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A review -wet flue gas desulfurization by the use of limestone spray dry scrubbing

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Abstract: *- In order to increase the comfort health safety and increase the durability of assets flue gas release from the coal power plants needs to be reduce. this paper helps us to understand the advantages of FGD application which helps in achieving the task as mention before focusing on the challenges which are face during the process also the principles research gaps and potential development has been discussed in this review paper. recent development has shown that limestone Spray dry scrubbing remove Sulphur oxides and cause this solution of calcium sulphate ($CaSo_4$) and decentralization process. low amount of these elements are found due to modern SGD which has great benefits in the future.*
Keywords: - lime stone dissolution; process optimization, WFGD. beneficial use coal combustion residues.

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I. Introduction

Open literature does not contain many research or investigation of desulphurization systems effective use of wet FGDS have been effectively used for all types of natural coal such as a better performance compared to other Technology out there during combustion process, amount of dust and pollutants are emitted SO_2 has been the maximum percentage emission during the combustion stage. it becomes necessary to reduce Sulphur Dioxide before it is exposed to the atmosphere systems are preferred in thermal power plants and heavy industries because of their efficiency is and the good ability to capture Dus outside the Sulphur dioxide.Wet lime desulphurization process is low cost but upon complete desulphurization of Sulphur dioxide additional 0.5% carbon dioxide is released into the atmosphere as well as increased coal consumption causes additional Greenhouse gas emission the first flue gas in India was established in December 2015 different type of system consists of Wet or dry depending on the flue gas reaction. A detailed phasing plan, for installation of FGD to be completed till 2024 was prepared by CEA prepared a paper on location specific norms for thermal power plants and suggested a graded action plan for FGD implementation in TPP which is summarized below. The paper was approved by MOP and forwarded to MOEF&CC for consideration in January, 2021

Most FGD systems use limestone or lime, although systems using sodium-based alkaline reagents are also available. Types of FGD Systems FGD systems are characterized as either “wet” or “dry” corresponding to the phase in which the flue gas reactions take place.

Date of Installation	PM	SO2	NOx	Mercury(Hg)
Before December 2003	100mg/Nm^3	600mg/Nm^3< 500MW 200mg/Nm^3>=500MW	600 mg/Nm^3	0.03mg/Nm^3 for >=500MW
January 2004 to December 2016	50mg/Nm^3	600mg/Nm^3 <500MW 200mg/Nm^3>=500MW	300 mg/Nm^3	0.03mg/Nm^3
January 2017 onwards	30mg/Nm^3	100 mg/Nm^3	100 mg/Nm^3	0.03mg/Nm^3

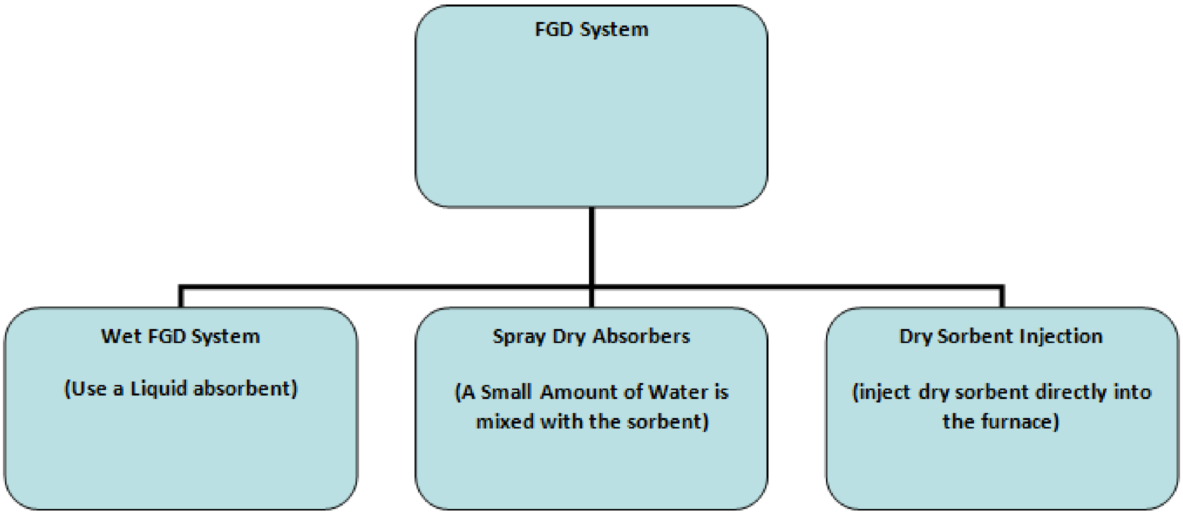
CEA monitors implementation of new norms and policies major challenge which can occurred during application of SGD system of FGD system in thermal power plants are as follows: -

