A Review of the Scrubber as a Tool for the Control of flue Gas Emissions in a Combustion System

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Abstract—This paper focuses on the description, function and working principles of the wet gas scrubber required to control air pollution emissions from a combustion system of a boiler. Important points to note in the selection and operation of the scrubber as well as the different types of scrubbers commonly deployed in the industries to cut down on emissions were addressed. A comprehensive review of the removal mechanisms and schemes of the scrubber were reported for various research on the subject. The packed tower scrubber, however, was recommended because of varying advantages and ease of operations.

Index Terms—Scrubber, Gas Emission, Combustion, Environmental Pollution.

I. INTRODUCTION

Reference [1] described scrubbers as devices utilised to remove gaseous constituents that has debilitating effects on the environment. These gases include NOx, SO2, etc basically from flue gas stream of combustion systems. The removal of these harmful gases must be removed in order to safeguard the receptors from the grave impacts of these gases to the health of human and animals. Depending on the absorber liquid used, high quantity of acids or bases are utilized with the formation of salts as end products. Most processes now use these products as commercially viable components to increase revenue needed to reduce the overall capital outlay of the air pollution control strategy. Most plants utilise the scrubber in addition to other air pollution schemes to achieve successful cleaning of the flue gas. Reference [2] recorded the combination of the scrubber with other control facilities to achieve better removal rates. Apart from the removal of hazardous gaseous components in the waste gas, scrubbers can also be utilised in the removal of fine particulate matter of boiler ducts [2]. In order for the scrubber to effectively remove this emission, a liquid entertainment, called scrubber liquid or solvent or absorber liquid, is used to contact the waste gases. The partial pressure differences or concentration gradient between the gas phase and the liquid phase acts as the driving force for mass transfer between phases and thereafter transfer of the gases into the liquid stream [3].

Reference [4] explained that a typical scrubber is structured in such a way that the dirty gases collected from the exhaust stream are channeled into the scrubber and the gases are entrained in the liquid. He retorted that scrubbers particularly wet scrubbers are very effective in the removal of both solid particulate matter and the gaseous pollutants. Depending on the design, specific factors govern the application and operation of the scrubber; reference [4] listed the following vital variables to look out for in deciding the optimal scrubber for use:

i. Characteristics of the particulate matter considered to be removed
ii. The size categorization of the particulate matter
iii. Concentration of the emission in the flue gas
iv. Characteristics of the scrubber liquid, for example, whether it is flammable or combustible
v. Desired removal efficiency
vi. Important actual process parameters of the flue gas as this will determine the scrubber sizing
vii. Required space for the scrubber

The potency and quality of separation and cleaning of flue gases with regards to air pollution control is depended on the solvent, therefore, the characteristics, operation, optimum condition must be evaluated before a choice is made. Other considerations are economic, handling and ultimately sustainability for operation. While the cost of installation of the absorber is fixed, operational expenses stems greatly from the cost of utilisation of the solvents.

II. TYPES OF SCRUBBERS

There are two types of scrubbers, the dry and the wet scrubbers. Reference [5] have described the principle of gases from flue gases as using a combination of dry reagents sprayed into the scrubber through the exhaust stream. This powdery substance reacts with the emission and neutralizes these extremely hazardous emissions. The product of this reaction is then collected at the base of the scrubber. The process involves three important stages: flue gas cooling, chemical injection, and proper filtering at the outlet of the exhaust stack in order not to carry over the chemicals into the atmosphere. Despite the gains of the dry scrubbers, it poses seriously land pollution because of the concern for the residual waste precipitate. This paper will focus mainly on the use of the wet scrubber for acid gases removal from waste streams.

Reference [6] classified wet scrubbers into seawater scrubbers, freshwater scrubbers as well as hybrid scrubbers. This classification was done with the mode and source of the solvent into the scrubber. Although this classification was done in marine operations, it still holds true for traditional industrial boilers. They described the seawater scrubbers as that which utilize untreated water from the sea with the use of the alkaline content of the sea water to neutralize acidic gases from the exhaust stream of the combustion chamber system. In this type of scrubber, no other external additions of the solvent are required.

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However, for fresh water scrubber, a dilute alkaline base predominantly caustic soda is injected into the water and used as the solvent. The type and source of water used is of no consequences but must be freshwater. The hybrid system is basically a combination of the sea water and freshwater scrubber operation techniques.

Another form of classification is with respect to the physical orientation of the scrubber. There are basically two types: the horizontal and vertical scrubbers. The horizontal type as the name implies requires the inlet and outlet gas streams to be in the same plane in contrast to the vertical type, which is most popular, requires that the inlet flue gas enters the scrubbers from bottom while the solvent enters from the top. This ensures better gas-liquid contact in the scrubber.

