https://doi.org/10.36375/prepare_u.iei.a258

Overview of Wet Flue Gas Desulphurisation System & Condensate Flow Study in view of new stringent environment regulations for fossil fuel based power plants in India

FIE Pradeep Kumar Sharma and Er. Rahul Singh

Mechanical system engineer
Bharat Heavy Electricals Limited
PPEI Building,HRDI & ESI Complex, Plot no 25, Sector 16A , Noida -201301

pksharma@bhel.in, rahul.singh@bhel.in

Abstract

In this article a general review of recent environment norms given by Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India to control the sulphur dioxide (SO_2) emission generated from fossil-fuel based power plants are discussed. The leading technology for sulphur dioxide reduction i.e. limestone based Wet Flue Gas Desulphurisation (FGD) owing to its high desulphurisation efficiency and long term stability is reviewed. Issues like corrosion problem to the inner side of the stack wall, stack liquid discharge and plume downwash are presented. It can be stated that selection of liner material for chimney is a critical aspect while considering the wet FGD. Effect of condensate on liner material is analyzed to provide insights into selection of liner material for chimney operated under wet FGD. This work also includes the review of Condensate Flow Study (CFS) required to know the effect of acid condensation and presents viable means to minimize the effect of acid condensation by providing suitable condensate collection system.

Keywords

Carryover; Wet stack; Re-entrainment; Plume downwash; Stack liquid discharge (SLD); Corrosion resistant material

INTRODUCTION

The combustion of fossil fuels such as coal and Heavy Fuel Oil (HFO) emits three major air pollutants viz. sulphur dioxide (SO_2), nitrogen oxide (NO_x), and particulates. SO_2 from the flue gas can be reduced at three stages, before combustion, during combustion and after combustion. Sulphur dioxide is a colourless & corrosive gas represents the major source of air pollution [1]. There is catastrophic effect of Sulphur dioxide (SO_2) on the environment and creates ecological imbalance in the planet earth. To mitigate the problem of sulphur emissions, the Flue-Gas Desulfurization (FGD) system is utilized as an effective solution.

In recent times "Ministry of Environment, Forest and Climate Change" (MoEF&CC) has released notifications, making environment norms more stringent for thermal power plants which emits various pollutant through exhaust flue gas into the atmosphere. Our scope of discussion revolves around the effect of SO_2 present in the exhaust flue gas generated from fossil-fuel based thermal power plants. In this article the number of issues involved in wet FGD along with its benefits are discussed. A review of the Condensate Flow Study and its importance are presented in the work along with technical insights for chimney (stack) selection with respect to the current norms released by MoEF&CC, Government of India to curb the level of SO_2 in fossil-fuel based thermal power plants in India [5,6,10].

Common absorbent medium i.e. Limestone or lime in the form of slurry is sprayed over dry flue gas from boiler and forms gypsum as a byproduct in the scrubber also known as absorber. Independent of the classification, most of the available literature [1-3,5] conveys that most dominantly used FGD system i.e. 87 % is based on wet limestone and globally accepted in view of high SO_2 removal efficiency level and lower O&M cost [3].

This paper summarize a general review of the Condensate Flow Study and its methodology while implementing wet limestone based FGD technologies for the thermal power plants in India. The paper call attention to the requirement to study the wet stack in detail and address probable issues associated with FGD in view of the growing FGD market scenario in our country.

BACKGROUND

The FGD systems in the coal based thermal power plants emerged during the industrial era in the early 1970s majorly in the developed countries such as United States (US) and Japan, and swiftly utilized during 1980s in European market [3]. In order to reduce the emissions from power plants, countries, have formulated stringent regulations. Targets for greenhouse gas emission reductions has been set through International agreements such as the Kyoto Protocol. Moreover, in order to mitigate the sulphur oxide emissions, many countries emerged with enforcement of laws and regulations to protect the environmental damage. Clean Air Interstate Rule was launched by the government of US and subsequently after detailed review the Acid Rain Program was revised during 2005 to control the sulphur dioxide

https://doi.org/10.36375/prepare_u.iei.a258

emissions. During 2008 the Large Combustion Plant Directive (LCPD) was reviewed and revised by UK, to set new sulphur dioxide emission limits. During 2005, China modified Atmospheric Pollution Prevention and Control Law (APPCL) and given directives for installation of flue gas desulphurization and dust separation equipment in all thermal power plants that exceed the set SO_2 emission levels [2]. In India, all stack emissions are measured in terms of concentrations only & not total emission per plant [11]. MoEF&CC vide Notification amendment as shown in Table 1, has set new emission norms for thermal power stations [5].

