Babcock Borsig Power Inc. is now
Babcock Power Environmental Inc., a
Babcock Power Inc. company.
www.babcockpower.com

TECHNICAL PUBLICATION

FGD TECHNOLOGY DEVELOPMENTS IN EUROPE AND NORTH AMERICA

by

Dr. Wolfgang Schuettenhelm
BBP Environment GmbH
Gummersbach, Germany

and

Thomas Robinson
and
Anthony Licata
Babcock Borsig Power Inc.
Worcester, Massachusetts

Presented at the
EPA-DOE-EPRI Mega Symposium
Arlington Heights, Illinois
August 20-24, 2001

BABCOCK BORSIG POWER

Babcock Borsig Power, Inc.
Post Office Box 15040
Worcester, MA 01615-0040
www.bbpwr.com

RST-171

FGD TECHNOLOGY DEVELOPMENTS IN EUROPE AND NORTH AMERICA

by
Dr. Wolfgang Schuettenhelm
BBP Environment GmbH, Gummersbach, Germany

and

Thomas Robinson
and
Anthony Licata
Babcock Borsig Power Inc., Worcester, Massachusetts

ABSTRACT

Over the past twenty years there have been significant advances in the design and operation of Flue Gas Desulfurization (FGD) systems. Due to the differences in fuels and economic pressures, advances have been different in North America and Europe.

This paper will discuss the evolution of the FGD technology focusing on the limestone/gypsum process. Babcock Borsig Power (BBP) has approximately 49,000 MW of wet FGD systems in operation in Europe, Asia and North America. The sulfur content of the fuel burned in these plants ranges from less than 1% to over 5%. This wide range of experience has resulted in many innovative developments. Some of the technology developments included are single and dual loop systems to optimize SO_2 removal and production of gypsum. These developments have resulted in operating systems with annual availability of over 99% and more than 95% SO_2 control efficiency with limestone single loop systems.

INTRODUCTION

During the last two years, there have been ongoing developments in FGD technology as well as in the business environment. There has been a concentration in the energy and environmental technology business resulting in the merger of four very traditional European companies and one U.S. company under the name of Babcock Borsig Power. BBP now includes the business units of DBA (Deutsche Babcock Anlagenbau), L&C Steinmüller, Austrian Energy & Environment (AEE), NOELL-KRC, and DB Riley.

Within BBP, more than 20 years of know-how and experience of FGD business has been combined and demonstrated by more than 100 FGD systems with 181 absorbers. More than 50 absorbers are made of stainless steel. Intensive experience with all types of organic coating systems including rubber lining and various plastics complete the product range. Several of the new developments were incorporated in the design of Southern Indiana Gas & Electric's F. B. Culley Plant scrubber system.

This paper will give a brief overview of the most recent developments in FGD design, and also compare the different technologies available.

FGD Technologies

Today, the limestone/gypsum process is the worldwide standard for wet flue gas desulfurization of fossil fuel power stations. The process is characterized by a comparably simple process management and a high technical standard that is supported by comprehensive operational experience. Further advantages of the limestone/gypsum process are the ready availability of the limestone sorbent, and the possibility to produce either gypsum as a marketable by-product or as an environmentally stabilized material for landfilling.

Of the 181 absorbers BBP currently has in operation, 20 use technologies based on lime and the balance are based on limestone. In the past several years we have converted several limestone absorbers to lime in order to gain fuel flexibility. With the advances in gypsum production using lime sorbents, this is also an option, where economically viable.

The core of the FGD limestone process itself is the absorber system. BBP employs either a single loop or a dual loop process depending on the degree of SO_2 control required, the level of SO_2 input, the price of the electricity, and the chosen materials of construction.

In contrast to sulfite scrubbers that are known to suffer from scaling problems and reduced operating availability, both BBP systems use the internal forced oxidation (IFO) process with an enhanced agitator oxidation air injection system. This system was first developed, installed, and operated in a full-scale version in the 560 MW power plant at Gersteinwerk, Germany more than a decade ago. Complete oxidation of the removed SO_2 to gypsum is ensured because the scrubbing liquid is always saturated with oxygen. This results in homogeneous reaction conditions in the absorption section of the absorber.

