POWER GENXT

Volume 8

Published on the day of 8th National Seminar
15th December, 2019

IMPLEMENTATION OF FGD IN COAL BASED INDIAN THERMAL POWER PLANTS

ENGINEERS' WELFARE FORUM
THE WEST BENGAL POWER DEVELOPMENT CORPORATION LIMITED
Recognised by WBPDCL Vide Letter No. : PDCL/CORP./HR/305/1495, Dated 3.3.2012
E-mail : wbpdclewf@gmail.com ● Visit us : www.wbpdclewf.org.in

GO GREEN :: SAVE ENVIRONMENT

POWER GENXT

VOLUME : 8

Published on the day of 8th National Seminar
15th December, 2019

IMPLEMENTATION OF FGD IN COAL BASED INDIAN THERMAL POWER PLANTS

ENGINEERS' WELFARE FORUM
THE WEST BENGAL POWER DEVELOPMENT CORPORATION LIMITED
(Recognised by WBPDCL Vide Letter No. : PDCL/CORP./HR/305/1495, Dated 3.3.2012)
E-mail : wbpdclewf@gmail.com ● Website : www.wbpdclewf.org.in

NEED
NATIONAL ENERGY EXCELLENCE DRIVE

POWER GENXT

VOLUME : 8

CONTENTS

- Massage

- Write-up

FGD by Injection of In-Situ NH_3 in Flue Gas of Coal Fired Thermal Power Plant — Page : 05-13
— *Prof. B. C. Meikap*

Comparison of Different FGD Technologies — Page : 14-17
— *Gautam Kr. Das*

Limestone grinding circuit design and its impact on economics of desulphurization of flue gas — Page : 18-22
— *Shravan Kumar, Barun Kumar Nandi, Pankaj Kumar Jain, Sumantra Bhattacharya*

A brief overview of present Energy scenario and relevance of FGD — Page : 23-25
— *Dr. Pranab bhattacharyya*

ENGINEERS' WELFARE FORUM
THE WEST BENGAL POWER DEVELOPMENT CORPORATION LIMITED
Regn. No. : S / 1L / 74829

Bidyut Unnayan Bhaban (3rd floor) 3/C,
Block-LA, Sector-III, Bidhannagar,
Kolkata-700098,
website: www.wbpdclewf.org.in

MANOJIT KUMAR BASAK
M. Tech., Gold Medalist(CU), MIE, C. Eng.
Chief Advisor & Founder Ex. President

Residence : Flat No. C1 "**ASHIRBAD**"
7/1, Bhattacharjee Para Lane, Kolkata-700036
Mob: 9432987079
E-mail: manojit1952@gmail.com

Date: 15-12-2019

MESSAGE

*I am very much glad and proud that “**Engineers’ Welfare Forum, WBPDCL** has organized their annual program NEED - National Energy Excellence Drive, 8th National Seminar on **“IMPLEMENTATION OF FGD IN COAL BASED INDIAN THERMAL POWER PLANTS”** on 15th December, 2019 at WBPDCL Auditorium “Bidyut Unnayan Bhaban”, Salt Lake City, Kolkata-700098.*

Now-a-day the proposed topic is the burning issue to the nation to reduce the pollution content in the air. This seminar will help to create a platform for knowledge shearing among the well experienced engineers of different power sectors.

*On the same auspicious day, Engineers’ Welfare Forum, WBPDCL will publish their technical journal **“POWER GENXT, Vol-VIII”** which will also be the knowledge shearing platform for the Engineers.*

I extend my best wishes for grand success of the seminar.

mBasak

(MANOJIT KUMAR BASAK)

SAVE ENERGY :: PRODUCE GREEN :: SAVE COUNTRY :: SAVE UNIVERSE

FGD by Injection of In-Situ NH_3 in Flue Gas of Coal Fired Thermal Power Plant

Prof. B. C. Meikap
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur
Email: bcmeikap@che.iitkgp.ernet.in

Introduction

The concern for air quality degradation has been a serious issue including India for the past few years. Growing urbanization along with industrial and vehicular pollution is leading to environmental degradation faster than in other countries. Suspended Particulate Matter constitutes one of the major air pollutants and cause many respiratory diseases including the dreaded silicosis. Vehicular traffic, coal fired thermal power stations, metallurgy industries and cement industries are the major culprits which contribute maximum SPM pollutant in the ambient air. The flue gas from a coal fired thermal power station contains fine particles of ash with size varying from 80 microns to less than 5 microns. The reduction of particulate emissions from coal burning units has been a particularly complex problem. While there are several options for controlling particulate emissions, there are three globally accepted technologies for the abatement of particulate matter. They are the Electro-Static Precipitators (ESP), cyclone separators and baghouse . Presently the power plants in India use an ESP as the pollution control device. However, the efficiency of the ESPs in India is adversely affected due to the sulfur content and the abrasive nature of high ash domestic coal. Existing precipitators were designed to provide a particular efficiency of collection for the coals in use or proposed at the time of design. From environmental legislation, state and federal requirements demand high efficiency removal of fly ash, even in older units. Additionally, many power companies have chosen to switch to low sulfur coal as a means of meeting environmental restrictions on sulfur dioxide emissions. Uncertain fuel supplies have often forced the burning of lower quality fuels. In many cases, these problems have resulted in the deterioration of precipitator efficiency with the result that particulate emissions exceed the limits. Considerable field experience indicates that fly ash in flue gas conditioning can materially improve the performance of these precipitators at relatively low cost. This process can be applied to existing precipitators and to new units as well. While flue gas conditioning has been known for some time, recent advances make a review of this area important.

Why is Flue Gas Conditioning Needed ?

Burning of coal in thermal power plants to produce electricity causes the emission of sulfur dioxide and sulfur trioxide, or acid gas. This gas is carried into the atmosphere, along with fly ash generated from the combustion of the coal. When these acid gases combine with moisture in the atmosphere, they form dilute solutions of sulfuric or sulfurous acid or “acid rain” which fall back to earth, damaging the environment.

High sulfur coal has traditionally been the standard fuel for coal-fired boilers and the fly ash produced from this fuel is readily collectable in electrostatic precipitators. Regulations restricting sulfur dioxide emissions are being implemented worldwide. In an attempt to comply with these new limitations, the power industry has begun the switch to lower sulfur coals. Low sulfur coal tends to generate more fly ash and flue gas per megawatt. Because of the higher resistivity of this ash, it is difficult to collect in existing precipitators.

The problem of regulatory compliance may be solved by the alternatives shown in **Fig. 1**. Two of the solutions are to install additional or much larger and more expensive precipitators or fabric filters for collection of the fly ash. Another, more cost-effective alternative, is flue gas conditioning as reported by WAHLCO, INC., USA. Flue gas conditioning restores the collection efficiency of the precipitators to performance levels consistent with the firing of high ash and sulfur coal.

