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Experimental Investigation on NOx Emission Control Using Pilot Plant Control System

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***Abstract*—*This paper is mainly focuses on design and experimental investigation on NOx removal process and to optimize the packed column parameters and the absorbent used to obtain high removal efficiency. The experiment is held with different absorbents such as water, HNO_3 andH_2O_2. Hence the result obtained is about the high removal efficiency above 98% by adding 0.1M of Hydrogen Peroxide. From the analysis the packing material used is optimized as Intolax ceramic saddles with 10mm diameter, liquid (absorbent) flow rate of 5 lph, gas flow rate of 1m3/hr and the packing height of 0.70m are optimized for the lab scale analysis of pilot plant based on the performance of packed column for improving NOx absorption rate.*

***Keywords*—** *NOx absorption, NOx removal efficiency, packed column, Flow rate, Hydrogen Peroxide*.

I. INTRODUCTION

Nowadays the most significant problem the world facing is atmospheric pollution. The most harmful and toxic gases next to SO_2 is NO_x (Nitrogen Oxides). Nitrogen oxides belong to the most troublesome gaseous components polluting atmospheric air. Among several nitrogen oxides (N_2O, NO, N_2O_3, NO_2, N_2O_4, N_2O_5), the most common in atmospheric air are nitrogen oxide (NO) and nitrogen dioxide (NO_2)in which NO (nitric oxide) account above 90% of NO_x. In chemical engineering and combustion techniques, their total content (NO + NO_2 converted to NO_2) is patent with a common symbol NO_x (J Kuropka., 2011). The main source which contributes the emission of NO_x are combustion industries, automobile engines, fossil fuel power plants and also by the electrical discharge of lightening in thunderstorms.

The NO_x is considered to be the main ingredient of photochemical smog and also for the acid depositions. Other sources of emissions of NO_x into atmospheric air are also includes industrial technologies which emit nitrogen oxides as a result of certain chemical reactions. This includes mostly chemical plants producing nitric acid and fertilizers, sulfuric acid by the nitric method, and nitric acid derivatives in organic syntheses. They also contributes other environmental issues such as the NO_x in atmosphere reacts with air and converted into nitric acid, which leads to acid rain(Y Jia et al., 2013; D Thomas et al., 2003). However it is the important nutrition for plant life, NO and NO_2 present in atmosphere leads to ozone layer depletion and also they are harmful to human life.

Generally the NO_x removal can be divided into combustion control and post-combustion treatment among this combustion control aims at reducing the NO_x formation during the combustion of fossil fuel and the post-combustion methods includes number of abatement technologies have been developed to reduce NO_x emissions such as low NO_x burners(LNB), flue gas recirculation(FGR), and low excess air (LEA), but they may reduce the efficiency and increase the cost of the combustion system, and may not be sufficient for stringent regulatory standards. Pollution control methods, including selective catalytic reduction (SCR) and selective non catalytic reduction (SNCR), can achieve high NO_x removal; however, such technologies can be very expensive [USEPA 1999]. Another technique with potentially lower cost [Haywood and Cooper 1998] is the oxidation of NO_x with subsequent wet absorption (i.e.) Flue Gas Desulphurization/Denitrification (FGD) process is being quite efficiently used in incinerators and boilers, so it may work for removal of NO_x then it will prove a more compact and cost effective technology. Flue gas desulfurization (FGD) is the effective and reliable NO_x removal methodology and it is classified as dry, semi–dry, and wet FGD Among these wet FGD processes have been widely accepted because of lower cost, simple operation and higher NO_x removal efficiency compared to other processes [Maheswari et al., 2013]. In FGD process different absorbents are used as solvent and hence the selection of the additive is based on the concentration of NO_x and through the range of solubility to oxidize insoluble NO to soluble NO_2 which can be absorbed into alkaline solution. Various oxidants such as H_2O_2 [de Pavia and Kachan, 1998], KMnO4 [Brogren et al., 1997; Chu et al., 2001], NaClO2 [Youngchul, et al., 2014; Hsu et al., 1998; chu et al., 2003], such that the solubility test has been made over these additives by regulating the flow rate and the molar ratio of the additives the NO_x removal efficiency can be enhanced.

TABLE I. Absorbent selection parameters.

Author	Absorbents used	mole conc./ feed rate of absorbent	Removal efficiency	Height/diameter of the packed column
H.K LEE et al.	$NaClO_2$	0-50ml/min	67%	Height-1.0m Diameter-0.015m
Collins et al.	H_2O_2	Molar ratio-1.0	>90%	Height-1.5m Diameter-0.05m
Kasper et al.	HNO_3 with externally added H_2O_2	HNO_3-0-2M H_2O_2-0.02M	90%	Height-2m Diameter-0.045m
E.Y.kieng et al.	Water with aqueous solution of HNO_3	5 mol% of HNO_3	37%	Height 6m, Diameter - 0.254m

The most commonly used device for the absorption process is packed column and the various parameters are

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considered for the design are given in table 1. There are several types of scrubbers proposed by researchers for FGD process such as bubbling jet reactor [Zheng et al., 2003], combined packed and spray tower absorber [Gomez et al., 2007], cable bundle wet scrubber, and packed column [Colle et al., 2001]. Packed column is taken for analysis because of its increased absorption rate by providing a good contact with liquid and gas.

