Removal Efficiency in Industrial Scale Liquid Jet Ejector for Chlorine-Aqueous Caustic Soda System

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***Abstract*— The prediction of removal efficiency of gas in liquid jet ejector is an important factor as it influences the design of the mass transfer equipment. The major factors which affect the efficiency of jet ejector are flow rates like gas and liquid and the concentration of absorbing liquid and solute in the gas. This paper deals with statistical modeling for removal efficiency of gas in multi nozzle jet ejector for industry scale jet ejector. The developed model is based on statistical techniques to predict removal efficiency for variation in gas and liquid Concentration. The model is simulated using STATGRAPHICS PLUS 4.0 software for plotting the response surface. The same model is validated by experimental data of industry scale jet ejector.**

I. Introduction

Venturi scrubbers in general have been successfully employed for gas cleaning applications over the last five decades, as they show potential for meeting stringent emission standards. They are very efficient even for fine particulate removal. The removal efficiency is not only depending on scrubber geometry but also on the flow rates. There are some models which are available for the same and they are based on statistical techniques. The collection efficiency model used in the algorithm is described in detail elsewhere (Ananthanarayanan and Viswanathan, 1998 and 1999; Agrawal, 2012 and2013).

The present study focuses on multi nozzle liquid jet ejector which is one type of venturi scrubber. Liquid jet ejectors are those which are using a mechanical pump to generate a high velocity fluid jet. This fluid jet creates suction and another fluid is entrained into it by transfer of momentum.

Over and above compact construction the liquid jet ejectors can generate high interfacial area and can handle very hot, wet, inflammable and corrosive gases.

The major factors which affect the efficiency of liquid jet ejector are liquid flow rate, gas flow rate, the concentration of absorbing liquid and the concentration of the solute in the gas. Ravindram and Pyla (1986) proposed a theoretical model for the absorption of SO_2 and CO_2 in dilute $NaOH$ based on simultaneous diffusion and irreversible chemical reaction for predicting the amount of gaseous pollutant removed. Agrawal (2012, 2013) proposed a statistical model for absorption of chlorine into aqueous NaOH solution.

Many researchers (Volgin et al., 1968; Ravindram and Pyla, 1986; Cramers et al., 1992, 2001; Gamisans et al., 2004, 2002; Mandal, 2003a, 2003b, 2004, 2005, 2005a, 2005b; Balamurugan et al., 2007, 2008; Utomo et al., 2008; Yadav, 2008; Li and Li, 2011.) have reported different theories and correlations to predict scrubbing efficiency of jet ejectors.

Uchida and Wen (1973) developed a mathematical model to predict the removal efficiency of SO_2 into water and alkali solution. The simulated results of their model were compared with experimental results and they found that there is a good agreement with the experimental results. They have also found enhancement factor to predict rate of the chemical absorption.

Gamisans et al. (2002) evaluated the suitability of an ejector-venturi scrubber for the removal of two common stack gases, sulphur dioxide and ammonia. They studied the influence of several operating variables for different geometries of venturi tube. A statistical approach was presented by them to characterize the performance of scrubber by varying several factors such as gas pollutant concentration, gas flow rate and liquid flow rate. They carried out the computation by multiple regression analysis making use of the method of the least squares method. They have used commercial software package, STATGRAPHICS, to determine the multiple regression coefficients.

Less attention has been paid in the area of mathematical and statistical modeling. The statistical models have edge over other models due to their capacity to handle random data correctly. There are several techniques available to relate the controllable factors and experimental facts. Due to complex nature of affluent gases in terms of its concentration of constituents, temperature, quality and quantity, it requires experimentation to improve existing processes and to develop new ones.

This paper deals with factors affecting the efficiency of jet ejector to remove solute gases from the gas stream. The major factors which affect the efficiency of jet ejector are liquid flow rate, gas flow rate, the concentration of absorbing liquid and the concentration of the solute in the gas.

In this paper, we have made an attempt to develop statistical model based on non linear quadratic multiple regression analysis to predict removal efficiency of jet ejector for Cl_2-aqueous $NaOH$ system.

II. Mathematical Modelling

We have used the non linear quadratic relation between independent variables and dependent variables and is as follows:

$$Y = \Psi_0 + \sum_{i=1}^{n} \Psi_i X_i + \sum_{i=1}^{n}\sum_{j=1}^{n} \Psi_{ij} X_i X_j \ldots\ldots\ldots\ldots (1)$$

Here, Y is a response variable, X is the main factor; Ψ_0 is the constant value of the regression; Ψ_i is the linear coefficient; Ψ_{ii} is the quadratic coefficient and Ψ_{ij} is the interaction coefficient. When $i = j$; $\Psi_{ij} = \Psi_{ji}$ and $2\Psi_{ij} = \Psi'_{ij}$. The computation was carried out by non linear regression analysis making use of the generalized minimal residual method.