i. Till the end of 2015 no SO2 norms were applicable, thus FGD manufacturing capacity was almost nonexistent in the country.
ii. FGD technology being new to our country, there are at present limited vendors with limited capacity to supply FGD components. Therefore, there is an availability constraint.
iii. A sudden surge of demand has arisen as all thermal generating units, about 470 running units of 180 GW capacity, have to implement FGD system in one go. Proper planning was not there for development of infrastructure to meet the demand surge.

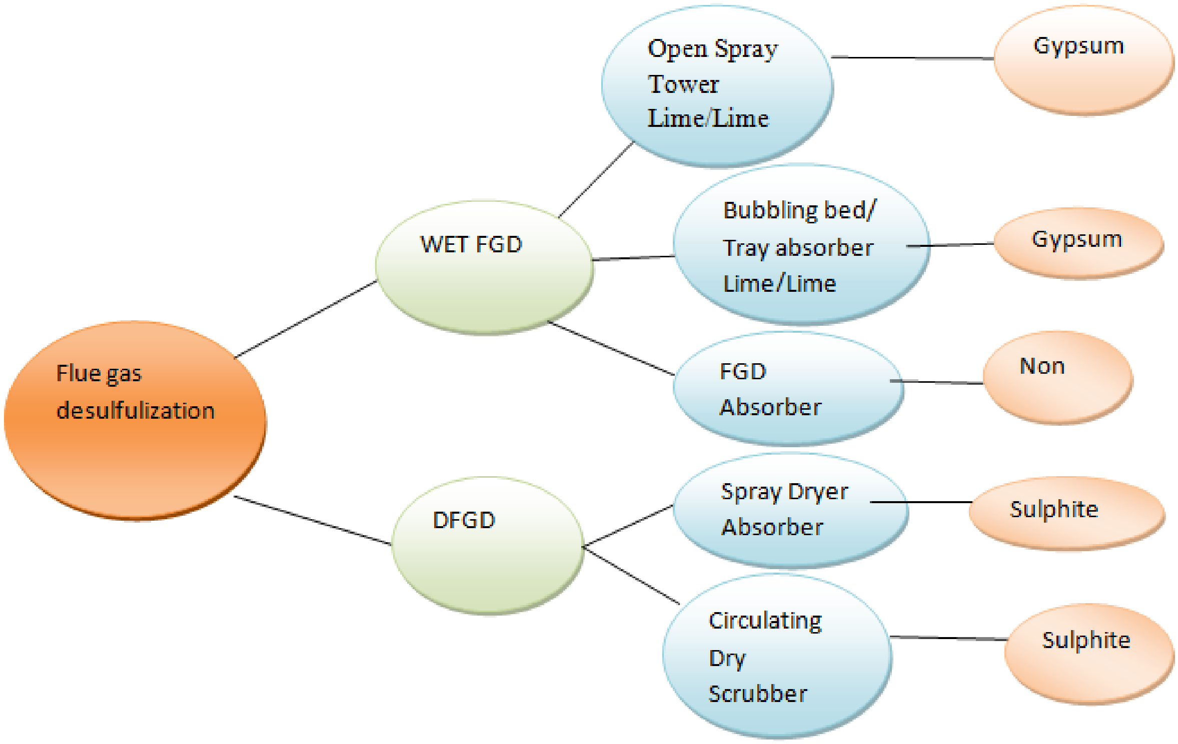
iv. Although India has the manufacturing capability of 70% FGD components, it depends on the imports from other country as manufacturing capacity is insufficient to cater to huge demand in a short period of time. To boost up the production for meeting huge demand as per required specifications, a few years' time is required.
v. Balance 30% of FGD component is not manufactured in India. Thus, import from other countries is the only option and to create a manufacturing capability of these items in India would take few years.
vi. A huge foreign exchange for importing technology, equipment and skilled manpower from other countries shall be required.
vii. Placing order (Rupees one lakh thirty thousand crores) for installation of FGD in all the plants simultaneously without ascertaining its performance in Indian condition may not be a correct decision.
viii. Thus, no time for fine tuning of the specification is possible, considering the implementation time of about 36 months and all the orders being placed in one go, targeting December 2022 deadline.
ix. Due to huge gap in demand and supply of FGD equipment, prices are escalating exorbitantly and it can also lead to market manipulation.
x. Impact of Covid-19 pandemic on planning, placing of order, supply chain of equipment and installation of FGD is severe.
xi. Finally increasing cost of electricity.

