Dry Flue Gas Desulfurization

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ABSTRACT

Increases in compliance oil prices and the commercialization of dry flue gas desulfurization (FGD) technology have made coal a more economical fuel than oil for many industrial boilers. However, the burning of coal vs. compliance oil makes it necessary to install air pollution control equipment to remove SO_2 and fly ash from the boiler flue gas. Conventional wet scrubbers collect SO_2 and fly ash as a wet sludge which is difficult and costly to handle; dry FGD systems produce a dry, insoluble waste that can easily be disposed of at any approved fly ash dumping site. The first commercial dry FGD system in the U.S.A. has been operating on the Strathmore Paper Company's coal-fired boiler (65,000 lb steam/hr (8.20 kg/s)) since July 1979 with an excellent on-line availability, and the system has passed all EPA compliance tests.

INTRODUCTION

The oil embargo of 1973 forced a change in the nation's declining use of coal as a fuel for industrial steam generators and other industrial processes. The Federal Government has encouraged industrial users of energy to convert existing power plants to coal from oil in order to reduce dependence on foreign sources of supply. Now, after a decade of increasing fuel oil prices, industrial users may conclude that it is actually more profitable for them to convert their power plants to coal. The profit margin remains attractive in spite of the increased investment costs for coal firing equipment, coal handling facilities, the problems of ash disposal, and the added cost of a pollution control system.

The pollution control equipment must be capable of controlling both particulate and sulfur oxide emissions at compliance levels. Currently there are three methods available for the control of sulfur oxides. These are fluid bed combustion, wet scrubbing, and dry scrubbing. Wet scrubbing has been applied quite extensively over the past 12 years and most of its strengths and weaknesses have been well defined and publicized. While fluidized bed combustion is being applied, it is still in the developmental stage and does not, strictly speaking, compete with the other technologies.

Dry scrubbing is the most recent and exciting of the control technologies. Within three years it has advanced from the embryonic stage to a point where it has a significant share of new orders for the air pollution control equipment market.

DRY SCRUBBING METHOD FOR FLUE GAS DESULFURIZATION

The term "dry scrubbing" is somewhat of a misnomer. Dry scrubbing in the true sense consists of the injection of dry reactant powder into a gas stream; the gas is absorbed by the dry powder and separated by means of particulate dust collectors. MikroPul has a total of 12,000,000 cfm (5,664 m^3/s) of dry scrubbing systems operating on primary aluminum smelters where dry alumina powder is injected into the gas stream to absorb fluoride gases; the spent alumina is returned to the smelter and used as feed stock in the smelting process.

While this technique has been evaluated using various dry reactants to remove SO_2 from flue gas, the technology has not achieved sufficiently high levels of performance to justify commercial acceptance.

In the popular sense, "dry scrubbing" is a hybrid method for SO_2 and particulate removal where an alkali reactant (in the form of a solution or slurry) is pumped to atomizers in a spray dryer-reactor. The alkali reacts with the SO_2 while the heat of the flue gas evaporates the water, leaving a dry powder.

While dry SO_2 scrubbing may employ a variety of alkali reactants, lime has been commonly selected as the most cost effective. It also results in a reaction product with low water solubility and high stability.

PROCESS DESCRIPTION

The system consists of two principle items of hardware: the spray dryer-reactor and a fabric filter. Each has a record of over 40 years of successful operation (in combination) involving a fundamentally similar operating duty cycle.

A typical dry SO_2 scrubbing system is shown in Fig. 1; Fig. 2 illustrates the process flow.

Bulk deliveries of quicklime (CaO) are pneumatically conveyed to a lime storage silo. From here, the lime is fed to a lime slaker where it is hydrated to $Ca(OH)_2$. Grit is removed as the hydrated lime is transferred to the agitated slurry holding tank. A progressive cavity pump delivers the lime slurry at a controlled rate and concentration to atomizers on top of the spray dryer. In the spray dryer, the atomizers create a spray of fine droplets which are intimately mixed with the hot incoming flue gas. The sulfur oxides contained in the flue gas are absorbed onto the surface of the fine droplets and react with the lime alkali to form insoluble calcium sulfite and sulfate (Fig. 3). At the same time, the hot flue gas evaporates the water in the droplets to produce an insoluble dry powder. The evaporation of water cools the flue gas to a temperature of 20 to 40^oF (11 to 22^oK) above the dew point to 140-160^oF (333 to 344^oK). The powder leaving the spray dryer consists of the reaction products (calcium sulfite and sulfate), fly ash, and a slight excess of unreacted lime. The scrubbed flue gas and suspended fly ash and powder are separated in the downstream fabric filter.

REAGENT PREPARATION

Soda ash and lime are the only two reagents which have been proven commercially feasible to date.

Lime is the reagent chosen for most dry scrubbers thus far because of its availability, low cost, and the stability of the reaction products it produces. The preparation of lime is more complicated than it is with soda ash since it must be slaked (hydrated) from the delivered form of quicklime (CaO) into a hydrated lime slurry ($Ca(OH)_2$). The technique applied in slaking lime can significantly effect its reactivity; therefore, the slaking method is one of the most important design considerations.

Slaking is usually accomplished either in paste slakers or detention slakers; in cases of high rate requirements, ball mill slakers may be the preferred method.

The water used for slaking must be of reasonably good quality. Ideally it should be softened to prevent scaling problems and must be low in sulfates and other chemicals which cause a reduction in the reactivity of the slaked lime.

