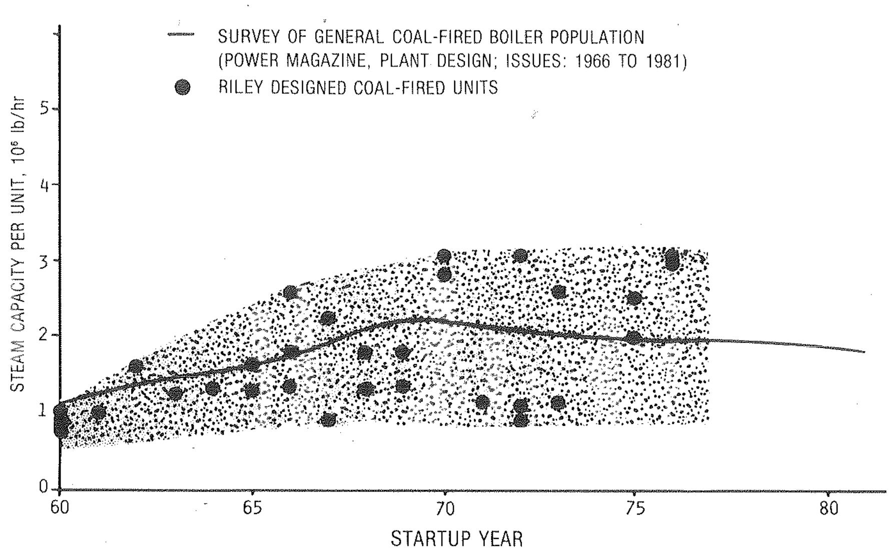


Figure 2 Steam Capacity vs. Startup Year for Riley Wall-fired Units

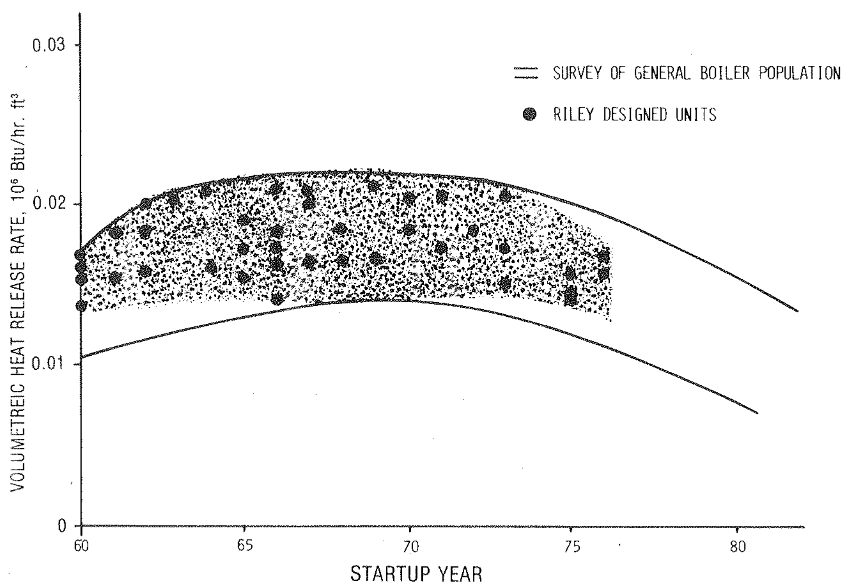


Figure 3 Volumetric Heat Release Rate vs. Startup Year for Riley Wall-fired Units

The general trends noted during this survey indicate that the period from 1965 to 1970 contains the units with the least amount of overages or leeways in design. Units were physically smaller and heat release volumes and rates were higher during this period. Also, the majority of units were designed for pressurized operation. The costs of induced draft fans and their associated controls were eliminated on pressurized units. By the mid-1970s, this trend had reversed, and nearly all units designed for coal firing were for balanced draft operation.

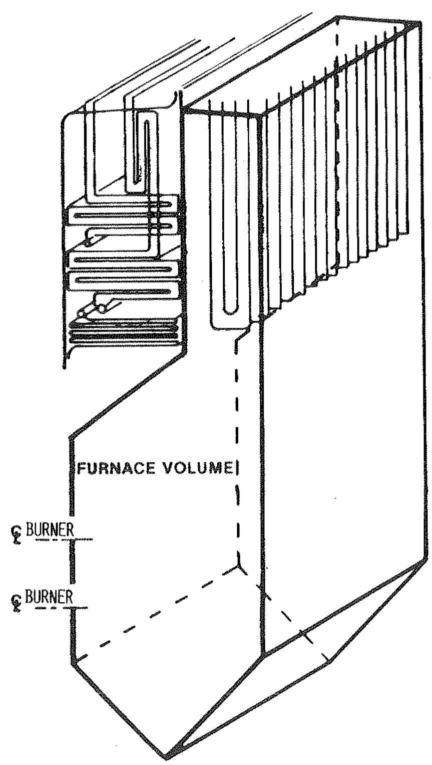
Figure 2 shows a plot of unit capacity versus start-up year. The unit capacity is in pounds of steam per hour, and there is a definite trend to increasing steam capacities up to 1970 where it has leveled off. There are a number of reasons for this, including the drop-off in supercritical unit designs and the switch to oil- and gas-fired units for the larger capacities.

Another consideration for the leveling off of the unit capacities is the advent of nuclear power. During the 1970s, nuclear units coming on line would handle the base load capacity requirements of the utilities. This left cycling and peaking type boilers, which were generally smaller in capacity than base loaded central station units, to meet the peak load demands.