Table 1 'Environmental (Protection) Amendment rules, 07 December, 2015

Pollutant	*'TPPs (units) installed after 01.04. 2004 up to 31.12. 2016'	TPPs (units) to be installed from 01.01.2017
Sulphur Dioxide (SO_2)	600 mg/Nm^3 (< 500MW capacity units) and 200 mg/Nm^3 (≥ 500MW capacity units)	100 mg/Nm^3

**TPP – Thermal power plant*

Installation of flue gas desulphurization plant (FGD) has become essential in all thermal power plants already operating or under construction [5, 10]. These regulations have become more stringent as time progressed, leading to the new market for FGD systems.

Most of the thermal power plant stations in India are in operation without FGD. In view of recent stringent regulations for emission the market for FGD system is expected to grow rapidly. Demand for FGD will be substantial for both a new power plants or retrofitting in the existing power plants. Wet limestone FGD technology is going to dominate FGD market because of its high desulphurisation performance and low operating cost.

Globally reheat system were used in FGD plants to reheat the flue gas in order to make it dry before it exit the stack, by the utilizing Gas to Gas Heater (GGH). However, owing to need of decreased SO_2 emission in power plants and/or high energy consumption cost flue gas heating are not in use these days in the new plants. Thus, eliminated from existing plants in service [4].

The dry stacks without FGD were designed for the higher flue gas velocity than the new wet stacks [19]. When operating these wet stacks often results in velocity higher than the recommended liner velocity, which makes the liquid collection difficult. Thus the majority of the liquid should to be collected in the absorber outlet ductwork [9].

MoEF&CC prescribed SO_2 emission limits to be mandated in all power plants at normal operating conditions. Suitable margins are considered by the purchaser in view of variable coal quality, peak load operation etc. [10]. The proposed guaranteed SO_2 limit for clean flue gas after FGD system is to be mentioned by the purchaser in the bid as per Table 2.

Table 2 'Proposed guaranteed SO_2 limit in the clean flue gas under full load condition.

SO_2 level stipulated by MoEF& CC	'Guaranteed SO_2 level in the treated flue gas under guarantee condition' (100% TMCR* load)
600 mg/Nm^3	500 mg/Nm^3
200 mg/Nm^3	150 mg/Nm^3
100 mg/Nm^3	70 mg/Nm^3

*Turbine maximum continuous rating

For many years wet FGD plants have been in use across the world, however, most of them were operated with dry stacks. However, to mitigate the unacceptable high levels of Stack Liquid Discharge (SLD) some power stations in late 1970s, have envisaged wet ducts and wet stacks [4].

Literature review

A 'wet stack' commonly named as chimney which is enclosed with one or more flue liners subjected to wet (i.e. containing acid & moisture) exhaust flue gases and is located downstream of FGD plant. These FGD plant utilizes absorber wherein generally limestone based slurry is sprayed over the incoming flue gases emitted after combustion of fuel in the boiler. This spraying action reduces the content of sulphur dioxide (SO_2) in the absorber but the flue gas gets saturated with water vapour and reduces the temperature of the flue gas in the range of 46°C to 55°C for bituminous and hard coals and in the range of 57°C to 63°C for lignite and sub-bituminous coals [9].

Wet limestone based FGD have advantages like high desulfurization efficiency, wide adaptation, long-run stability and low operating cost. However, it creates serious corrosion problems inside surface of stack wall [7]. Due to the high moisture content in the flue gas after the absorber, condensation occurs in these stacks during steady-state and start-up conditions [9].

https://doi.org/10.36375/prepare_u.iei.a258

Condensation will take place if the flue gas temperature gets lower than the acid dew point temperature resulting in chimney corrosion. The minor constituent in the flue gas is in the form of sulphur trioxide (SO_3). The SO_3 is due to oxidation of a small part of the more abundant SO_2 and owing to its greater affinity towards moisture, the traces of SO_3 present in the flue gas condenses in the form of fine mist [13].