Single loop system

The principal elements of the single loop system are shown in Figure 1. The absorber system consists mainly of the scrubber circulation pumps, agitators, and an integrated oxidation air injection system. This system is characterized by:

- one scrubbing circuit / loop
- one scrubbing liquid securing a uniform chemical environment in the absorption section
- constant pH value depending on designed L/G, coal type burned and limestone grinding size. (Usually the pH is in the range of 5.2 to 5.5)
- simple and compact design without internals and absorber with smooth inner surface, limiting deposits and the potential for scaling

Within this system the reaction conditions influencing the SO_2 control behavior become uniform. The individual suspension spray banks can be switched on or off depending on volumetric flue gas flow rate and SO_2 input. Consequently, the electrical power consumption of the circulation pumps and the booster fan can be optimized in event of major load deviations and/or fuel switching. The simple design of the absorber without internals is a further benefit of the single loop system. More than 60% of the BBP wet FGD installations are the single loop design. This design has been applied to absorbers with capacities greater than 650 MW.

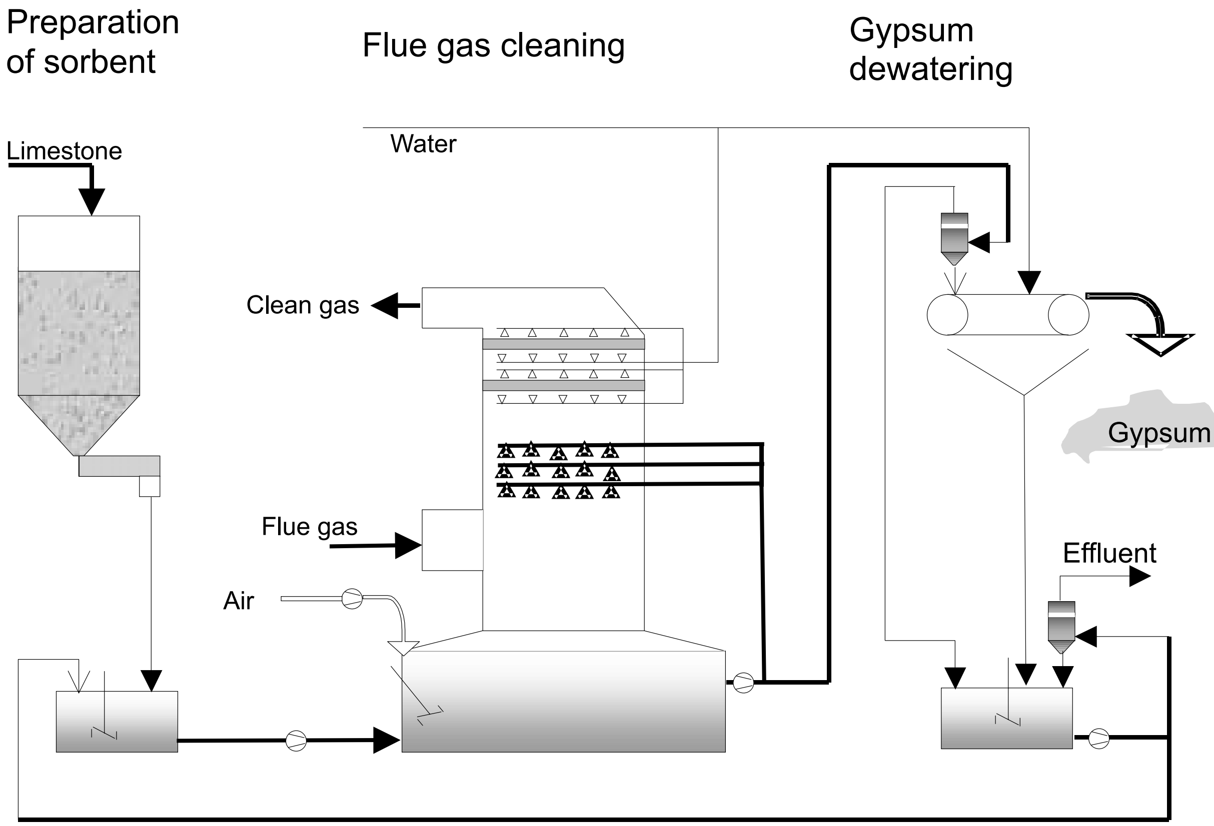


Figure 1 Single Loop System

The F. B. Culley FGD (Vectren) system located near Evansville, Indiana uses the single loop approach and employs many of the new European developments. The scrubber was designed to remove 95% of the SO_2 based on a 10 lb/MMBtu fuel. A unique feature of the project is that it uses one absorber to serve two generating units with no bypasses. The system uses low-grade limestone but generates high-grade gypsum. Since the unit began operation in 1995, there has never been a forced outage caused by the FGD system. Some of the advanced design features are:

- Double eccentric flow spray nozzles (discussed below)
- C 276 metallurgy in the liner design

Dual loop system

The principal overview of the dual loop system is shown in Figure 2. The system consists of the coupling of the main components, scrubber with quench, oxidation and absorption, absorbent dosing, and gypsum slurry purge. The flue gas enters the first loop (called the quench loop) from the bottom and passes the quench spray bank level into the second loop (called the absorber loop). This loop absorbs most of the SO_2. The cleaned flue gas exits the scrubber at the top after having passed demister packages. The intermediate collection bowl separates both loops and collects the scrubbing liquid of the absorber loop. The return pipe connects the collection bowl with the external sump tank.