The quantity of water consumed in lime slaking may be small compared with the volume used to dilute the slaked lime to the proper slurry concentration. Water used to dilute the slurry need not be as soft and pure as the water used in the slaking operation.

Temperature control is important in the lime slaking process; slaking is an exothermic reaction and therefore produces much of its own heat. The best results are achieved by holding a relatively constant temperature of 190^oF (361^oK). At start up, the water used for slaking should be heated until the slaking process produces enough heat to maintain a proper temperature. In the use of paste slakers, it may not be necessary to heat the water during the normal stabilized operating periods; in the case of the detention-type slaker, it is usually necessary to use feed water at a temperature of 130 to 140^oF (328 to 333^oK).

It has been found that, in certain cases, recycle of some of the collected product from the fabric filter with fresh slurry can improve the overall lime utilization. This recycling method permits the reuse of unreacted lime in the spent product and, if the fly ash is high in alkalinity, it may reduce the required amount of lime reagent.

The amount of pumped slurry required falls in the range of 0.2 to 0.4 gpm/1000 acfm (26.7 to 53.5 cm^3/m^3). Wet scrubber slurry pumping rates are approximately 200 times this rate.

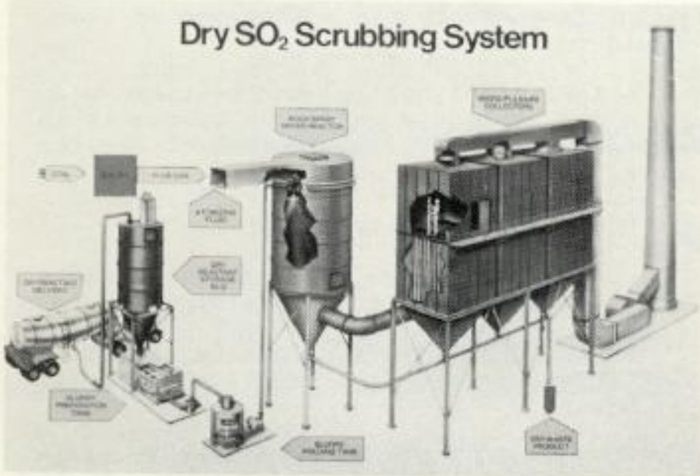

Fig. 1. A typical dry SO_2 scrubbing system.

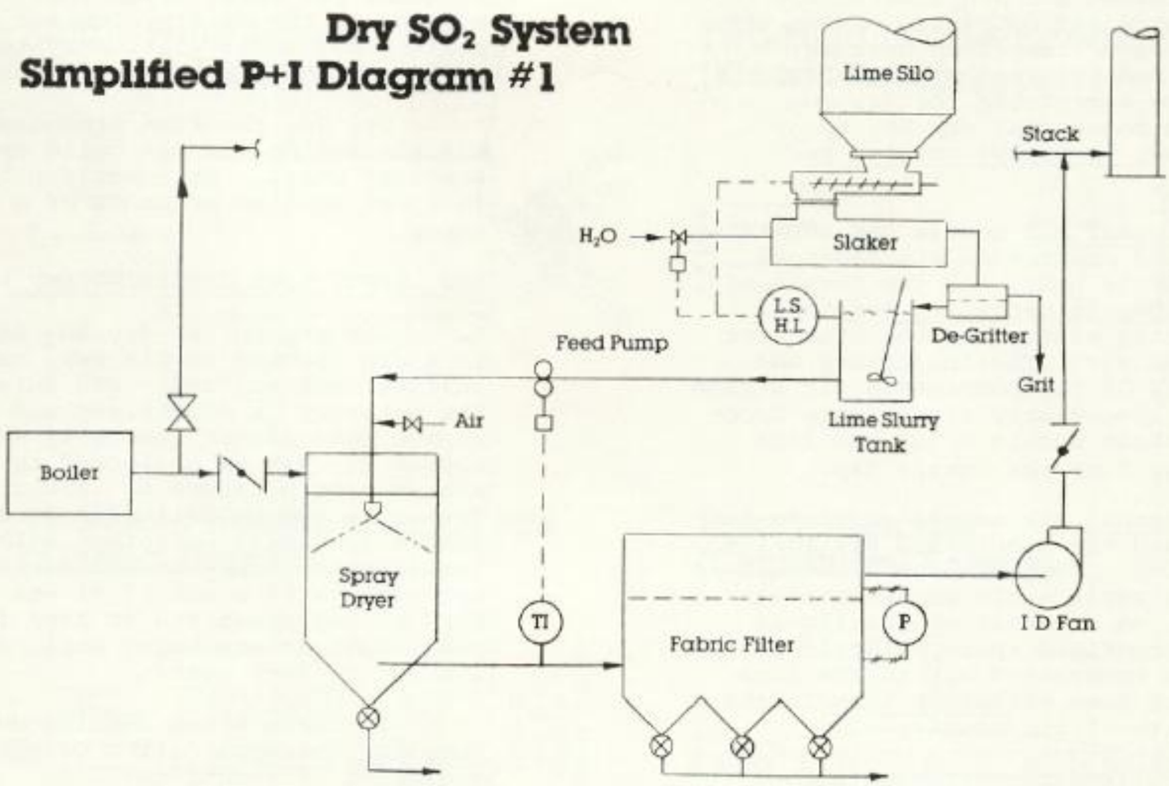

Fig. 2. Simplified P&I diagram of a dry scrubbing system.