II. Types of FGD systems

Four types of FGD systems are currently available:



• Circulating Dry Scrubbers (CDS) are either dry or semi-dry systems. is also as a type of FGD process.

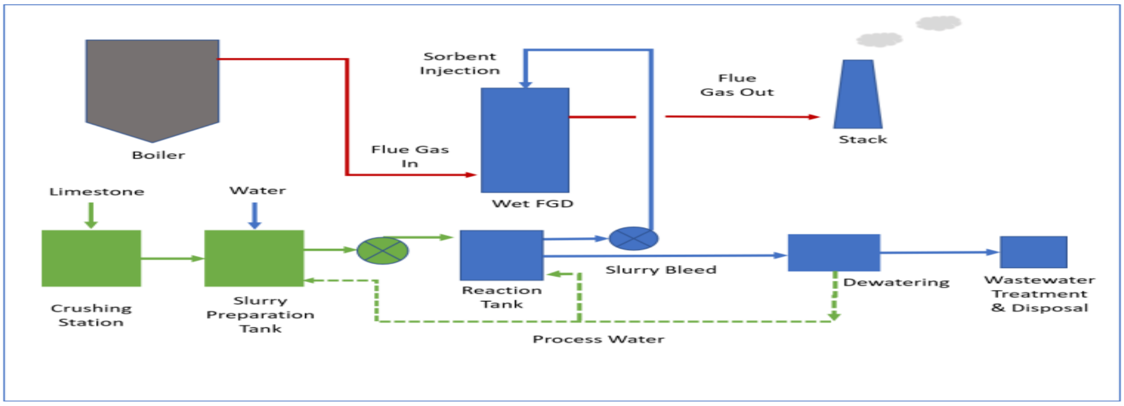


Most common principles for flue gas desulphurization fig.no-1

Wet FGD systems uses solutions to control Sulfur dioxide emissions containing alkali regions since wet every system is considered regenerable. where the system is capable to recycle the sorbent back into the system being salt as the only by product example gypsum regenerable systems, high ever costly what are the most beneficial were disposal of options are limited. The main advantage and Sulphur dioxide. The main advantage is Sulphur dioxide is removed using a line stones which can be collected from the bottom of the tower latest wet FGD systems have very high efficiency up to 98% with Sulphur Dioxide removed completely calcium sulphate and calcium chloride being harmful at a positive in the Pack Tower FGD system **.**However, regenerable systems may be the best option for plants where disposal options are limited or nearby markets for byproducts are available Most wet FGD systems use a limestone slurry sorbent which reacts with the SO_2 and falls to the bottom of the absorber tower where it is collected.