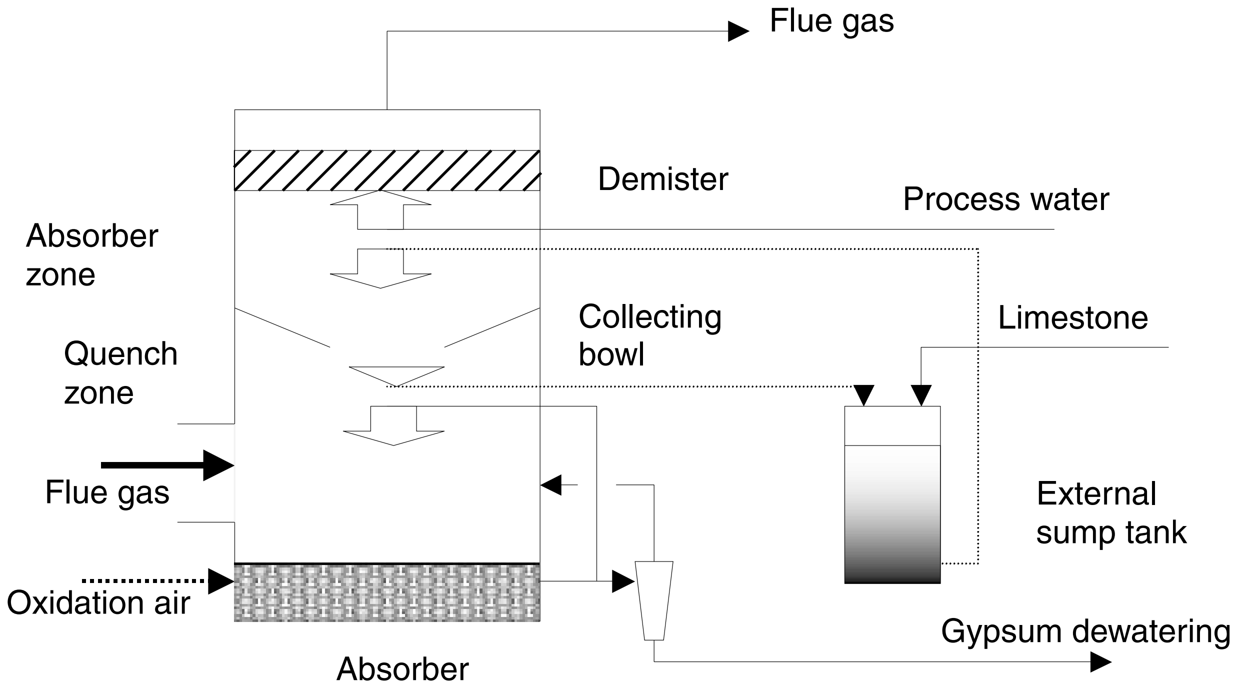


Figure 2 Dual Loop System

The main features of BBP's dual loop system are:

- two scrubbing loops (quench circuit and absorber circuit) separated with a collecting bowl
- the scrubbing liquids of both loops differ in solid content, solid composition, and in pH value:
    - Quench loop: pH = 4 – 5
    - Absorber loop: pH = 5.8 – 6.2
- Pre-removal in the first loop (quench loop) of fly ash, HCl, HF and SO_2 while oxidation takes place at favorable low pH
- Almost complete removal of SO_2 in the second loop (absorber loop) with high efficiency since the pH value is rather high.
- The contact zone of the absorber loop can easily be increased.
- External sump tank which collects the scrubbing liquid of the absorber loop

The dual loop system permits the removal of the higher SO_2 contents. Experience shows that when burning high sulfur coal and/or with the requirement of SO_2 control efficiencies of greater than 97%, the dual loop system is usually superior to a single loop system. Due to the separation in both loops, the system has a higher buffer capacity in case of load deviations or peaks of SO_2. Furthermore, lower quality limestone and limestone with larger particle size can be used. Altogether, the flexibility of the dual loop system is much higher.

