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Absorption of Nitrogen Dioxide into Sodium Carbonate Solution in Packed Column

Dr. Jafar Ghani Majeed

Department of Materials Engineering College of Engineering Al-Mustansiryia University, Baghdad, Iraq

ABSTRACT: *Absorption of nitrogen dioxide (NO2) gas from (NO2/Air or NO2/N2) gas mixture into sodium carbonate (Na2CO3) alkaline solution was performed using packed column in pilot scale. The aim of the study was to improve the Absorption efficiency of this process, to find the optimal operation conditions, and to contribute to the application of this process in the industry. Absorption efficiency (η) was measured by using various operating parameters: gas mixture flow rate (QG) of 20-30 m3/h, nitrogen dioxide inlet concentration (YNO2) of 500-2500 ppm, experimental temperature (T) of 30-50 ℃, Na2CO3 solution concentration (CNa2CO3) of 10-30 wt %, and liquid holdup in the column (VL) of 0.02-0.03 m3according to experimental design. The measured η was in the range of η = 60.80-89.43 %, and of η = 60.10-91.50 % respectively depending on the operating parameters investigated. Computer program (Statgraphics/Experimental Design) was used to estimate the fitted linear models of η in terms of (QG, YNO2, CNa2CO3, T, and VL), and the economic aspects of the process. The accuracy of η models is ± 2.3 %. The linear models of η were adequate, the operating parameters were significant, and the interactions were negligible. Results of η obtained reveal that a negligible influence of oxidation with a maximum deviation of 2.2 %.*

Keywords: *Packed column, NO2 absorption, Na2CO3 solution, Absorption efficiency.*

I. Introduction

The most important gas- purification is the chemical absorption in which one or more soluble components of a gas mixture are dissolved in the solution. The sources of emissions of toxic gases to atmospheric air are chemical factories as a result of certain chemical reactions or producing different chemical products [1, 2]. Absorption of toxic gases from gas mixtures into chemical solutions is very important task for environment protection. Nitrogen oxides belong to the most troublesome gaseous components polluting atmospheric air. Among several nitrogen oxides (N_2O_3 NO_3 N_2O_3, NO_2, N_2O_4, N_2O_5), the most common in atmospheric air are nitrogen mono oxide (NO) and nitrogen dioxide (NO2) [1, 3, 4]. In combustion techniques, the total content of (NO + NO_2 converted to NO_2) is marked with a common symbol NO_x [1, 3]. Those pollutions are heavily toxic for human environment. In concentrated nitric acid producing plant, the colorless nitrogen mono oxide (NO) is one of the emissions gases of nitrogen oxides (NOx) to atmospheric air. The NO gas produces commercially by oxidizing of ammonia gas by air as shown in the chemical equation (1):

$$2\,NH_3 + 2\frac{1}{2}\,O_2 \longrightarrow 2\,NO + 3\,H_2O \tag{1}$$

Oxidation of nitrogen mono oxide (NO) gas by pure oxygen in presence platinum as catalyst producing brown color gas nitrogen dioxide (NO_2) as seen in the equation (2):

$$2\,NO + O_2 \leftrightarrow 2\,NO_2 \tag{2}$$

The applied methods of absorption of nitrogen oxides from flue gases in recent years belong to following groups [1, 5]:

* Catalytic reduction (non-selective catalytic reduction (NSCR), and selective catalytic reduction (SCR).
* Adsorption.
* Absorption (acid and alkaline).

Catalytic reduction is an efficient but very expensive method of gas treatment. It used mainly in highly industrialized countries to neutralize nitrogen oxides from energetic exhaust fumes and from industrial flue gases, which formed during production of nitric acid [1, 5]. Absorption methods exploiting traditional adsorbents have not been commonly used in installation for absorption nitrogen oxides from industrial flue gases, mainly for economical reasons and because of difficulties connected with regeneration of adsorbent or its utilization. Methods of absorption of nitrogen oxides in solutions belong to the earliest ones in technology of industrial flue gases treatment. Those methods are based on fundamental properties of nitrogen oxides present in gases: their solubility in water [1] or in solutions of nitric acid [6] and sulphuric acid [7] as well as their ability to form appropriate salts, nitrates, and nitrites in reactions with substrate of alkaline character [8]. Application of the alkaline absorption to protect environment is determined by physicochemical properties of nitrogen oxides. Nitrogen dioxide has sufficiently high solubility and reactivity with water and with aqueous alkaline solutions, and as such it can be absorbed in solutions [8-10]. Generally, the methods of absorption are characterized by a simplified technological outlines and simple, typical apparatuses.

In present work alkaline solution of sodium carbonate (Na_2CO_3) is used to absorb nitrogen dioxide (NO_2) from NO_2/Air and NO_2/N_2 gas mixtures separately Solution of Na_2CO_3 will react with NO_2 gas to produce ($NaNO_3 + NaNO_2$) solution with evolving of CO_2 gas as in the following equation (3):

$$2\ NO_2 + Na_2CO_3 \longrightarrow NaNO_3 + NaNO_2 + CO_2 \quad (3)$$

It was difficult in this work to separate $NaNO_3$ and $NaNO_2$ solutions from each other, dilute nitric acid of (5-7 wt % HNO_3) is added to produce $NaNO_3$ solution and could be seen in the equation (4):

$$3\ NaNO_2 + HNO_3 \longrightarrow 3\ NaNO_3 + 2\ NO + H_2O \quad (4)$$

$NaNO_3$ solution and NO gas send to HNO_3 producing factory for further treatment operations.

NO_2 gas is more toxic than NO gas according to OSHA standard. The allowable concentrations for exposure time of 8 hours for NO and NO_2 gases are 25 ppm. and 1 ppm. respectively, where (1 ppm. NO = 1.227 mg/m3, while 1 ppm. NO2 = 1.882 mg/m3). Many processes have been developed for NO2 removal from flue gases [11-14] which are based on absorption in aqueous solutions of soluble alkali metal compound. Sodium compounds are preferred over potassium or the other alkali metals strictly on the basis of cost.