Flue gas condensation occurs due to self or heterogeneous nucleation phenomena. Self-nucleation is defined as vapour condensation by collision of vapour molecules and the formation of tiny liquid droplets that grows by coagulation. Heterogeneous nucleation occurs at the surface of the dust particles. More complex situations can be arisen due to presence of two different molecular species [13]. Roedel (1979) studied formation of sulphuric acid which takes place due to collision of water & SO_3 molecules under saturated condition (high relative humidity). Theoretically condensation will also take place even when flue gas temperature is above dew point of sulphuric acid in case the relative humidity is higher approximately 80% or above [13].

A study by Dynaflow System Laboratory for Israel Electric Company (IEC) at Rutenberg power station found that the main source of liquid droplets is condensation. Mainly bulk & surface condensation processes are responsible to condense most of the water. Mist eliminator carryover is found to be less than 0.15 kg/s. While, the amount of condensation on liner wall is around 8.1 kg/s. The dew point calculation was carried out to know the condensation rate. To know the rate of condensation dew point of the flue gas at stack inlet was calculated 0.09 kg of water vapour is found to be present per kg of flue gas. Bulk condensation majorly contributes to 7.5 kg/s approximately, and a very small amount of thermal condensation will take place. The latent heat of vapour is absorbed in the gas during bulk condensation. As no heat transfer takes place in this process it is termed as "adiabatic condensation" [16].

Thus, it is absolutely necessary to protect stack corrosion after the FGD installation. In 1980s Electric Power Research Institute (EPRI) has sponsored many programs to understand the wet FGD systems' process and to determine the key factors contributing to liquid entrainment [15]. By the late 1990s, power plants were installed with liquid collectors for wet stack & ductwork to understand the practical basis of Wet stack design guidelines, resulting in publication of second report by EPRI [4].

PROBLEMS ASSOCIATED WITH WET FGD

The condensation in the duct and stack will not take place due to higher outlet temperature of flue gas coming out of Air preheater, which is in the range of 120 ºC to 140 ºC and exceeds the acid dew point (40 ºC to 60 ºC). Whereas, vice-versa will take place if the outlet temperature is lower than acid dew point resulting in chimney corrosion. Further, Internal pressure and irregular geometry of structure are also contributing to corrosion in Chimney [12].

The major factors of the chimney corrosion are:

Production of corrosive medium

Coal contains sulphur which is converted to sulphur dioxide (SO_2) during the burning process. Usually 1 to 5 % of sulphur dioxide is converted to sulphur trioxide (SO_3) which has greater affinity to combine with water vapour in the flue gas to form gaseous sulphuric acid [14]. After the wet FGD, SO_2 and SO_3 conversion in the flue gas is 95% & 20% respectively [12]. Acid dew point is often 100ºC to 150ºC considering H_2O & SO_3 concentration by volume. The outlet temperature of wet FGD are typically 80ºC with GGH and 40ºC to 50ºC without GGH. Thus, the corrosive fluid medium will remain even after installation of GGH, however the situation gets worsen after elimination of GGH. If the chimney surface in contact with flue gas is cooler than the acid dew point, sulphuric acid can condense on it and is the major culprit for corrosion in stack & ductwork [12].

The rate of deposition of acid (H_2SO_4) on the stack liner is more significant for corrosion because of the difference in temperature of acid dew point & liner [8]. The cooling effect of flue gas will take place due to leakage losses, heat conduction process through the surface of ducts & stacks and chimney draft [13].

Chimney internal pressure

An important factor in chimney design is gas temperature and pressure inside the chimney. Negative pressure is required inside the chimney to prevent the venting out of the corrosive and acidic flue gas to the ambient air through the cracks in the wall, various openings, manholes etc. provided in the concrete shell. If maintained with positive pressure inside the chimney it is not possible to prevent venting. Flue gas temperature is low for the FGD plants without GGH, density of gas & positive pressure region will expand [12].