Volumetric heat release rate has been plotted in Figure 3 for both Riley designed units and the general boiler population. The volumetric heat release rate is defined as the gross heat input to the furnace divided by the furnace volume (see Figure 4). The volumetric heat release rate is used as an indication of availability of space to complete the combustion process. Both trends are similar and show a gradual increase in heat release rate until approximately 1970 when the value started coming down in magnitude.

The effective projected radiant surface (EPRS) is calculated by creating an imaginary plane through the center line of waterwall and radiant superheater tubes. The flat surface is then calculated considering both sides of the plane on radiant superheater or waterwall platens and the furnace side of the waterwalls proper. The heat release rate on a square foot of effective projected radiant surface, shown in Figure 5, follows the same trend as volumetric heat release. There is a tendency to increase during the 1960s and to taper off during the 1970s. While part of this reduction can be attributed to air pollution requirements, the remainder can be explained by the reductions in coal quality. Lower rank Western sub-bituminous coals are low in both heating value and sulfur content, and more units are being designed for these coals during the 1970s.

Coal rank can affect many parameters in boiler design. During the 1960s and early 1970s, bituminous coal was used for the bulk of units designed for solid fossil fuel firing. During the middle and late 1970s, Western subbituminous and lignite coals permeated the market to the point that they represent approximately 50 percent of the coals used for new designs during that period.



NOTE:
FURNACE VOLUME IS FIGURED TO THE FURNACE EXIT PLANE MINUS THE VOLUME OF THE RADIANT SUPERHEATER TUBES

Figure 4 Illustration of Furnace Volume for Heat Release Calculations

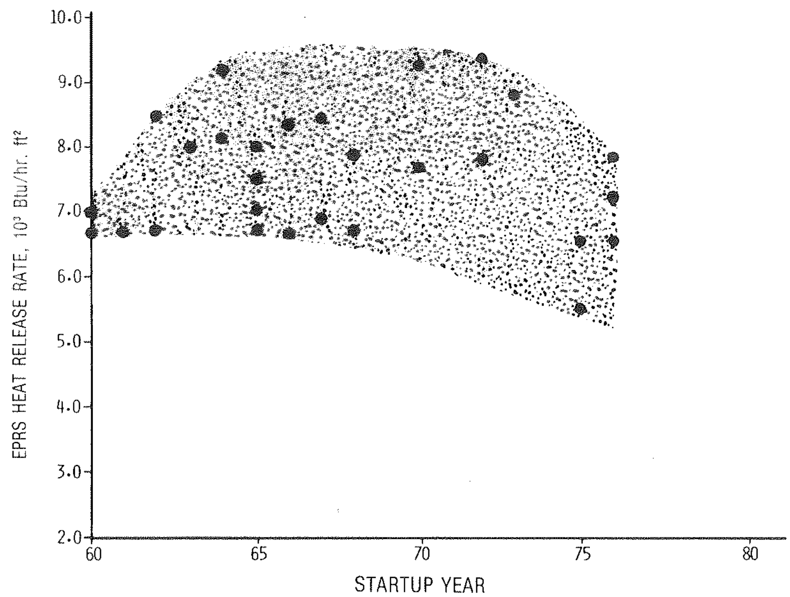


Figure 5 EPRS Heat Release Rate vs. Startup Years for Riley Wall-fired Units

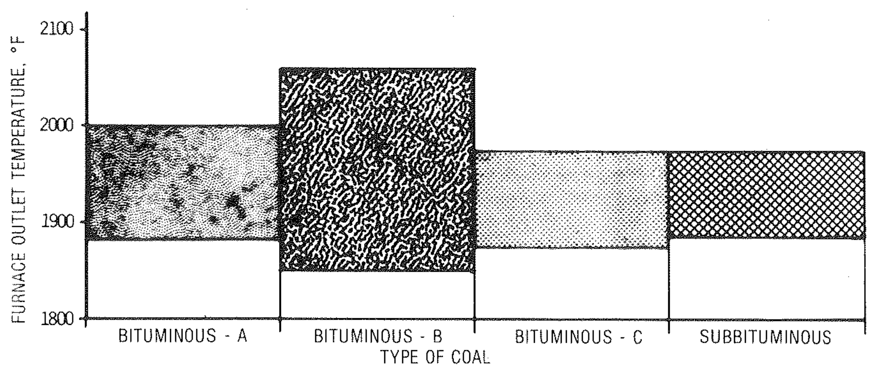


Figure 6 Furnace Outlet Temperature vs. Type of Coal for Riley Designed Units

Furnace exit gas temperatures have not changed significantly between the various ranks of coal. As shown in Figure 6, the furnace exit gas temperature range is plotted against the type of coal used in Riley Stoker designs. The predominance of the data is between 1900 and 2000°F. Part of the variance is due to an effort to maintain the furnace exit gas temperature well below the ash softening temperature of the coal. (Riley Stoker does not have any pulverized lignite fired units so lignite is not shown in Figure 6.)

In the early 1970s, government regulations for air quality control forced a turnaround in the size of the furnaces. During that period, one of the first methods of NO_X control was to lower peak temperatures in the flame zone, requiring larger furnaces to cool the combustion process and complete burnout of the fuel. This resulted in a decrease in heat release rates and furnace exit temperatures.