In a dual loop system, the higher pH value in the absorber loop, the total L/G, and consequently the power consumption, is less than a single loop system. When there is high SO_2 control efficiency, the additional cost for the external sump tank is more than compensated by the lower operational cost. Since the pH value and the chloride content in the scrubbing liquids of each loop are different, a staged material concept could be employed which would result in cost benefits.

Dry and Semi-Dry FGD

The wet FGD process has been employed in the majority of the larger power plants (> 250 MW). Dry and semi-dry systems are becoming of interest for FGD retrofits. BBP has supplied dry and semi-dry installations for more than 5,000 MW.

The most recent trend for lower cost FGD retrofits in Eastern European medium sized power stations is to use Fluidized Bed (CFB) technology for higher efficiency dry processes. The BBP Turbosorp™ process was developed in the early 90's and is able to remove up to 95% of SO_2 with a 1.1 to 1.2 Ca/S ratio. Since its investment and maintenance costs are lower than a classical semi-dry spray absorption process and its operation is simple, we expect that this technology will gather significant interest in the market.

Figure 3 shows the principle of the Turbosorp™ process. The flue gas enters the reactor from the bottom and passes through a cylindrical apparatus to the top. The bed material is made up of solids consisting of calcium hydroxide, calcium carbonate, solid reaction products, and fly ash. Fresh and active adsorbent is injected into the reactor with solids that have previously recirculated from the downstream bag filter into the reactor. To lower the temperature of the flue gas, water is injected by means of a nozzle in the raw gas inlet. The gas inlet is a venturi nozzle. A high flue gas velocity in the venturi prevents collapse of the fluidized bed or solid particles from entering the venturi. A principal advantage is that the water used for cooling and the sorbent are injected separately, optimizing sorbent utilization and reducing maintenance cost.

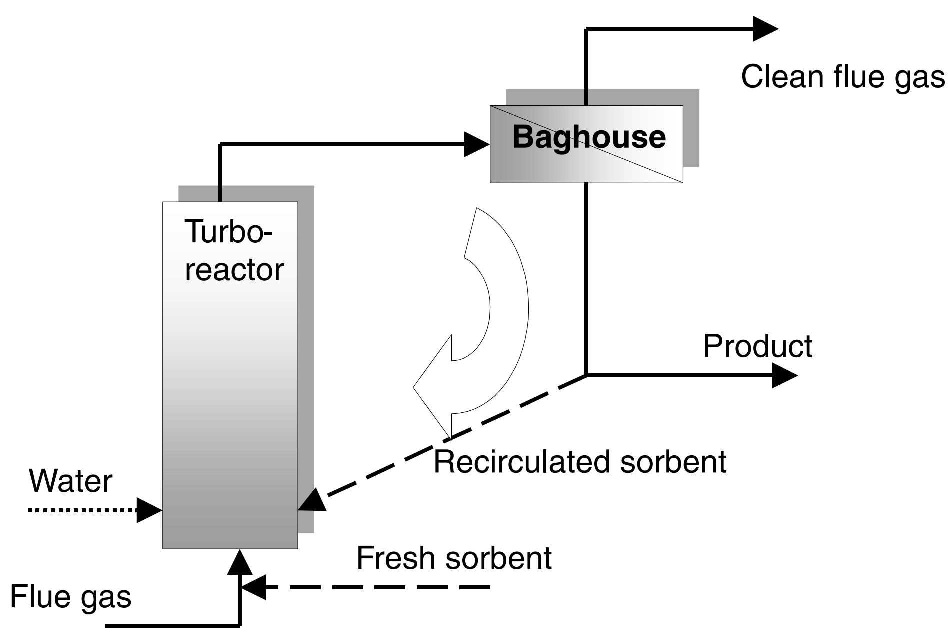


Figure 3 Principle of the Turbosorp™ Process

Since the cooling of the flue gas is accomplished by water injection into the reactor, there is no need for slurry preparation, feeding, and evaporation. The particulate concentration is about 1000 g/Nm^3. We have not observed deposit build-up on the walls or moist filter bags in the downstream bag filter.

At present, three plants are in operation employing the Turbosorp™ process with more than six years of operating experience. The contract for a fourth Turbosorp™ FGD in Sierkierki, Poland was awarded at the end of last year. Sierkierki is a 250 MW_{th} district heating power plant. The volumetric flow rates per reactor vary from 260,000 to 530,000 m^3/h @ STP, wet respectively 150,000 to 320,000 wscfm. Their design SO_2 control efficiency is in the range of 85 to 93%. More details about this technology can be taken from reference 1.

Developments for wet FGDs

New technology developments for wet FGDs during the past few years have been driven by the requirement to lower investment costs and operating costs while increasing plant performance and fuel flexibility. Since the American FGD market has been on a low level during the last decade, most new developments have taken place in Europe and Asia where the newer wet FGDs have been installed. Some significant improvements have been made based on experience gained from completed contracts in the eastern part of Germany.