WET STACK SELECTION

Chimney or wet stack in the industries is used for venting hot flue gases or smoke from a boiler to the outside atmosphere [18]. Maximum negative pressure to be obtained in the flue gas during Chimney selection [8]. Sizing of chimney depends on many factors that are difficult to quantify. Chimney is sized such that it can exhaust a given quantity of flue gases at suitable elevation with a velocity that will ensure the ground level concentration of pollutants within the prescribed pollution-regulation standards [19].

https://doi.org/10.36375/prepare_u.iei.a258

Chimney Diameter & Height Selection

The chimney flue internal diameter is selected based on exit flue gas velocity limitation, draft requirement, and environmental regulation consideration which in turn decides the major dimensions of the chimney concrete shell with the consideration of power station capacity and no. of the units. Sizing of chimney /flue depends on flue gas flow & temperature, ambient temperature, barometric pressure, available draft (see (1)), friction losses and exit losses of the chimney, future expansion and maintenance requirement [19].

Theoretical draft = pressure of air – pressure of flue gas (both at the level at which flue gas enter a chimney

$$= 0.029 \text{ B x } H_d \left\{\frac{1}{Va.Ta} - \frac{1}{Vg.Tg}\right\} \text{mm of Hg} \quad (1)$$

Chimney height is assumed and then mid-height elevation for portion H_d is determined, T_a is ambient temperature at this height and B is corresponding barometric pressure. T_g is average flue gas temperature at flue entry.

Different chimney arrangements are commonly being employed in the power stations, single flue chimney & multi-flue chimney. Individual chimney arrangement where each unit of the power station has individual chimney and exit stack velocity is constant with an advantage of ease in maintenance during the annual shutdown or overhauling of the power station. Multi-flue chimney arrangement is common for two or more units of the power station. The flues of each unit is located inside the concrete shell which supports the flue and take care of the wind, seismic and provide structural stability [19].

There was no mandate for SO_2 emission but only stack heights are mandated to disperse far away diluting plume concentration. MoEF&CC directed power plants more than 500 MW to build 275 m stack height, those between 210 to 500 MW, stack height of 220 m height and for less than 210 MW, stack height (H) is calculated based on the SO_2 emission using H=ln (Q)^0.3 where Q is Emission rate of SO_2 (kh/hr) [11].

The required height of the chimney for thermal power stations fitted with FGD depends on flow rate of SO_2 being emitted from the chimney, stipulated by MOEF&CC notification [6], as shown in Table-3.

As the saturated flue gas enters the stack directly, water vapour content in the flue gas condenses creating a liquid film over the outlet duct and stack liner which needs collection and drainage system called as ’wet stack operation’.

Table 3 Stack height in Thermal power plant with wet FGD

Power generation capacity	Stack height
100 MW and above	$H=6.902\ (Qx0.277)^{0.555}$ Or 100 m whichever is more
Less than 100 MW	$H=6.902\ (Qx0.277)^{0.555}$ Or 30 m whichever is more

Q = Emission rate of SO_2 kg/hr
H = Physical stack height in meter

In the event of no proper collection and drainage system being installed in the stack, results in the exit of large liquid droplets from the stack top to the ground resulting in the phenomena called Stack liquid discharge (SLD**)** or spitting or acid mist fall out or rain out. These large acidic droplets on reaching ground shall corrode the metallic structures and equipment in the vicinity of the stack. In view of this, there is a reduction in the allowable velocity in the range of 16.8 to 18.3 m/s for different types of liner materials being used in the wet stack such as C276, Titanium alloy, Fibre reinforced plastic (FRP) and Borosilicate materials resulting in the larger diameter chimneys [9].

Velocities recommendation values as shown in Table 4 are based on the laboratory testing values by EPRI in the vertical wind tunnel under ideal condition of smooth surface without surface discontinuities in the liner considering the slight reduction in the velocities to accommodate practical constraints in the field erection quality.

Table 4 Recommended Wet Stack Design Velocity

Liner Material	(m/s)
Borosilicate Block	18.3
FRP	16.8
Alloy	16.8
Coatings	16.8
Acid Resistant Brick	13.7

The value of recommended design velocity is optimally selected in lower side to accommodate the increase in flow of flue gas due to increase in plant output, plant efficiency or change in the fuel source [9]. Earlier optimum chimney flue sizing is carried out considering the stack exit gas velocity without FGD system in the range of 20 to 25 m/sec. for mild steel flue lined stacks ensuring positive draft requirement [19].

In India Central Electricity Authority (CEA) has suggested a standard technical specification for chimney height for

https://doi.org/10.36375/prepare_u.iei.a258

retrofitted wet FGD in power plants installed as on 31st December, 2016 [10] as shown in Table 5.