Currently, there is essentially no new fossil fuel utility boiler construction. When the utility industry does pick up, it is expected that the trends that were observed in the late 1970s will continue. Units will be of moderate size due to high interest rates and a slowdown in the growth rate of load demand.

The remainder of this paper discusses the approach to achieving both low-NO_X and low-SO_2 emissions using LIMB technology (see Figure 7). The effect on the boiler and the balance of plant equipment associated with the limestone injection technology is also discussed.

APPROACH

The goal of the ongoing EPA-sponsored LIMB program is to develop in-furnace sorbent injection combined with low-NO_X burner technology leading to industry demonstration and commercialization of LIMB technology in the near term. In consideration of this, specific LIMB objectives include a 50 to 60 percent reduction from uncontrolled levels of both SO_2 and NO_X in retrofit applications. Objectives for new LIMB-equipped plants would include a 70 to 90 percent reduction in SO_2 and a 70 to 80 percent reduction in NO_X from uncontrolled levels. These objectives are believed to be achievable with LIMB alone in the retrofit case and LIMB in combination with additional sulfur removal technology (if required) for new units.

LIMB appears to be particularly attractive since it is not space, hardware, or maintenance intensive and is therefore retrofittable to many existing plants at a fraction of the cost of scrubbers. Costs are expected to be at least $100/kW less than for scrubbers.[4] LIMB cost predictions to date have varied from ten to fifty percent of scrubber cost.[5,6,7]

Much basic research and pilot scale work has been and continues to be done toward the achievement of these objectives, and a full scale utility demonstration project is scheduled to commence late this year with start-up in late 1986.

Various configurations of LIMB-equipped plants have been conceived to meet the SO_2 and NO_X removal objectives discussed above at a cost significantly less than that of scrubber-equipped plants. Significant variables affecting plant design include:

- Boiler/firing configuration
- Burner design for low NO_X
- Coal type/sulfur content
- Sorbent type/size
- Calcium-to-sulfur molar ratio
- Time/temperature requirement for sorbent/SO_2 reaction
- Sorbent injection method
- Slagging/fouling/erosion potential
- Ash loading and resistivity
- Ash constituents' effect on disposal

Discussion in this paper is directed toward utility size pulverized coal boilers equipped with low-NO_X burners. Effects of various coal sulfur contents are discussed where they are expected to have a significant impact on LIMB design. The sorbent considered is high calcium limestone with calcium-to-sulfur molar ratios ranging from approximately 2 for high sulfur coal to 4 for low sulfur coal, where a higher percent sulfur capture is feasible. Limestone is finely ground and pneumatically introduced in the furnace separate from the coal. Soot blowers are provided as necessary for control of fouling. Existing particulate removal equipment is expected to be maintained on retrofit application. Because of increased ash loading and increased ash resistivity, modifications such as added mechanical collectors, precipitator renovation/expansion, and/or flue gas conditioning will be required on many applications with older precipitators. New units are expected to be equipped with fabric filters. Ash must be handled dry to avoid the cementitious characteristics of the alkaline material when wetted, and ash disposal will be complicated by the increased ash quantity and unknowns relative to LIMB ash disposal requirements.

EFFECT ON BOILER

The heart of the LIMB system is the low-NO_X burners and the sorbent injection system. Low-NO_X burners are generally designed with combustion air added in a staged manner, ensuring a fuel-rich zone early in the combustion process. This chemically reducing zone tends to lower NO_X production from oxidation of the

