Utility and Application of FGD System (Flue Gas Desulphurization) in Chemical and Environmental Engineering

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***Abstract*—SO_2 is a major constituent in air pollution. and affects the environment in number of ways like acid rain, corrosion and severe damages to the health. So our aim of the project is to reduce the emission of SO_2 in environment and to produce a product with SO_2, Hence SO_2 emission can be controlled. Laboratory studies were conducted to know about the effect of concentration of NaOH, and $Ca(OH)_2$, pH of solution, flow of flue gases in impingers, temperature of solutions and time period for reaction for absorption of SO_2 contained in flue gases. In accordance with the invention, flue gases containing SO_2 are passed through a solution which was rich with Na/Ca ions using SO_2 monitoring kit of SO_2 measurement, and then SO_2 reacts with these ions to produce respective sulphate. All most complete removal of SO_2 in flue gases has been observed using this Process in the thermal power plant Rajasthan, India.**

***Index Terms*—Calcium sulphate, desulphurization, flue gases, sodium sulphate.**

I. INTRODUCTION

Thermal power plants are major sources of air pollutants. Three major air pollutants emitted from thermal power plant are SPM, SO_x, and NO_x. The amount of pollutants emitted from any power plant depends upon the type of the fuel used, burning method and type of control equipment. These pollutants finally found in ambient air. Coal is re-emerging as a dominant fuel for power generation in various power plants. [1]-[2] various coals such as petcock, lignite, bituminous etc. used in power plants in which % S has 6.0 %, 4.0 % and 3.8 % respectively. The common elements in fuel are Carbon, which is principle combustible constituted of all fossils. Oxygen, nitrogen, hydrogen, and Sulphur (S) are not combustible elements. Sulphur in coal cannot be destroyed it can only be converted to one form to another during the combustion process, sulphur react with oxygen and formed SO_2 and SO_3. SO_2 is a major constituent in air pollution. SO_2 which affects the environment by no. of ways like acid rain, corrosions and severe damage to the health. SO_2 causes a wide variety of health and environmental impacts because of the way it reacts with other substances in the air. Particularly sensitive groups include people with asthma who are active outdoors and children, the elderly, and people with heart or lung disease. Intensity of SO_2 emission can be observed by following example. " A typical 6 MW power generation unit using furnace oil containing 2 % Sulphur will emit 388 tons of SO_2 per year, based upon 320 working days or A 22.5 MW power generation unit will emit 1690 tons of SO_2 per year by using Pet Coke." [3]-[4].

Flue gas desulphurization (FGD) is the current state-of-the art technology used for removing sulphur dioxide from the exhaust flue gases in power plants. SO_2 is an acid gas and thus the typical sorbent slurries or other materials used to remove the SO_2 from the flue gases are alkaline. The reaction taking place in wet scrubbing using Ca $(OH)_2$ and NaOH slurry produces $CaSO_3$ and Na_2SO_3 and can be expressed as:

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$$
$$2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$$

Some FGD systems go a step further and oxidize the $CaSO_3$ and Na_2SO_3 to produce marketable $CaSO_4 \cdot 2H_2O$ (gypsum) and Na_2SO_4 (Sodium Sulphate): [5]-[6].

$$CaSO_3 + ½O_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O$$
$$Na_2SO_3 + ½\,O_2 \rightarrow Na_2SO_4$$

There are three control technologies which have major application in the field of Sulphur di Oxide control [7]-[8].

- Adsorption.
- Catalytic Oxidation / reduction.
- Absorption.

Adsorption is a control technology for control of SO_2 from stack gases but suffers from several following drawbacks viz:

1. Higher energy requirements.
2. Penetration of SO_2 in the granule is difficult.
3. Highly active absorbent surfaces cause oxidation of SO_2 to SO_3 which react with moisture in flue gases to form acid.
4. Regeneration techniques are costlier.

Catalytically oxidation / reduction is a control technology for control of from stack gases but suffers from several following drawbacks viz:

1. Higher energy requirements
2. Large equipment size.
3. Costly Catalysts.
4. Regeneration and disposal of catalysts is also a problem
5. Contractor design is complex.

Absorption is a control technology for control of SO_2 from stack gases is most widely practiced.

However this technology also suffers from following drawbacks:

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1. Stack gas cooling and reheating is required.
2. Mist elimination is required.