III. Experimental Results

The experimental work was carried in industrial scale multi nozzle jet ejector and is as follows

A. Experimental set up

1. The experimental Setup for industry scale jet ejector is shown schematically in Figure 2.

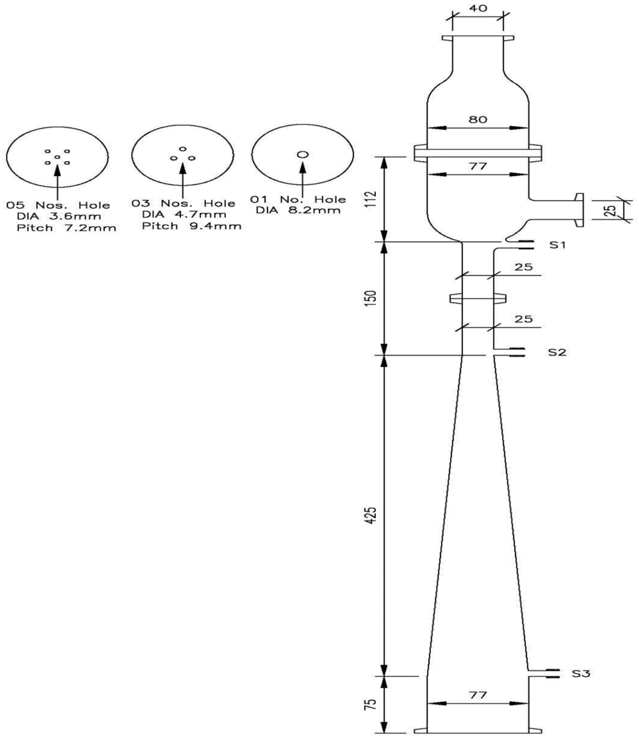

Fig. 1 Detail of the jet ejector used in experimental setup

These experiments were conducted on industrial stage ejector. The details of ejector are shown in Figure 1 and Table 1.

2. The schematic flow diagram as in Figure 2 is self indicative.
3. The ejector is having 3 sample point S1, S2 and S3. Sample S0 is drawn from tank T1 directly. The air flow rate is measured by using electronic anemometer. There is a rotameter for measuring Cl_2 flow rate and a soap film meter to calibrate the rotameter. There are two tanks T1 and T2. Tank T1 is used to prepare sodium hydroxide solution and tank T2 is ejector outlet tank. V1, V2, V3 and V4 are control valves. The pump P1 is provided to circulate sodium hydroxide solution through the ejector. Pressure gauge P1 is provided to measure the primary fluid pressure (water).

B. Experimental procedure

1. Before starting the experiment the rotameter for chlorine was calibrated by soap film meter.
2. The required nozzle plate was fitted.
3. The required sodium hydroxide concentration was prepared by circulating the solution and operating valve V5, V4, V2 and V3.

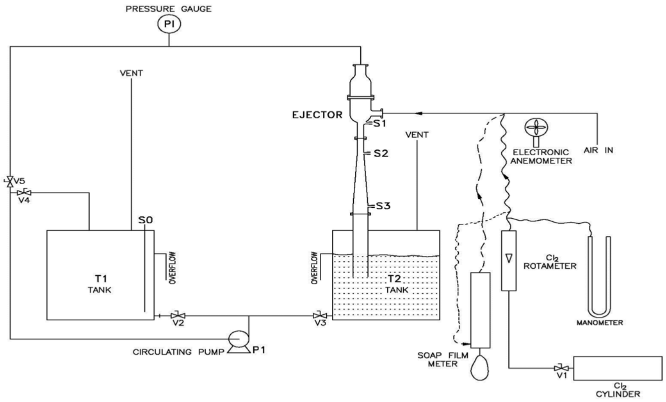

Fig. 2 Schamatic diagram of experimental setup

4. The primary fluid (aqueous $NaOH$ solutions) flow rate was adjusted to the required value by operating valve V5 and V4. The secondary air flow rate was measured by electronic anemometer. The flow rate is kept constant throughout the experiment.
5. The required chlorine rate was adjusted by operating valve V1. After the system reaches steady state the liquid sample S0, S1, S2 and S3 were drawn and analyzed.
6. The experiment was repeated for different concentrations of sodium hydroxide and chlorine and nozzle plates.