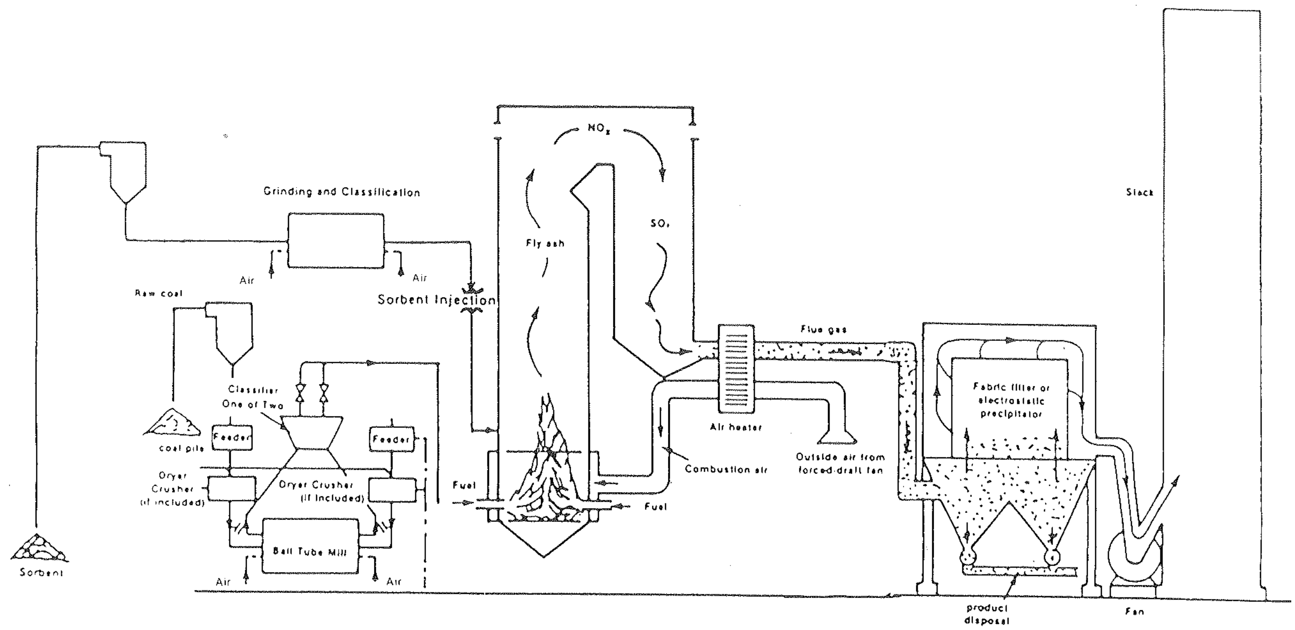


Figure 7 LIMB System Schematic

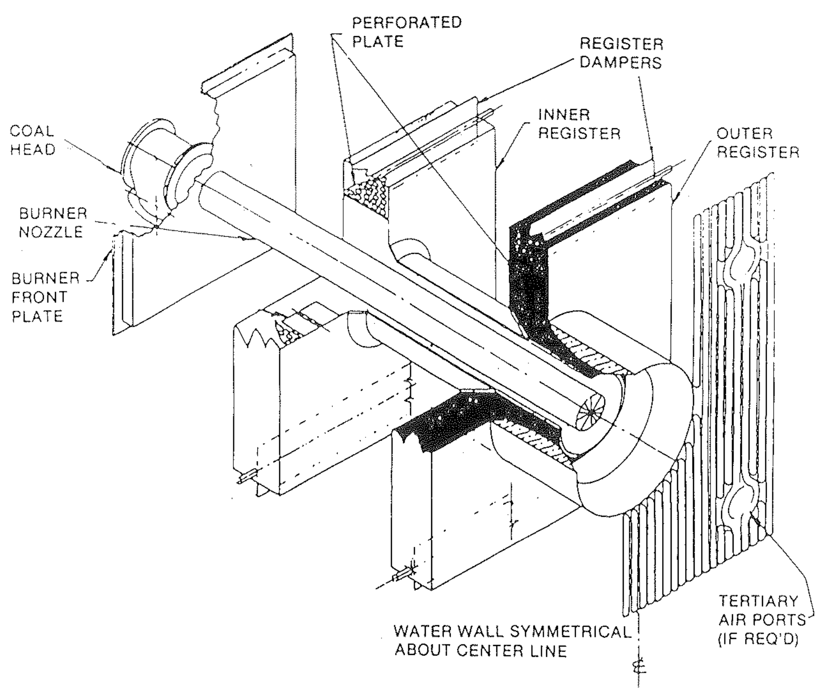


Figure 8 Riley Stoker Distributed Mixing Burner

nitrogen in the fuel and combustion air. Figure 8 illustrates a Riley Stoker low-NO_X burner concept and shows how combustion air is added in a staged sequence with the coal. This burner, which incorporates tertiary air ports for staging, was designed according to criteria developed under EPA low-NO_X burner demonstration programs. Although not shown in Figure 8, the coal nozzle incorporates the same venturi discharge section and conical coal spreader as that used in a retrofit low-NO_X burner design called the Controlled Combustion Venturi (CCV) burner.[8]

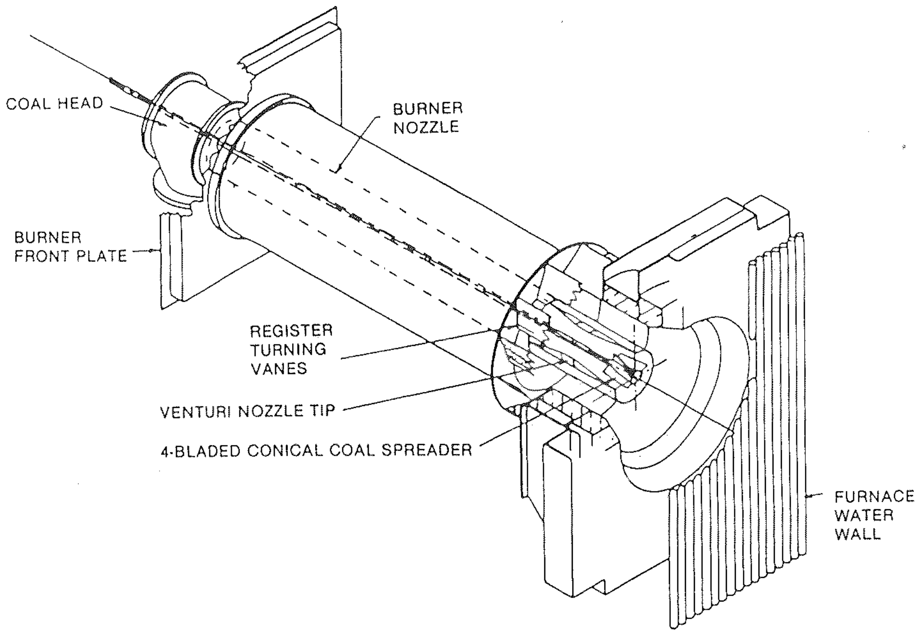


Figure 9 Riley Stoker Controlled Combustion Venturi (CCV) Burner

The CCV burner is shown in Figure 9. The design is very similar to pre-NSPS equipment (single-register flare burner) with the exception of a smaller diameter modified coal nozzle and spreader. The round coal nozzle discharge was modified to include a venturi section while the original multi-vaned coal spreader was replaced with a four-bladed conical shaped spreader. Both the spreader position and the nozzle setback position can be adjusted during operation. These modifications produce the mixing and combustion characteristics necessary for low-NO_X. Figure 10 shows the flame shape produced by the CCV burner as compared to the flame shape typical of the pre-NSPS (flare type) burner. The CCV burners have been retrofitted to existing units, with test results showing a 50 percent reduction in NO_X levels achieved with acceptable unit performance.