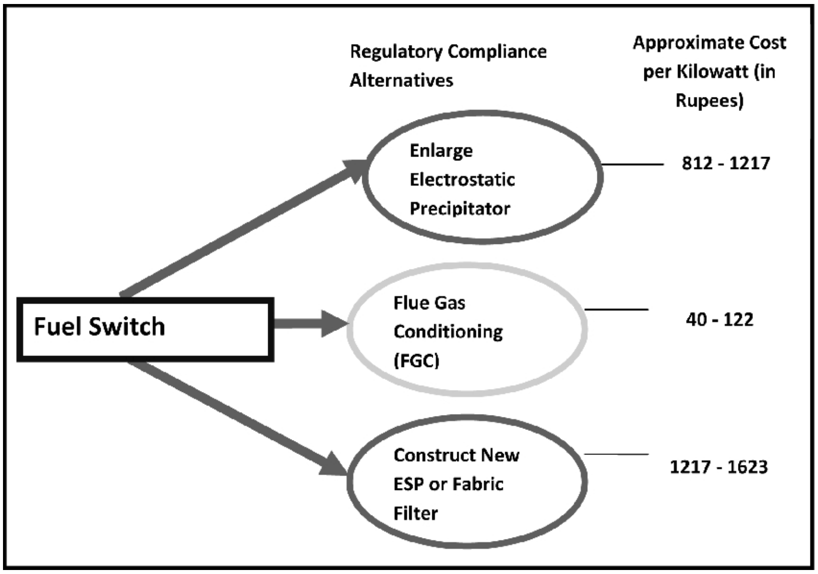


Fig. 1. Schematic diagram for solutions to regulatory compliance alternatives

What is Flue Gas Conditioning ?

Flue gas conditioning is required for low-sulfur coal containing less than 1.5% of S when gas humidity is lower than 15%. Conditioning agents cause adsorption of moisture on the particle surface, thus increasing its conductivity. Water, steam, ammonia (NH_3), sulfur trioxide (SO_2), sulfuric acid (H_2SO_4), sodium chloride (NaCl), hydrogen chloride (HCl), calcium chloride ($CaCl_2$), sodium sulfate (Na_2SO_4), lithium iodide (LiI), sodium carbonate (Na_2CO_3), ammonium sulfate ($(NH_4)_2SO_4$), ammonium bisulfate (NH_4HSO_4), sulfamic acid (NH_2SO_3H), phosphorus pentoxide, ferric sulfate, triethyloamine, or cyclohexylamine are used as conditioning agents to increase dust conductivity (Jaworek et al., 2007; Harker and Pimparkar, 1988; McLean, 1988; Castle, 1980; Dalmon and Tidy, 1972; Baxter, 1968; Reese and Greco, 1968). More complex organic mixtures have also been proposed for gas conditioning, but NH_3 and SO_3 are still the most popular agents used. The effect of a particular conditioning agent depends on fly ash composition. The ammonia additive is used at levels up to 20 ppm by volume. The concentration of SO_3 is usually lower than 1000 ppm by volume, but it can be used at temperatures lower than 190°C, when acid can condense on the particles. Gaseous SO_3 results in almost 100% adsorption by fly ash, while its aqueous solution is absorbed only about 20–70%. The adsorption is higher at lower gas temperatures. Sodium carbonate and sodium sulfate can be used at the boiler inlet by mixing them with coal (Crynack, 1996). These additives cause an increase in electrical conductivity of fly ash. Ammonia also increases cohesiveness of the particles, allowing their agglomeration (Chang et al., 1996). The number of particles re-entrained during electrode rapping is also reduced (Dismukes, 1975).

The disadvantage of certain conditioning agents is that they can decrease the breakdown potential, change the acid dew point in flue gas, and increase adhesion and cohesion forces, thus making rapping more difficult.

Why Inject Ammonia ?

Ammonia has been used in boilers firing high sulfur coal for many years to improve precipitator performance, reduce the acid dew point and corrosion, and in some cases eliminate the ‘blue plume’ from high sulfur trioxide emissions. In some cases of high ash resistivity, sulfur trioxide flue gas conditioning is not effective.

Ammonia injected into flue gas in the presence of sulfur trioxide and flue gas moisture reacts to form many ammonia compounds, principally ammonium sulfate and bisulfate compounds. These particles nucleate on sub micron particulate in the gas stream and help to agglomerate and increase ash particle size. The ammonia also reacts with ‘acidic’ ash to facilitate absorption of sulfur trioxide. The resulting ammonium bisulfate is a sticky compound above its melting point of about 143°C. It is believed to help agglomerate the ash and improve the ash cohesivity. Another observed effect is an increase in the flow of ions, electrons and charged particulate in the interelectrode space, or space charge. Ammonia has been used as an additive to flue gas and although not apparently affecting the resistivity of the particles (Dismukes, 1975), has increased their cohesiveness leading to an increased agglomeration and greater effective particle size (Chang et al., 1996). Ammonia is also the most successful material tested for the prevention of acid condensation because it diffuses rapidly and reacts immediately with SO_3 in flue gas environments. The Possible facts of ammonia injected as a flue gas additive for fly ash conditioning in electrostatic precipitators is presented in Fig. 2.

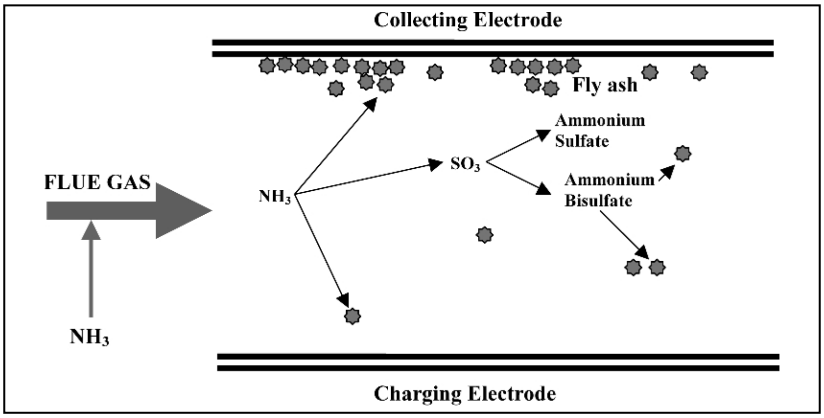


Fig. 2. Possible facts of ammonia injected as a flue gas conditioning in ESP

The addition of liquid ammonia (NH_3) into the gas stream as a conditioning agent has found wide use in recent years. The ammonia reacts with H_2SO_4 contained in the flue gas to form an ammonium sulfate compound that increases the resistivity of the dust. Ammonia vapor is injected into the duct leading to the precipitator at concentrations of 15 to 40 ppm by volume. The injection of NH_3 has improved the resistivity of fly ash from coal-fired boilers with low flue gas temperatures (Katz, 1979).

Urea to Ammonia

Ammonia is highly volatile noxious material with adverse physiological effects, which becomes intolerable at very low concentrations and presents substantial environmental and operating hazardous risk. It is classified as a hazardous material and many precautions are required in transporting and handling it safely. Urea, on the other hand, is a stable, non-volatile, environmentally benign material that is safely transported, stored and handled without such risk and, accordingly, and can serve as a safe source of ammonia. The processes of this invention minimize the risks and hazardous associated with the transport, storage and use of anhydrous and aqueous ammonia. Using urea as the source of ammonia for the SCR/SNCR system has the obvious advantages that no ammonia shipping, handling and storage is required. The technology has proven to be a safe and relatively reliable alternative to either anhydrous or aqueous ammonia in recent commercial applications.

Urea is available in solid form as prills or granulated material, and as urea solution in de-ionized water. Almost all SCR/ SNCR urea to ammonia installations use solid urea. Ammonia is generated from urea by a hydrolysis reaction that yields a vapor phase mixture of ammonia, carbon dioxide and steam. Several alternative process designs are available commercially for the conversion of urea in to ammonia. Solid urea is normally delivered by rail cars for large consumption rates and by trucks for smaller installations (Bhattacharya et al., 2003; Spencer et al., 2001).