II. Experimental Work

2.1 Experimental apparatus:

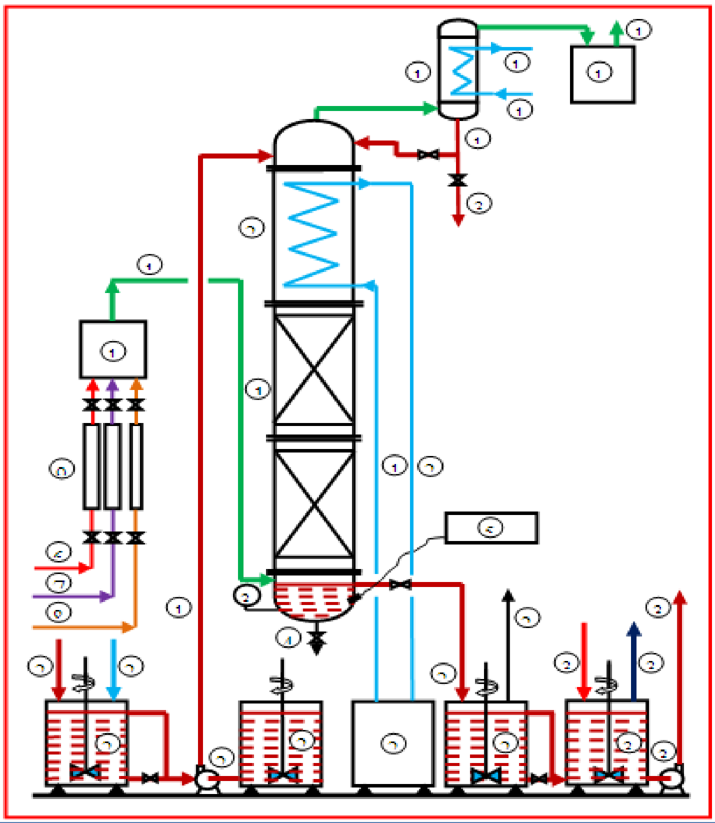

Figure 1: Schematic diagram of the experimental apparatus for NO2 gas absorption from gas mixture into Na2CO3 solution in packed column.

The main equipment of the experimental apparatus as shown in Figure 1 is the packed column (1), and its heat exchanger (2), the size to gather of 3.5 m height and 0.150 m in diameter. The main complementary apparatus and pipe lines are as follows: Temperature gage (3), discharge point (4), digital pH- meter (5), compressed nitrogen in (6), compressed air in (7), nitrogen dioxide gas in (8), nitrogen gas, air, and nitrogen dioxide gas rotameters respectively (9), mixing chamber (10), gas mixture in (11), gas mixture out (12), Na_2CO_3 solution in (13), liquid recycle to top of the column (14), condenser (15), cold water in (16), cold water out (17), NO_2 gas analyzer (18), water to heat exchanger from thermostat (19), water from heat exchanger to thermostat (20), solid Na_2CO_3 (21), process water (22), mixing tank to prepare Na2CO_3 solution (23), feeding pump of Na_2CO_3 solution to packed column (24), Na_2CO_3 solution tank (25), thermostat water bath (26), (Na_2NO_3, and Na_2NO_2) solution tank (27), (Na_2NO_3, and Na_2NO_2) solution from bottom of column (28), CO_2 gas out (29), stirred tank for reaction of $NaNO_2$ solution and (5-7 wt %) HNO3 acid (30), (5-7 wt %) HNO_3 acid in (31), NO gas to nitric acid plant (32), discharge pump of Na_2NO_3 solution (33), Na_2NO_3 solution to sub plant at nitric acid plant for producing powder Na_2NO_3 (34), and drain line (35).

2.2 Operating parameters:

The preliminary experiments were carried out to absorb of NO_2 gas from gas mixture into Na_2CO_3 solution in pilot scale packed column by using experimental apparatus as shown in Figure 1 to find the proper operating parameters could be used in this work. Operating variable parameters were as follows:

* Gas mixture flow rate ($\boldsymbol{Q_G}$): 20-30 m^3/h.
* NO_2 gas inlet concentration ($\boldsymbol{Y_{NO2}}$): 500-2500 ppm.
* Na_2CO_3 solution concentration ($\boldsymbol{C_{Na2CO3}}$): 10-30 wt %.
* Experimental temperature ($\boldsymbol{T}$): 30-50 ℃.
* Liquid holdup in the column ($\boldsymbol{V_L}$): 0.02-0.03 m^3.

2.3 Absorption of NO_2 gas from NO_2/Air gas mixture into Na_2CO_3 solution:

Sodium carbonate (Na_2CO_3) solution and NO_2/Air gas mixture were prepared in the following manners:

2.3.1. Preparation of Na_2CO_3 solution:

Solid Na_2CO_3 (21) and process water (22) are added to mixing tank (23) to prepare Na_2CO_3 solution in the proper concentration range of (10-30) wt % which are required to perform present study.

2.3.2. Preparation of NO_2/Air gas mixture:

The valves of compressed air line (7) and NO_2 gas line (8) are opened in order to measured their volumetric flow rates by using calibrated air and NO_2 rotameters (9), valves in compressed nitrogen line (6) is closed before and after nitrogen rotameter in this case. The NO_2/Air gas mixture (11) is prepared to proper required gas mixture flow rate in the range of (20-30) m^3/h, NO_2 gas inlet concentrations in the range of (500-2500) ppm by using the valves before their rotameters, and by mixing them in mixing chamber (10). Volume percent used to determine NO_2 gas inlet concentration in the gas mixture (0.05 v/v % = 500 ppm.).