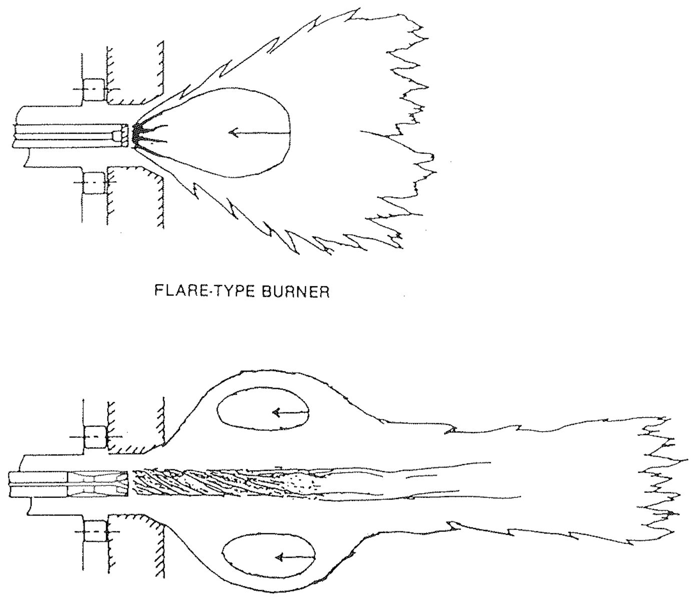
New unit designs could incorporate the CCV burner with tertiary air ports installed to get even greater reductions in NO_X levels based on uncontrolled measurements with pre-NSPS burner equipment.

The use of tertiary air ports or overfire air ports with low-NOx burners provides alternate locations for injection of the sorbent. As mentioned previously, initial work with sorbent injection showed low SO_2 capture due to sorbent deactivation. This occurred when the sorbent, which was injected directly with the fuel, reached high temperatures and sintered, forming a hard crust which prevented the SO_2 from reaching the sorbent pores and reacting. With injection through tertiary or overfire air ports, the limestone particles are allowed to cross the flame without crossing the highest temperature zone.[9] This aids in producing inert calcium compounds which can be removed in a particulate collection device and disposed of in an environmentally acceptable manner. These calcium compounds are formed in proportion to both sulfur content in the fuel and calcium-to-sulfur molar ratios for the sorbent injection process.

Figure 11 shows a conceptual view of the LIMB process. The limestone is calcined rapidly to lime which then combines with SO_2 to form calcium sulfate. The chemical reactions are shown in the following equations:

$$CaCO_3 \rightarrow CaO + CO_2 \quad (1)$$

$$CaO + SO_2 + \tfrac{1}{2}\, O_2 \rightarrow CaSO_4 \quad (2)$$



FLARE-TYPE BURNER

CONTROLLED COMBUSTION VENTURI BURNER

Figure 10 Typical Flame Shapes

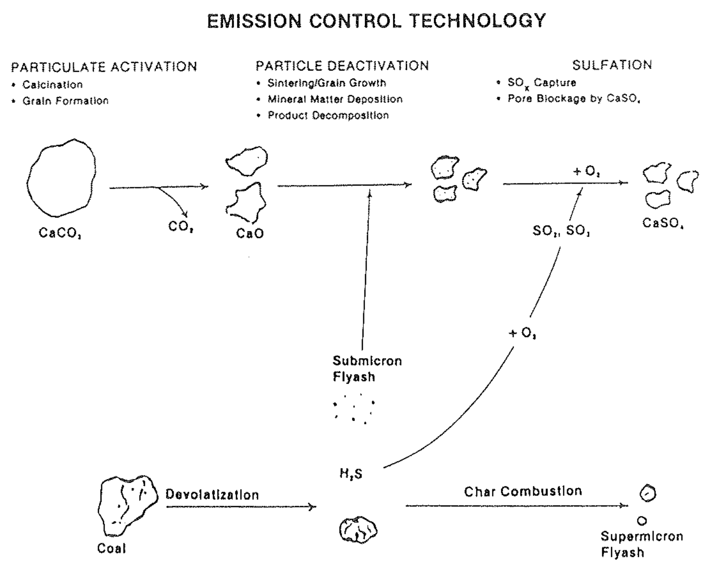


Figure 11 Limestone Transformations in a Pulverized-Coal Flame

The sorbent should be in the gas temperature regions above approximately 2200°F for a very short period of time to prevent deactivation or dead burning. Conversely, the limestone will only minimally calcine below approximately 1400°F. The optimum then is to produce sufficient residence times in the 2200°F to 1400°F temperature zone within the boiler.[10] This temperature zone usually occurs between the entrance to the radiant superheaters to a point approximately half way through the convection passes of the boiler, as noted in Figure 12. Typical residence times in these areas are from 1 to 2 seconds, depending on the unit design, the slagging and fouling characteristics of the fuel being burned, the erosion and corrosion tendencies, and fan capabilities. Some units, especially in the mid to late 1960s, were being designed in a very competitive market, and fewer leeways were incorporated in an attempt to keep costs down.