Hydrolysis Process

The basic chemistry employed in the process is a reverse of that employed in that industrial production of urea from ammonia and carbon dioxide and employs two reaction steps, as follows.

$$\mathbf{NH_2CONH_2 + H_2O} \xrightarrow{-\text{Heat}} \mathbf{NH_2COONH_4} \qquad \Delta H_1 = -15.5 \text{ KJ/mole} \quad (1)$$

(Urea) (Water) (Ammonium Carbamate)

$$\mathbf{NH_2COONH_4} \xrightarrow{+\text{Heat}} \mathbf{2\ NH_3 + CO_2} \qquad \Delta H_2 = +177 \text{ KJ/mole} \quad (2)$$

(Ammonium Carbamate) (Ammonia) (Carbon dioxide)

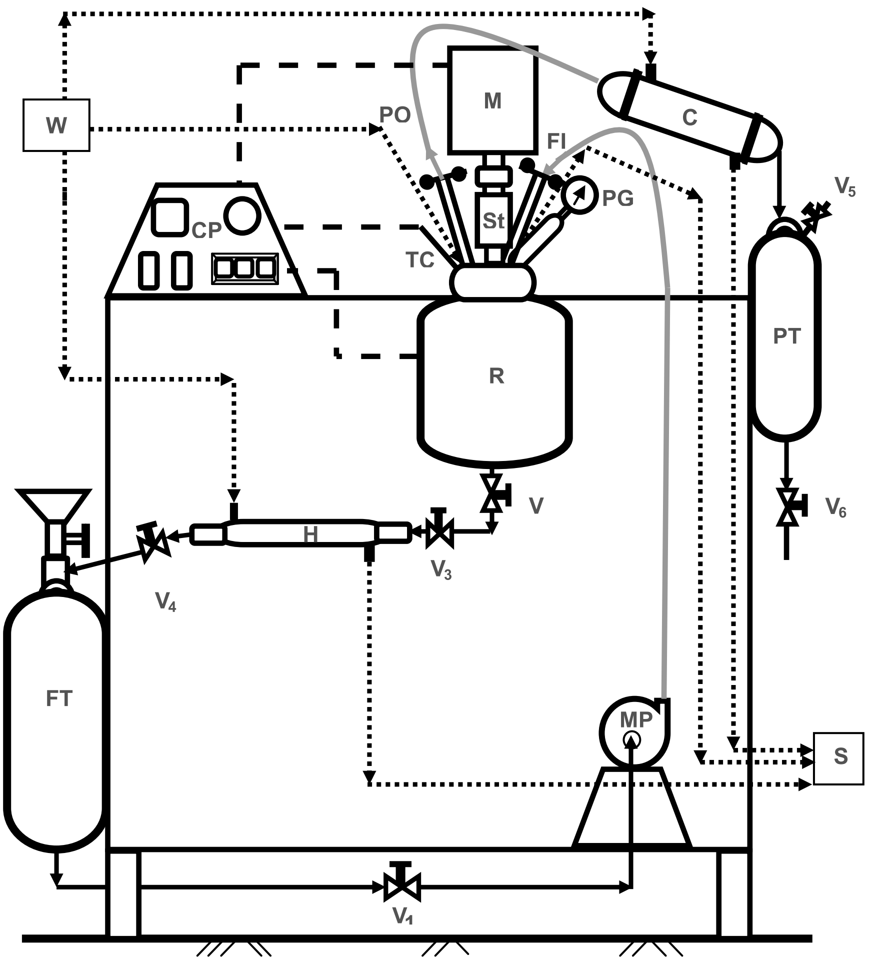
The first reaction in which urea hydrolyzes to form ammonium carbamate is mildly exothermic, while the second, in which ammonia and carbon dioxide are produced, is strongly endothermic, with the result that the reaction to release ammonia and carbon dioxide requires heat and quickly stops when the supply of heat is withdrawn. Excess water promotes the hydrolysis reaction; the overall reaction is given in equation (3). The overall reaction is endothermic and the first reaction, i.e. urea to ammonium carbamate reaction is very first and goes towards completion. The formation of ammonium carbamate takes place within 110^{0}C.

$$\mathbf{(1+x)\ H_2O + NH_2CONH_2 \longrightarrow 2NH_3 + CO_2 + xH_2O} \quad \Delta H_{overall} = +161.5 \text{ KJ/mole} \qquad (3)$$

In the thermal hydrolysis process of the invention, the liberation of ammonia commences at around 110^{0}C and becomes rapid at around 150^{0}C to 160^{0}C, with or without catalytic assistance (Brooks et al., 2006; Macarthur et al., 2005; Bhattacharya et al., 2003; Spencer et al., 2001).

Experimental Setup (Urea Hydrolysis)

The schematic diagram of experimental setup is shown in Fig. 3 and the photographic view is shown in Fig. 4. The experimental setup mainly consists of a high pressure (100 kg/cm^2) reactor, heat exchanger, condenser, metering pump, feed tank, control panel and product storage tank. The reactor is of a type of continuous stirred tank reactor (CSTR) having a capacity of 2000 cc volume, which was made up of stainless steel-316. A metering pump was used to feed the urea solution to the reactor at high pressure at controlled flow rate against a positive differential head between pump suction and discharge. The shell and tube type condenser was used to exchange heat between products (NH_3, CO_2, $H_2O(V)$) and cooling water. The system have also heat exchanger to cool the un-reacted urea for recycle to the reactor where tap water at room temperature without any pressure is used for the purpose of cooling. Apart from above it also have two storage vessels one for urea solution another for product storage. The hole set up was built in stainless steel to prevent corrosion. The reactor contains two openings. One is for feeding urea solution and another for withdrawing the product to condense the gaseous product from the reactor where tap water is used for the purpose of condensation. To measure the temperature and pressure of the reactor thermocouple and pressure gauge was attached to the reactor through the control panel. Cooling coil was placed inside the reactor to cool the reactor when required, same tap water also used here as a coolant. There is a control panel to control the required temperature and speed of the stirrer. To supply the necessary heat, electrical heating coil outside the reactor wall was provided at a controlled rate by means of control panel. The control panel consists of several controllers and instruments. The control panel consists of indicators are connected by electrical wire, mains ON/OFF switch, stirring motor ON/OFF switch with variable speed inverter drive and speed indicator, electrical heater ON/OFF switch, alarm system, fuses, P.I.D. temperature controller. The whole set-up is placed on a stand with moving arrangement.



Experimental Setup: C - Condenser, CP - Control Panel, FI – Feed Inlet, FT–Feed Tank, H - Heat Exchanger, M – Motor, MP – Metering Pump, PG-Pressure Gage, PT – Product storage Tank, R - Reactor, S-Sink, St – Stirrer, TC – Thermocouple, V_{1-6}– Valves, W – Water Supply, ⟶ Process Line, ⟶ High Pressure Process Line, -------► Tap water Line, — —► Electrical Line

Results and Discussions

Study of Equilibrium Conversion at Atmospheric Pressure

Experiment has been conducted for hydrolysis of urea at atmospheric pressure in a batch reactor at different temperature and concentration and both equilibrium and kinetic study has been done. Urea samples have been characterized by HPLC to find out the impurity. It has been observed that Tata urea shows highest percentage of purity i.e. 94% having biuret content of 1.25% while IFFCO urea contains 2.05% biuret and its purity is 91.21. Table.1 shows the impurity data of different grade of urea.

From the initial concentration and final concentration the conversion was found out and the equilibrium study of hydrolysis reaction without stirring has been studied. Here the effect of equilibrium conversion on temperature and concentration has been studied.