Experiments of absorption of NO_2 gas from NO_2/Air gas mixture into Na_2CO_3 solution have been carried out using the mentioned various operating parameters by using experimental apparatus as shown in Figure 1, according to experimental design plan seen in Table 1. The gas mixture (11) enters the packed column (1) from lower part, while Na_2CO_3 solution from solution tank (25) by feeding pump (24) enters the upper part of the column. The heat exchanger (2) is maintain the desired temperature constant in packed column (1) during the all experiments runs by circulation water [(19), and (20)] from and to thermostat water bath (26) through the heat exchanger (2). Gas mixture from the top of column enters the condenser (15) to condense any liquid drops with it by cold water (16). The liquid (14) returns back to upper part of the column as recycle liquid or drain out from drain line (35). The NO_2 gas concentration in dry outlet gas mixture is measured by NO_2-gas analyzer (18), then the gas mixture (12) to atmosphere air with few traces of NO_2 gas. In the column, the liquid temperature measured by temperature gage (3), while the pH of the liquid is measured by digital pH-meter (5), the value was in the range of (pH = 6.8- 7.3). The liquid (28) contains ($NaNO_3$ + $NaNO_2$) solution from downer part of column sent to solution tank (27).The CO_2 gas (29) evolves to atmosphere air. In stirred tank (30) there is ($NaNO_3$and $NaNO_2$) solution, it is difficult to separate them from each other, for that reason (5-7 wt %) HNO_3 acid (31) is added to the stirred tank (30). In the tank, the dilute HNO_3 acid reacts with $NaNO_2$ solution to produce $NaNO_3$ solution and NO gas. The NO gas (32) sends to HNO_3 concentrated acid production plant to oxides it to NO_2 gas in presence of platinum as catalyst. The NO_2 gas used to producing nitric acid, while the NaNO3 solution (34) from tank (30) is transfer by using solution pump (33) to sub plant belongs to HNO_3 acid plant for concentration, crystallization, draying, and milling to produce powder $NaNO_3$, which is demand product.

2.4. Absorption of NO_2 gas from NO_2/N_2 gas mixture into Na_2CO_3 solution:

In order to check the effect of oxidation on the Absorption efficiency of NO_2 gas absorption into Na_2CO_3 solution in packed column, experiments were performed by using NO_2/N_2 gas mixture instead of NO_2/Air gas mixture according to experimental design plan seen in Table 1, and by using the same experimental apparatus shown in Figure 1.

2.4.1. Preparation of Na_2CO_3 solution:

Na_2CO_3 solution in the concentration range of (10-30) wt % is prepared by the same manner mentioned in section 2.3.1.

2.4.2. Preparation of NO_2/N_2 gas mixture:

From nitric acid plant, compressed nitrogen gas (N_2) and nitrogen dioxide gas (NO_2) are coming to experimental apparatus via lines (6) and (8) respectively after their valves are opening and closing the valve of compressed air line (7). Volumetric flow rates of N_2 gas and NO_2 gas are measured by using their calibrated rotameters. The amount of volumetric flow rates of N_2 gas and NO_2 gas are regulated by valves fixed on their lines before the rotameters. The NO_2/N_2 gas mixture flow rate in line (11) and the inlet NO_2 gas concentration are obtained by mixing the required amounts of flow rates of N_2 gas and the NO_2 gas in mixing chamber (10) by volume relation. The gas mixture flow rate and NO_2 gas inlet concentration in gas mixture were in the range of (20-30) m^3/h and (500-2500) ppm. respectively.

Table 1: Experimental design plan for absorption of NO_2 gas from gas mixture into Na_2CO_3 solution.

Run No.	**Gas mixture flow rate (Q_G)**	**NO_2 gas inlet concentration (Y_{NO2})**	**Na_2CO_3 solution concentration (C_{Na2CO3})**	**Experiment temperature (T)**	**Liquid holdup in the column (V_L)**
	(m^3/h)	**(ppm)**	**(wt %)**	(℃)	**(m^3)**
1	20	500	30	50	0.020
2	20	2500	10	50	0.020
3	30	2500	10	50	0.030
4	25	1500	20	40	0.025
5	30	500	10	30	0.020
6	30	500	30	30	0.020
7	20	500	30	50	0.030
8	25	1500	20	40	0.025
9	20	2500	10	30	0.030
10	20	500	10	50	0.020
11	20	2500	30	30	0.030
12	30	2500	30	50	0.030
13	20	500	10	30	0.030
14	20	500	10	30	0.020
15	30	2500	30	50	0.020
16	30	500	30	30	0.030
17	30	2500	10	30	0.020
18	25	1500	20	40	0.025
19	20	500	30	30	0.030
20	30	1500	10	30	0.030
21	30	500	30	50	0.020
22	20	2500	30	50	0.030
23	30	500	10	50	0.030
24	20	2500	10	50	0.030
25	20	2500	30	50	0.020
26	30	2500	30	30	0.020
27	30	500	30	50	0.030
28	30	500	10	50	0.020
29	30	2500	10	50	0.020

30	30	2500	30	30	0.030
31	20	2500	30	30	0.020
32	20	500	30	30	0.020
33	30	500	10	30	0.030
34	20	500	10	50	0.030
35	20	2500	10	30	0.020

III. Results and Discussion

The absorption of NO_2 gas from **NO_2/Air** gas mixture (***a***) into sodium carbonate (Na_2CO_3) solution were carried out according to experimental design plan in Table 1 with the variation of gas mixture flow rate (Q_G), NO_2 gas inlet concentration (Y_{NO2}), experimental temperature (T), Na_2CO_3 solution concentration (C_{Na2CO3}), and liquid holdup in the column (V_L).

In order to check the influence of oxidation on the Absorption efficiency (η) of NO_2 gas, experiments were performed by using **NO_2/N_2** gas mixture (***b***) instead of **NO_2/Air** gas mixture (***a***) using the same experiment design plan presented in Table 1

3.1 Definition of Absorption efficiency:

The NO_2 Absorption efficiency (η) was defined as [2, 15]:

$$\eta = \frac{Y_{NO2,in} - Y_{NO2,out}}{Y_{NO,in}} \text{ x } 100 \quad (5)$$

Where,

η = Absorption efficiency in (%).