The chemistry and the basic process of FGD are well known, although specific phenomena such as blinding originating from high dust / heavy metal input or the exact influence of the grinding size of the limestone on the L/G are still difficult to calculate numerically. In that respect the experience from similar reference plants is decisive.

Therefore, more effort has been placed on investigating the gas and liquid flow inside the scrubber to detect uneven flue gas velocity profiles and bypass streams in the area of the spray banks. Both effects will locally limit the removal efficiency of the process. Since these effects can never be totally excluded, usually some safety margin is added on the design L/G. When there is low energy consumption, it is mandatory to hold the design to the theoretical minimum L/G. Computerized Flow Design (CFD) modeling has been employed to reduce the above-mentioned problems. One result of such modeling is a change of the location and number of nozzles per spray level. BBP applied that method to optimize the position of the nozzles for two single loop absorbers located in Matra, Hungary (2 x 300 MW, lignite fired).

It is obvious that due to the simple construction of the single loop system there are few possibilities for major developments. On the other hand, the process is well known, long operating references are available, and especially systems with forced oxidation have proven to have superior availability. Therefore, redundant scrubbers are not required. In Europe, many projects trend to the lowest capital cost with less importance placed on energy consumption. As a result, the scrubber design velocity was increased from about 3 to 3.3 m/s (9.8 – 10.8 ft/s) to almost 4 m/s (13 ft/s) in order to decrease the diameter of the scrubber (and its cost). On the other hand, the pressure drop of the system increased. The decision regarding the design velocity depends on the energy price and fan capacity (in case of a retrofit) and must be reviewed for each case.

The dual loop system has been modified and improved considerably during recent years. The optimization is based mainly on the experience of the first years of operation of the FGD in Jänschwalde, Germany, where twelve dual loop scrubbers are used to desulfurize 3,000MW (see reference 2). The FGDs were commissioned in 1995 and 1996. High sulfur lignite coal is used as fuel. The SO_2 inlet concentration is 7,700 mg/m^3 (2695 ppm) @ 6% O_2, STP dry, which have to be to controlled to below 400 mg/m^3 (140 ppm) @ 6% O_2, STP dry. There are two units (Tampa and Belledune) operating in North America with a capacity of 900 MW on high sulfur fuel.

Constructive measures could be taken in the area of the collection bowl to remove problems with deposits as a result of insufficient oxidation from sulfites to sulfates. These deposits have not influenced the operation of the power station on BBP units.

Undesired consecutive reactions in the absorber loop are now avoided by simply injecting air in the return pipe from the collecting bowl into the external sump tank. This measure reduces the super-saturation of sulfites and consequently the potential of plugging to a minimum.

The following design optimizations have been identified for the dual loop system and are introduced as a standard for new installations[3].

Flue Gas Inlet Duct Designs

Tangential flue gas inlets have been shown not to have an advantage compared to central flue gas inlets. Indeed, the gas distributions inside the scrubber have proven to be more uniform when employing a central gas inlet. Therefore, the number of spray banks in the quench loop can be reduced to one, sometimes two, being fed by the one quench circulation pump. The result is a reduced total height of the scrubber. Single and dual loop systems have been designed with the same optimized geometry of the flue gas inlet (Figure 4).