Effect of Temperatures on Conversion

It can be seen from the Fig. 5 that the conversion is function of temperatures. It increases exponentially with increase in temperatures. For 10% urea solution the conversion increases from 2% to 17% when temperature increases from 110°C to 180° in 10°C interval. Similarly trend has been observed for 20 and 30 % feed solution and the conversions are 9 and 8% respectively at 170°C.

The conversion was slightly affected by the initial concentration of urea that is feed to the reactor. It can be seen from Fig. 6 that with increases in initial concentration of urea the conversion decreases marginally. For each initial concentration the temperature was varied from 110°C to 180°C. Keeping temperature constant at 180°C the conversion decreases from 11% to 9% when concentration varies from 10% to 30%. Similarly for 120°C, 130°C, 140°C, 150°C, 160°C, 170°C and 180°C the equilibrium conversion decreases from 2.5 % to 2.3 %, 3.25 % to 3 %, 5.3% to 3.8%, 7% to 5%, 8.5% to 6.7% and 12.2% to 9% respectively when the initial concentration of urea increases from 10% to 30%.

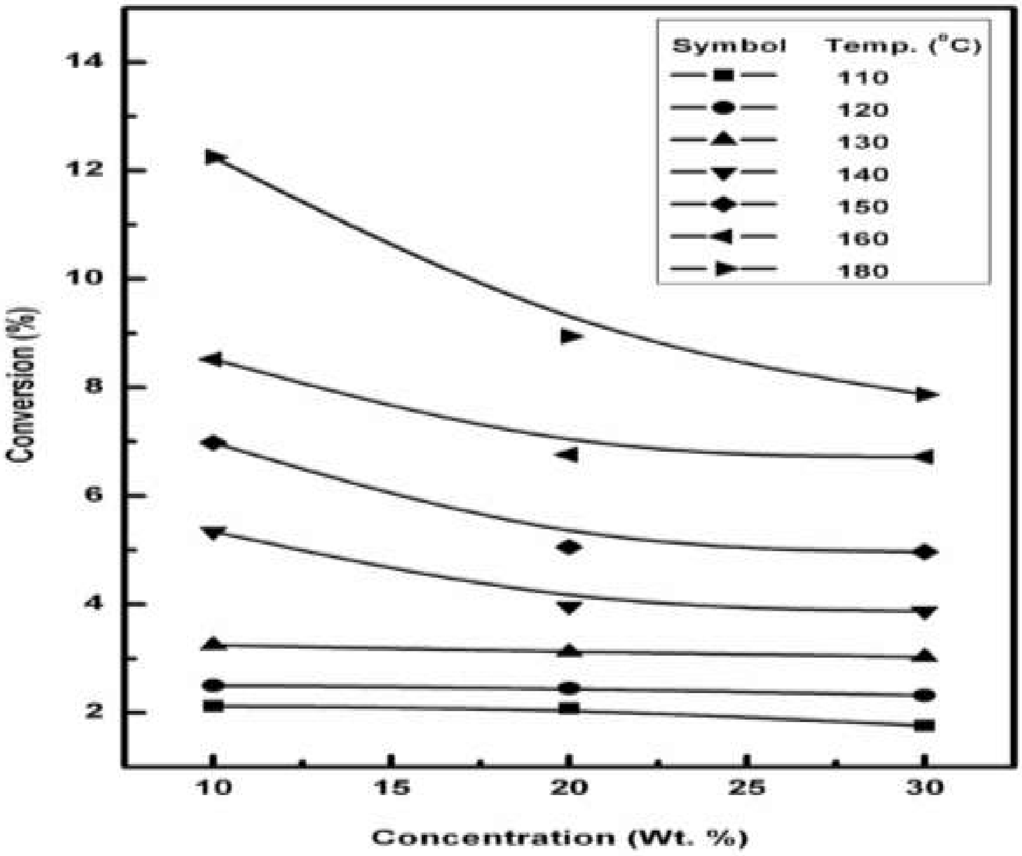


Fig.-4 Effect of concentration on conversion at different temperature

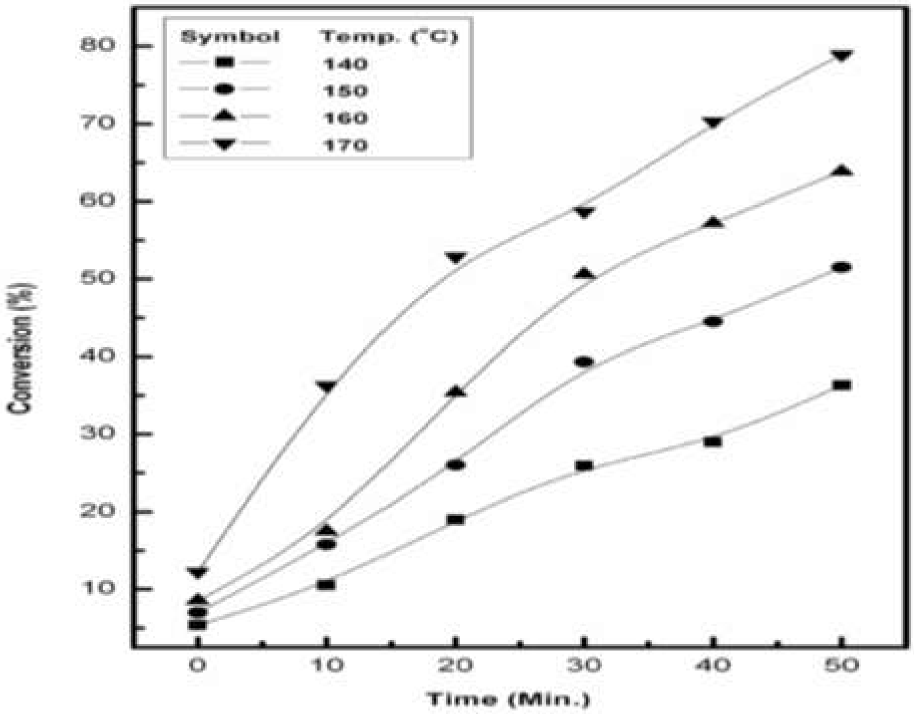


Fig.-5 Effect of time on conversion at different temperature for constant 10 Wt. % solution

Conclusions

Number of experiments was carried out in a batch reactor without stirring at different temperatures and pressures taking different concentration of urea solution from 10 to 40% by weight and both equilibrium and kinetic study has been made.

From equilibrium study at atmospheric pressure, it is concluded that with increase in temperature the equilibrium conversion increases and a maximum conversion of 18% is possible with 10% concentration and at 180°C temperature. The equilibrium conversion decreases with increase in concentration. It has also been found that the forward reaction is a pseudo first order reaction with rate constant varies from 0.0080571 to 0.0274359 min^{-1} within the temperature range of 140°C to 170°C.

From equilibrium study at high pressure, it is concluded that with increase in temperature and pressure the equilibrium conversion increases and a maximum conversion of 30% is possible with 10% concentration and at 160°C temperature and 896.32 KPa pressure. The equilibrium conversion decreases with increase in concentration. It has also been found that the forward reaction is a pseudo first order reaction with rate constant varies from 0. 0134 to 0.22 min^{-1} within the temperature range of 140°C and 150°C respectively.

The activation energy and frequency factor of urea hydrolysis reaction at atmospheric pressure is found to be 60.93 KJ/mole and $4.259 x 10^{5}$ min^{-1}, respectively.