$Y_{NO2,in}$ = NO_2 gas inlet concentration in gas mixture in (ppm).

$Y_{NO2,out}$ = NO_2 gas outlet concentration in gas mixture in (ppm).

Absorption efficiency (η) was calculated by using equation (5). The Absorption efficiency of NO_2 gas absorption from gas mixture (***a***) was in the range of **η = 60.80- 89.43 %,** and the Absorption efficiency of NO_2 gas absorption from gas mixture (***b***) was in the range of **η = 60.10-91.50 %.** The results of Absorption efficiency are summarized in Table 2 and Table 3. The η increased with the increase in $Y_{NO2,in}$, C_{NaCO3}, and V_L, and decreased with an increase in Q_G, and T. The biggest effect of operating parameters on Absorption efficiency was the gas mixture flow rate (**Q_G**), and smallest one was the liquid holdup in the column (**V_L**).

Table 2: Data base of experimental design and results of NO_2 gas absorption from gas mixture (NO_2/Air) into Na_2CO_3 solution.

Run No.	Gas mixture flow rate (Q_G)	NO_2 Gas inlet concentration (Y_{NO2})	Na_2CO_3 solution concentration (C_{Na2CO3})	Experiment temperature (T)	Liquid holdup in the column (V_L)	Absorption efficiency (η)
	(m^3/h)	(ppm)	(wt %)	(℃)	(m^3)	(%)
1	20	500	30	50	0.020	75.39
2	20	2500	10	50	0.020	79.72
3	30	2500	10	50	0.030	81.55
4	25	1500	20	40	0.025	76.83
5	30	500	10	30	0.020	63.90
6	30	500	30	30	0.020	72.20
7	20	500	30	50	0.030	76.60
8	25	1500	20	40	0.025	75.12
9	20	2500	10	30	0.030	85.78
10	20	500	10	50	0.020	62.52

11	20	2500	30	30	0.030	89.43
12	30	2500	30	50	0.030	81.30
13	20	500	10	30	0.030	70.20
14	20	500	10	30	0.020	68.33
15	30	2500	30	50	0.020	79.10
16	30	500	30	30	0.030	72.44
17	30	2500	10	30	0.020	79.32
18	25	1500	20	40	0.025	74.10
19	20	500	30	30	0.030	77.77
20	30	1500	10	30	0.030	81.55
21	30	500	30	50	0.020	65.55
22	20	2500	30	50	0.030	83.38
23	30	500	10	50	0.030	62.90
24	20	2500	10	50	0.030	81.67
25	20	2500	30	50	0.020	86.16
26	30	2500	30	30	0.020	80.13
27	30	500	30	50	0.030	68.70
28	30	500	10	50	0.020	60.80
29	30	2500	10	50	0.020	77.92
30	30	2500	30	30	0.030	82.50
31	20	2500	30	30	0.020	88.40
32	20	500	30	30	0.020	74.92
33	30	500	10	30	0.030	65.80
34	20	500	10	50	0.030	64.86
35	20	2500	10	30	0.020	83.62

Table 3: Data base of experimental design and results of NO_2 gas absorption from gas mixture (NO_2 /N_2) into Na_2CO_3 solution.

Run No.	**Gas mixture flow rate (Q_G)**	**NO_2 gas inlet concentration (Y_{NO2})**	**Na_2CO_3 solution concentration (C_{Na2CO3})**	**Experiment temperature (T)**	**Liquid holdup in the column (V_L)**	**Absorption efficiency (η)**
	(m^3/h)	**(ppm)**	**(wt %)**	**(°C)**	**(m^3)**	**(%)**
1	20	500	30	50	0.020	75.20
2	20	2500	10	50	0.020	80.01
3	30	2500	10	50	0.030	81.02
4	25	1500	20	40	0.025	77.20
5	30	500	10	30	0.020	68.70
6	30	500	30	30	0.020	69.90
7	20	500	30	50	0.030	77.20
8	25	1500	20	40	0.025	74.90
9	20	2500	10	30	0.030	91.50
10	20	500	10	50	0.020	60.10

11	20	2500	30	30	0.030	90.10
12	30	2500	30	50	0.030	80.90
13	20	500	10	30	0.030	71.20
14	20	500	10	30	0.020	68.10
15	30	2500	30	50	0.020	78.10
16	30	500	30	30	0.030	75.80
17	30	2500	10	30	0.020	79.90
18	25	1500	20	40	0.025	73.93
19	20	500	30	30	0.030	78.11
20	30	1500	10	30	0.030	81.20
21	30	500	30	50	0.020	63.10
22	20	2500	30	50	0.030	82.88
23	30	500	10	50	0.030	63.20
24	20	2500	10	50	0.030	81.21
25	20	2500	30	50	0.020	86.90
26	30	2500	30	30	0.020	80.30
27	30	500	30	50	0.030	68.80
28	30	500	10	50	0.020	61.20
29	30	2500	10	50	0.020	80.00
30	30	2500	30	30	0.030	81.98
31	20	2500	30	30	0.020	86.00
32	20	500	30	30	0.020	75.10
33	30	500	10	30	0.030	65.23
34	20	500	10	50	0.030	64.55
35	20	2500	10	30	0.020	83.42

3.2 Correlation models of Absorption efficiency:

Computer program (Statgraphics/Experimental Design) were used to estimate the fitted linear models of Absorption efficiency (η) of NO_2 gas absorption from different gas mixtures into Na_2CO_3 solution in packed column in terms of operating parameters: Q_G, Y_{NO2}, T, C_{NaCO3}, and V_L.