Table 5 Suggested height of chimney, in meters in retrofitted wet FGD

Unit size	Stack height	
	'No. of units connected to the chimney'	
	1	2
	'Suggested height of wet chimney' (m)	
< 250 MW	100	125
≥ 250 MW and < 500 MW	125	150
≥ 500 MW	150	150

However, the criteria are different for the new power plants which are going to be equipped with wet FGD after 1st January,2017 as shown in Table 6.

Table 6 Suggested height of chimney, in meters, in new power plants with wet FGD

Unit size	Stack height	
	'No. of units connected to the chimney'	
	1	2
	'Suggested height of wet chimney' (m)	
< 250 MW	100	100
≥ 250 MW and < 500 MW	125	125
≥ 500 MW	150	150

Chimney liner material

The trend to use wet flue gas desulfurization (FGD) has had a great impact on the choice of chimney liners used today. With the resulting 49 – 54 ºC flue gas temperature, the use of induced draft fans rather than buoyancy moves the gas through the ductwork and chimney liner.

Wet lime/limestone based FGD system is a widely accepted FGD techniques in power plants industry worldwide. However, it comes with some serious issues like corrosion to the inside surface of stack due to three most common conditions in a FGD based power plant such as: (1) FGD with bypass fully open. In that case temperature of flue gas is above 120 ºC. Flue gas is completely dry which leave no chance of corrosion, which happens due to presence of water contents in flue gas at lower temperature. (2) Bypass is fully closed (FGD installed without GGH is completely in operation). Flue gas enters into the stack is at around 50 ºC with high humidity which leads to considerable acid condensation on the inside of stack liner (3) FGD in operation with partial opening of bypass which leads to cyclic wet-dry condition. Acid condensation occurs due to lower flue gas temperature in the both conditions (2) & (3) where FGD is used without GGH. This leads to corrosion which would generates a need for good corrosion resistant material [7].

Zhao (2016) in an experiment based analysis tested some corrosion resistant materials in real operation like in coal based thermal power station. As per literature laboratory experiments and prevailing engineering practices, materials selected such as epoxy glass coatings, corrosion resistant steels, fibre reinforced plastics (FRP), polyurea, titanium alloy & Borosilicate (i.e. foam glass blocks) are popularly considered as corrosion resistant materials. In this study, six corrosion resistant materials are classified in three categories, such as coating materials includes Polyurea and vinyl ester glass flake (VEGF), lining materials includes ND steel (Fe, Mn, Cu, and Cr, etc) , titanium alloy & fiberglass reinforced plastics (FRP) and the last category of lightweight insulation material include foam glass blocks. Even a short period of thermal shocks could make a significant impact on VEGF's the corrosion resistance property. FRP has also shown the sign of degradation under high temperature of above 180 ºC even for shorter duration. It was observed that vinyl ester glass flake can withstand upto 120ºC temperature but it is not suitable for exhaust flue gas at high temperature as high as 180ºC. FRP may cause corrosion failure under prolonged exposure in power plant stacks. On the other hand, weight & appearance of ND steel, Borosilicate and Titanium alloy remained almost same because of their high thermal conductivity, better heat resistant and excellent heat dissipation property [7].

Ghanem et al. (1996) demonstrated the heat resistant property of a low alloy steel by measuring the weight of the corrosion film over the material after an exposure for 480 hours within the temperature range of 75°C to 250°C. Cai et al. (2010) reported the significant increment of tensile ductility & thermal stability for the temperature above 150 °C. Better anti corrosive behaviour of foam glass block at higher temperatures due to its low viscosity was noted by Song et. al (2010). Thus it was concluded that low alloy steel, Borosilicate and ND steel can be applied in higher temperature flue gas stacks in thermal power station [7].

During the tests at variable temperature, VEGF failed with significant mass loss on the other hand all other materials viz. polyurea, titanium alloy, ND steel and foam glass blocks did not fail in similar corrosive conditions, However FRP shown significant appearance change so not suitable with this standpoint. Thus, it was concluded that FRP & VEGF are not suitable for cyclic temperature change and high temperature. However, in long run corrosion failure may occur in FRP material. The three material viz. titanium alloy, Borosilicate and ND steel are able to withstand for variable temperature condition following wet stack operation in power station [7].