ATOMIZING TECHNIQUES

Slurry atomization is the heart of the dry SO_2 scrubbing system. Slurry atomization in the spray dryer-reactor can be accomplished by any of four devices which are shown in Fig. 4 and described as follows: Single-fluid orifice nozzles using hydraulic energy, two-fluid nozzles (external or internal mix) using kinetic energy, and rotary atomizers using centrifugal energy. Koch Engineering has installed commercial spray dryer systems using all three atomization techniques. Experience has dictated preference for two-fluid nozzles in the case of the dry SO_2 scrubbing applications to industrial size boilers.

SINGLE-FLUID NOZZLES Single-fluid nozzles are generally not regarded as satisfactory for dry SO_2 scrubbing applications for a number of reasons such as high pressure requirements (2,000 to 3,000 psig (14,000 to 21,000 kPa))to achieve 40 micron (0.004 cm)droplets, nozzles plugging at swirl insert and orifice, abrasion of small orifice, flow limitation to only a few gpm/nozzle resulting in an excessive number of nozzles, and limitations of liquid turndown.

TWO-FLUID NOZZLES Two-fluid nozzles utilize compressed air and lime slurry to form finely atomized droplets. There are two basic types of two-fluid nozzles: external mix and internal mix nozzles. Both types are acceptable for dry SO_2 scrubbing; a commercial dry SO_2 spray dryer uses four to twelve nozzles per reactor.

The external mix nozzle has separate lime slurry and compressed air passages within the nozzle body. At the nozzle tip, two concentric exit paths are provided; one for the lime slurry and the other for the compressed air. The trajectory and kinetic energy of the compressed air stream shatters the lime slurry stream into droplets when contact occurs about one inch (2.54 cm) away from the nozzle tip.

The internal mix nozzle contacts the lime slurry and the compressed air inside the nozzle body. The air-liquid contact is confined to a replaceable abrasion-resistant insert. As a result of gas-liquid contact in a confined space, kinetic energy transfer from compressed air to the lime slurry is much more efficient than in the external mix two-fluid nozzle.

Each nozzle type--external and internal--has different characteristics. The external mix nozzle shows essentially zero wear but consumes much power (3.0 to 3.5 hp/1000 acfm (4.74 to 5.53 $kW \cdot s/m^3$)). The internal mix nozzle, like the rotary atomizer, consumes little power (0.8 to 1.0 hp/1000 acfm (1.26 to 1.58 $kW \cdot s/m^3$)) but requires abrasion-resistant inserts.

In general, the advantages of two-fluid nozzles are:

- Individual nozzles can be taken off line and inspected while the system is in operation with negligible loss of SO_2 removal efficiency (Fig. 5).

- High reliability.

- A simple design with no moving parts makes nozzles easy to maintain.

- Abrasion-resistant inserts are easily and inexpensively replaced in a matter of 15 minutes.

ROTARY ATOMIZATION Rotary atomization occurs as slurry is fed onto a high-speed wheel which is rotating in the range of 10,000 to 15,000 rpm (167 to 250 rev/s). Slurry flowing off the rotating wheel leaves as small droplets. The dynamically-balanced atomizer wheel is driven by a shaft through a bearing assembly by means of a high-speed motor or speed increaser-type drive. A single rotary atomizer is capable of handling high liquid flow rates; therefore, it is customary to use one atomizer per spray dryer-reactor. Support systems of the rotary atomizer include a bearing oil recirculation system and a sealing and cooling air fan.

Dry SO_2 reaction products are insoluble solids and can build up on the atomizer wheel. This buildup is difficult to clean on-line by means of a fresh water spray.

ASH, SPENT LIME GATHERING AND DISPOSAL

The product of dry SO_2 scrubbing is a dry mixture of fly ash, calcium sulfite and sulfate, and unreacted lime. The material is discharged and gathered in the same manner generally applied to common fly ash as collected in electrostatic precipitators or fabric filters. The waste may be delivered directly to a simple land fill operation without the requirement of any stabilization of the material as is required of wet scrubber sludge. Alternatives to land fill disposal methods are being explored including end product uses.

In cases where dusting may be a problem, the application of pelletizing equipment is recommended.

THE STRATHMORE PAPER COMPANY DRY SO_2 SCRUBBING SYSTEM

In September of 1978, the Hammermill Paper Company, Erie, PA awarded the

Lime Slaking

$$CaO(S) + H_2O \longrightarrow Ca(OH)_2\,(S) \rightleftharpoons Ca^{++} + 2OH^-$$

SO$_2$ Absorption

$$SO_2(G) \rightleftharpoons SO_2(L)$$

Reaction With Hydroxide

$$SO_2(L) + OH^- \rightleftharpoons HSO_3^-$$

$$HSO_3^- + OH^- \rightleftharpoons SO_3^= + H_2O$$

Partial Oxidation Of Sulfite

$$SO_3^= + \tfrac{1}{2}O_2(L) \rightleftharpoons SO_4^=$$

Precipitation Of Products

$$SO_3^= + Ca^{++} \rightleftharpoons CaSO_3(S)$$

$$SO_4^= + Ca^{++} \rightleftharpoons CaSO_4(S)$$

Overall Reaction

$$SO_2(G) + Ca(OH)_2(S) \xrightarrow{H_2O} CaSO_3(S) + H_2O$$

$$SO_2(G) + Ca(OH)_2(S) + \tfrac{1}{2}O_2(G) \xrightarrow{H_2O} CaSO_4(S) + H_2O$$

Fig. 3. Chemistry of SO_2 absorption.