Finally it can be concluded that the hydrolysis of urea to form ammonia and carbon dioxide behaves as a first order reaction with respect to urea. Also it can be concluded that the initial reaction rate is slower and it becomes rapid at around 130°C. At this temperature the production of ammonia is higher than that at lower temperature. Further the reaction rate constant is function of temperature.

References

1. Aoki, H., Fujiwara, T., Morozumi, Y., Miura, T., 1999. Proceedings of the fifth international conference on technologies and combustion for a clean environment. Lisbon, 115-118.
2. Baxter, W.A., 1968. Recent electrostatic precipitator experience with ammonia conditioning of power boiler flue gases. Journal of the Air Pollution Control Association 18 (12), 817–820.
3. Bhattacharya, S., Peters, H.J., Fisher, J., Spencer, H.W., 2003. Urea-to-Ammonia (U_2A^{TM}) Systems: operation and process chemistry presented at the 2003 Mega Symposium.
4. Borio, D., Rader, P., Walters, M., (1999). Ammonia Scrubbing: Creating Value from SO_2 Compliance; ABB
5. Brooks, B., Jessup, W.A., Macarthur, B.W., 2004b. International Application Published WO 2004/048268 A1 – Method of quantitatively producing ammonia from urea.
6. Castle, G.S.P., 1980. Mechanisms involved in fly ash precipitation in the presence of conditioning agents-A review. IEEE Transactions on Industry Applications 16 (2), 297–302.
7. Chang, J.S., Thompson, H., Looy, P.C., Berezin, A.A., Zukeran, A., Ito, T., Jayaram, S., Cross, J.D., 1996. Control of trace elements in combustion flue gas by a corona discharge activated conditioning agents and electrostatic precipitators. Sixth International Conference on Electrostatic Precipitation, Budapest, 2–7.
8. Cooper, H.B.H., Spencer, H.W., 1998a. Canadian Patent CA 2284292 A1 – Methods for the production of ammonia from urea and uses thereof.

Comparison of Different FGD Technologies

Gautam Kr. Das
Deputy General Manager
Development Consultants Pvt. Ltd.
Email: gautamkd@gmail.com ; chakraborly@gmail.com

The selection of Desulphurization process depends on a number of factors including technical suitability, economic aspects and commercial considerations. The sorbent utilization will be a major criterion for selection as the cost of transportation of the limestone is likely to be very high. A wide range of technologies are available to reduce the SO_2 from burning of coal. This includes:

- Fuel Desulphurization
- Flue Gas Desulphurization System

FUEL DESULPHURIZATION

A major portion of Sulphur (30 – 70%) in coal is usually present in the form of pyrites or FeS_2. The FeS_2 can be removed by washing. Other chemical processes are available to remove the organically bound Sulphur from coal.

The rejects generated from the washing process is also a source of other environmental problems like ground and soil water contamination.

Coal desulphurization is a very costly method for reduction of SO_2 emission and may lead to other environmental problems.

FLUE GAS DESULPHURIZATION

Nearly all flue gas desulphurization processes depend on the fact that SO_2 is acidic in nature and use an alkaline substance, most commonly lime or lime stone to neutralize it. Other alkalis like sodium based, magnesium-based alkalis and other type of alkalis such as Ammonia etc. are also used. FGD processes may be broadly classified into three different types:

- Dry / Semi Dry process
- Wet FGD process
- Dry Sorbent Injection System

DRY/SEMI DRY PROCESS

Dry FGD technologies include the more established Spray Dryer Absorber (SDA) system, which sprays a fine dry must of lime into the flue gas, and the relatively new concept of employing circulating fluidised bed (CFB) technology, with boiler ash and lime circulated through an absorber reactor.

Dry scrubbing technology has much lower capital cost and uses less water than wet FGD technology. The various semi dry technologies are discussed below.

Spray-Dry Process

Spray Dryer Absorption (SDA) is a dry scrubbing process that is generally used for low-sulfur coal. SDA FGD systems are typically located after the air preheaters, and the waste products are collected in the Electrostatic Precipitator (ESP). However, to achieve sulfur dioxide (SO_2) reduction above 80% with good reagent use, the dry scrubber is used. Flue gas is treated in an absorber by mixing the gas stream concurrently with atomized lime slurry droplets. The droplets absorb SO_2 from the gas and reacts the SO_2 with the lime in the slurry. The desulfurized flue gas, along with reaction products, unreacted lime, and the dry ash passes out from the dry scrubber to the bed-house.

In spray-dry process, a very finely atomized spray of very thick slurry of the sorbent is introduced into the flue gas stream upstream of the ESP. The normal sorbent for the process is quick lime, which is slaked at site to generate Calcium Hydroxide. SO_2 reacts with $Ca(OH)_2$ to form Calcium Sulfite, which then collected with ash in the ESP. The gas and the sorbent may be mixed either in a spray-dryer vessel or in the duct. The process can achieve a removal efficiency of 90-95%, with a spray-dryer vessel, for medium Sulphur (up to 2.5%) coals. The semi-dry is one of the lowest capital cost option for desulphurization of flue gas, typically being about 70% of the cost of the Limestone-Gypsum plant. The spray-dry FGD process is suitable for low and medium Sulphur coal, where a desulphurization efficiency of 90% can be achieved with the process.

Circulating Fluidized Bed / Circulating Dry Scrubber Process

In the Circulating Fluidized Bed (CFB) FGD or Circulating Dry Scrubber (CDS) process, flue gas from the air heater is carried through the inlet venturi throat through a fluidized bed of lime, reaction products and fly ash particles contained within the vertical reactor tower. Here the lime reacts with SO_2 to produce a mixture of calcium compounds. The gas is then passed through an ESP where the ash and calcium compounds are collected. The clean gas is then discharged through the ID fans and Stack. The normal sorbent for the process is lime which is slaked at site to form Calcium Hydroxide (slaked lime).

The process is capable of achieving up to 97% removal of the SO_2 and all of the SO_3 and HCl from the flue gas. It is a relatively simple process and has low space requirement. The capital cost of the process is low and the process has very good turn down capability.

Although the CFB process is very simple compared to Wet FGD systems and has a lower capital cost, the operational cost is among the highest (similar to the spray-dry process) due to its poor lime utilization, costly reagent and additional cost incurred in handling the lime and waste generated from the process.

Combined De-SO_X / De-NO_X Process

Another new development in dry process is the combined SO_X – NO_X removal process. This is a cold end process after the ESP in which the flue gas is passed through two beds of activated coke. SO_2 is absorbed by activated coke in the first bed after which NH_3 is introduced in the flue gas which then passes through the second bed of activated char. The coke here, acts as a catalyst for reduction of NO_X to N_2. The saturated coke from the first bed is regenerated continuously in another chamber which produces a very concentrated stream of SO_2. This can be used to produce a commercially saleable elemental Sulphur or Sulphuric Acid.

The SO_2 removal efficiency of such process is up to 95-99%. The process has the added advantage of ~90% removal of NO_X. However, the combined process is very complex with a very high capital cost.

WET FGD PROCESS

In the wet process, thin slurry of sorbent is sprayed into the flue gas streams, typically after the ash has been removed in the ESP. The water dissolves most of SO_2 from the flue gas to form H_2SO_4 which then reacts with the sorbent. Lime stone and quick lime are some of the most commonly used sorbents, although other sorbents like ammonia, sodium & magnesium are also used commercially. One particular process, uses the natural alkalinity of sea water to scrub SO_2 in a process called sea water washing.

The wet FGD system is located downstream of the ESP. Most wet systems have an additional capability of removing a significant percentage of inlet dust. This allows a smaller ESP for controlling SPM, the remaining reduction occurring in the FGD system.