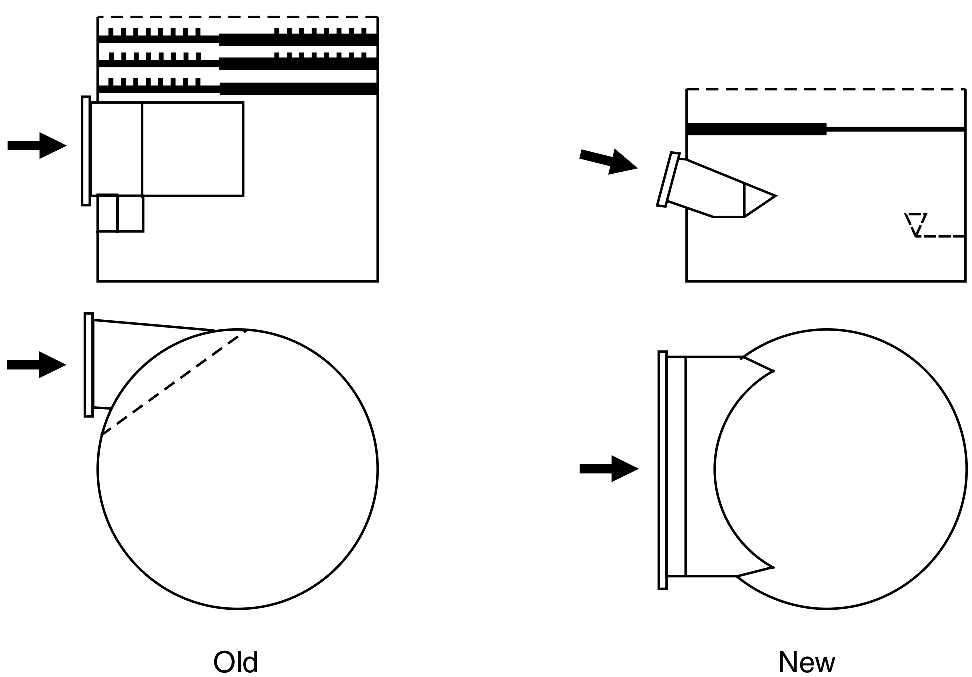
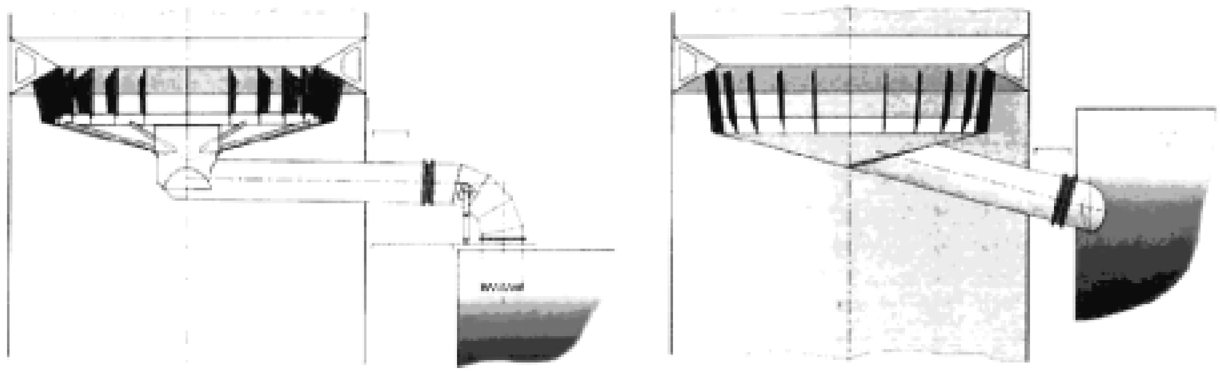


Figure 4 Comparison of the Old and New Optimized Flue Gas Inlet Arrangements for Dual Loop Systems

Collecting bowl and liquid return pipe

Lowering the bowl in the return pipe of the absorber loop returning recirculation liquid to the external sump tank saves both investment and operating costs. The head of the absorber loop circulation pumps is reduced because the liquid level inside the external sump is increased (see Figure 5). Analysis in every detail of this new design was made by modeling, and was used for the first time at Boxberg Power Station, Unit 4.

Boxberg unit 4 is a lignite-fired power station of 907 MW capacity. Two dual loop scrubbers were installed and commissioned in 2000.

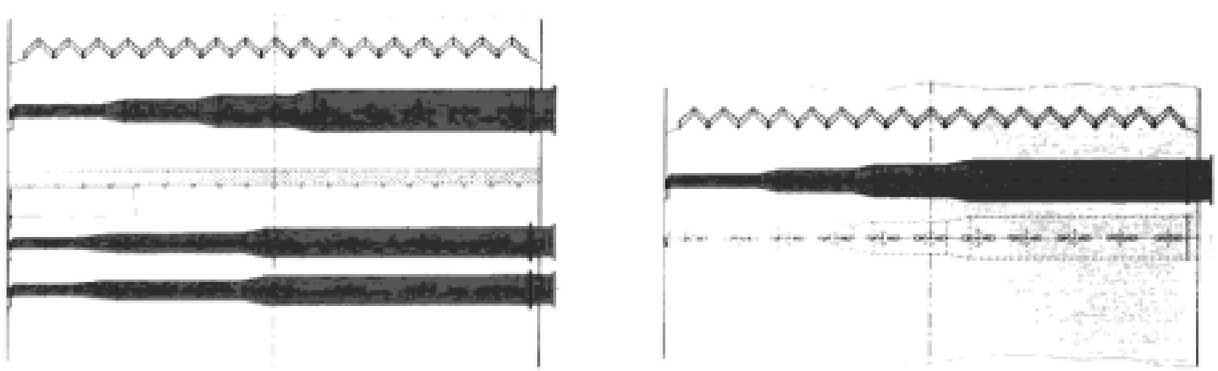


Old New

Figure 5 Comparison of the Old and New Arrangements of the Return Pipe for BBP Dual Loop Systems

Absorber loop

The experience gathered in many reference plants until 1995 demonstrated that scrubber internals intended to enhance mass transfer are not required. Consequently, investment costs could be lowered on future installations due to reduced scrubber height and elimination of internals (see Figure 6). This measure was realized at Boxberg Unit 4 and other more recently designed absorbers in Europe and Asia.