The model of η in case of NO_2 gas absorption from NO_2/Air gas mixture is:

$$\eta = 73.091 - 0.152\, T - 0.454\, Q_G + 180.937\, V_L + 0.263\, C_{Na2CO3} + 0.007\, Y_{NO2} \quad (6)$$

While, the model of η in case of NO_2 gas absorption from NO_2/N_2 gas mixture as follows:

$$\eta = 74.229 - 0.194\, T - 0.452\, Q_G + 242.813\, V_L + 0.218\, C_{Na2CO3} + 0.007\, Y_{NO2} \quad (7)$$

The validity range for the models in equation (6) and equation (7) are:

$30 \leq \boldsymbol{T}$ □ 50 ℃

$20 \leq \boldsymbol{Q_G}$ □ 30 m^3/h

$0.02 \leq \boldsymbol{V_L}$ □ 0.03 m^3

$10 \leq \boldsymbol{C_{Na2CO3}}$ □ 30 wt %

$500 \leq \boldsymbol{Y_{NO2}}$ □ 2500 ppm

The accuracy of the $\boldsymbol{\eta}$ models is ∓ 2.3 %.

The linear models in equation (6) and equation (7) were adequate, and the operating parameters were significant and were in ordered of $\boldsymbol{Y_{NO2}} > \boldsymbol{C_{Na2CO3}} > \boldsymbol{Q_G} > \boldsymbol{T} > \boldsymbol{V_L}$, and in ordered of $\boldsymbol{Y_{NO2}} > \boldsymbol{Q_G} > \boldsymbol{C_{Na2CO3}} > \boldsymbol{T} > \boldsymbol{V_L}$ respectively. The interactions of operating parameters were negligible.

3.3. Comparison of Absorption efficiencies:

The Pareto Chart of Absorption efficiency ($\boldsymbol{\eta}$) of NO_2 gas absorption from NO_2/Air gas mixture (***a***), and from NO_2/N_2 gas mixture (***b***) could be seen in Figure 2 and Figure 3.

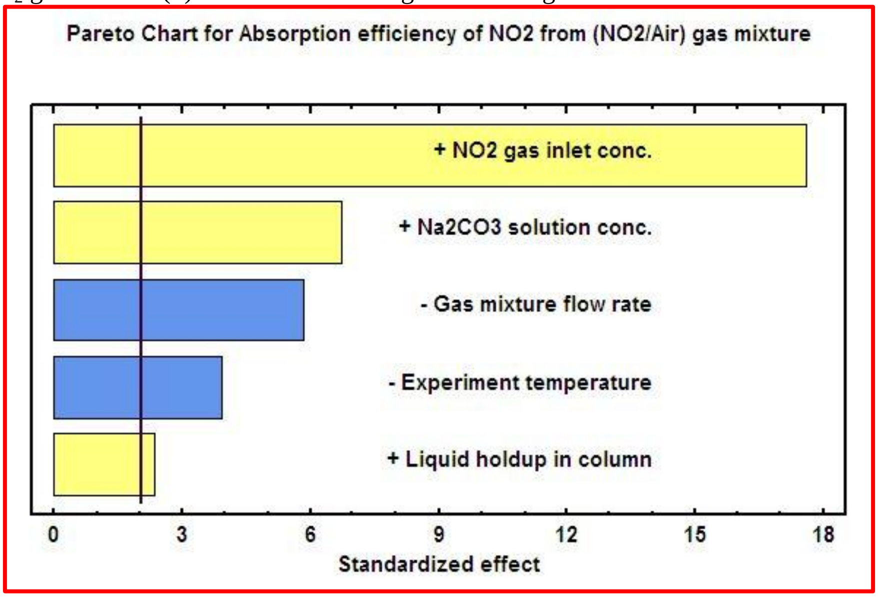

Figure 2: Effects of operating parameters on Absorption efficiency of NO_2 gas

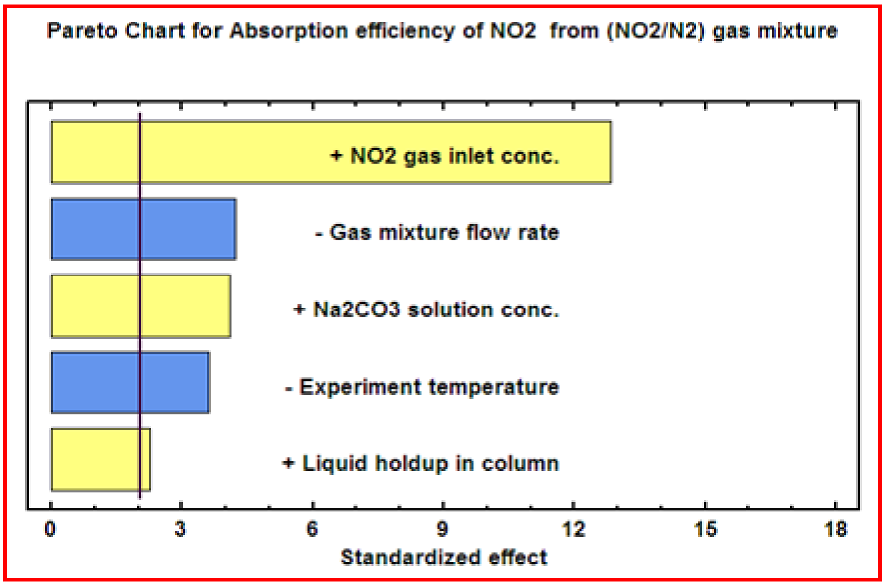

Figure 3: Effects of operating parameters on Absorption efficiency of NO_2 gas

The main effects of operating parameters on Absorption efficiency of NO_2 gas absorption from gas mixers NO_2/Air (***a***) and from NO_2/N_2 (***b***) are seen in following Figures (4, 5):