New wet FGD systems can achieve SO_2 removal of 99% and HCl removal of over 95%. Packed tower wet FGD systems may achieve efficiencies over 99% for some pollutant-solvent systems. However, packed tower wet FGD systems are not widely used due to the potential for deposits of calcium sulfate and calcium chloride on the packing mate The wet lime FGD system uses hydrated lime, instead of limestone, in a countercurrent spray tower. The lime is shipped to the plant as quicklime and hydrated to form the lime slurry using a wet ball mill. In the sodium-based wet scrubbing process (e.g., Wellman-Lord process), a regenerable process, SO_2 is absorbed in a sodium sulfite solution in water forming sodium bisulfite which precipitates. Upon heating, the chemical reactions are reversed, and sodium pyrosulfite is converted to a concentrated stream of sulfur dioxide and sodium sulfite. The sulfur dioxide can be used for further reactions (e.g., the production of sulfuric acid), and the sulfite is reintroduced into the process. A dual alkali scrubber uses an indirect lime process for removing acid gas with a sodium based absorbent. The sodium absorbent is regenerated through reaction with lime in a secondary water recycle unit. Calcium sulfite/sulfate is precipitated and discarded. Water and sodium ions are recycled back to the dual alkali scrubber. The system has zero liquid discharge. The precipitated calcium sulfite/sulfate is typically sent to a landfill. One benefit of wet FGD systems is their ability to also reduce mercury emissions from coal combustion by dissolving soluble mercury compounds (e.g., mercuric chloride). The level of mercury reduction depends on the mercury speciation, as flue gas from coal combustion contains varying percentages of three mercury species: particulate-bound, oxidized (Hg2+), and elemental. The Hg2+ species is the only soluble form. Consequently, wet FGD systems are more effective at reducing mercury emissions where the fraction of Hg2+ in the waste gas stream is higher. The fraction of Hg2+ is generally higher in coal containing higher levels of chlorine, such as bituminous coal. Facilities may enhance mercury oxidation by directly injecting bromide or other halogens during combustion, mixing bromide with coal to produce refined coal; or using brominated activated carbon. Dry Flue Gas Desulfurization Systems Dry Lime FGD systems are also called SDA (sometimes called Semi-Dry Absorbers) and are gas absorbers in which a small amount of water is mixed with the sorbent. Lime (CaO) is usually the sorbent used in the spray drying process, but hydrated lime (Ca(OH)2) is also used and can provide greater SO2 removal. Slurry consisting of lime and recycled solids is atomized/sprayed into the absorber. The SO2 in the flue gas is absorbed into the slurry and reacts with the lime and fly ash alkali to form calcium salts. The scrubbed gas then passes through a particulate control downstream of the spray drier where additional reactions and SO2 removal rials.

Wet FGD system using limestone as the sorbent. Most wet FGD systems use a limestone sorbent that is prepared by first crushing the limestone into a fine powder using a ball mill and then mixing the powder with water in the slurry preparation tank. Particle size of the limestone impacts the efficiency of SO2 removal. In the typical wet limestone FGD system, the limestone is ground to an average size of 5 to 20 µm. The sorbent slurry is pumped from the slurry preparation tank to the absorber. The flue gas is ducted to the absorber where the aqueous slurry of sorbent is injected into the flue gas stream through injection nozzles



Flow Diagram for a wet FGD system fig.no-2

Although there are several different designs of absorbers, the most common is a counter flow, vertically oriented spray tower, where the flue gas flows upwards and the sorbent slurry is sprayed downwards. The flue gas inlet temperature is typically between 300 and 700oF. The design and location of the injection nozzles in the spray tower are selected to ensure the sorbent is evenly dispersed in the flue gas stream and that contact between the flue gas and sorbent is optimized. The flue gas becomes saturated with water vapor as a portion of the water in the sorbent slurry is evaporated and the sorbent becomes fine droplets. SO_2 and other acid gases dissolve in the slurry and react with the sorbent to produce salts. The sorbent slurry falls to the bottom of the absorber tower where it is collected and transferred to a waste handling system. Due to the acidic properties of flue gas, corrosion is a significant issue for FGD systems. Methods for mitigating corrosion are discussed in more detail later in this section (see the section titled Potential Operating Issues for Wet FGD Systems Corrosion). The waste from the absorber (called the slurry bleed) is collected, dewatered, and transferred to an onsite or offsite disposal. Alternatively, the calcium sulfate may be recovered and sold to wallboard manufacturers. Where calcium sulfate is recovered and sold to wallboard manufacturers, the solids are typically dewatered with a vacuum belt and the liquid returned to the FGD system as reclaimed water.

The wet FGD system may be a “regenerable” system where the sorbent is recovered from the waste slurry and recycled back to the absorber, or “once-through” system where the waste slurry is sent to a landfill for disposal or sold as byproduct. The majority of wet FGD systems are once-through systems. For systems using limestone, the overall reactions are summarized by the following equations. The chemical equation pertaining to most prevalent

Wet limestone FGD, DSI FGD and Sea water FGD technology are given as under for reference:

Table no-1

1-	**Wet lime FGD technology**
1	$CaCO_3(s) + SO_2(g) \rightarrow CaSO_3(s) + CO_2(g)$
2	$Ca(OH)_2(s) + SO_2(g) \rightarrow CaSO_3(s) + H_2O(l)$
3	$CaSO_3(aq) + 2H_2O(l) + \frac{1}{2}O_2(g) \rightarrow CaSO_4{\cdot}2H_2O(s)$ **(Gypsum)**