However these problems can be easily encountered with proper engineering design used. Besides this less operator's intensiveness, less cost and ease of handling of liquid sorbent makes it an attractive option. It is one of the most widely used control technology employed for removal of SO_2 [9]-[10].

II. MATERIAL AND METHODS

All experiments were conducted on Stack monitoring Kit (Model No. and Make -VSS1, 141 DTH -2005,Vayubodhan). First of all Stack monitoring kit of SO_2 monitoring was set up for experiment at *chimney* inlet of Boiler No. - 4 of SCL. Flue gas containing SO_2 was supplied from *chimney* via probe connected with flexible pipe of stack monitoring kit. The flow of flue gas was controlled using an inlet line Rota meter and was maintained at a value of 3 liter per minute and other end of flexible pipe carrying air and SO_2 respectively was connected to a impinger of 10 cm diameter and 100 cm length. The impinger was filled with 100 ml of scrubbing media in this experiment i.e. Sludge solution, Calcium hydroxide solution, Sodium hydroxide solution.

The concentration of SO_2 in flue gases was first measured by Stack monitoring Kit.

$$C_{SO2} = \frac{K_2(V_t - V_{tb})N(V_{soln})}{V_{m(std)*}V_a}$$

C_{SO2} = Concentration of sulphur dioxide, dry basis converted to standard conditions, mg/NM$^{3.}$

N = Normality of barium per chlorate titrant mili equivalent/ml.

K_2 = 32.03 mg/meq.

V_t = Volume of barium per chlorate titrant used for the sample, ml.

V_{tb} = Volume of barium per chlorate titrant used for the blank, ml

$V_{m(std)}$ = Dry gas volume measured by the dry gas meter, corrected to standard conditions, NM$^{3.}$

V_a = Volume of sample aliquot-titrated, ml.

Five sets of reading were taken by varying concentration of every solution. 100 ml of solution was taken in first two different impinges for better absorption of SO_2 and 30 ml of H_2O_2 was taken in the third for determination of remaining $SO_{2.}$ Respective sulphate has been formed in solution. Dissolved sulphate can be extracted from solution by heating till dryness. Three parameters regards to % SO_3 (gravimetric), % SO_2 (Volumetric) and % alkalinity have been analyzed in precipitate. The methods used as Indian standard method from bureau of Indian standard.[11]-[13] During the experiments pipette out 10 ml of NaOH solution in every 15 minutes and pH was analyzed, titrate with 1M oxalic acid determination for fall in conc. of NaOH. Similarly Experiments were conducted on Indirect Flow (By taking water in first impinger) and Direct Flow (Without Water in First impinger). Similarly all experiments were conducted at different temperatures and at different times of interval for reaction. Operating condition of SO_2 absorption is given in table – 1. Schematic diagram of experimental protocol shows in figure 06.

TABLE I: OPERATING CONDITION OF SO_2 ABSORPTION IN SCRUBBING MEDIA

S. No.	Operating Condition	Value
1	Initial Concentration of Scrubbing media	Varying
2	pH of solution	Varying
3	Total liquid hold up	100 ml
4	Temperature of solution	Varying
5	Time period for reaction	Varying
6	Flow of flue gas in impinger	3 LPM
7	SO2 load in flue gas	3000 – 3200 ppm
8	Flue gas Temperature	135 oC
9	Flue gas flow in duct of ESP O/L	150522 M3/hr
10	Pet Coke Feeding Rate	13 Ton/ hr
11	Lime Stone Feeding Rate	1.0 Ton/hr

TABLE II: EFFECT OF CONC. OF $CA(OH)_2$ SOLUTION AND RECOVERY OF SO_2

S. No	Concentration of Ca(OH)2 (%)	Initial Concentration of SO2 at I/L of absorbing media (ppm)	Concentration of SO2 at O/L of absorbing media (ppm)	Recovery of SO2 (%)
1	5.00%	2980	621	80.15
2	10.00%	2980	739	76.2
3	15.00%	2980	898	70.85
4	20.00%	2980	1097	64.18
5	25 .00%	2980	1279	58.06

TABLE III: Analysis Results of Precipitate which was Prepared by Ca(OH)$_2$ Solution and SO$_2$

S. No.	Concentration of Ca(OH)2 Sample	Yield of precipitate (g)	Mg+2	Percent CaSO4	Percent SO2 (By Volumetric)	Alkalinity Percent	L/G ratio
1	5.00%	5.55	3.61	8.75	4.12	0.02	33.55
2	10.00%	10.89	2.41	7.51	3.53	.0216	50.33
3	15.00%	15.06	1.96	7.34	3.45	.0252	67.11
4	20.00%	20.42	1.29	5.03	2.36	.0324	83.89
5	25.00 %	25.18	1.24	4.18	1.96	.0540	100.67