New unit designs are more conservative with larger furnaces and lower heat release rates to accommodate low-NO_X burner requirements. Also, the use of Western subbituminous fuels with their inherently high ash content has necessitated wider tube spacings and lower velocities through the tube bundles. New unit designs lend themselves well to the sorbent injection technology.

The calcination reaction is endothermic, which means that the process will absorb heat during the reaction. The heat required for calcination of pure limestone is approximately 2,000 Btu/lb. The sulfation process is exothermic and releases approximately 4,000 Btu/lb of lime (CaO). However, only about ½ lb of CaO is produced for every 1 lb of limestone, and only 25 percent of this is sulfated. This can result in a small energy penalty and reduce overall flue gas temperatures slightly.

Based on a 10^6 lb/hr steam boiler with turbine conditions of 1000/1000°F and 2400 psi throttle pressure, approximately 25,800 lb/hr of limestone is required, based on a high (3.4 percent) sulfur Midwestern bituminous coal, to produce a Ca/S molar ratio of 2. The basic quantities for these conditions are tabulated below. It is readily apparent that the ash quantities passing through the unit under these conditions are more than doubled.

Basic Quantities

Main steam flow	1,000,000 lb/hr
Reheat steam flow	853,900 lb/hr
SH/RH outlet steam temperature	1005°F
Turbine throttle pressure	2400 psig
Fuel flow	128,000 lb/hr
Fuel ash flow	10,750 lb/hr
Sorbent flow	25,800 lb/hr

Note: Coal fuel—10,650 Btu/lb HHV
3.4% S
8.4% Ash

This high ash quantity can affect heat transfer within the boiler in different ways. High ash loadings can affect flue gas emissivities as well as physically blocking radiation which might normally go to the waterwalls. In addition, the added particulate loading may increase slagging tendencies within the furnace. This slag layer can reduce the heat absorption in the waterwalls, preventing absorption in the generation side of the steam process. Field tests performed approximately 15 years ago did not reveal any significant problems due to slagging because of the addition of sorbent injection. However, there is only a limited amount of data, and some questions have been raised as to whether or not the units were on line long enough to produce slagging problems. More information is needed to be able to predict the slagging tendencies of various coals with sorbent injection with any degree of certainty.

The increased flyash quantities produced by sorbent injection can also affect fouling tendencies of the fuels. Again, the results of the field tests some 15 years ago are inconclusive, showing influences of limestone injection on fouling from slight to severe. Some of the deposits were hard and difficult to remove while on other units there were more deposits but they were softer in nature and easily removed. In general, however, fouling deposits are increased because of the increase in particulate flowing over the convection surface. For existing units, increased numbers of soot blowers, increased blowing pressures, or increased blowing frequency may be needed to handle increased ash flows. For new units, the tube spacing in a transverse direction from side to side can be increased, preventing the fouling buildups from plugging the convection passes by bridging over between the various assemblies of 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 (see Figure 13).