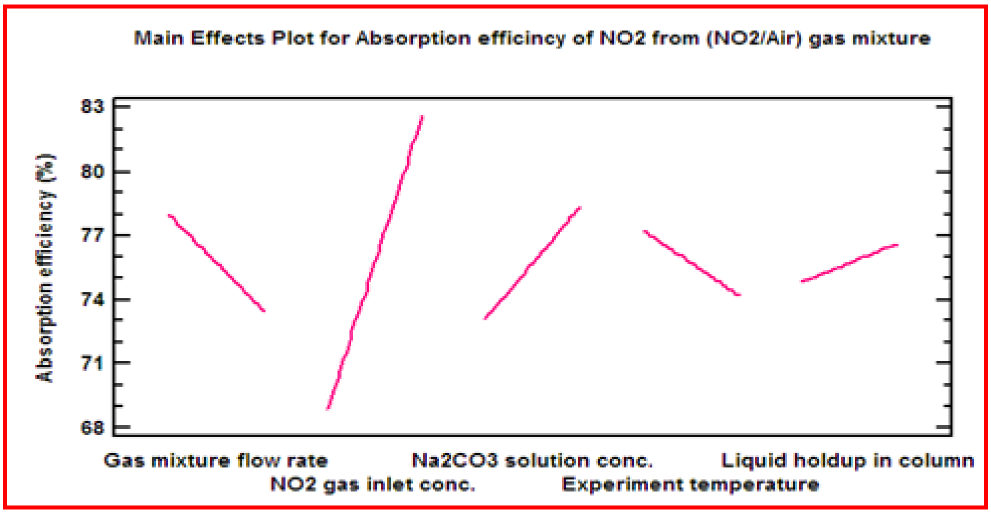

Figure 4: Main effects of operating parameters on Absorption efficiency of NO_2

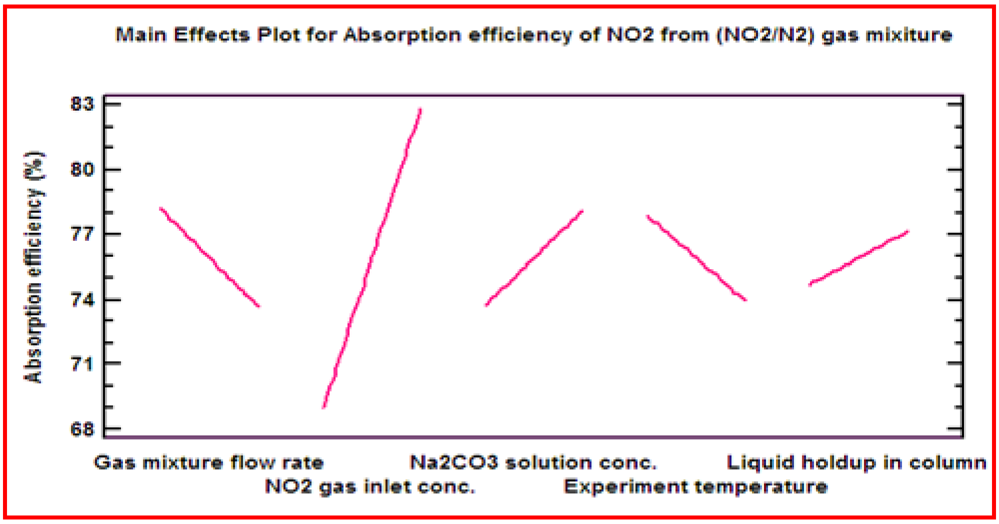

Figure 5: Main effects of operating parameters on Absorption efficiency of NO_2

The observed and predicted Absorption efficiency of NO_2 gas absorption from (NO_2/Air and NO_2/N_2) gas mixture are represent in following Figures (6, and 7) respectively:

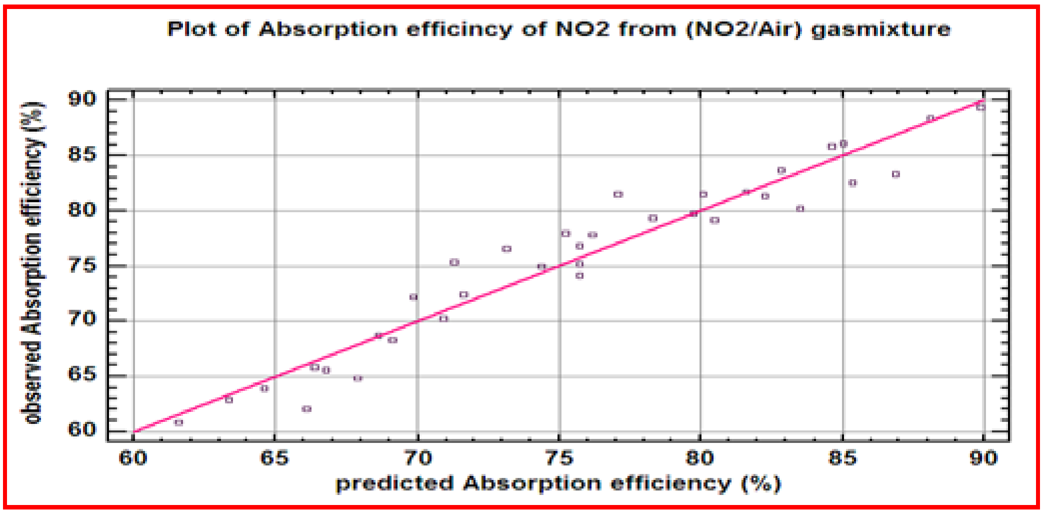

Figure 6: Observed vs. predicted Absorption efficiency of NO_2 gas.

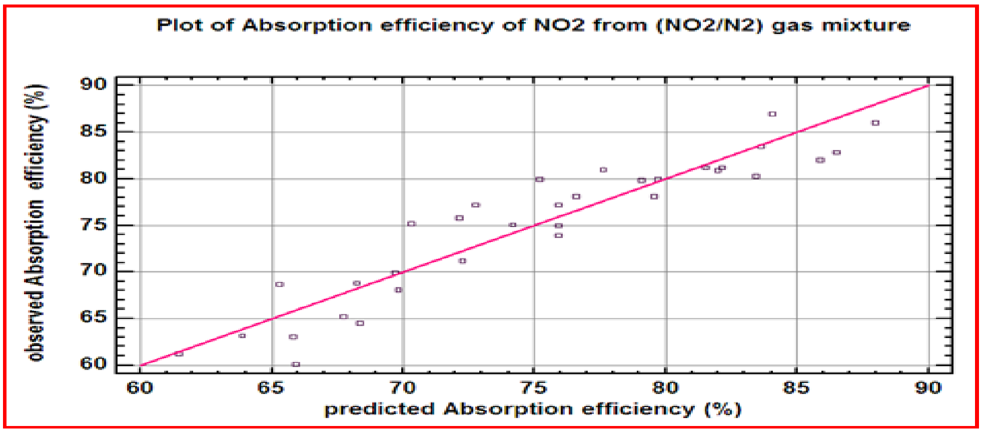

Figure 7: Observed vs. predicted Absorption efficiency of NO_2 gas.