Bloyce et al. (1998) and Mabilleau et al. (2006) observed cracks with craters appeared on ND steel sample subjected to acid condition in cyclic wet-dry operation. However, nearly zero rate of corrosion for Titanium alloy was observed in samples during static & dynamic conditions, because of formation of oxide film on the material surface which prevented further corrosion. Unlike other materials, no significant change in colour or corrosion signs were observed which shows its good corrosion resistant property in acidic and cyclic conditions. The formation of TiO_2 layer on the metal surface of Titanium alloy makes it an excellent corrosion resistant material, thus can be used as material for stacks despite being expensive [7].

Contrary to titanium's excellent performance under accelerated acid condition and variable & static high temperature condition its corrosion resistance was poor in sulphuric acid at high temperature. However, Borosilicate has not shown any significant impact due to exposure in acidic environment or cyclic wet & dry conditions. The formation of protective SiO_2 & B_2O_3 over the surface of borosilicate material makes it better resistant to corrosive environment during experiments explained by Soo Park et al. (1999) [7].

The comparative performance analysis of above mentioned six materials in respect of corrosion prevention in stacks due to acidic environment were evaluated for wet stacks in coal based thermal power station. To prevent corrosion Titanium alloy and Borosilicate glass blocks could be applied in the stack for the best performance to prevent chimney corrosion [7].

In India, Alloy steel lining materials are found to be expensive for power generation chimney applications. However, the same is being used in various power plants such as 250 MW Rourkela project at Jharkhand and 2X800 MW NTPC Karimnagar project at Telangana in view of the long material life. However, FRP is being used as liner material in under construction 2X660 MW Maitree project at Bangladesh where initially no provision of FGD bypass was envisaged, so the flue gas inlet temperature is less hence FRP is suitable. Borosilicate block lining systems are also being installed in the short height chimney for power station, despite having less life than alloy but comparatively cheaper option, such as in 2X490 MW NTPC Dadri project at Uttar Pradesh on a mild steel liner.

Condensate Flow Study

As per the two reports of EPRI as mentioned in the literature review, a detailed fluid dynamic analysis is required to design & install effective wet stack in wet FGD outlet ducting/stack system, liquid collection and drainage system. The design of wet stack by the use of flow modelling is carried out in the laboratory. There are five different phases to carry out the complete wet stack study [4].

1. Phase I - Initial review of the proposed system design
2. Phase II - Condensation calculations
3. Phase III - Design and development of the liquid collection system
4. Phase IV - Study of the plume downwash
5. Phase V - Field installation and operational inspections

The design of wet stack system can be finalized by using the results of above first four phases. and the same are being utilized to prepare technical bids & specification The liquid collection system is reviewed by field engineer during installation & inspection which is defined in fifth phase. The preliminary design review based on experience is carried out to review proposed geometry of absorber outlet duct and stack breach by analysing the change in system geometry such as breach aspect ratio and expansion joint locations. Comparison of gas velocities, breaching height to width ratio & size of liner with the existing plants that have effective wet stacks can be done. The liquid collection and preliminary evaluation of the condensation rate in the duct & stack is estimated [4,9].

Water droplet in wet stack system originates from two source, first from the mist eliminator at FGD absorber, and second & major sources of liquid droplet is flue gas condensation at FGD outlet ducting and stack liner wall. There are two kinds of condensation which are encountered in the wet stack and FGD outlet ductwork. Firstly, thermal condensation takes place at the FGD outlet ducting and wet stack liner due to difference in the flue gas and ambient air temperature. The transfer of heat energy occurs from the flue gas through the liner, insulation, air in annular space and the outer concrete wall to the ambient air. The amount of thermal condensation changes with outside air temperature, wind speed & direction, flue gas flow, thermal conductivity and stack geometry. Other kind of condensation is adiabatic condensation which takes place in the majority of the flue gas flow as a result of decrease in flue gas pressure along the stack height. However, it does not add up to the SLD as very small sized liquid droplet evaporates before it reaches the ground [15].