Lime / Limestone-Gypsum Forced Oxidation Process

In this process, thin lime or limestone slurry is sprayed in the flue gas. Alternatively, the flue gas passes through a bed of lime / limestone slurry. The reactions between lime / lime stone slurry and SO_2 produces a mixture of calcium sulfite and calcium sulfate. The calcium sulfite sludge is further oxidized in an oxidized tank to yield gypsum.

The gypsum slurry is bled off from the tank and dried in a Dewatering plant, from where the gypsum is taken for sale.

The Lime / Limestone-Gypsum Forced Oxidation (LSFO) process is capable of achieving up to 98% SO_2 removal for high Sulphur coals. Further, the process is well proven with a number of operating units and manufacturers. Further, the gypsum by-product of the process is marketable. However, the wet LSFO FGD process is a very complex as compared to the dry process and requires a large foot print area. The availability of high quality lime from local source is another issue which favors the use of limestone. The process is the most well proven technology to achieve high desulphurization efficiency with high Sulphur coal, with a large number of reference plants.

Sea Water Process

The sea-water washing (SWW) process uses natural alkalinity of the untreated sea water in order to neutralize the SO_2. The gas from ID fan passes through a booster fan (optional) into the scrubber, where sea water is sprayed into the flue gas. The sea water dissolves most of the SO_2 and practically all of HCl. The clean gas is again passed through a re-heater before discharge through stack.

The acidified liquor is collected in a sump and then taken to a mixing basin where more sea water is mixed and air is blown through the water to reduce its chemical oxygen demand, before being discharge into the sea. The sea water process is a very simple process with no requirement for any additional reagent. The sea water is capable of achieving desulphurization efficiency upto 95% with low and medium Sulphur coal.

Ammonia Process

The process is similar to the Lime / Limestone-Gypsum Forced Oxidation process, except that the reagent is an aqueous ammonia solution. The reaction between Ammonia solution and SO_2 produces a mixture of ammonium sulfite and sulfate. The ammonium sulfite sludge is further oxidized in an oxidization tank to yield Ammonium sulfate which can be used as fertilizer.

The Ammonia FGD process is capable of achieving up to 98% removal of SO_2. The byproduct of the process ammonia is a very high value fertilizer.

The process is very high in capital cost and has very high auxiliary power consumption (2-3%). The storage and handling of aqueous ammonia is potentially risky and proper planning is required. The system requires a large foot print area, similar to the limestone gypsum FGD system.

DRY SORBENT INJECTION TECHNOLOGY

A Dry Sorbent Injection (DSI) system is a dry process in which a sorbent is pneumatically injected either directly into a coal-fired boiler or into ducting downstream of where the coal is combusted and exhaust (flue) gas is produced. The goal of the sorbent injection is to interact the sorbent with various pollutants in the flue gases such as sulfur trioxide (SO_3), various acid gases including hydrochloric acid (HCI), and sulfur dioxide (SO_2), such that some fractions of these pollutants are removed from the gas stream. After the appropriate chemical interactions between the pollutants in the flue gas and the sorbent, the dry waste product of reaction is removed at the ESP.

DSI is a mature technology that has been widely applied since the early 2000 for SO_3/HCL/HF emissions reduction. Low installed capital cost w.r.t Wet Limestone FGD & semi dry FGD.

Comparison of Different FGD Technologies

Item	Spray Dry Process	CFB/ CDS Dry	Wet Limestone-Gypsum	Ammonia process	DSI
Sorbent	Lime	Lime	Limestone	Ammonia	Sodium bicarbonate
Coal Sulphur Limit	For low and medium ulphur content coal	No limit	No Sulphur content limit	No Sulphur content limit	For low and medium Sulphur content coal
Removal efficiency	90-95%	Above 95%	Above 95%	Above 95%	<85%
Process	Hard to obtain	Hard to obtain	Local	Depends on availability	Depends on availability
Sorbent source	Hard to obtain	Hard to obtain	Local	Depends on availability	Depends on availability
Sorbent Utilization	Poor	Poor	Good	Good	Poor
By-product	Waste Mixture of Calcium compounds (Sulfite and sulfates)	Waste Mixture of Calcium compounds (Sulfite and sulfates)	Gypsum	High value fertilizer Ammonia sulfate solution	Along with Fly Ash
Aux. Power	Low	Low	High	Very High	Low
Capital Cost	Low	Low	High	High	Low
Operating Cost	High	High	Low	Low	Very High
Reference Plants above 500 MW	Few	Few	Many	Few	Few

Limestone grinding circuit design and its impact on economics of desulphurization of flue gas

Shravan Kumar, Barun Kumar Nandi,
Pankaj Kumar Jain, Sumantra Bhattacharya
Indian Institute of Technology (Indian School of Mines) Dhanbad
Department of Fuel Minerals and Metallurgical Engineering

Abstract

Removal of SO_2 from flue gas through chemical reaction with limestone depends on quality of limestone, mass transfer and chemical reaction rate in water slurry of limestone and SO_2 gas. Further temperature of slurry, stoichiometric ratio, particle size and surface area of limestone play important role. It is therefore important to grind limestone to desired fineness and at low energy consumption so that unit electricity generation cost remains low. Among the various options available, ball mill has its own advantage in view of its easy availability, simple operation, and ease of control of the operating parameters. The design of limestone grinding circuit in addition to equipment selection may include selection of instruments such as level transmitter, density meter, pressure gauge, flowmeters and other utilities. The use of advanced control tools has shown significant improvement in the performance of a grinding circuit.

Introduction

Cement blended with limestone is known around the world. Its use has interesting economic and environmental advantages as it allows a reduction in energy consumption and greenhouse gas emissions. The rapid increase in the production of Portland Limestone Cement (PLC) has initiated the need of grinding of limestone to the required fineness at reduced energy consumption rate. Based on the type and quality of PLC, the content of ground limestone varies from 6-35%, by weight. The major raw material for the clinker is usually limestone mixed with other class of materials that may include clay, shale, sand, iron ore, bauxite, fly ash and slag.

The grinding of the clinker is generally done by blending both these classes of materials, or separately ground and then mixed. However, due to the different grindibilities of two classes of materials, it is usually not preferred to grind them together. The present paper discusses the various aspects of limestone grinding at low energy consumption along with the philosophy of limestone grinding circuit design.

Operating the limestone grinding circuit under optimum conditions can contribute significantly to the improvement of the energy efficiency of the grinding process. The demand for ultra-fine mineral particles has continuously been increasing over the years. As a result, the manufacturing industry is setting a very stringent specification for these mineral particles including finer particles with closer control of mean particle size or width and cut-off of the particle size distribution.

Particle breakage and inter-particle interaction are the two counteracting processes that influence the performance of fine grinding. Particle breakage is dependent on micro-crack propagation controlled on the most basic level by the Griffith criterion of brittle material fracture, given here after. It affects the kinetics of the comminution processes and increases the specific surface area of the grinding product. The energy release rate, G, is defined as the energy that flows to the crack tip per unit of new crack surface created. An energy balance shows that

$$G = -\frac{\partial \Pi}{\partial s},$$

where s is the fracture surface and Π is the potential energy given by

$$\Pi = \int_{v} W\,dV - \int_{S_t} \mathbf{t}\cdot\mathbf{u}\,dS - \int_{v} \mathbf{b}\cdot\mathbf{u}\,dV,$$

Where, W is the strain energy density, v is the region occupied by a body, S_t is the surface of the body upon which tractions, t, are prescribed, u is the displacement field, and b is the body force

Desulphurization using ground limestone

Desulphurization of Flue Gas (FG) using limestone can be carried out using (a) dry limestone powder (b) semi solid-liquid and (c) in slurry of limestone. Among these slurry of limestone gives the highest efficiency. The reason behind their individual efficiency lies on mass transfer mechanism of SO_2 gas on limestone surface. Generalized compositions of limestone as reported in various literatures are summarized in Table 1.