The procedure was repeated for different set of liquid concentration and gas concentration. The results are compiled.

The factors which affect the absorption efficiency are gas concentration and the scrubbing liquid concentration. In this work the jet ejector is operated on critical value of liquid flow rate. For a given geometry, reduction in the liquid flow rate will lead to reduction of induced gas flow rate. Therefore, in the present work the liquid flow rate is kept constant. Effect of C_{B0} and $C_{Ag,in}$ on the removal efficiency ($\%RE$) of the ejector have been investigated in this work.

TABLE I
DIMENSIONS OF EJECTORS

Nozzle diameter (mm)	D_N	8.2	4.7	3.7
Number of Nozzle (orifice)	n	1	3	5
Nozzle No.		N5	N6	N7
pitch *		$2D_N$		
Area ratio (appx) **	A_R	9.3		
Diameter of Throat/ mixing tube (mm)	D_T	25		
Length of Throat/ mixing tube *** (mm)	L_T	150		
Projection ratio #	P_R	4.5		
Angle of convergent	θ_{con}	well rounded		
Angle of divergence of conical diffuser ##	θ_{div}	7^0		
Length of the conical diffuser (mm)	L_d	425		
Diameter of the diffuser exit (mm)	D_C	77		
Diameter of the suction chamber (mm)	D_S	77		
Length of the suction chamber (mm)	L_S	122		
Distance between nozzle & commencement of throat (mm)	L_{TN}	112		
Diameter of secondary gas inlet (mm)	$D_{G,in}$	25		
Reference : : * Panchal (1991), ** Acharjee et al (1975), *** Biswas et al. (1975), # Yadav et a., (2008) ## Mukherjee et al. (1988)				

The experimental values for the operating variables used in the present work are presented and the experimental data are tabulated in Table 2 and 3

TABLE III
CODIFICATION OF THE OPERATING VARIABLES FOR THE STATISTICAL ANALYSIS

Code	Variable	Values
X_1	Gas concentration (kmole/m^3)	$(0.6\ to\ 4.3) \times 10^{-3}$
X_2	Liquid concentration (kmole/m^3)	0 – 0.95
Y	Removal efficiency (%)	0 – 100

TABLE IIIII
EXPERIMENTAL MATRIX FOR CHLORINE REMOVAL EFFICIENCY USING SETUP

Run No.	Nozzle No.	$10^3 C_{Ag,in}$ $(kmole/m^3)$	$10^3\ C_{B0}$ $(kmole/m^3)$	RE (%)
301	N5	2.95538	0.79	21.07
302		1.966803	0.79	43.18
303		1.475102	0.79	69.09
304		0.983402	0.79	97.88
321	N5	2.984934	0.57	47.42
322		1.986471	0.57	57.01
323		1.489853	0.57	57.01
324		0.993236	0.57	62.71
325	N5	2.984934	0.11	36.04
326		1.986471	0.11	34.20
327		1.489853	0.11	34.20
328		0.993236	0.11	34.20
305	N6	2.95538	0.79	17.24
306		1.966803	0.79	28.79
307		1.475102	0.79	19.19
308		0.983402	0.79	28.79
317	N6	2.95538	0.57	45.98
318		1.966803	0.57	57.58
319		1.475102	0.57	69.09
320		0.983402	0.57	63.33
329	N6	2.984934	0.11	49.32
330		1.986471	0.11	42.75
331		1.489853	0.11	38.00
332		0.993236	0.11	51.31
309	N7	2.95538	0.79	22.99
310		1.966803	0.79	28.79
311		1.475102	0.79	26.87
312		0.983402	0.79	23.03
313	N7	2.95538	0.57	19.16
314		1.966803	0.57	20.15
315		1.475102	0.57	19.19
316		0.983402	0.57	23.03
333	N7	2.984934	0.11	45.53
334		1.986471	0.11	62.71
335		1.489853	0.11	57.01
336		0.993236	0.11	45.61