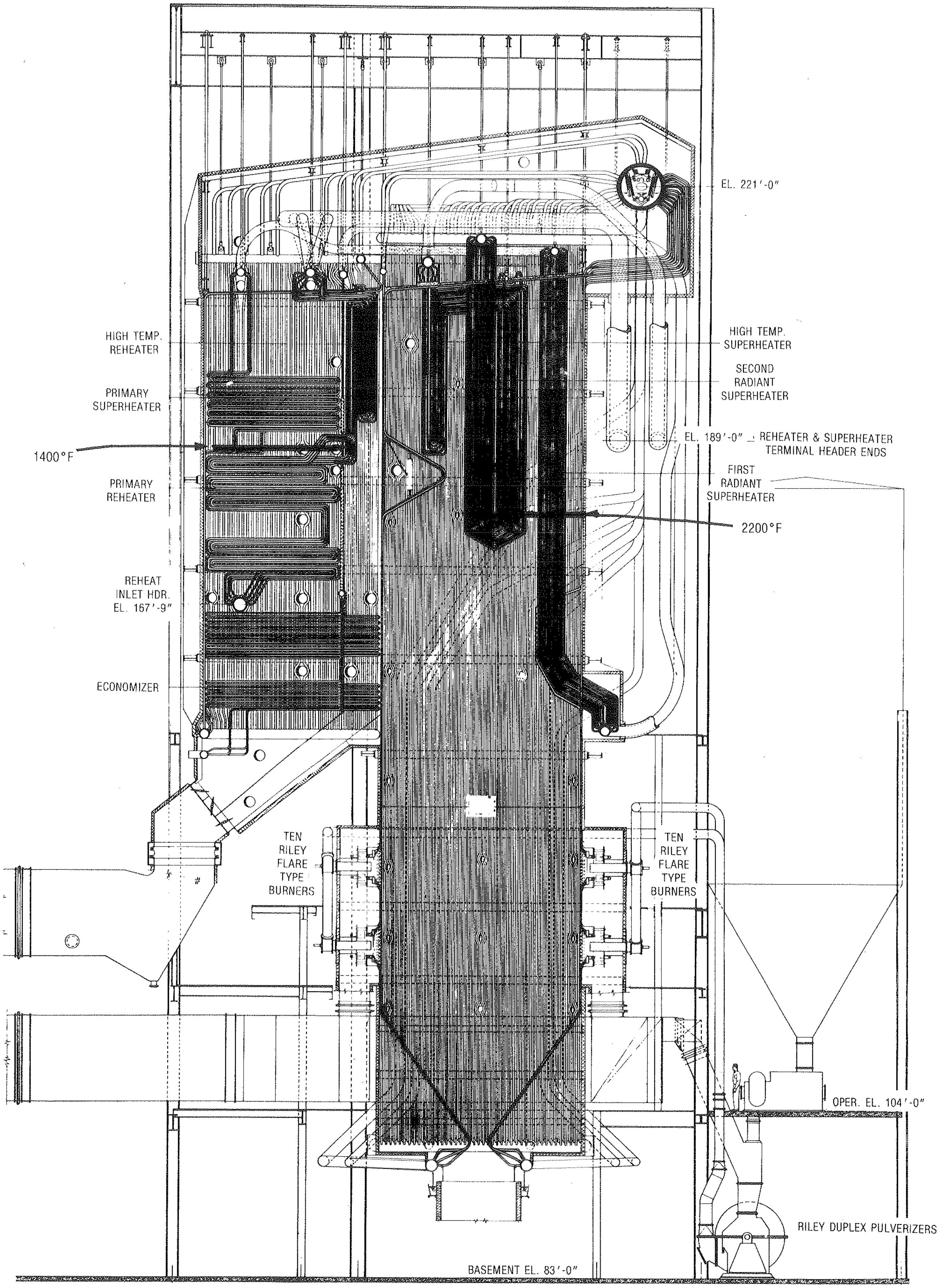


Figure 12 Approximate Temperature Zone for Optimum Sorbent Reaction

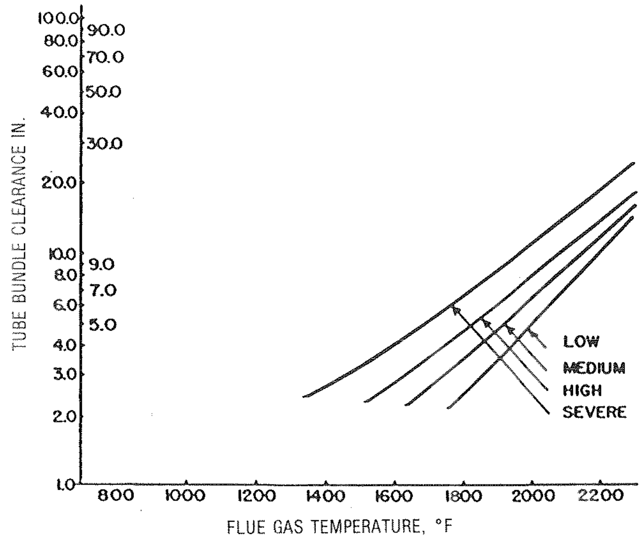


Figure 13 Tube Bundle Clearance vs. Flue Gas Temperature for Different Fouling Potential Coals

Erosion tendencies are increased with the 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 configuration while still maintaining adequate heat transfer surface to perform the required duty. Shields can be installed on tubes but these are only a temporary stopgap and the erosion will continue, making the shields a maintenance item. For new units, the designs can incorporate wider tube spacings or increased depth of the gas passages to bring flue gas velocities down to a safe level. Below 3600 ft/min, 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.

The increased particulate loading also has an adverse effect 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 be attributed to a lowering of the ash sintering temperature by the sorbent ash particles.

Bottom ash quantities and bottom ash removal may not be adversely affected by sorbent injection. In general, the limestone will be injected around or above the burners and conceivably in a much finer size consist than pulverized coal. It is expected that this small, lighter material will be swept upward with the flue gases, especially if injected above the burners through overfire air ports, and not increase the amount of ash in the bottom of the furnace hopper.

A complementary technology that may substantially decrease the concerns about particulate flows from the LIMB process is coal cleaning. This process, one study of which is now underway at EPRI's Waltz Mill facility, can substantially reduce the ash and sulfur content of the coal fuel. Ash and sulfur removals of 70 and 30 percent, respectively, have been reported. These reductions tend to cancel out the additions to solid waste flows associated with sorbent injection.[11]

EFFECT ON BALANCE OF PLANT

Sorbent Handling

One of the major impacts of retrofitting LIMB to an existing plant is the need for a sorbent handling system. Based on the 10^6 lb/hr boiler discussed earlier, which burned 3.4 percent sulfur coal with a Ca/S molar ratio of 2, approximately 25,800 lb/hr (as limestone) is required at the boiler. Although optimum sorbent selection criteria, including grind size, are the subject of continuing research, it is expected that a high surface area (i.e., high reactivity) stone will be required, finely ground to approximately 90 percent passing through a 325 mesh screen.

It is expected that most retrofit plants would receive the sorbent by truck. It would 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 stone, it may then require crushing to an intermediate size (3/8 to 3/4 x 0 in.) and drying prior to final fine grinding. Candidate mills for pulverization include ball, roller, high speed hammer, attrition, and pin mills. Grinding power to produce a finely ground product such as 20 μm 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 become appropriate to consider other grinding techniques.

Following final milling, the sorbent would be stored in one or more outside day silos and would be pneumatically injected into the furnace. The pneumatic 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 product because of its agglomeration tendencies. Silos, for example, would be mass flow design with slot bottoms to prevent bridging. Heating would be provided where necessary to prevent condensation. For extremely fine sorbent, it may be better to directly inject the product as it leaves the mills to avoid silo storage.

It is expected that new units would have similar sorbent systems. Some units would have provisions for rail or barge delivery of sorbent, and portions of the receiving facility might be used in common with the coal handling system.