II. Materials and Method

Theoretical Analysis for the New Design Strategy

From various studies the technique used for the NOx absorption process is considered to be the wet scrubbing process in the packed column. The analysis shows that the packed column used here have high mass transfer ratio to attain the maximum NO_x removal efficiency. Here the required removal efficiency is above 98% such than to attain maximum removal efficiency some of the design parameters and the materials to be selected. The design of packed column for the NO_x absorption process is based on mathematical modelling (Coulson and Richardson's, chemical engineering, Volume-6, 2005). The parameters to be considered for the design of the packed column are liquid flow rate to the packed column(5-30lph), gas flow rate to the packed column(1-5m3/hr), packed area(0.45-0.70m), packing materials to be used are Intolax ceramic saddles with 6mm diameter, Poly propylene pall rings with 10mm diameter and Rasching rings with 10mm diameter and the absorbents/additives used for the analysis are H_2O_2, $NaClO_2$, aqueous HNO_3, HNO_3 with externally added H_2O_2 with different concentration and water. The inlet concentration of NO_x is 100-500ppm with minimum inlet pressure of 0.1bar.

Process Analysis

The efficiency of an absorption process is always depends on the gaseous contaminant solubility. The packed column is used for the liquid-gas absorption process in the form of vertical tube filled with the appropriate packing material. Then it has a spraying liquid along the spraying tower which is placed at the top of the packed column. The liquid injected through the spraying tower are in the form of fine droplets which is placed counterpart to the gas distributer at the bottom of the packed column. The liquid/additive which is to be sprayed is pumped into the packed column using peristaltic pump which has the capacity to regulate the liquid flow up to 5 lph with maximum speed of 100 rpm. After the cycle of operation the liquid collected at the bottom of the packed column re-circulated into the additive tank and it can be pumped into the packed column continuously.

Chemical Analysis

This technique intentionally raises the oxidation state of the nitrogen atom by injecting hydrogen peroxide (H_2O_2) into the flue gas flow, converting NO to NO_2 and HNO_3. Water absorption of the NO_x is easier (especially if the pH is raised by caustic addition) because of the greater solubility of NO_x at higher oxidation states. The absorption process is described by the mathematical model based on a two-film theory of gas-liquid absorption for mass transfer analysis. Complete mixing takes place in gas and liquid phases and the interface is at equilibrium with respect to pollutant molecules transferring in or out of the interface.

III. Experimental Analysis

Packed column is designed for the purpose of obtaining proper liquid to gas mixing, which leads to the efficient removal of soluble NO_x from gas stream. The experimental setup comprises of acid tank with the capacity of 5 liters and the flue gas cylinder with NO_x gas maintained at the concentration of 500ppm. NO_x gas flow rate is maintained as 1m3/hr. From the gas chamber, the flue gas is entered at the bottom of the packed column.

Acid tank is filled with H_2O_2 with the required concentration and it is pumped in to the packed column through the peristaltic pump at the flow rate between 0-5 lph. The liquid is entered at the top of the packed column and the gas is entered at the bottom and both are blended together in the packed column area. Absorption with chemical reaction takes place in the packed column and due to this NO_x from the gas phase is dissolved in to the liquid phase by making a chemical reaction between them. Then the untreated gas exists through the gas outlet of the packed column. Hence the concentration of the inlet an outlet concentration of NO_x gas is measured through the NO_x gas sensor and it transmits the equivalent current signals to the computer through the VIPID-03 DAQ card is shown in figure 1. Based on the concentration of the untreated NO_x gas the flow rate of the H_2O_2 is regulated.

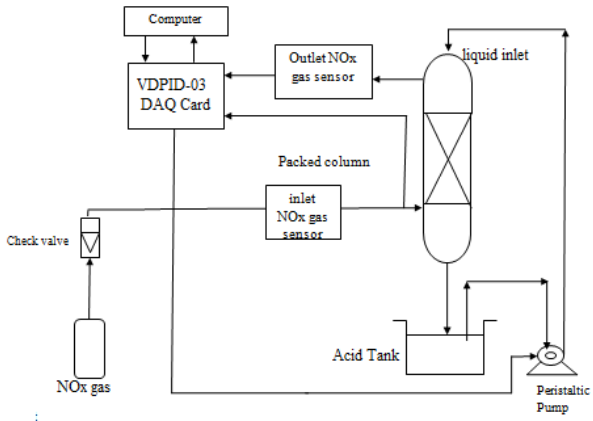

Fig. 1. Proposed experimental system for NO_x emission control using packed column.

IV. Results and Discussions

The maximum NO_x removal efficiency is achieved through the optimization of packed column parameters. For this optimization various experimental runs are carried out in the packed column such as by varying the absorbents and by varying the flow rate of the H_2O_2.The effect of NO_x removal efficiency is studied through these experimental results.