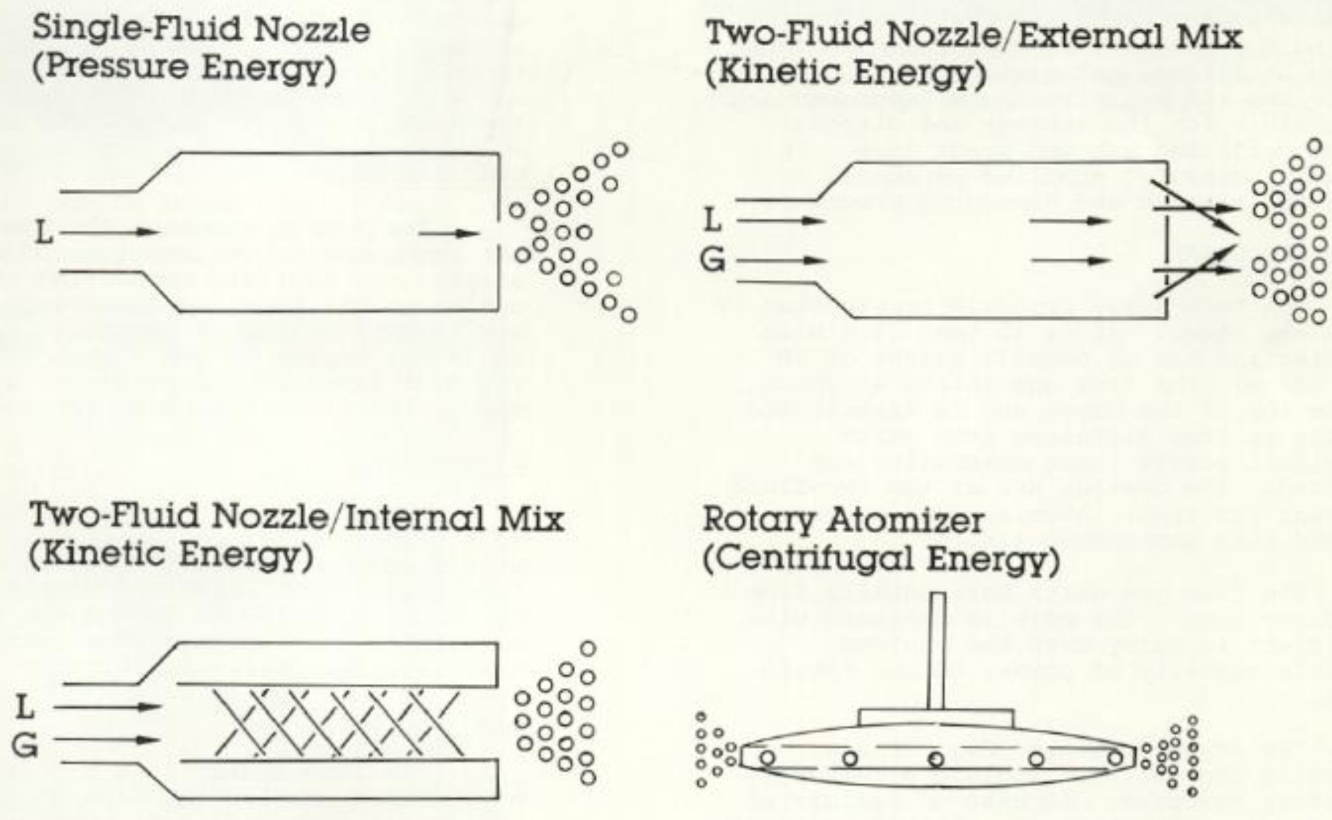

Fig. 4. Atomization techniques for dry scrubbing.

MikroPul Corporation a contract to install a dry SO_2 scrubbing system to remove SO_2 and particulates from the flue gas stream of their Riley pulverized coal-fired power boiler at the Strathmore Paper Company, Woronoco, MA. The boiler has a maximum steam rate of 95,000 lb/hr (11.98 kg/s) and a coal rate of up to about 75 tons/day (0.79 kg/s), and is designed to operate with supplemental oil firing at a rate not to exceed 30% in terms of heating value of the fuels.

It was required that the system (Fig. 6) comply with the Commonwealth of Massachusetts emission standards for the Pioneer Valley District while firing coal of sulfur contents up to 3.0%. This requirement includes both SO_2 and particulate regulations which are a maximum of 1.2 lb of SO_2 per million Btu (0.52 g/J) and a maximum of 0.12 lb of particulate per million Btu (0.052 g/J). These levels are equivalent to the federal new source performance standards.

The reactant selected was calcium hydroxide (the raw feed is pebble lime). However, the system is also designed to function with a sodium base reactant, soda ash (not applied as yet).

MikroPul's responsibility included complete plant design and installation including foundations, footings, connections of raw utilities, and tie-in to the boiler and to the stack. Strathmore Paper was responsible for the storage and disposal of the collected ash and spent lime. In addition, MikroPul supplied personnel to cover the startup and debugging procedure.

THE SPRAY DRYER

The Koch spray dryer is constructed of stainless steel. It is 15 feet (4.6 m)in diameter and has an overall height of 40 feet (12 m). The flue gas enters a plenum at the top of the dryer and is distributed equally to four diffusers into which individual nozzle lance assemblies are inserted. The nozzles are of the two-fluid external mix type. Atomization is accomplished with compressed air.

The flue gas exits horizontally from the dryer cone; the exit is designed with the intent to carry over the maximum possible quantity of powder to the fabric filter.