Table 1 General composition (%) of limestone

CaO	MgO	SiO_2	Fe_2O_3	Al_2O_3	Moisture	LOI
49.9-54.5	0.3-4.6	0.2-12.6	0.1-3.6	0.2-6.7	0.04-0.95	32.7-44.4

Theoretically, limestone corresponds to $CaCO_3$ (MW: 100), which during heating decomposes to CaO (MW: 56) and CO_2 (MW: 44). Hence, it should have 44% ignition loss. However, due to presence of various impurities, its CaO content varies. During removal of SO_2 from FG, apart from CaO, other alkali compounds like MgO, Na_2O, K_2O etc also take part in reaction. All such compounds react based on their affinity to CO_2, reaction rate constant, stability of formed carbonate salt, temperature of slurry or mixture etc.

Overall, entire flue gas removal process is part of simultaneous mass transfer with chemical reactions. Hence, all the aspects of mass transfer for solid-liquid-gas diffusion as well as chemical reactions are involved. Various reactions and physical steps for the process (absorption process within a limestone slurry) are as follows

(1) Diffusion of SO_2 through the gas film near the gas–liquid interface.

(2) Diffusion of SO_2 in the liquid phase.

(3) Dissolution of SO_2 on water phase and reaction with $CaCO_3$.

(4) Also in parallel dissolution of $CaCO_3$ in water.

(6) Reaction between SO_2 and $CaCO_3$.

Apart from all the steps, dissolution rate of $CaCO_3$ or solubility of $CaCO_3$ is an important parameter, which depends on particle size distribution of limestone, quality of limestone etc. During the reaction, one mole of $CaCO_3$ or $Ca(OH)_2$ react with one mole of SO_2, to form one mole of calcium sulfite di-hydrate ($CaSO_3.2H_2O$). Thus, a 100% stoichiometric limestone or hydrated lime requirement means one mole of $CaCO_3$ or $Ca(OH)_2$ for each mole of SO_2 feed. The 150% stoichiometric requirement means 1.5 mole of $CaCO_3$ or $Ca(OH)_2$ for each mole of SO_2 fed. Theoretically, higher is the stoichiometry, higher the SO_2 absorption. A generalized reaction is given below.

$$CaCO_3+SO_2+H_2O=CaSO_3.2H_2O+CO_2$$

Various experimental studies reported in literature suggest that the total sulfation capacities of limestone and hydrated lime slurries are different depending on origin and chemical composition of limestones and their hydrated limes. Strong relationship between the total sulfation capacities of slurries and $CaCO_3$ and $Ca(OH)_2$ content of sorbents had been reported. The total sulfation capacities of all slurries got shifted to higher values as the sorbent content of slurries increased. The SO_2 removal efficiencies of slurries got decreased with the increase in temperature.

Mill selection and grinding circuit design:

A typical grinding circuit used in mineral processing industry includes ball mill in closed circuit with classifying cyclone (Figure 1). The material is fed to the ball mill using belt conveyor and the ground slurry from the mill discharges to a sump. This slurry is pumped to hydrocyclone at desired pressure in order to separate the coarse and fines. The unground materials are recycled back to the mill generally in the range of 150 to 250%, also known as recirculation load of the grinding circuit.

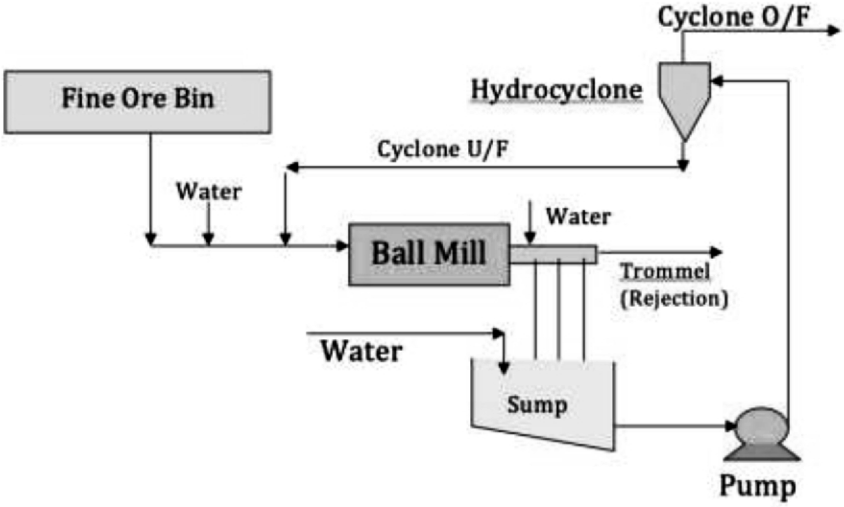


Figure 1. Typical closed circuit grinding

Ball mill discharge streams, in particular overflow type, usually pass through a trommel screen attached to the mill outlet to prevent ball scats from reaching subsequent processing equipment and to prevent a build-up of pebbles/ balls in the mill. Trommel screen is one of the oldest equipment, which is essentially a rotating drum with holes in the surface through which the undersize material passes. The performance of trommel screen directly affects the grinding circuit efficiency in terms of scat removal and recovery of undersize materials to be pumped to cyclone in closed circuit.The properties of materials that governs the separation efficiency of trommel screen are feed bulk density, material granulometry, moisture content, maximum and average granule weight, etc. On the other side, the trommel drum diameter, drum speed, pitch of trommel screw and slope are the major machine parameters governing the trommel performance.

In order to meet the desired product size of limestone from a ball mill grinding circuit, following points must be taken into account:

1. Feed rate control to ball mill
2. Pulp density inside mill
3. Pulp density of cyclone feed sump
4. Feed pressure to cyclone
5. Level of slurry in mill discharge sump

The Ball Mill control system objectives are to maintain stable operation of the process while minimizing the variations in the Particle Size Distribution (PSD or P80) of the slurry received from the cyclone overflow. The control strategy adjusts the pump speed to maintain a stable cyclone pressure. The Ball Mill sump level is allowed to change over a specified range so that minor variations in production rate are managed in the sump. This approach avoids unnecessary changes to the cyclone pressure - or the number of cyclones in service - resulting in increased stability of the cyclone pressure and the P80. Dilution water to the sump is adjusted to maintain slurry density to the cyclone, which is also an important factor in stabilizing cyclone performance.

Relatively older grinding circuits contain PLC or DCS based control systems in which the field instruments measures the operating parameters and transfers the information to the main control system/software. The software has features to change the set point and process parameters and take corrective measures as specified by the operator. However, modern plants use Advanced Control Tools or Expert System, which works on artificial intelligence. These are basically advanced softwares, which are trained/calibrated with set of operating parameters and results thereof. Particle Size Analyzer (PSA) is one of the important instruments that measure the particle size distribution of the material received from cyclone overflow (grinding circuit product) on continuous basis. Based on the particle size distribution data, the mill feed rate is increased or decreased. If the product is coarser than the required size, then it is expected that the feed is having higher BWI (Bond Work Index, a measure of hardness) than the average value and hence it is time to reduce the feed rate. Because, at reduced feed rate it is expected that the particles will experience higher residence time in ball mills or more interaction with media, i.e. grinding balls usually made of cast iron (CI) to reduce its size.