TABLE IV
PARAMETERS FOR MULTIPLE REGRESSION ANALYSIS

Properties to be Operated	Nozzle N5 with no. of orifice 1	Nozzle N6 with no. of orifice 3	Nozzle N7 with no. of orifice 5
Adopted Technique	Nonlinear Regression	Nonlinear Regression	Nonlinear Regression
Dependent variable	Y	Y	Y
Independent variables	X_1, X_2	X_1, X_2	X_1, X_2
Function to be estimated	$b_1X_1 + b_2X_2$ $b_{11}X_1X_1 + b_{22}X_2X_2 + b_{12}X_1X_2$	$b_1X_1 + b_2X_2$ $b_{11}X_1X_1 + b_{22}X_2X_2 + b_{12}X_1X_2$	$b_1X_1 + b_2X_2$ $b_{11}X_1X_1 + b_{22}X_2X_2 + b_{12}X_1X_2$
Initial parameter estimates	b_1=0.1 b_2=0.1 b_{11}=0.1 b_{22}=0.1 b_{12}=0.1	b_1=0.1 b_2=0.1 b_{11}=0.1 b_{22}=0.1 b_{12}=0.1	b_1=0.1 b_2=0.1 b_{11}=0.1 b_{22}=0.1 b_{12}=0.1
Estimation method	Marquardt	Marquardt	Marquardt
	Estimation stopped due to convergence of residual sum of squares.	Estimation stopped due to convergence of residual sum of squares.	Estimation stopped due to convergence of parameter estimates.
Number of iterations	4	4	4
Number of function calls	26	26	25
Fitted model	$Y = 20.6505X_1 + 263.417X_2 - 4.09009X_1X_1 \pm 293.901X_2X_2 \pm 16.134X_1X_2$	$Y = 67.9698X_1 - 99.2834X_2 - 15.4581X_1X_1 + 95.9406X_2X_2 \pm 17.0609X_1X_2$	$Y = 17.4129X_1 + 166.782X_2 - 0.923805X_1X_1 \pm 88.6827X_2X_2 \pm 19.0502X_1X_2$

IV. RESULTS AND INTERPRETATION

Statistical analysis

STATGRAPHICS Plus 4.0 is used to predict the removal efficiency (Y) using statistical model (equation 1) for the nozzles N5, N6 and N7.The results are summarized in Table 4 and 5. Table 4 demonstrates the parameters as outcome of simulated results of STATGRAPHICS plus 4.0. The regression coefficients of fitted models are summarized in table 5.

The analysis of variance (ANOVA) for the operational variables C_{B0} and $C_{Ag,in}$ indicate that removal efficiency is well described by nonlinear quadratic models. The convergence is obtained successfully after 4 iterations for estimation of regression coefficients.

Furthermore, the statistical analysis showed that both factors (C_{B0} and $C_{Ag,in}$) had significant effects on the response (RE) and the liquid concentration is more significant between two.

It may be observed that fitted models do not contain the independent term (Ψ_0). This implies that the removal efficiency (RE) is a function of the factors considered only.

TABLE V
REGRESSION COEFFICIENT FROM MULTI REGRESSION ANALYSIS

Parameters	Nozzle N5 with no. of orifice 1	Nozzle N6 with no. of orifice 3	Nozzle N7 with no. of orifice 5
b_1	20.6505	67.9698	17.4129
b_2	263.417	- 99.2834	166.782
b_{11}	- 4.09009	- 15.4581	- 0.923805
b_{22}	$\pm$ 293.901	+ 95.9406	$\pm$ 88.6827
b_{12}	$\pm$ 16.134	$\pm$ 17.0609	$\pm$ 19.0502

Tests are run to determine the goodness of fit of a model and how well the non linear regression plot approximates the experimental data. As the results are multi numerical they are presented in Figures 3 to 17 and Tables 6 to 17. Statistical tests like R-squared, R-squared (adjusted for d.f.), standard error of estimate, mean absolute error and Durbin-Watson statistic are covered. The tables containing confidence interval, analysis of variance (ANOVA) and residual analysis are also reported.

A. Results of statistical analysis in STATGRAPHICS Plus 4 for different nozzles:

Nozzle N5 with no. of orifice 1

TABLE VI
ESTIMATION RESULTS FOR NOZZLE N5

Para-meter	Estimate	Asymptotic Standard Error	Asymptotic 95.0%Confidence Interval	
			Lower	Upper
b1	20.6505	8.51199	0.522786	40.7782
b2	263.417	42.0993	163.868	362.966
b11	- 4.09009	2.9974	-11.1778	2.99764
b22	- 293.901	46.3188	-403.427	-184.374
b12	- 16.134	9.4982	-38.5937	6.32578

TABLE VII
ANALYSIS OF VARIANCE FOR NOZZLE N5

Source	Sum of Squares	Df	Mean Square
Model	24459.2	5	4891.85
Residual	414.451	7	59.2073
Total	24873.7	12	
Total (Corr.)	3082.07	11	