TABLE IV : Effect of Conc. of NaOH solution and recovery of SO$_2$

S. No.	Concentration of NaOH (%)	Initial Concentration of SO2 at I/L of absorbing media (ppm)	Concentration of SO2 at O/L of absorbing media (ppm)	Recovery of SO2 (%)
1	5 %	3067	75	97.96
2	10 %	3067	158	95.08
3	15 %	3067	306	90.18
4	20 %	3067	324	88.02
5	25 %	3067	455	85.19

TABLE V: Analysis Results of Precipitate which was Prepared by NaOH Solution and SO$_2$.

S. No.	Concentration of NaOH Sample	Yield of precipitate (g)	Percent SO3 (By gravimetric method)	Percent Na2SO4	Percent SO2 (By volumetric)	Percent Alkalinity	L/G ratio
1	5 %	4.88	20.76	35.49	39.21	0.62	16.30
2	10 %	9.76	5.67	17.00	25.61	1.17	32.60
3	15 %	14.15	1.49	9.81	20.54	1.64	48.90
4	20 %	18.62	0.52	5.77	19.47	1.68	65.21
5	25 %	23.28	0.24	3.99	17.62	1.75	81.51

TABLE VI : Effect of pH of NaOH solution for absorption of SO$_2$

S. No.	Time (Min.)	pH of solution	Volume of 1 M Oxalic acid consumed in titration using phenolphthalein indicator (ml)	Conc. of NaOH (%)
1	0	12.57	20.05	80.06
2	15	10.62	15.56	62.2
3	30	8.82	3.5	14.2
4	45	7.95	1.23	4.8
5	60	5.62	0.56	2.2
6	75	4.75	0.32	1.2

TABLE VII : Effect of Direct and Indirect Flow of Flue Gases in NaOH Solution and Removal Efficiency of SO$_2$

S. No.	Flow of SO2 gas	Initial Concentration of SO2 (ppm)	Concentration of SO2 after formation of Sodium sulphate (ppm)	Recovery (%)
1	Direct	3050	145	95.25
2	Indirect	3050	1818	59.62

TABLE VIII: Effect of Temperature of NaOH Solution and Recovesry of SO$_2$

S. No.	Temperature of NaOH solution	Initial Conc. of SO2(ppm)	Conc. of SO2 after formation of Sulphate(ppm)	Recovery (%)
1	20-25 oC	3080	302	90.18
2	25-30 oC	3080	566	81.62
3	30-35 oC	3080	675	78.08

Table IX: Effect of time intervals of reaction and recovery of SO2

S. No	Time for reaction(Min)	Initial conc. of SO2 (ppm)	Conc. of SO2 after formation of SO4(ppm)	Recovery (%)
1	20	3075	761	75.25
2	40	3075	609	80.18
3	60	3075	360	88.27