Quality of mill product as obtained from the hydrocyclone overflow (Fig. 1) is typically 90% passing 40-45 microns size with minimum percentage of <10-15 microns size. Because of the soft nature of limestone, BWI = 6-8 kWh/ t, single stage ball milling is adequate to achieve that. Finer product the size, more is the operational expenditure on account of power consumption, wear and tear of mill liners, balls, pumping cost etc.

Summary

Proper grinding of limestone is an important aspect that governs the overall economics of limestone processing for FGD system along with governing the quality of SO_2 removal from flue gas. The grinding circuit design and control using advanced control tools is needed to optimize the process. Further, good quality of limestone and reliable information about chemical reaction between limestone slurry and SO_2 is important for efficient removal of SO_2 from flue gas. Real challenge in designing a limestone grinding circuit is to ensure more than 90% of the mass to the desired fineness, yet not doing overgrinding because that escalates the operating cost.

Acknowledgement:

This paper is the off shoot of a project carried out by the authors at IIT(ISM) Dhanbad and sponsored by BHEL Hyderabad vide project number PCE/CONS/3775/2017-18.

A brief overview of present Energy scenario and relevance of FGD

Dr. Pranab bhattacharyya
Variable Energy Cyclotron Centre, Kolkata

ABSTRACT

One of the most important issue of today's India is generation of power maintaining the environment cleanliness. The present article gives an idea about the current energy production status of India along with future demands. It compares different alternative solutions. It also touches upon the idea of flue gas desulphurization(FDG) for thermal power plants considering environment protection.

1. Introduction:

The human development Index (HDI) is a strong function of energy consumption per capita.Fig-1 demonstrates the same for selected countries.

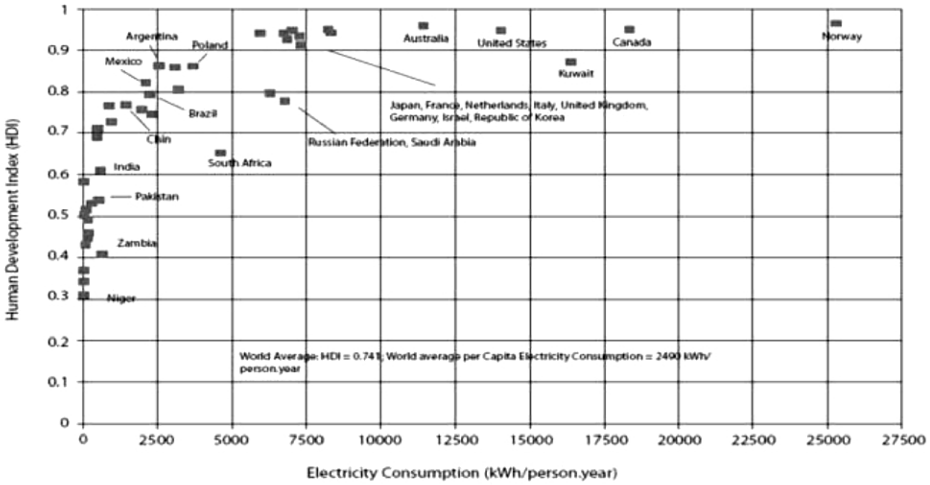


Fig. 1. Human development index vs Energy Consumption per capita

The flat zone of the graph shows after knee point that further increase in electricity consumption would not improve the quality of life much. At least, we need to target the knee point of that graph to improve the HDI to sustain economic growth.

Looking at a modest life style of 2000 kWh/Yr., India needs about 3400 TWh per year. A realistic evaluation of all renewables is expected to produce 1229 TWH/yr. Shortfall of 2171 TWH/Yr will need much higher growth of and input from nuclear energy.

For such large requirements all sources of energy have to be deployed. Presently 86% of our electricity needs are met by burning coal/oil. However the coal/oil option, has severe global impacts on environment and commerce in addition to huge infrastructure needs.

2. Energy production in India

Thermal, hydro, Renewable and nuclear contribution were 64.8%, 13.2%, 20% and 2% respectively.

Total installed capacity at end of March 2018:

Thermal	-	222693 MWe
Hydro	-	45403 MWe
Renewable	-	69022 MWe
Nuclear	-	6780 MWe
Total	-	343898 MWe

3. FDG:

It is evident that in present energy scenario the thermal power plant is lion share holder. Hence, one of the major main concern is to mitigate the effect of pollutants to avoid global climate change. As a matter of fact Indian coal (contents more Sulphur) based plants are one of the largest emitter of SO_X. Flue gas Desulphurization (FDG) is need of present time. A schematic of FDG is shown in Fig.2.

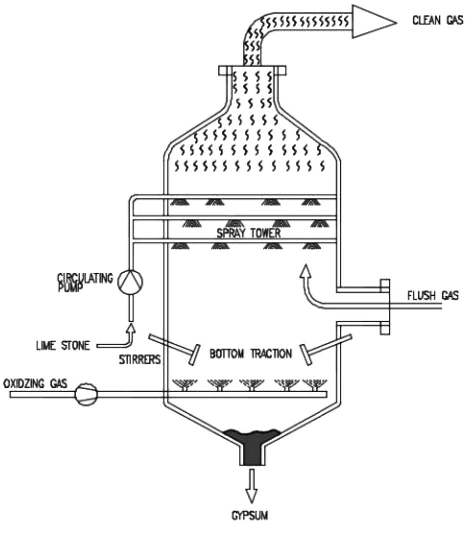


Fig. 2. FDG Schematic

Limestone slurry is sprayed on the incoming flue gas. The sulfur dioxide gets absorbed . The sulfur dioxide and the limestone react as follows :

$CaCO_3 + H_2O + 2SO_2 \longrightarrow Ca^{+2} + 2HSO_3^{-} + CO_2$

$CaCO_3 + 2HSO_3 + Ca^{+2} \longrightarrow 2CaSO_{3+}CO_2 + H_2O$

Other alternatives use sea water or Ammonia based scrubber as well. All the methods have their own merits and demerits.

4. Conclusion:

In present India, the challenge is twofold. One is to increase generation of power for quality life . And the second is to keep the environment clean and mitigate release of pollutant gases in the environment.

The first can be obtained by mixing different energy options. The implementation of FDG is one of the contributing factor for maintaining a clean environment.

A third approach may be use of energy efficient light like LED. This will significantly reduce the consumption. A fire fly has the maximum illumination efficiency. It has inspired scientists to innovation of energy efficient lights.

5. Reference:

[1] Dr Steve Chu, Department of Energy, US

Save Energy
Save Environment
Save Earth

Switching off power for only **half an hour** a week can make a big difference. So, come, be a part of the noble endeavour to save Mother Earth. Let's strive for a brighter future!

Our pledge **Green Earth**

Some other ways to save power

- Save up to 85% electricity by using LED bulbs
- Check BEE Label and number of stars on electric appliances while purchasing
- Set AC temperature at 24 degrees to save up to 35% energy
- Switch off lights, fans and other electric gadgets after use

WEST BENGAL STATE ELECTRICITY DISTRIBUTION COMPANY LIMITED

(A Govt. of West Bengal Enterprise)

Regd. Office: Vidyut Bhavan, Block-DJ, Sector-II, Bidhannagar, Kolkata - 700 091
CIN: U40109WB2007SGC113473, cecorpmont@gmail.com, www.wbsedcl.in