Table no -2

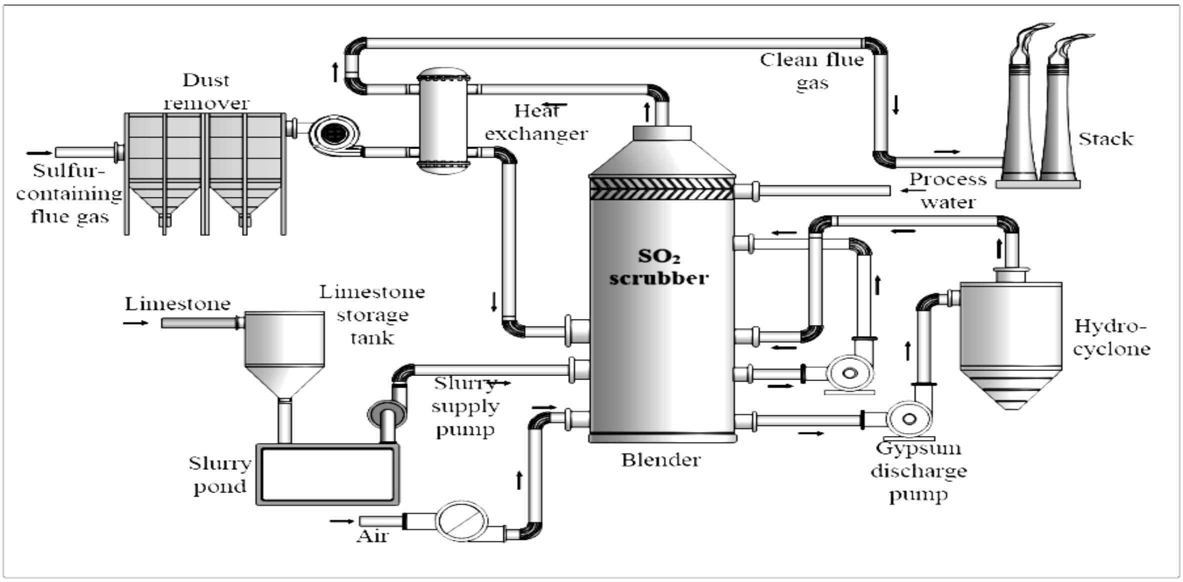
2-	Dry Sorbent Injection (DSI) FGD technology
1	$2NaHCO_3(s) + heat \rightarrow Na_2CO_3(s) + H_2O(g) + CO_2(g)$
2	$Na_2CO_3(s) + SO_2(g) + 1/2(O_2) \rightarrow Na_2SO_4(s) + CO_2(g)$
3	$Na_2CO_3(s) + SO_3(g) \rightarrow Na_2SO_4(s) + CO_2(g)$

Table no- 3

3-	Seawater FGD technology
1	$SO_2(g) + H_2O(l) + ½O2(g) \rightarrow SO_4(s)(aq) + 2H+$
2	$HCO_3- + H+ \rightarrow H_2O(l) + CO_2(g)$