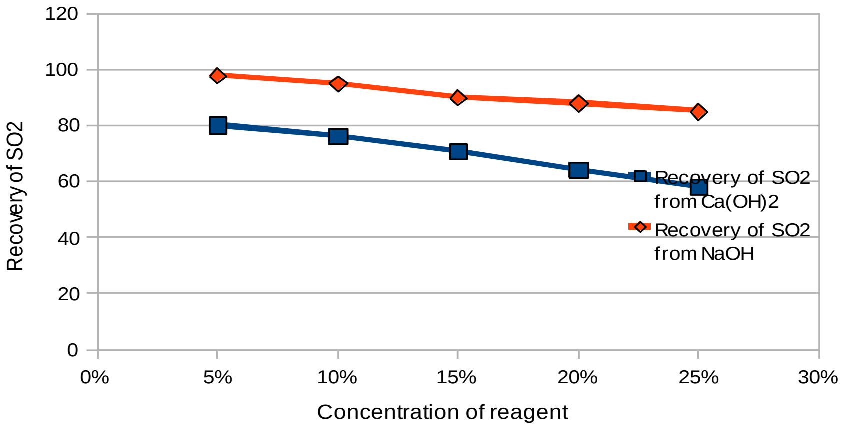


Fig 1. Comparative Study of recovery of SO_2 with different reagents

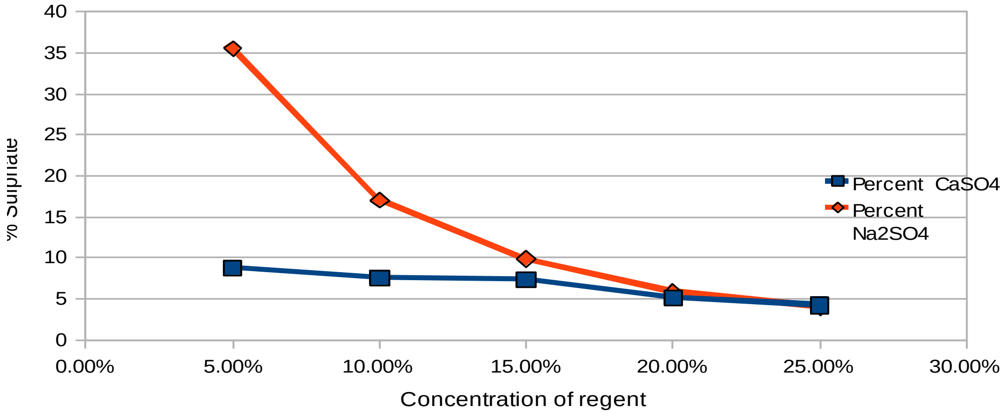


Fig 2. Comparative Study of Conc. of different reagents with % sulphate of precipitate

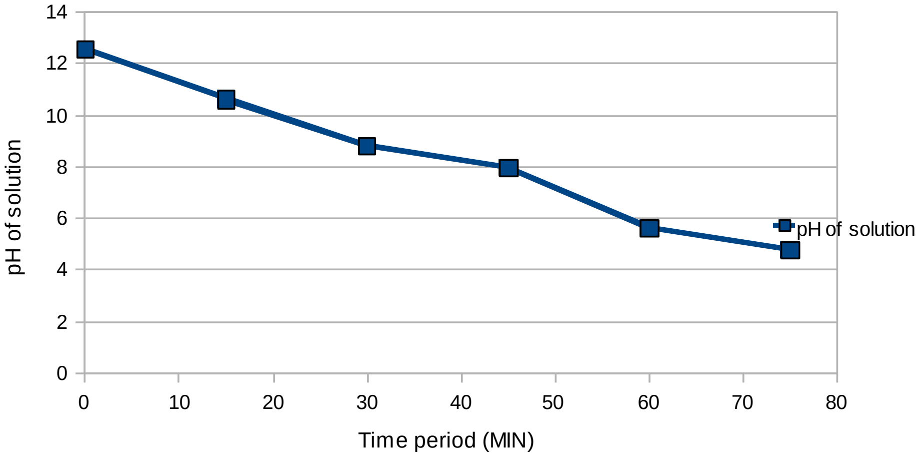


Fig 3. Figure depicting relation between pH of NaOH solution and absorption of SO_2

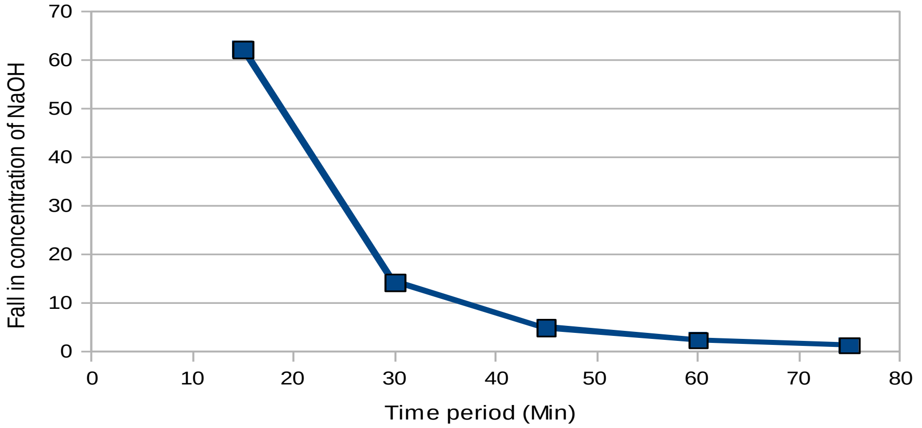


Fig 4. Figure depicting relation between time period and falls in conc. of NaOH.