Depending also on the position of the inlet of the flue gas stream and the outlet cleaned gas to the atmosphere. Countercurrent and concurrent scrubber classification is based on this principle. For the countercurrent scrubbers, the solvent injection is opposed to the flue gas inlet flow while for the concurrent type the opposite ensures.

Reference [7] stated that apart from the emission control function of the wet scrubbers, there is an added function of heat recovery and subsequent utilization in the process stream. The study also highlighted major advantages of using the scrubbers as follows:

i. Reduced space challenge
ii. Almost total elimination of PM
iii. Flexibility to handle any gases temperature stream
iv. Ability to remove multiple component emissions.
v. However, some drawbacks include: Corrosion concerns
vi. Significant energy consumption as a result of heavy-duty coolers and fans installed to draw out the cleaned gases to avoid pressure drops in the scrubber.
vii. Disposal issues as well as recovery by the solvent.

Another classification is made by operation. This classifies scrubbers into distinct three types. These includes spray tower, venturi and packed bed scrubbers. The operations will be highlighted.

A. Spray Tower Scrubbers

Bhargava (2016) described the spray tower scrubber as low energy type scrubber with wide range of application which is able to remove coarse particulate matter as well as other gaseous pollutants from the exhaust stream of combustion systems. In this type of scrubber, the rich gas from the flue gas of the combustion chamber is channeled into a chamber where there is adequate contact between the solvent and the introduced flue gas. The solvent is introduced via spray nozzles mostly at the top of the chamber forming droplet jets in the process and developing high velocity flowing down through baffles and plates with the main objective being the maximization of the gas-liquid contact. Open holes are set on the plates in the chamber which aids the solvent to flow downward and correspondingly allows the gases introduced at the base of the chamber to accelerate upwards also. In order to avoid a carry-over of PM from the tower, a demister is placed at the gas outlet to limit any carry-over. As the solvent flows down by gravity and the gases flow up by the energy of the exhaust gases because of concentration gradient, the pollutants are removed into the liquid stream and the slurry desorbed and re-circulated. The choice of the solvent is reached after thorough research and simulation studies. Another variant of this is the cyclonic spray chamber, reference [4] posits that the only difference is the fact that the gas stream enters the tower with a cyclonic motion. This motion aids effective contact between the gas and the solvent stream. Important variables required to design and operate a spray tower scrubber is the flow rate of the gas, droplets formation rate, the outline and shape of the tower, residence time for contact as well as diffusion considerations [4].

B. Venturi Scrubber

Reference [8] described the Venturi scrubber as a converging-diverging air pollution control device. There are three parts of this device, the converging section, the throat, and the diverging section. The converging section constructs the cross-sectional area of the flow path causing the flue gas to increase its velocity with an attendant heavy turbulence. This agitation of the gas stream is expected to provide adequate mixing of the gas stream as well as the solvent which is injected at the throat section. The solvent injection is carried out on any point in the throat section, the throat is a uniform cross-sectional area section where the contact takes place. The diverging section occasions a drop in velocity thereby effecting separation of the pollutants from the cleaned gas stream.

Reference [8] posits that the Venturi scrubber in comparison to the tower scrubber is more expensive with higher PM collection advantages. Because of the higher gas velocities as well as turbulence in the throat section of the Venturi scrubber, the cleaning performance of 70% to 99% is achieved for particle sized greater than 1µm and higher than 50% particles with a submicron size [8]. One major drawback for the Venturi scrubber is the relatively higher operating cost due to the higher energy demand by increasing its efficiency via pressure drop elevated operation. Another drawback using the tray tower scrubber tray towers is that the tray tower may not deal with particles with submicron size and large PM could block the perforated holes in the plates causing lower scrubber performance [8].

C. Packed Tower Scrubber

Reference [8] described packed towers as columns with packing materials placed in the column to enhance adequate contact between the gas and liquid. This packing materials increase the surface area of contact in the column which helps in the removal of the pollutants. Since the operating cost of streaming any plant is very vital key consideration, the packed columns require less use of the liquid in comparison with other scrubber types. The major drawback for this type of scrubber includes: higher maintenance cost, clogging and fouling issues, pressure drop concerns, installation cost is considerably higher as well as water pollution control issues [9].

Designs and operations of the packed tower scrubber requires important parameters, these includes: pollutant solubility, liquid-to-gas ratio, pollutant removal efficiency,
pressure drop, size and type of packing material, construction details of the scrubber as well as corrosion characteristics of material of construction [10], [11], [12], [13] concluded in their research that two important factors are necessary for optimal performance of the packed tower with regards to the choice of packing material. These considerations include adequate surface area as well as the materials void fraction. The report also recorded that structured packing orientation of the packing material as opposed to random packing ensures lower re-boiler duty which is good because that ensures minimal solvent injection which further reduces operating cost.