Physical model in the scale range of 1:8 to 1:16 is built from outlet of mist eliminator of absorber up to approximately four stack liner diameter above the top elevation of breaching duct. Physical model is fabricated from transparent thermoplastic i.e. acrylic or plexiglass which cater the requirement of the accurate visualization of flue gas and liquid droplet flow patterns. This allow better visual droplet trajectories, liquid film movements and flow pattern. Behaviour of liquid droplet in the flue gas flow and motion of liquid film on liner wall is evaluated by the physical model being fabricated in the laboratory [9]. On the basis of the flow pattern observed through physical model, Liquid Collection Systems (LCS) viz. gutters, ring collectors etc. are placed, fabricated and put in place. Commercial available materials such as FRP or Haste alloy (C276) are used to fabricate LCS.

Plume downwash is a phenomena of flue gas entrainment between the stack shell & liner in downwind side, normally occurs at stack top due to lower flue gas velocity and high crosswind velocity resulting in lower pressure region. The vertical component of flue acidic flue gas is deflected towards wind direction resulting of shell corrosion. If the system is designed considering the high flue gas velocity, it resulted in stack liquid discharge and if the system is designed at low flue gas velocity, it will result in plume downwash mostly at higher wind speed. It normally occurs due to lower flue gas velocity during part load operation in power plant & high wind episodes. Plume downwash is more pronounced in multiple liners because of large size of shell enclosing multiple liners. During plume downwash condition, saturated flue gas enters into the extension, stack hood, and stack shell resulting in acidic corrosion [4].

To avoid plume downwash, momentum ratio should be above two for single flue chimney. Momentum ratio is calculated by knowing the ratio of vertical component of plume momentum to the horizontal component of wind momentum. The same can be achieved by increasing liner height above the shell or reduction of flue liner diameter or by installing a nozzle like geometry (known as 'Choke') at the top of stack liner [4].

Computational fluid dynamic (CFD) modelling is ideally suited for plume downwash study in different weather & plant operating condition. A study is conducted by constructing a 3-D model of the stack for the portion covering one-third from the stack top [9]. Small to medium sized droplet gets drifted at the liner surface while large droplet gets deformed due to drag velocity of the gas and no longer have spherical shape [16]. Correlation explained by Ishii et al. (1979) predicted the distortion limit of 1.7mm droplet diameter at the stack, so, droplets less than 1.7 mm flow in spherical shape while the larger droplets are deformed or distorted. Drift velocity of distorted or deformed droplet is asymptotic & does not depend on droplet diameter. The droplet drift is simulated in the CFD model [16,17]. However, CFD model is incapable of accurately simulating the development of liquid film and its motion in the liner wall and ductwork are difficult to simulate accurately by the use of CFD models but it is useful to predict movement of the droplets and flow pattern [4,9].

The last phase includes the review and support of field construction and inspection. The correct installation of LCS is checked for proper installation and the changes / deviations at the site w.r.t the installation drawings are evaluated and rectified. Site inspection is highly recommended when 80-90% installation is complete to identify errors, on the spot modifications & corrective actions on site. Inspection of LCS need to be carried out during operation on routine basis to ensure satisfactory long term operation of LCS without plugging, deposition and drainage problems [4, 9].

The sole purpose of wet stack study is to ensure maximum collection of moisture and acidic content in condensate formed inside the stack and ductwork through the help of liquid collection & drainage system and to prevent the stack liquid discharge (SLD) with least possible re-entrainment by the use of liquid collectors and the drain collected is connected to the absorber [4,9,15].

CONCLUSION

Alloys are expensive & can be operated at 16.8 m/s velocity. Acid resistance bricks are in use but has velocity limitation of 13.7 m/s as they have rough surfaces. Borosilicate lining can be effectively operated above 18.3 m/s velocity which can optimize the chimney diameter and found to be cheaper option as compared to the alloys. In India, most of the power generating industries have also followed for the non-reheat option in view of associated cheaper operation and maintenance cost, however there are some power plants which are still going for wet FGD with GGH in operation.

New FGD plant including a wet stack are designed to take care of chimney corrosion to prevent the stack liquid discharge, minimize potential for droplet re-entrainement & retrofit. Considering the outage time required for the lining modifications in the existing chimney, it is economical to build new low height stack & use existing chimney for emergency FGD bypass condition. One can opt for GGH as per the assessment on the basis of results of techno-economic analysis. Gas to gas heater (GGH) usage in flue gas desulphurization plant requires additional space, more pressure drop leading to higher energy consumption with the leakage issues which makes it an unviable solution.