The dryer controls (Fig. 7) are basically typical, but include a number of safety features. In case of failure of lime supply the system is switched to water (which is also applied during shutdown in order to purge the system of residual lime). The slurry and water piping is insulated and strip heated to prevent freezeup during cold weather.

FABRIC FILTER

The fabric filter system consists of three top access Mikro-Pulsaire Collectors in parallel with manually operated isolation dampers so that any single unit may be taken off line for service.

Based on 40,000 cfm (18.9 m^3/s), the filtration velocity is 3.9 ft/min (20 mm/s with three units on line and 5.8 ft/min (29 mm/s)with one unit off line. Because of the temperature reduction as a result of the drying process, the filter velocity is actually somewhat lower.

The hoppers and tubesheets are constructed of stainless steel, while the balance of the unit is constructed of steel with a coal tar epoxy coating.

The filter medium is homopolymer acrylic felt with MikroPul's special treatment finish (designated HCE-II). The bag retainers are constructed of mild steel with a high-temperature epoxy coating.

The collected powder is discharged from the collector (and spray dryer) by means of eight-inch (0.20 m)Mikro-Airlocks which feed into the screw conveyors that discharge to the ash container. The structural support of the Pulsaires had to be elevated to a level which would allow for passage of a truck which is used to remove ash from the existing ash silo.

DUCT SYSTEM

The duct connecting the Ljungstrom Air Preheater to the dryer is of COR-TEN steel; the manifold connecting the dryer outlet to the Pulsaire Collectors is of stainless steel as is the duct from the collector outlet to the system fan inlet. The duct from the outlet of the system fan to the stack breaching is of COR-TEN.

LIME STORAGE

The quicklime storage silo is 12 feet (3.6 m)in diameter and 40 feet (12m) high with a holding capacity of 4,500 cubic feet (127 m^3). A Mikro-Pulsaire Bin Vent Collector, located on top of the silo, eliminates dusting while receiving the bulk lime deliveries.

LIME SLAKER

The lime slaker is a BIF detention-type slaker constructed of mild steel and includes an integral grit remover as well as the necessary controls. It has a capacity for slaking 2500 lb/hr (0.315 kg/s) of quicklime.

Fig. 5. This nozzle lance (one of four) can be removed and replaced in five minutes with no significant loss in SO_2 removal efficiency.

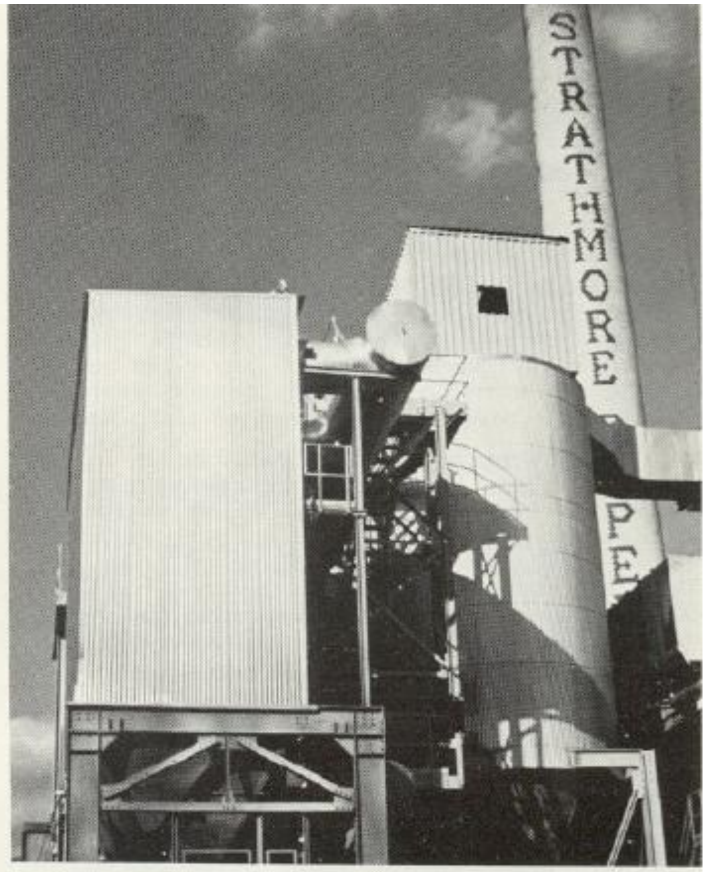

Fig. 6. North America's first commercial dry SO_2 scrubbing system at the Strathmore Paper Company, Woronoco, Massachusetts.

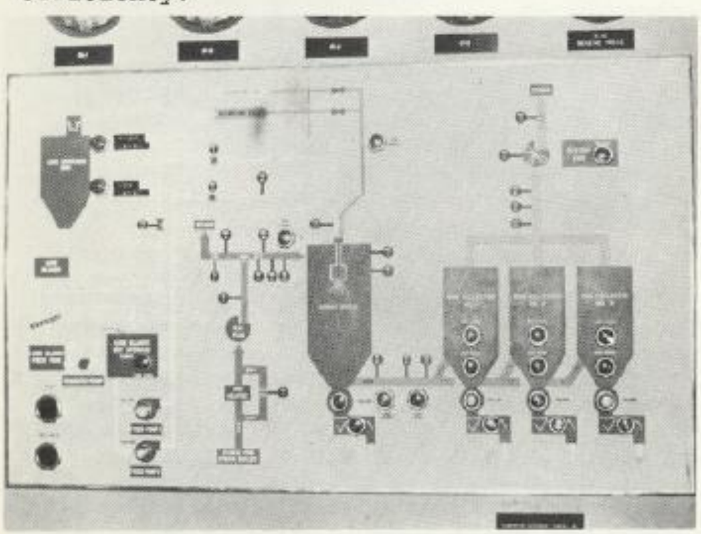

Fig. 7. Strathmore dry SO_2 scrubbing system control panel.