A packed tower is placed vertically with the inlet gas flow channel located at the base of the column, a slop outlet for residual slurry liquid. The top contains a channel for the cleaned gas while the internals are equipped with solvent injection nozzles, packing materials, packing supports and a gas distributor plate.

Reference [14] supports the use of the wet gas scrubber because it has a relatively higher removal efficiency of 90 – 95% as well as having considerable cheaper operational cost. It also has better removal of both gases and particulate matter with reduced hazards that could lead to fire or accidents.

One very common scrubber application in the industry is the removal of sulphur from combustion gases. This process is known as Flue Gas Desulphurization (FGD). Mostly utilized in the treating of flue gases in industrial boilers [15]. The removal of sulphur from combustion systems using a scrubber yields elemental sulphur with a viable commercial value with an attendant revenue earner [15].

Reference [16] stipulate that the most important requirements for a packing column are to achieve uniform distribution of both phases in contact (gases and liquid phase) create adequate surface area for contact and providing a reduced resistance to the movement of the gas in the scrubber.

Reference [17] listed vital characteristics considered for choice of a scrubber, these include:

i. Flow volume
ii. Gas and liquid properties
iii. Possible emissions from flue gas
iv. Pressure drop and energy requirements
v. Corrosion issues

III. REMOVAL SCHEMES OF THE SCRUBBER

Reference [18] concluded in their research that multiple pollutants cleaning in the thermal plants is gradually becoming common for instance the removal of both SO2 and CO2 from waste streams. Hugely popular processes of FGD techniques must also embrace processes to deal with other emission stream like NOx and other hydrocarbon gases. This will save cost and improve air quality. In order to develop better air pollution control schemes, basic simulation of parameters and variations to gas and liquid characteristics will offer considerable optimal conditions to run a gas cleansing system.

Reference [19] reported an outstanding removal efficiency 90% for the elimination of mercury from waste gas of a major thermal process plant that energizes a third of Slovenia with power. This is achieved using the wet scrubber. Apart from the regular SOx, NOx and PM emission, the wet scrubber has the capacity to remove metallic emissions with the right choice of solvent and operating condition. The injection of calcium bromide, a chemical additive has been highlighted to have a profound removal of mercury from waste gases [19].

To understand and find a justification for the inculcation of air pollution controls to power plants most especially scrubber retrofits, a study by [20] paints a clear picture. The study made comparative studies of the overall difference in PM2.5 impact in Pittsburg during peak power plant operation and a period when the plant was shut-down. The report demonstrated a 0.94µg/m³ decrease during shut-down compared to during plant run. Incremental additions of various exhaust releases into the atmosphere will correspondingly lead to poor air quality therefore the elimination of emission from source by the use of scrubbers is recommended.

It is worthy to note that apart from the emission removal capability of the scrubber, exhaust waste heat reduction is another equally important consideration for opting for wet scrubbers. An abundant heat energy in the form of waste heat is discharged into the water ways by power plant exhaust systems. This practice will affect the water ecosystem temperature balance and lead to a corresponding increase in global atmospheric temperature with an attendant global warming index. The scrubber systems operate best at reduced temperatures; super coolers are utilized to reduce the temperature of the flue gas. This recovered heat energy is used in other process formation [21]. The overall recovery of heat from exhaust streams will correspondingly reduce global warming.

For running plants without retrofitted scrubbers, the choice of development might be challenging with cost considerations, however, reference [22] poses a potent question of finding a balance between the advantage of electricity generation and the attendant environmental degradation that comes with it. Since the quantification of illness generated from pollution scheme is a complex subject, the extreme impact to human, animal and materials is overwhelming. Therefore, since we cannot do without the gains of power plants, retrofitting wet scrubbers to reduce emission to minimal levels should be encouraged.

Reference [23] outlined and discussed varying CO2 capture techniques and concluded that the use of solvents in an absorption process offers the best option. This process can be achieved considerably in a scrubber system. CAPEX and OPEX is however on the high side with regards to this technique [24]. Therefore, further research is needed to limit the cost of running carbon capture retrofitted plants.

IV. CONCLUSION

Environmental pollution especially air pollution is aided in most industrialized cities with power plant facilities. This plant utilizes fossil fuels as combustion fuels to generate the energy needed for electricity generation. An attendant menace of this system is the production of combustion product gases like SO2, NOx, and PM predominantly and CO during off specification operations. A lot of air pollution
control devices have been proposed with the scrubber commonly used in the industry with documented gains. Our future research will seek to design and develop a retrofitted flue gas cleansing unity with capacity to cut down SO2, NOx and CO emissions from the exhaust stream for a boiler combustion stack.

REFERENCES