TABLE VIII
RESULTS OF STATISTICAL TESTS FOR NOZZLE N5

R-Squared	86.5528 %
R-Squared (adjusted for d.f.)	78.8687 %
Standard Error of Est.	7.69463
Mean absolute error	5.15937
Durbin-Watson statistic	1.95717

TABLE IX
RESIDUAL ANALYSIS FOR NOZZLE N5

Estimation	Validation
N	12
MSE	59.2073
MAE	5.15937
MAPE	14.7485
ME	0.271349
MPE	-0.381023

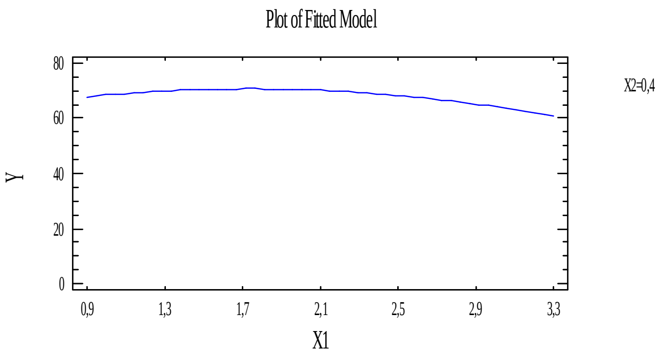

Fig. 3 Removal efficiency (Y) versus gas concentration (X_1) for constant liquid concentration ($X_2 = 0.4$) for nozzle N5

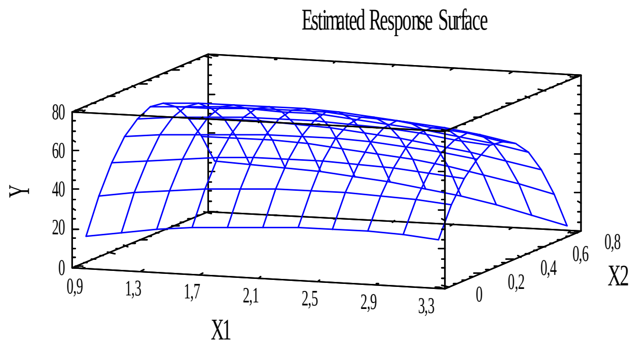

Fig. 4 Removal efficiency (Y) response surface versus gas concentration (X_1) and liquid concentration (X_2) for nozzle N5

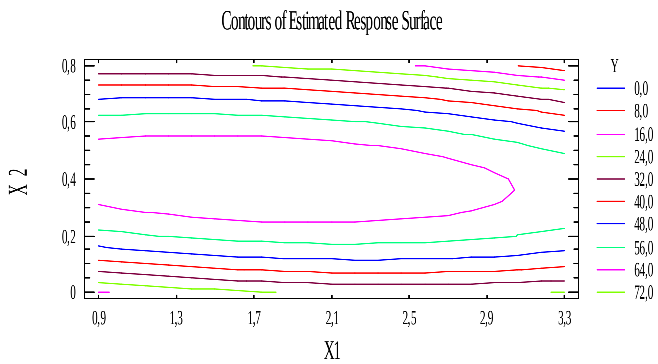

Fig. 5 Contour plot for removal efficiency (Y) for nozzle N5

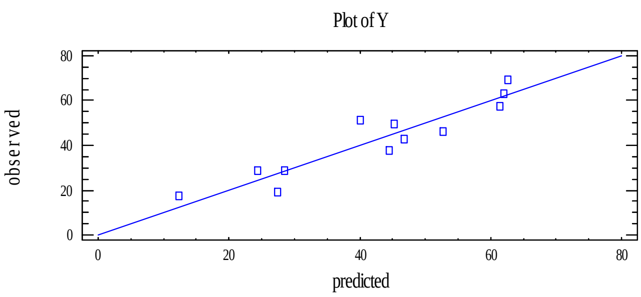

Fig. 6 Predicted removal efficiency (Y) versus observed removal efficiency (Y) for nozzle N5