A 24-inch (0.61 m) SWECO Screen was included to remove grit from the slurry delivered from the slaker. The object was to avoid grit of a particle size larger than 48 mesh from passing into the lime system.

INSULATION

In consideration of the severity of the winter weather of western Massachusetts, the entire system from the I.D. fan outlet to the stack is insulated with six inches (0.15 m) of block insulation and aluminum external lagging.

COMPRESSOR

The compressor selected was an Ingersoll-Rand Unit. The compressed air system includes a desiccant dryer which allows the dry scrubber to operate without freezing during the winter period from December through February. It was believed that during the balance of the year the drying system would not be necessary.

MONITORING INSTRUMENTS

The contract did not include the SO_2 monitoring instrument system. MikroPul installed its laboratory DuPont Model 460 SO_2 Analyzer and Recorder at the Strathmore site. Probes were installed at three points: dryer inlet, dryer exit, and fabric filter outlet. A strip chart located adjacent to the control panel continuously records the SO_2 levels at the three points in ppm of SO_2.

While it is necessary to monitor fabric filter exit loadings only, the three-point system provides a means of measuring the efficiency of the two-phase desulfurization system independently, i.e. the SO_2 removal in the spray dryer itself and the removal in the fabric filter.

In addition to the SO_2 monitoring, the following key items are recorded: slurry flow rate, dryer inlet temperature, dryer outlet temperature, and Pulsaire Collector temperature. An annubar is placed in the fabric filter outlet duct to measure the gas flow through the system.

SYSTEM PERFORMANCE

FABRIC FILTER

The Pulsaire Collector System has delivered outstanding performance. In spite of numerous upsets in the spray dryer, the bags never became wet. The differential pressure has always been controllable in the range of two to four inches (0.5 to 1.0 kPa) at a pulse cleaning rate of about a seven-minute cycle. When one unit is isolated, adjusting the cleaning cycle down to three minutes maintains the desired differential pressure. There has never been a problem of moisture condensation or corrosion anywhere in the dust collector chamber even during operations carried through many days of subzero weather.

There was a serious problem with the first bag set in that within a few weeks of initial operation, the bags shrunk over the retainer and did not respond properly to the pulse cleaning process. Their performance, however, was sufficient to allow continuing operations until such time as the problem of shrinkage could be determined and corrected.

It was quickly determined that the felt manufacturer did not properly heat set the felt.

At the MikroPul Laboratory in Summit, N J, we determined a proper heat setting procedure and instructed the felt manufacturer to produce the required quantity of felt according to these specifications. A new set of bags were produced and installed. These bags, treated with MikroPul Proprietary HCE-II finish, proved to be ideally stabilized. That particular bag set, as of June 1, 1981, has been in service for more than 19 months with zero failures and has maintained an emission discharge of not more than 0.004 grains/ft^3 (9.2 mg/m^3).

Periodically, a bag is removed from the collector and returned to the MikroPul Laboratory for analysis. To date, we have had no sign of blinding and have found that the fiber strength is equal to that of the new homopolymer acrylic felt.

SPRAY DRYER

During the early stages of operations, it soon became evident that the spray dryer as initially designed had some serious shortcomings. The symptoms of the weaknesses were manifest in frequent wetting of the dryer chamber walls and in insufficient SO_2 removal.

It was quickly noted that the original two-fluid nozzles were inadequate; the atomization was poor and the abrasion rates were extremely high. The nozzles were replaced with technologically improved, two-fluid external mix nozzles. The result was dramatically favorable in terms of proper atomization and the elimination of abrasion; however, wetting out continued (although less frequently) and there was still a deficiency in SO_2 removal.

MikroPul's relationship with the original designer was discontinued late in 1979 and a new relationship with Koch Engineering Company, Inc. was established. Koch Engineering's expertise and capabilities in dry SO_2 scrubbing systems include:

- Ten years of spray drying experience.

- A sophisticated dry SO_2 scrubbing pilot plant operating since October 1978 at Abcor, Koch's high-technology unit in Wilmington, MA. (Startup of a dedicated coal-fired boiler is scheduled for July 1981.)

- An eight-foot (2.4 m) diameter X40-foot (12 m) tall adjustable-bottom spray-dryer semi-works unit at Koch's commercial development laboratories in Wichita, KS.

After a thorough study and analysis, Koch Engineering proposed some rather drastic changes in the aerodynamics of the dryer for the purpose of providing a more efficient means of mixing the flue gas with the atomized slurry. Koch also proposed changes in the slurry feed and distribution system.

In March of 1980 we were able to take advantage of a three week boiler maintenance shutdown period to modify the lime system and install the proprietary Koch spray dryer internals.

Startup and operation were, from this point forward, guided for the most part by Koch's high-technology unit, Abcor, Inc.

After the modifications were completed, the system was capable of meeting performance levels above and beyond those specified in the contract. (This will be covered later on in a section on the "COMPLIANCE TEST.") As a result of the successful working relationship between Koch Engineering and MikroPul on the Strathmore system, the two companies are now working as a team for the design and construction of commercial dry SO_2 scrubbing systems.