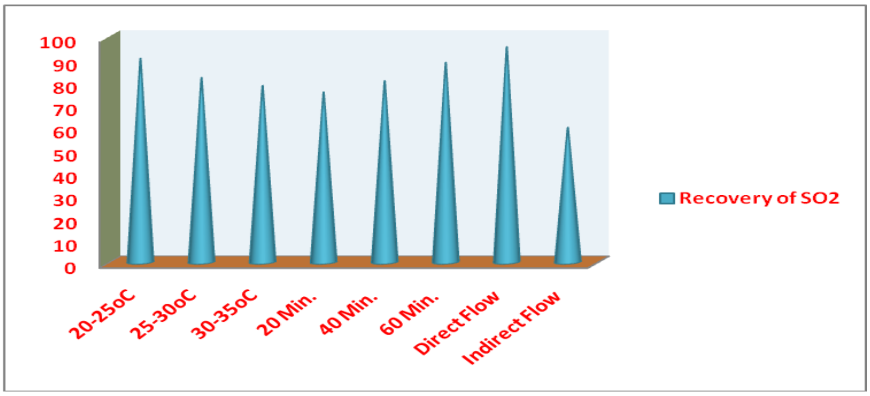


Fig 5. Comparative study of recovery of SO_2 with different parameters

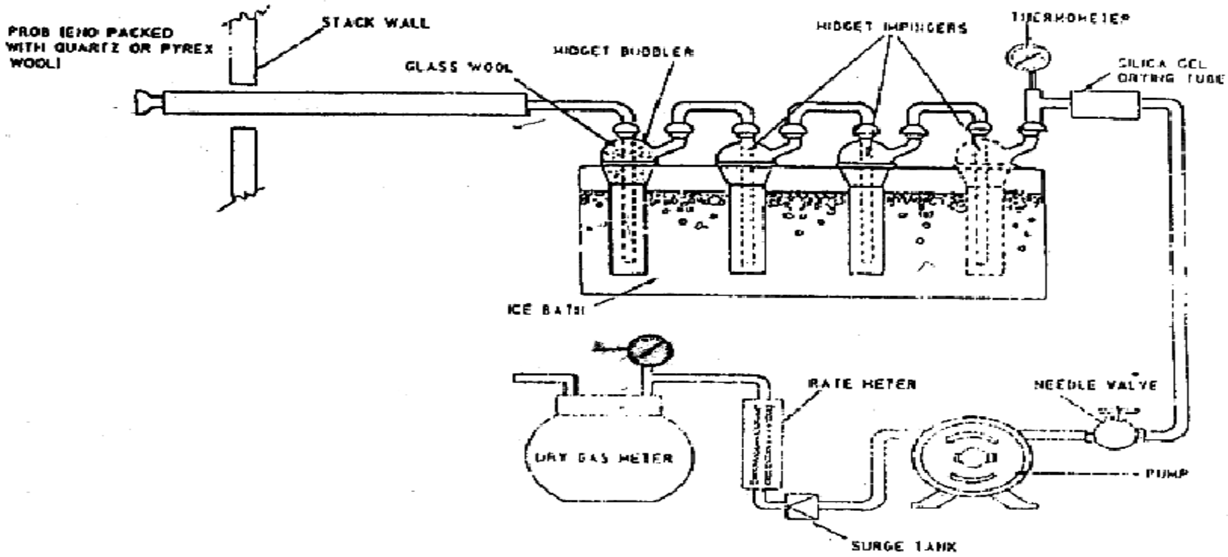
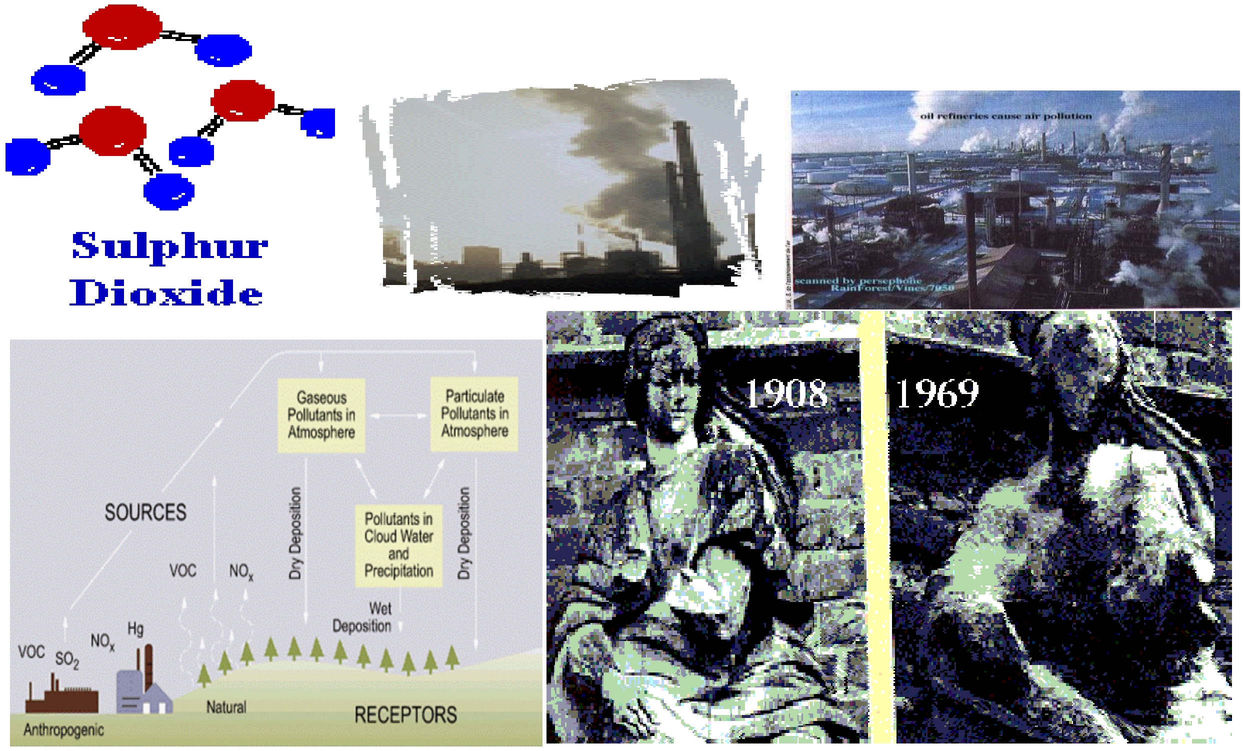
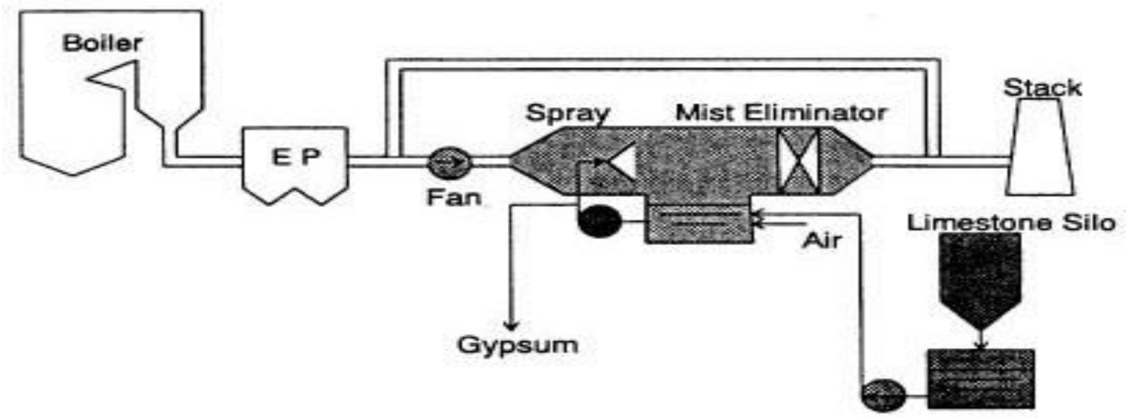


Fig 6. Schematic diagram of experimental protocol

Fig.7.Experimental set up by research scholar using SO_2 monitoring kit.



Snap 1. Photographs showing harmful effects of SO2 during acid rain



Snap 2. Photograph showing flow diagram of FGD process

III. RESULT AND DISCUSSION

Table 2 to5 reports that relation between recovery of absorption of SO_2 using varying concentration of Sodium hydroxide, & Calcium hydroxide, with analysis results of precipitate. As can be seen from figure – 1 that recovery of SO_2 using, Calcium hydroxide, is far below that using Sodium hydroxide. Figure -2 shows the results of % respective Sulphate of precipitate which was prepared by two different reagents and % SO_2 in flue gases. Figure -3 shows relation between pH and time period of reaction and confirm that when time period for reaction increases than ph were decreases. Similarly Fig- 4 shows that relation between concentration of reagent & time period for reaction and it is confirm that when SO_2 gases were absorbed in solution then conc. were decreases. Fig- 5 reports that comparative study of recovery of SO_2 with different parameters.