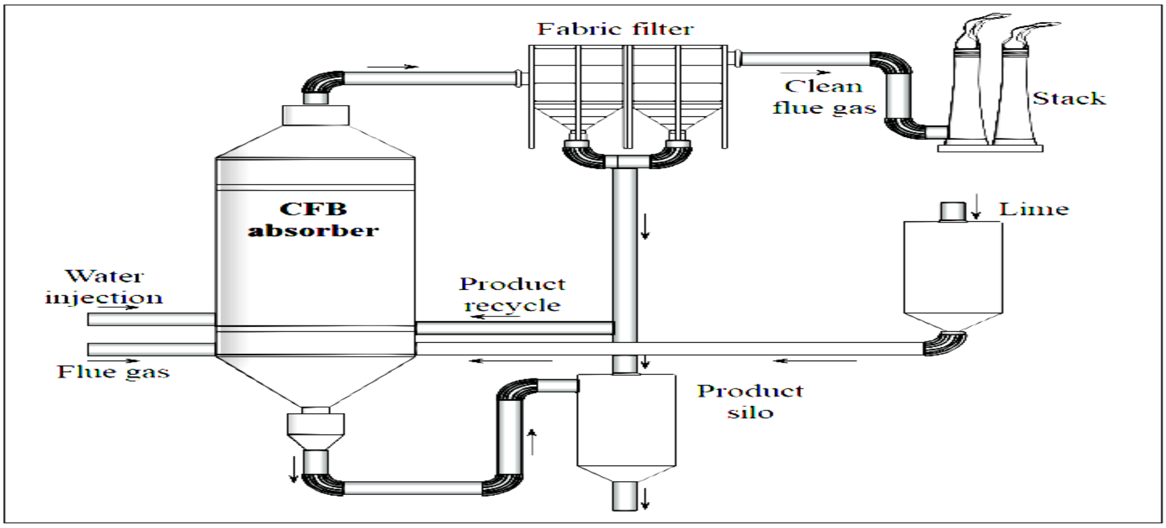
III. WET FGD PROCESSES

Wet FGD technology is the most commonly used commercial scrubbing system in power plants due to its reliability and high SO_2 removal efficiency. It accounts for up to 87% of the Total FGD commissioned capacity of NTPC so far is 1,340 MW. It uses either lime or limestone as a sorbent forming gypsum as a product. The reliability and availability of the sorbent, the formation of a stable sellable product (gypsum) and high SO_2 removal efficiencies have made wet FGD technology a choice for many power utilities. This technology has low operational costs due to the availability of the sorbent; however, it has a significantly high capital cost. Typically, in a wet FGD system, flue gas at high temperature enters the absorber through the flue gas duct situated slightly above the slurry tank. Limestone slurry is prepared by crushing or milling limestone into fine powder of the desired particle size before mixing with a proportionate amount of water in the slurry tank. It is then pumped into the absorber where it is dispersed via spray nozzles. The flue gas comes in contact with dispersed slurry counter-currently, effectively increasing the gas-liquid interaction and subsequently removing SO_2 from flue gas. SO_2 in flue gas reacts with calcium in slurry forming $CaSO_3$ and $CaSO_4$ which drops into the slurry tank. At the same time, air is injected into the slurry tank to enhance oxidation of $CaSO_3$ to $CaSO_4$ which is a stable product. The slurry tank provides sufficient time for complete reaction between the slurry and dissolved SO2, and for dissolution of the fine limestone particles. For effective utilization of the sorbent, the slurry is usually recirculated into the absorber using a circulation pump with the slurry entering the absorber via spray nozzles located at the top of the absorber. Clean flue gas, free of SO_2 leaves the top of the absorber through the outlet duct before entering the chimneys.



A typical wet FGD system is shown in Fig.no-3

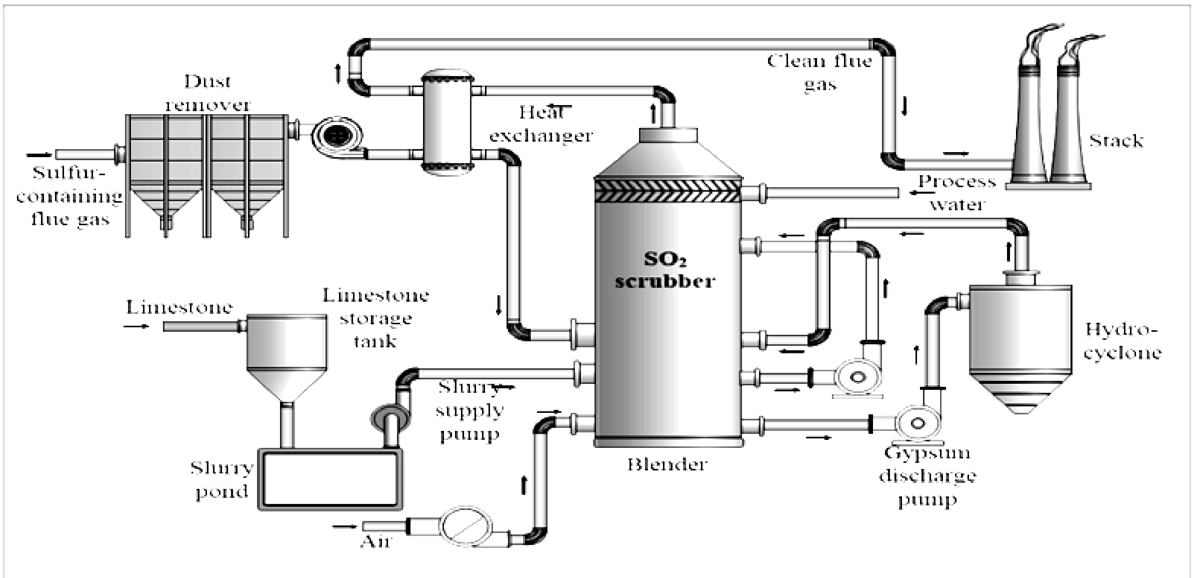
CFB technology is increasingly getting attention because it has lower capital costs similar to spray dry absorption with potentially high SO_2 removal and lower PM emissions. It also produces a dry waste by-product which does not require sludge handling equipment and related operational and maintenance requirements. This process can achieve SO_2 removal efficiency of approximately 98% depending on the conditions of application.