Effects of (Q_G, Y_{NO2}, T, C_{NaCO3}, and V_L) on Absorption efficiency (η) of NO_2 gas from NO_2/Air gas mixture (***a***), and gas NO_2/N_2 gas mixture (***b***) as shown in Figures (8, 9):

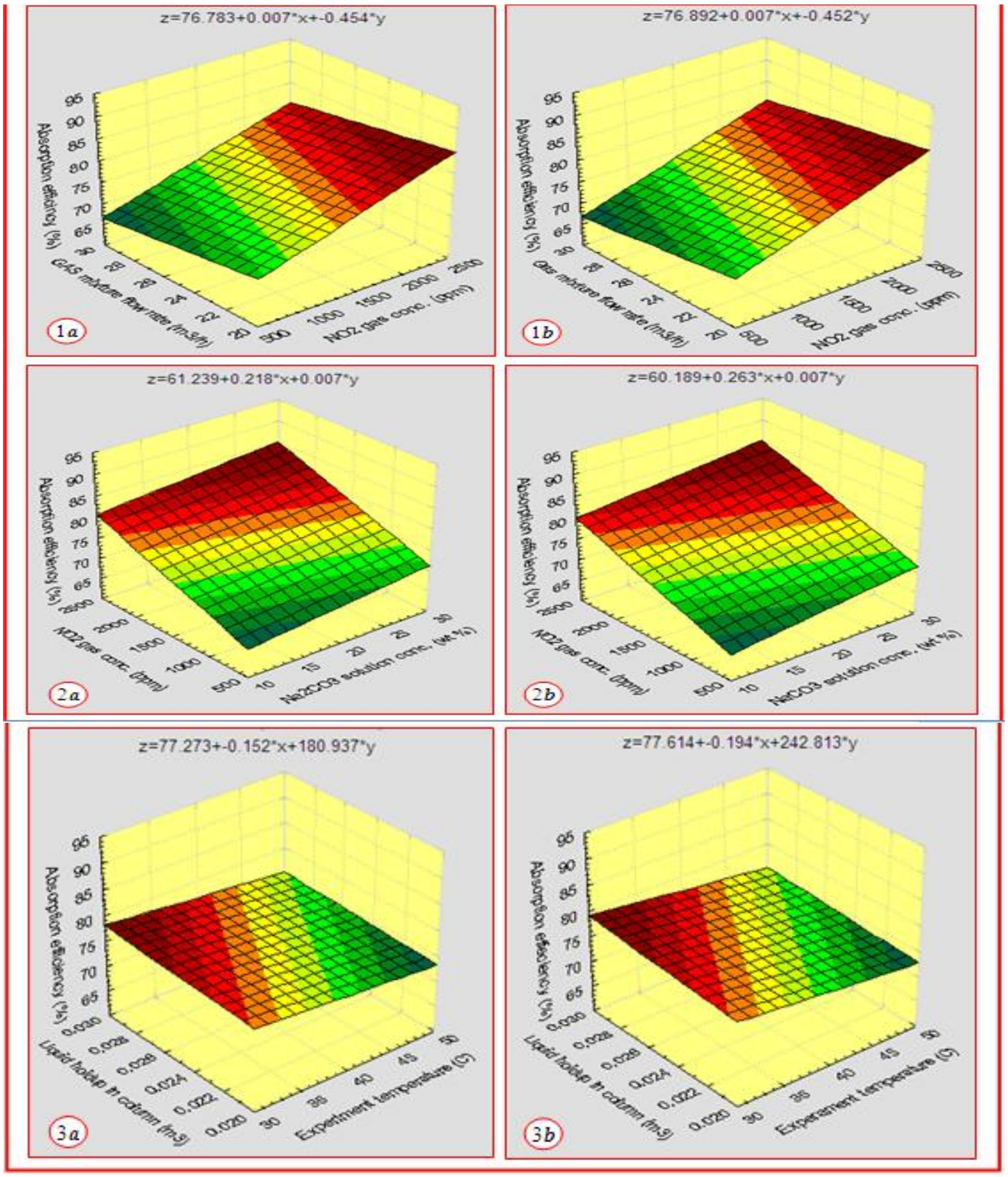

Figure 8: Effects of operating parameters on Absorption efficiency on of NO_2

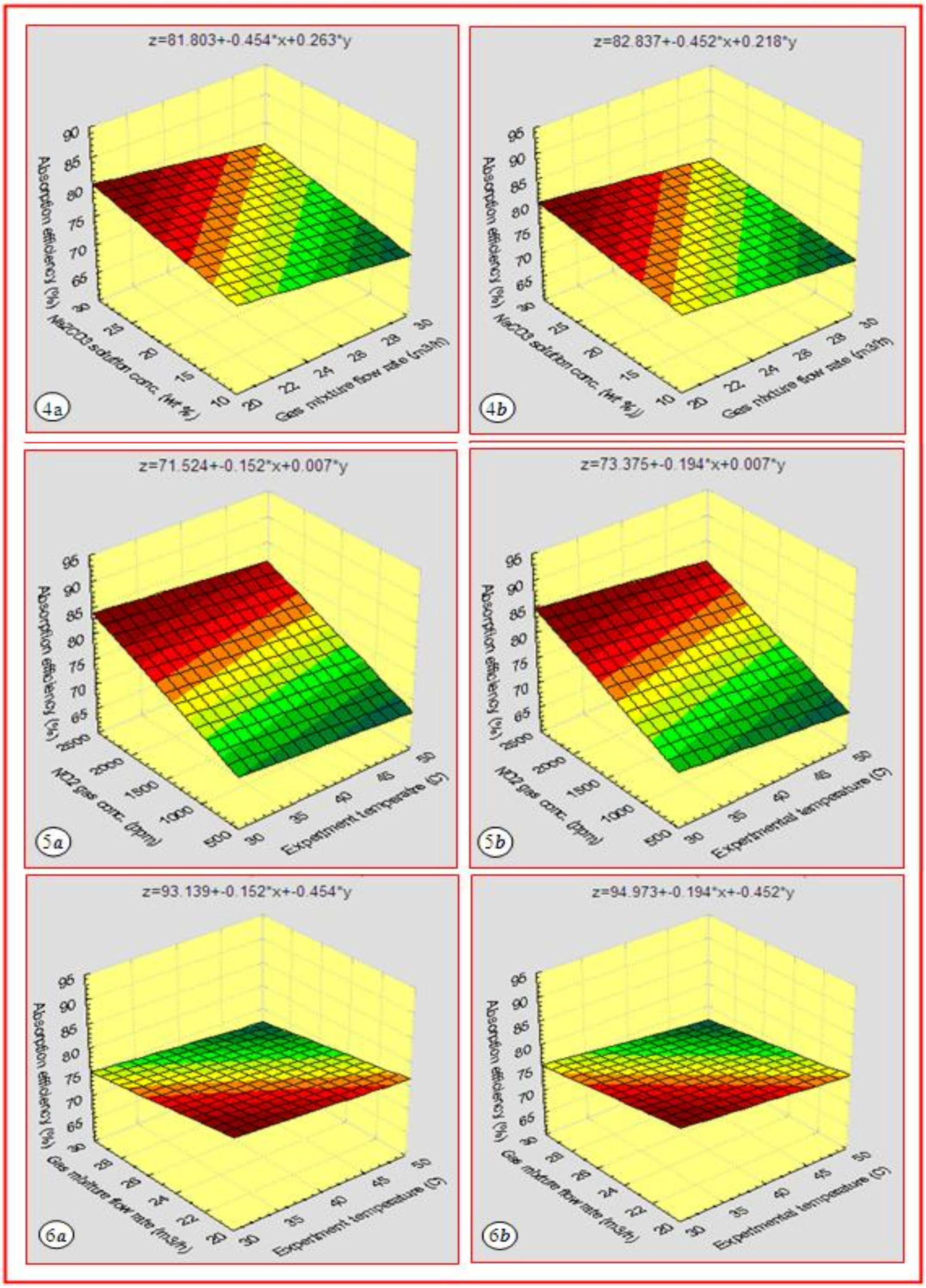

Figure 9: Effects of operating parameters on Absorption efficiency on of NO_2

Figures (8, and 9) are represent the influences of operating parameters (***Q_G*, *Y_{NO2}*, *C_{NaCO3}*, *T*,** and ***V_L***) on Absorption efficiency (***η***) of NO_2 gas absorption from gas mixtures (***a*** and ***b***). In general the ***η*** increases with increasing in (***Y_{NO2}*, *C_{NaCO3}*,** and ***V_L***), and decreases with increasing of (***Q_G*,** and ***T***),

3.4. Optimal Response:

The optimum operating parameters for present work were obtained using the computer program to analyze the experimental results. The goal of optimizing was to maximize the Absorption efficiency (***η***) of NO_2 gas absorption from different gas mixtures. The results of optimizing were summarized in Table 4:

Table 4: Optimum operating parameters and optimum Absorption efficiency of NO_2 gas.

Operating parameters	Low value	High value	Optimum value
Gas mixture flow rate (m^3/h):	20	30	**20**
NO_2 gas inlet conc. (ppm):	500	2500	**2500**
Na_2CO_3 solution conc. (wt %):	10	30	**30**
Experimental temperature (℃):	30	50	**30**
Liquid hold up in column (m^3):	0.02	0.03	**0.03**
Absorption efficiency of NO_2 gas from NO_2/Air gas mixture (%):			**89.88**
Absorption efficiency of NO_2 gas from NO_2/N_2 gas mixture (%):			**90.38**

IV. Conclusions