Old New

Figure 6 Comparison of Old and New Arrangements of the Absorber Loop of the Dual Loop System, With and Without Internals

Result of the new developments

All these process and design features have been incorporated into a new optimized dual loop absorber. It has proven to be cost-effective and simple, yet resulted in high availability for the process and equipment. Figure 7 shows its principal arrangement.

Figure 7 New Design of BBP Environment's Dual Loop Absorber

Some additional benefit could be derived by employing optimized process components. One example is double eccentric-type nozzles, which can be applied for both single and double loop systems. These special nozzles distribute the suspension by means of two sprays in counter-flow as well as in concurrent flow direction relative to the gas flow. Double eccentric nozzles have been shown to be beneficial in the F. B. Culley project.

These are to be characterized as follows:

- increasing fine distribution of the suspension droplets by means of doubling the sprays
- increasing the specific droplet surface area by means of collision of the droplets (droplet-break-up).

As result, the operating costs are reduced due to:

- reducing the amount of suspension to be recirculated per loop.
- decreasing the gas side pressure drop by means of partial concurrent injection of liquid into the flue gas.

Absorber material concepts

The selection of suitable materials for the absorber is greatly dependent on the differing process conditions resulting from the fuel (such as bituminous or lignite coal), and its high or low chloride content. The pH value in the case of the dual loop is different in each stage making it possible to specify the wall material for each loop.

The following main properties must be taken into account with regard to the differences between bituminous and lignite coal:

- the process temperature for bituminous coal applications ranges from 45 to 50°C (113° to 122°F) where lignite coal applications range from 65 to 70°C (149° to 158°F).
- the chloride content is usually lower in lignite coal applications

There are two basic alternative material concepts for the absorber. First, it can be constructed from normal carbon steel with a rubber lining as corrosion protection in the "wet" part of the scrubber interior, with a special lining for the required temperature resistance in the absorber inlet. Second, the absorber can be constructed as a full metal design. In addition, a mixture of these concepts is conceivable (e. g., metallic absorber inlet and rubber-lined absorber walls) but these hybrid designs do not affect the basic considerations.

Rubber Linings

Rubber linings have fundamental advantages so that neither the physical nor the chemical properties of the scrubbing liquid have any major effect upon its service life. The main parameter affecting the life of the design is the diffusion of water vapor through the rubber that attacks the metal surface and the process temperature.

Bituminous coal applications

The first single loop absorbers used on bituminous coal units were made of carbon steel and 4 mm rubber lining. Altogether more than 250,000 m^2 of absorber surface has been rubber lined in BBP absorbers with about half of it for bituminous coal plants.

For example, the Bergkamen Power Station has been in service for more than fifteen years without major repairs of the rubber lining. In most of our bituminous coal reference plants with rubber lining, only about 3% have been relined[4].

These excellent operating results presuppose careful selection of the rubber grade for the process conditions, special knowledge and experience in absorber internal design suitable for rubber lining, and careful surface preparation plus experience in quality control during the application work.

With regard to the excellent long-term experience with a single layer of 4 mm rubber lining on carbon steel, we have a proven and economical material alternative to metal cladding.

Lignite coal applications

As far as lignite plants are concerned, the higher process temperature inevitably means a higher partial pressure of water vapor, which results in an increased risk of water vapor diffusion through the rubber lining.

Nevertheless, BBP has also achieved good operational results with rubber-lined absorbers downstream of lignite-fired power stations. The spray headers zone and the bottom preferably should be double rubber lined to achieve service times of about 80,000 hours.

Full metal

As an alternative material concept to rubber lining, full-metal designs are also used. Full metal or plates of high alloy on carbon steel provide the necessary corrosion resistance.

The main parameters influencing corrosion in the environment represented by flue gas and scrubbing liquid are temperature, pH value, and chloride content. However, the most severe corrosion attack is anticipated under deposits and scaling residues due to the increase of chloride concentration and the resulting crevice corrosion and pitting.