Circulating fluidized bed scrubbing system fig.no-4

IV. SPRAY DRYING ABSORPTION FGD TECHNOLOGY

Spray drying absorption process is based on a concept that has been refined over the years into an effective system. This scrubbing process utilizes either limestone (pre-calcined CaO), lime slurry (hydrated lime) or sodium carbonate prepared in a slurry tank where it is continuously mixed to prevent sedimentation or agglomeration. Lime slurry ($CaOH_2$) is the most commonly used sorbent because it is highly reactive towards



Lime Spray drying FGD process fig.no-5

SO_2 compared to limestone and it is cheaper than sodium carbonate. The slurry is introduced at the top of the reaction chamber through the spray nozzles or atomizers which disperses it into hot flue gas in the chamber cooling it from around 150 °C to as low as 17 °C above the adiabatic water saturation temperature. The spray nozzles atomize the slurry to form fine mist of droplets containing the $CaOH_2$, which reacts with SO_2 contained in flue gas as it flows downwards through the chamber. The gas residence time in the scrubber is 12 to 17 seconds which is sufficient time to allow SO_2 and other gases to react with the sorbent and for water evaporation. The dispersal of the slurry allows maximum interaction between flue gas and the slurry resulting in a dry product mainly consisting of $CaSO_3$ and small amounts of $CaSO_4$. Part of the dry product is collected at the bottom of the reaction chamber with the remaining solids collected in particulate control device (i.e., ESP or fabric filter/baghouse) as flue gas passes through. To improve sorbent utilization, part of the collected dried product is normally recycled back into the slurry vessel. The particulate control device is an integral part of the

FGD system where particles continue to react with SO_2 in the gas and where removal of SO_3 takes place. To ensure effective system performance, critical variables should be closely monitored.

Limestone Scrubbing

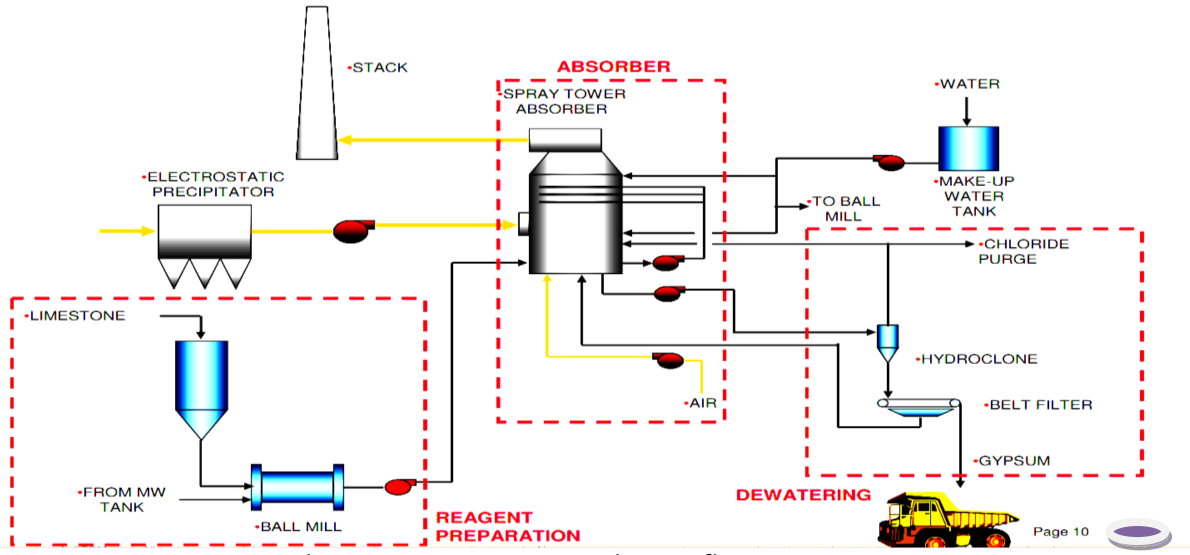
Limestone slurry is sprayed on the incoming flue gas. The sulfur dioxide gets absorbed The limestone and the sulfur dioxide react as follows:

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

$$CaCO_3 + 2HSO_3^{-} + Ca^{+2} \text{ ----> } 2CaSO_3 + CO_2 + H_2O$$

Lime – Spray Drying

- Lime Slurry is sprayed into the chamber
- The sulfur dioxide is absorbed by the slurry
- The liquid-to-gas ratio is maintained such that the spray dries before it reaches the bottom of the chamber
- The dry solids are carried out with the gas, and are collected in fabric filtration unit
- This system needs lower maintenance, lower capital costs, and lower energy usage



Limestone WFGD Process Diagram fig-no-6

FGD material production and beneficial use

%Beneficial use	FGD gypsum	Stabilized FGD	Dry FGD material	Totals
Concrete/use	**0.42**	**0**	**0**	**0.42**
Cement manufacturing	**1.31**	**0.12**	**0**	**1.43**
Structural fills	**1.59**	**0.31**	**0**	**1.90**
Mining application	0.81	0.58	13.38	**14.77**
wallboard	**11.22**	**0**	**0**	**11.22**
Waste stabilization	0.02	0	0.13	**0.15**
agriculture	**1.34**	**0**	**0**	**1.34**
Other uses	**0.04**	**0.15**	**0.05**	**0.24**

Lime-based semi-dry FGD technology

• Control the temperature to meet high performance
• Multi-pollutant control: High efficiency removal of SO2, SO3, PM, HCl, and HF
• Fuel flexibility of up to 2.5% sulphur coal or higher
• Several types –

Spray Dryer Absorber (SDA) Slurry based –
Circulating Dry Scrubber (CDS) Introducing water and recycle solids independently in one or several high velocity sections (venturi's)
- NID™ Premixing of recycle solids and water

V. GENERAL METHODS FOR CONTROL OF SO_2 EMISSIONS

Change to Low Sulfur Fuel
- Natural Gas
- Liquefied Natural Gas
- Low Sulfur Oil
- Low Sulfur Coal

Use Desulfurized Coal and Oil Increase Effective Stack Height
- Build Tall Stacks
- Redistribution of Stack Gas Velocity Profile
- Modification of Plume Buoyancy

Flue Gas Desulfurization
SO_2 scrubbing, or Flue Gas Desulfurization processes can be classified as:
- Throwaway or Regenerative, depending upon whether the recovered sulfur is discarded or recycled.
- Wet or Dry, depending upon whether the scrubber is a liquid or a solid.

Flue Gas Desulfurization Processes
The major flue gas desulfurization (FGD), processes are :
- Limestone Scrubbing
- Lime Scrubbing
- Dual Alkali Processes
- Lime Spray Drying
- Wellman-Lord Process

VI.CONCLUSIONS

Different types of flu gas desulphurization processes and its method to improve the efficiency wet and dry methods has been discussed in this review paper it can be understood by revising the benefits of FGD application that FGDG can be used for the synthesis of complete cement, assault, carbonate products and other construction materials as well as in the agricultural sector what it treatment is among the best application of FGDG Technology. latest FGD processes are very advanced which will allow in the development of environmental safer FGDG in coal power plants around the world which will be good for sustainable development. Dual alkalis scrubber uses an indirect line process for removing acid gas with a sodium base absorbent calcium sulphide and Calcium sulphate is precipitated and discarded when sodium observed is regenerated through reaction with lime in a second water recycle unit the advantage is that the system has no liquid discharge. This FGDG is a great source of gypsum for several applications, but a good portion of this FGDG is currently being disposed of in landfills. This FGDG could be a more important source of gypsum in the future, considering the use of renewable energy would increase while coal combustion would decrease.

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