The arrangement of applying four separate spray nozzles in the dryer allowed for on-line maintenance of nozzles and lances without interruption of the performance of the system. It takes an operator about five minutes to remove a nozzle lance and place a spare nozzle in its place. The process of inspection and cleaning a nozzle takes about 15 minutes at a work bench. When a nozzle is removed, one can note that the SO_2 outlet level begins to rise slowly, but the automatic controls of the dryer quickly supply additional slurry to the remaining three nozzles and the level of SO_2 removal stabilizes at the previous level.

We have demonstrated during the period of operation that the two-fluid nozzle system provides a means for unusually high on-line performance. We conducted a demonstration period over 90 days in which the system was on stream 99% of the boiler availability.

MANPOWER

As far as manpower requirements are concerned, we provided one operator for every shift. Our experience indicates that when the dryer operations are integrated with the boiler house manpower team, the manpower requirement can be reduced.

LIME SLAKER

The slaker problems, for the most part, related to the development of operator techniques and training, as well as to the adjustment of slaking various types of lime. We found that the volumetric feeder was somewhat of a problem as various types of limes were applied. In the future, we would be inclined to favor gravimetric feeders.

As noted above, various limes were tested including high calcium pebble lime, pulverized lime, granulated lime, and dolomitic lime. Also, some attempts were made in the application of waste lime products of high alkalinity. The results were negative.

We were hopeful that the dolomitic lime would have performed acceptably, since it is much less expensive and more readily available. While the results from the laboratory on the dolomitic lime were encouraging, the field results were disappointing when high slurry concentrations were required for burning high sulfur coal. We found that the high calcium pebble lime was best for this particular case; and we confirmed reports of others that great care should be applied to the selection and control of the quality of the lime used for dry scrubbing.

WASTE DISPOSAL

The waste products are deposited in portable containers (referred to as "roll-offs") that have been adapted to receive material directly from the dust collectors. The containers had to be modified so that they were properly sealed to the point where powder would not escape to the atmosphere during transit to the land fill operations. The rate of filling the containers depends on the amount of ash in the coal and the amount of lime required to remove the sulfur dioxide. Under peak demand conditions it is necessary to remove one of the containers every 24 hours.

BOILER

Since startup, we have handled quite a variation in the sulfur levels of coal. It has varied from a low of near compliance levels to 5% sulfur. We did demonstrate the capability of the system to reach compliance levels when handling 5% sulfur coal. The heating value of the coal generally ranges from 12500 to 13500 Btu/lb (29.0 to 31.4 kJ/g).

Soot blowing did create some early operating problems. The problems developed because the actual amount of steam consumed during soot blowing was higher than that which had been specified. It was found that the best procedure during soot blowing was to have the operating engineers or firemen give the FGD system operators advance notice of the plan to soot blow. The operator would then switch the dryer controls from the automatic mode to a manual mode insofar as the slurry feed is concerned. We found that the automatic dryer controls did not respond properly during the erratic conditions of the boiler during soot blowing. The soot blowing period varied from 20 minutes to 40 minutes each shift.

Boiler conditions became somewhat erratic during the removal of the bottom ash from the boiler. It was found that switching to the manual mode of operation during that procedure as well was helpful. Bottom ash removal is much less frequent than the soot blowing operations.

COMPLIANCE TEST

The system compliance tests were performed by Mostardi-Platt Associates, Inc. on March 25 and 26, 1981. Mr. R. Wineberg of the Massachusetts Department of Environmental Quality observed the tests.

During this test program the average particulate emission rate based on three test runs was 0.015 lb/10^6 Btu (6.4 ng/J) at an average volumetric flow rate of 34,312 acfm (16.19 m^3/s). The boiler was operated at a steady load of approximately 65,300 lb steam/hr (8.24 kg/s).

The average SO_2 emission rate as determined in the outlet duct was 0.410 lb/10^6 Btu (176 ng/J). All emission rates were determined with F-factors calculated from flue gas analyses obtained with an Orsat analyzer during the course of each test run.

The efficiency of the SO_2 scrubber system ranged from 90.12 to 96.66 percent with an average efficiency over six tests of 92.42 percent:

	As Tested	Allowable Limit
Particulate	0.015 lb/10^6 Btu (6.4 ng/J)	0.10 (43)
SO_2	0.410 lb/10^6 Btu (176 ng/J)	1.12 (482)

During the course of the tests, fuel samples were taken for analysis to obtain the data required for emission rate calculations. Sample increments were taken every 15 minutes. The "as received" coal had a sulfur level of 3.79% and a heating value of 12,905 Btu/lb (29.97 kJ/g), while the dry basis was 3.95% sulfur and 13,456 Btu/lb (31.25 kJ/g). During the test the heat input fraction was 0.9424 coal and 0.0576 oil.

In regard to the performance of particulates, the measured emission was one seventh of the allowable limit. In terms of particulate exit loading, the rate was 0.004 grains/ft^3 (9.2 mg/m^3). What is really remarkable is that these filter bags were in service for 18 months when tested and continue to perform with zero failures.

Throughout the period of operations that commenced in August of 1979, the data on SO_2 was taken from the DuPont 460 Analyzer. During the first year of operations, various operating problems did occur; however, through the joint efforts of DuPont, Koch Engineering, and MikroPul, the instrument is now performing extremely well.

To confirm the DuPont Analyzer's performance, five extensive EPA method-six tests were conducted at spaced time intervals to compare results. In all cases the deviation was in the range of 10 to 15 percent. Since the Mostardi-Platt tests compare so well with the data from the DuPont Analyzers, we are confident that our reported results are valid.