IV. CONCLUSION

From the comparative study of two different reagents regarding to removal of SO_2 , it is observed that Sodium hydroxide is superior as compare to calcium hydroxide. The initial rate of absorption is higher for sodium hydroxide as compared to calcium hydroxide. All the absorption methods coupled with a chemical reaction. It may be suggested that Sulphur dioxide is a weak acid and it is a well known fact that reaction of a weak acid with a strong base is fast, meaning stronger the base faster would be the reaction Therefore sodium hydroxide is a strong base compared to calcium hydroxide so this evident that sodium hydroxide is a better solvent for removal of SO_2. The lower Concentration of the reagent is found to be optimum. Increasing concentration of solution is not very fruitful for maximum absorption of SO_2 in exhaust flue gases. This is because of load of SO_2 in flue gases is very low (at ppm level), so the reagent remains as it is in solution after completely absorption of $SO_{2.}$ On the basis of our study we can recommended that if flue gas desulphurization system (FGD System) would be set up before Chimney then maximum SO_2 is trapped, resulting lowers the SO_2 concentration in environment and lowers the air pollution.

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REFERENCES

[1] D. A. Butler, M. Fan, and C. R. brown, "Comparison of polymeric and conventional coagulants in arsenic removal," J. Env. Engg, vol 74, pp 308-313, 2002

[2] L. Wangl and L. Huangj, Zhaiy "Contamination assessment of copper,lead, zinc, manganese and nickel in street dustof Baoji, NW China," *Journal of Hazardous Materials*, vol. 161, No. 2-3, pp. 1058–1062, 2009

[3] M. fan and C brown, "a process for synthesizing polymeric ferric sulfate using sulphur di oxide from coal combustion," *Int. J. Env*. Poll., vol 17 ,pp 102-109, 2002

[4] P. Sunx and L. Yamauchit "Concentrations of toxic heavy metals inambient particulate matter in an industrial areaof northeastern China," *Frontiers of Medicine in China*, vol. 2, No 2, pp. 207-210, 2008.

[5] P. BGrgic, I. tursic and J. Bercic G "Influence of atmosphericcarboxylic acids on catalytic oxidation of sulfur(IV) ," *Journal of Atmospheric Chemistry*, vol. 54, No 2, pp. 103–120, 2006.

[6] K. N. Sheth Patel and J. P. Neha, "effect of concentration in absorption of Sulphur dioxide with sodium hydroxide," *Env. Poll. Cont.* J, vol 9, pp 14-18, 2006

[7] S. W. Sung and R. C. brown, "synthesis, characterization and coagulation performance of polymeric ferric sulphate," *Int. J. Env. Poll*, vol 128, pp 483-490, 2002

[8] G. Wang and N. L. Wangl "Identification of dicarboxylic acids and aldehydes of PM10 and PM2.5 aerosols in Nanjing, China" *Atmospheric Environment,* vol.36, No 12, pp. 1941–1950, 2002

[9] G. W. Zhuang, S. Chen, and A. Zheng "Characteristics and sourcesof formic, acetic and oxalic acids in PM2.5 and PM10 aerosols in Beijing, China," *Atmospheric Research*, vol. 84, No 2, pp. 169–181, 2007

[10] W. Manika "A Mn(II)-catalysed S(IV) oxidation and its inhibition byacetic acid in acidic aqueous solutions," *Journal of Atmospheric Chemistry*, vol. 60, No 1-102, pp.1 - 17, 2008

[11] Y. Fangm, and C. C. Hoklees "Characterization of dicarboxylic acids in PM 2.5 in Hong Kong," *Atmospheric Environment*, vol. 38, No 7, pp. 963–970, 2004

[12] Y. Yule, "Measurements of oxalic acid, oxalates, malonic acid, and malonates in atmospheric particulates," *Environmental Science and Technology*, vol. 42, No 24, pp. 9268-9275, 2008

[13] Z. P. W. Bronkowska "Rate constants for atmospheric trace organics scavenging SO^{-4} in the Fe-catalysed autoxidation of S(IV) ," *Atmospheric Environment*, vol. 39, No 8, pp.1431-1438, 2005