Special corrosion-resistant materials have been developed for FGD applications. As a general rule, nickel (Ni) and molybdenum (Mo) improve corrosion resistance in a reducing environment, chromium (Cr) increases corrosion resistance in an oxidizing environment. Molybdenum and tungsten (W) increase both the pitting resistance and the crevice corrosion resistance. The pitting index normally serves as a measure for evaluation corrosion resistance. The lower the index, the lower is its resistance against chloride. Typical applied materials are alloy 317LNM (German Mat.-No. 1.4439) for low chloride environment up to 10,000 ppm, alloy 31 (1.4562) for medium chloride environment up to 30,000 ppm and alloy C-276 (2.4819) and alloy 59 (2.4605) for high chloride environment up to 200,000 ppm.[5] C-276 was used in the F. B. Culley station due to the potential for high chlorides in their coals.

Since these materials are quite expensive, especially as the nickel content increases, usually only a thin layer is applied on the inner surface of the absorber. The absorber shell is made of carbon steel. Either the carbon steel is cladded with the alloy material or it is wallpapered. Cladding is done by means of attaching the alloy onto the entire surface after rolling, whereas wallpapering is done by means of tack-welding of overlapping sheets onto the carbon steel surface and seal welding at the alloy-to-alloy welds.

Special attention has to be paid to the execution of the welds, which must consist of the same corrosion resistance material as the actual plate surface. Alloy to carbon steel welds must either be hidden behind a covering strip of alloy material, or be executed by a special welding procedure ensuring the same quality at the weld surface as the alloy lining.

As a consequence, the investment cost for a full-metal absorber is considerably higher than for a rubber-lined absorber. However, cost prognosis over a lifetime of a power station may indicate use of a full metal concept. During 20 years of operation, the alloy concept needs only some minor repairs, but the rubber linings have to be replaced at least one time - especially in lignite coal power stations.

In dual loop scrubbers, the pH value and the chloride concentration usually varies, resulting in a different material choice for each loop. Consequently, most of BBP's dual loop systems are based on a full metal material concept. The total cost of the dual loop system will be lower when compared with a single loop system since the high alloy material has to be employed only for the quench loop and not the complete absorber.

In each case, the absorber system including the material selection has to be evaluated in order to find the overall optimal solution.

CONCLUSION

BBP's wet FGD references of more than 49,000 MW capacity demonstrate the high reliability of both single and dual loop systems to the satisfaction of our customers.

As described above, the dual loop system has undergone several improvements within the last five years. Due to its higher flexibility in regard to SO_2 peaks, it appears to be a preferred system for FGD downstream of boilers with high sulfur coal and/or SO_2 control efficiencies of more than 97%. In addition, the lower pH value of the quench loop improves the mercury control behavior of the scrubber, enhancing the application of the dual loop system within a multi-pollutant control approach.

Besides the criteria discussed in detail, other important factors also have to be taken into account. These apply mainly to flue gas discharge (wet stack, cooling tower discharge, or stack with flue gas re-heating), limestone grinding, by-product (stabilized end product or gypsum), gypsum quality and redundancy concept.

An unequivocal evaluation of the question, “Which system is superior?” cannot be given. The decision must be based on the specific plant with its own constraints. Depending on the SO_2 raw gas input, SO_2 removal efficiency, evaluation of electrical power, material concept, and available space, the single or the dual loop system shows more advantages. A separate and detailed consideration of all these constraints is necessary to identify the optimal solution.

REFERENCES

1. Reissner, K.H.; Brunner, C; Bärnthaler, K.; Spieß-Knafl, K.; Krammer, G.: TURBOSORB® - A Dry Technology for Flue Gas Desulphurisation (FGD) and Flue Gas Cleaning (FGC), Proceedings, PowerGen Europe, Bruxelles, May 2001

2. Heinze, G., Sparmann A., Welp, H., und Braun, W.: Betriebliche und energetische Optimierung der Rauchgasentschwefelungsanlagen Jänschwalde. VGB Kraftwerks-Technik 12/99

3. Braun, W; Heinze, G.; Valbert, G.: Erfahrungen von Einkreis- und Zweikreis Rauchgasentschwefelungsanlagen hinter braunkohlebefeuerten Kraftwerken, Conference “Die neuen Kraftwerke der VEAG Vereinigte Energiewerke AG”, November 1130 - December 1, 2000

4. Willibald, U; Schneider, G.: Planning and Design of an Optimised FGD Plant Adapted to Site Conditions, Proceedings, PowerGen Europe, Madrid, June 1997

5. Zauter, R.; Braun, W; Ladwein, T.L.: Recent Experience with Stainless Steels in Flue Gas Desulfurization Plants, published in Stainless Steel World, 2000