COST BENEFIT OF COAL VS. OIL

Records of the costs involved in the use of coal by the Strathmore Paper Company have been compiled. These include labor, maintenance, power, reactant, and disposal; these costs amount to $15 per ton ($16.52/metric ton) of coal burned. Over most of this time period, the cost of rail delivery of coal has been $42 per ton ($46.25/metric ton).

The cost of number six compliance fuel oil (1% sulfur) on an equivalent Btu basis was (in March 1981) in the range of $145 per ton ($159.69/metric ton). The savings are therefore \$88 per ton (\$96.92/metric ton) of coal burned. So, in the case of 75 tons per day, the daily net savings are about \$6,600. Fig. 8 shows the spread in coal and compliance oil pricing.

CONCLUSION

Dry SO_2 scrubbing is a cost-effective alternative to conventional wet scrubbers for SO_2 and particulate removal in boiler flue gas. Although it was developed fairly recently, the commercial feasibility of dry SO_2 scrubbing technology has been demonstrated at the Strathmore Paper Company system, the first full-scale operating dry SO_2 scrubbing system in North America. Here a commercial dry SO_2 scrubbing system has passed all EPA compliance tests after operating since July 1979 with an on-line availability of over 90%. With dry SO_2 scrubbing systems being offered by several manufacturers and the price of compliance fuel oil skyrocketing, coal is now a more economical fuel than oil for many industrial users.

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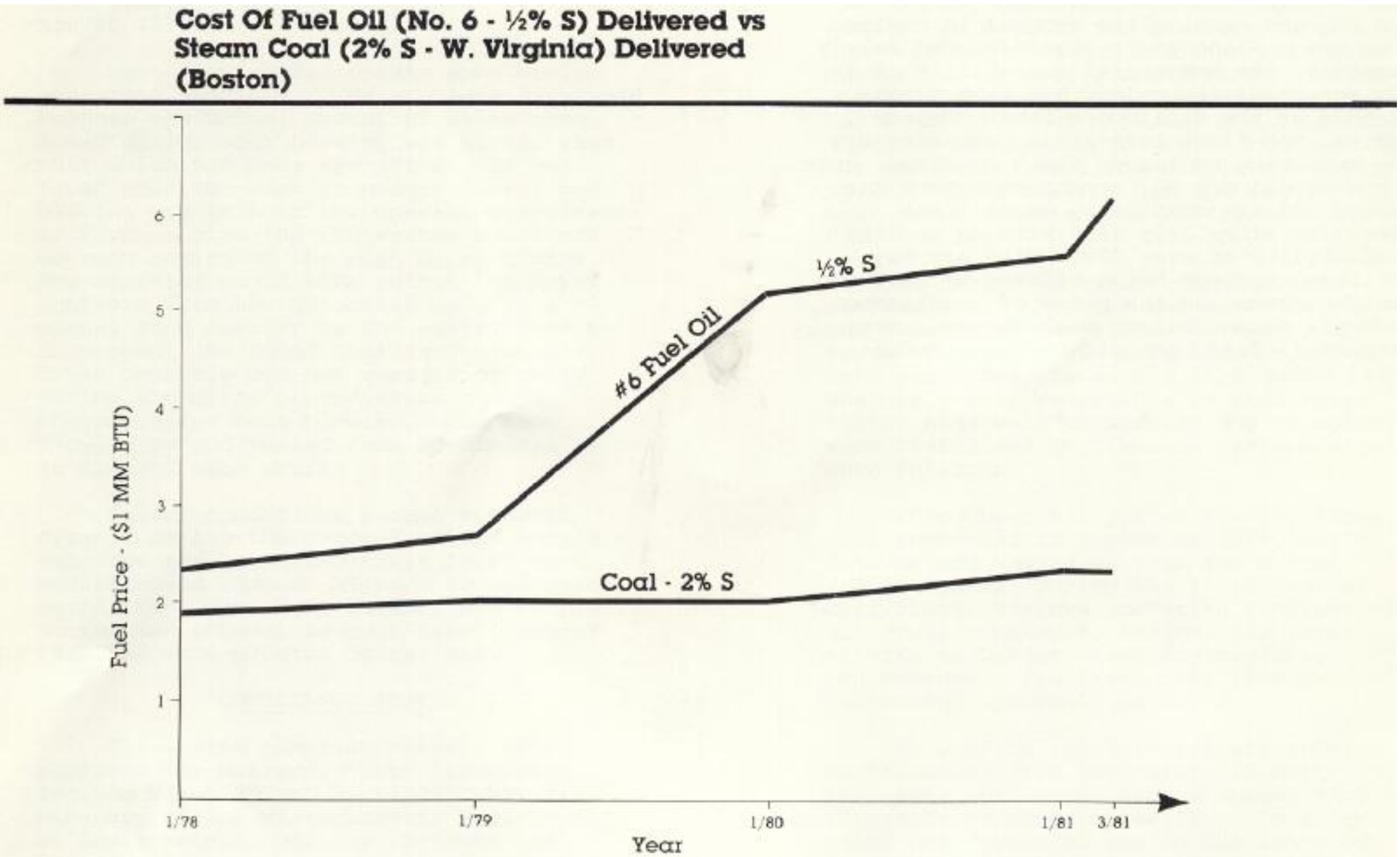

Fig. 8. Coal is a more economical fuel than no. six compliance oil. (Note: 10^6 Btu = 1.05 GJ.)