Effects of Absorbents on NO_x Removal Efficiency

The effect of absorbents used for the NO_x absorption process using packed column by conducting various experiments such that each experiment is made for 2 hours

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continuously with each absorbent. The effect of the each absorbent with respect to the removal efficiency for the different absorbents such as water, H_2O_2, HNO_3 are recorded and shown in figure 2. From the figure, it is observed that the removal efficiency obtained from water is between 35 to 50% of the inlet NO_x concentration hence it is not considered for present study. During the reaction between NO_x and HNO_3 the removal efficiency is improved in the range of 80-87% and while it is compared with the hydrogen Peroxide the removal efficiency is considered to be low. As such the reaction between NO_x and H_2O_2 the removal efficiency is maintained above 90%.

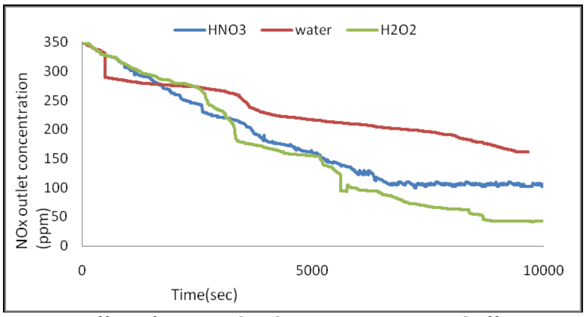

Fig. 2. Effect of various absorbents on NOx removal efficiency.

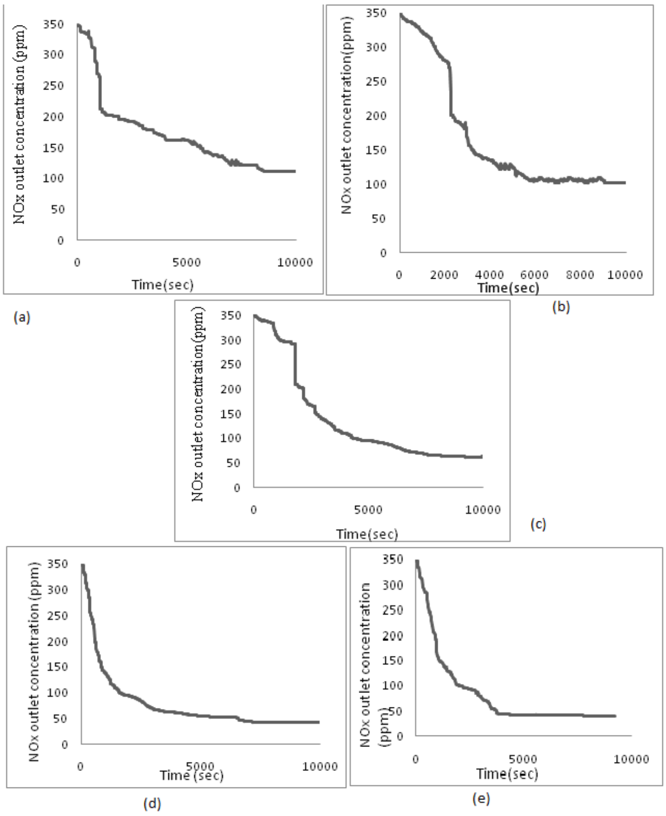

Fig. 3. (a) Process reaction curve for 20% opening, (b) Process reaction curve for 40% opening, (c) Process reaction curve for 60% opening, (d) Process reaction curve for 80% opening, (e) Process reaction curve for 100% opening.

Effect of H_2O_2 on NO_x Absorption

The pure Hydrogen Peroxide 0.1M is added gives better removal efficiency such that its effect on NO_x at various flow rate of H_2O_2 is recorded and shown in figure 3. The various flow rate of H_2O_2 is maintained through the VDPID-03 Digital controller and these various flow rate has the direct influence on the NO_x removal efficiency. From the figure 3 it is shown that the increase in the concentration of H_2O_2 improves the NO_x absorption process.

V. CONCLUSION

The injection of H_2O_2 to obtain maximum NO_x removal efficiency is obtained in the range of 98% such that by using lab scale packed column following various parameters and experimental conditions. The Hydrogen Peroxide used as the oxidizing agent at 0.1M produces high removal efficiency as compared to the other absorbents, since it has the direct influence on the NOx removal rate. Hence this packed column is developed with the inner diameter of 50mm to receive the maximum liquid flow rate of 5 lph and gas flow rate at 1 m3 /hr. The packed height is selected as 0.45m with Intolax ceramic saddles as the packing material with 10mm diameter are chosen for the analysis because they produce better NOx removal efficiency. With these of optimized parameters a suitable controller will be developed to reduce the NOx emission, by regulating the flow rate of H_2O_2.

Nomenclature

H_2O_2	Hydrogen Peroxide
HNO_3	Nitric Acid
SO_2	Sulphuric Acid
NO_x	Nitrogen Oxide
$NaClO_2$	Sodium Chlorite
DAQ	Data Acquisition Card

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