Technical specification for the design of effective wet stack system need to be prepared for complete FGD absorber outlet ducting to the stack top. Wet stack study is conducted for each unit if the layout of FGD ductwork up to the stack top is different. In order to control stack liquid discharge and corrosion problem, a proven liquid collection system is required to be designed for efficient chimney operation. Liquid collection system for the stack and ductwork is developed by considering different phases of the wet stack study as discussed in previous section.

https://doi.org/10.36375/prepare_u.iei.a258

This arrangement requires longer flue gas duct work from ID fan outlet resulting in the higher pressure drop and thereby increase in ID fan rating and thus, additional power consumption. Lastly, in India, in view of new stringent environmental norms it is imperative that a thorough study for implementation of wet FGD is required, to enable utility engineer for arriving at right techno-economical decision suited well in the project(s).

REFERENCES

[1] Poullikkas, A.: 'Review of design, operating, and financial considerations in flue gas desulfurization systems', Energy Technology & Policy, 2015, 2, (1), 92-103

[2] 'Flue-gas desulfurization systems market analysis to 2020, 2013 update', https://www.marketresearch.com/product/sample-7906426.pdf, accessed 14 September 2018

[3] Cordoba, P.: 'Status of Flue Gas Desulphurisation (FGD) systems from coal-fired power plants: Overview of the physic-chemical control processes of wet limestone FGDs', FUEL 144., 2015, pp. 274–286

[4] Anderson, D.K., Maroti, L.A., 'Solving stack drain problem', in Brown: (Powermag, March 2006, Vol.150)

[5] 'Ministry of Environment, Forest & Climate change, Government of India', Notification (7 December 2015), http://www.moef.gov.in/sites/default/files/Thermal%20plant%20 gazette%20scan.pdf, accessed 14 September 2018

[6] 'Ministry of Environment, Forest & Climate change, government of India', Notification (29 June 2018), http://www.moef.nic.in/sites/default/files/Final-Amd-TPPs-Notifi.pdf, accessed 14 September 2018,

[7] Zhao, S., et al, "Prevention of stack corrosion under wet flue gas desulfurization conditions in a coal fired power plant: performance analysis and comparative study", Environmental system research, 2016, 5, (21)

[8] Krakowiak, S., Darowicki, K.:'Degradation of protective coatings in steel chimney of flue gas desulphurization systems', Progress in Organic Coatings, 2018, 117, pp 141-145

[9] Anderson, D., Maroti, L.: 'Revised wet stack design guide' EPRI Technical report 1026742, 2012

[10] CEA., 'Standard Technical Specification for Retrofit of Wet Limestone Based FGD System in a Typical 2 x 500 MW Coal Based Thermal Power Plant', December 2017

[11] Guttikunda, S., Jawahar, P., Goenka, D.: 'Regulating air pollution from coal-fired power plants in india', Economic & political weekly, 2015, 1

[12] Pei, Z., Kun, W.: 'Analysis on Chimney inner wall anit-corrosion in GGH eliminated wet desulphurisation system'. 11th international conference on electrostatic precipitation, Hangzhou, 2008, pp. 597-601

[13] Jarman, R.T., Turville, C.M.D.: 'Condensation of flue gas vapour in ducts and chimneys', Atmospheric environment, 1983, 17, (9), pp 1873-1844

[14] Ganapathy, V.: 'Steam plant calculation manual' (Marcel dekker, Inc, 1994, 2nd edn. 1994)

[15] Maroti, L.A: 'Entrainment in Wet stacks' Final report EPRI-CS-2520, August 1982

[16] Minzer, U., Moses, E.J., Toren, M., et al.: 'Two-Phase Phenomena In Wet Flue Gas Desulfurization Process',In Ben-Haim, Y. (Ed.). Conference Proceedings, Israel, May 1998, pp. 705.

[17] Ishii, M., Zuber, N.: 'Drag coefficient and relative velocity in bubbly, droplet or particulate flows', AICHE, 1979, 25, (5), pp 843

[18] Chandra, k., Kain, V,. Dey, G.K.: 'Accelerated corrosion of a boiler chimney: causes and preventive steps', ASME international, 2011, 11, pp 466-472

[19] Manohar, S.N.: 'Tall chimneys design and construction', (Tata McGraw-hill, 1985)