Particulate Removal

A second major impact of retrofitting LIMB to an existing plant is a markedly increased flue gas particulate loading. For the 10^6 lb/hr steam boiler discussed earlier, the flyash load increased by a factor of 2.4. This assumes a finely ground sorbent, essentially all of which is entrained in the flue gas. Although flyash particle size distribution is expected to change very little, earlier tests[1] have indicated increases in resistivity by about two orders of magnitude. These factors present problems for older installed precipitators, most of which have specific collecting areas (SCAs) well below 400 ft^2/1000 acfm. Many of these units would require renovation, expansion, and/or flue gas conditioning to maintain effective particulate removal.

It is believed that SO_3 injection can effectively reduce resistivity to manageable levels on retrofits. There are also several older plants that have recently been retrofitted with larger precipitators. These units may be able to handle increased LIMB ash loading without conditioning and without major modification. The use of cleaned coal together with LIMB could prove to be an economical retrofit solution in precipitator-limited cases.

New unit applications are expected to favor the use of fabric filters which would be insensitive to the increased resistivity. Fabric filters could also see application on some retrofits in combination with an existing precipitator, should this approach prove economically attractive.

Ash Handling and Removal

The increased fly ash loading affects the ash handling equipment of the particulate removal device as well. Necessary modifications to this system on a retrofit may include larger size and/or increased number of precipitator hopper ash removal lines and increased capacity pressure or vacuum producing equipment, including any added support facilities/systems required. Larger or added ash silos would be required, as well as provision for dry handling of the alkaline ash because of its cementitious properties.

Since essentially all sorbent injected into the furnace is expected to be entrained in the flue gas, the bottom ash system should see minimal impact. Any sorbent in the bottom ash is expected to be sintered and relatively unreactive; however, bottom ash sluice/pond water pH would require scrutiny, and suitable pH controls should be installed, if necessary.

The ash disposal site envisioned would consist of a properly designed landfill, although possibilities for commercial use of the product (e.g., as an aggregate fill) exist as well. Although there is little data on hazards associated with LIMB ash disposal, it has been found that ash in alkaline matrices, including fluidized bed combustion ash and dry scrubber ash has, in general, not presented hazardous leachate problems. More research may be necessary to resolve this issue for LIMB.

As in the case of the particulate removal equipment, the use of lower ash content or cleaned coal would help reduce the impact of LIMB on the ash handling system by reducing overall ash quantity.

Sorbent Postcombustion Treatment

In order to achieve 70 to 90 percent SO_2 reduction, as required by NSPS on new units, LIMB (in combination with additional sorbent post combustion treatment devices) may be necessary. With this configuration, LIMB would capture the majority of the SO_2 in the furnace and provide a highly reactive calcined sorbent product in the flyash that could be effectively used by a downstream device such as a spray dryer. It is anticipated that the flyash would be caught in a mechanical collector, slurried, and sprayed into the absorption chamber of the spray dryer where about 80 percent or more capture of the inlet SO_2 is possible.[12] A fabric filter would be used for final particulate removal, and this could contribute to another 5 to 20 percent inlet SO_2 capture.

The combination of these SO_2 capture techniques would result in the NSPS-required 70 to 90 percent SO_2 reduction in what is expected to be a cost-effective manner. The system could be optimized by bypassing a portion of the flue gas stream around the spray dryer to the extent that the required SO_2 capture is achieved. This would reduce spray dryer costs and avoid the need for flue gas reheating. Operating costs are expected to be comparatively low because the equipment is relatively uncomplicated and the sorbent (assuming limestone) cost is low.

Soot Blowing

As discussed earlier, LIMB retrofits are expected to require additional soot blowers to control fouling. Also, the required blowing pressures and blowing frequencies may have to be increased. Either air or steam soot blowers may be used. If air is the selected medium, new soot blowing air compressors and distribution systems would be required at many installations. Steam soot blowing may prove to be a more economical solution in many cases.

COST

EPRI has estimated the incremental cost of LIMB on new units equipped with fabric filters to range from $15 to $30/kW, depending on coal sulfur content and Ca/S molar ratio.[6] Retrofits could cost two to three times as much to account for upgrading of soot blowing, precipitators, and ash handling and disposal systems. EPRI estimates 30-year, levelized operating costs of 3 to 12 mills/kWh, depending on coal sulfur content and required Ca/S molar ratio.

More detailed cost estimates are currently being prepared by the authors of this paper and others on behalf of the EPA. These estimates will address a wide range of utility plant sizes, both new and retrofit, with high and low sulfur coals. It is expected that these estimates will confirm that the cost of LIMB will be at least \$100/kW less than that for scrubbers.

CONCLUSIONS

Sufficient field information is not available on sorbent injection to determine its effectiveness as a viable means of reducing air pollutants. Full-scale demonstrations of the sorbent injection process using various coals, sorbents, and boiler designs, could provide this information.

An area of concern is not whether sorbent injection can remove SO_2 before the flue gases discharge into the atmosphere from the stack, but rather how much of the SO_2 can be removed. This paper has noted various areas which must be considered in any sorbent injection installation. These include sorbent handling and injection, fouling in the convective passes and air preheaters, particulate removal in electrostatic precipitators or fabric filters, and disposal of the products of combustion and sorbent injection. Although these concerns are significant, the alternatives to sorbent injection for SO_2 removal may be more costly and present more problems. LIMB technology offers the potential for low cost reductions in NO_x and SO_2 in response to acid rain concerns, and this should be evaluated carefully for both retrofit and new units.

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