* Absorption of NO_2 gas from (NO_2/Air or NO_2/N_2) gas mixture into Na_2CO_3 solution was carried out in pilot scale packed column. The Absorption efficiency (η) of NO_2 gas was measured at various operating conditions (Q_G, Y_{NO2}, T, C_{NaCO3}, and V_L) according to experimental design. The measured Absorption efficiency was in the range of η = 60.80-89.43 %, and of η = 60.10-91.50 % respectively. The η could be improved and increases by increasing in the Y_{NO2}, C_{NaCO3}, and V_L and with decreasing of Q_G, and T.
* A negligible influence of oxidation on Absorption efficiency was observed in this work with a maximum deviation of **2.2 %**. For economical reasons we conclude to absorb NO_2 gas from gas mixture by using **Air** as carrier gas instead of N_2 in the gas mixture.
* A computer program (Statgraphics/Experimental Design) was used to estimate the linear fitted models of Absorption efficiency (η) in terms of operating conditions (Q_G, Y_{NO2}, T, C_{NaCO3}, and V_L. Both linear fitted models of η were adequate, and operating parameters were significant, while the interactions were negligible. The accuracy of Absorption efficiency models is $\pm$ **2.3 %.**
* Using the same computer program the optimum operating conditions were obtained with values of Q_G = **20** m^3/h, Y_{NO2} = **2500** ppm, C_{NaCO3} = **30** wt %, T = **30** ℃, and V_L = **0.03** m^3. The optimum Absorption efficiency (η) was in values of **89.88** % and **90.38** % respectively.
* On the base of results of measured Absorption efficiency, we conclude to scaling up the size of the pilot plant used in this study by 3-4 times to commercial size plant and using the optimum operating parameters obtained in future work.

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