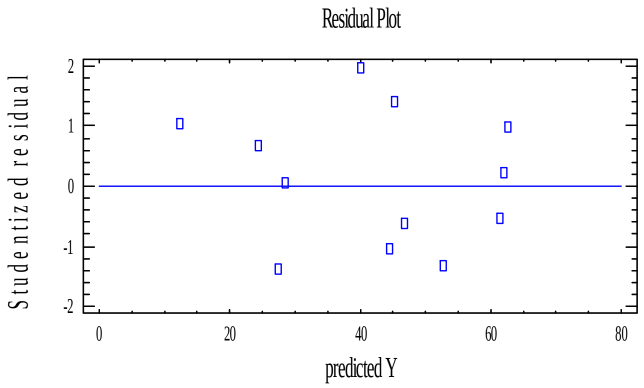

Fig. 7 Residual plot for nozzle N5

Nozzle N6 with no. of orifice 3

TABLE X
ESTIMATION RESULTS FOR NOZZLE N6

Parameter	Estimate	Asymptotic Standard Error	Asymptotic 95.0% Confidence Interval	
b1	67.9698	7.85634	48.746	87.1937
b2	-99.2834	42.5687	-203.445	4.87873
b11	-15.4581	2.76621	-22.2268	-8.6894
b22	95.9406	44.9216	-13.9789	205.86
b12	-17.0609	10.17	-41.9459	7.82414

TABLE XI
ANALYSIS OF VARIANCE FOR NOZZLE N6

Source	Sum of Squares	Df	Mean Square
Model	14787.6	5	2957.52
Residual	301.333	6	50.2222
Total	15088.9	11	
Total (Corr.)	2570.73	10	

TABLE XII
RESULTS OF STATISTICAL TESTS FOR NOZZLE N6

R-Squared	88.2783 %
R-Squared (adjusted for d.f.)	80.4638 %
Standard Error of Est.	7.08676
Mean absolute error	4.43336
Durbin-Watson statistic	2.20699

TABLE XIII
RESIDUAL ANALYSIS FOR NOZZLE N6

Estimation	Validation
N	11
MSE	50.2222
MAE	4.43336
MAPE	17.9304
ME	0.347291
MPE	-0.243646

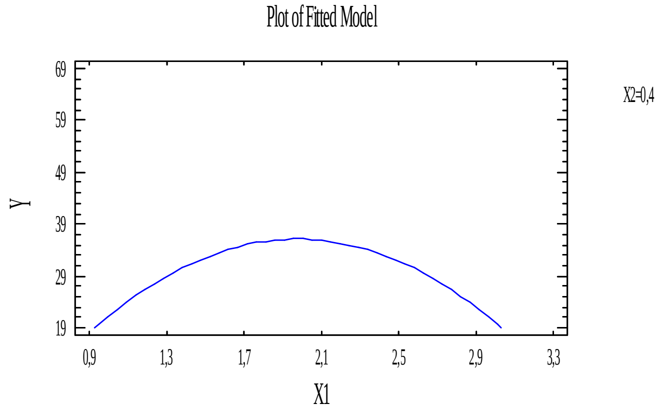

Fig. 8 Removal efficiency (Y) versus gas concentration (X_1) for constant liquid concentration ($X_2 = 0.4$) for nozzle N6

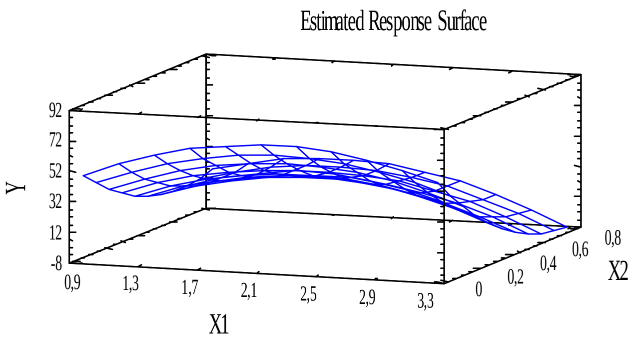

Fig. 9 Removal efficiency (Y) response surface versus gas concentration (X_1) and liquid concentration (X_2) for nozzle N6

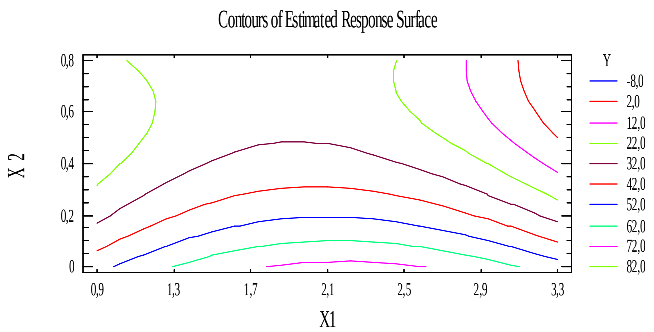

Fig. 10 Contour plot for removal efficiency (Y) for nozzle N6

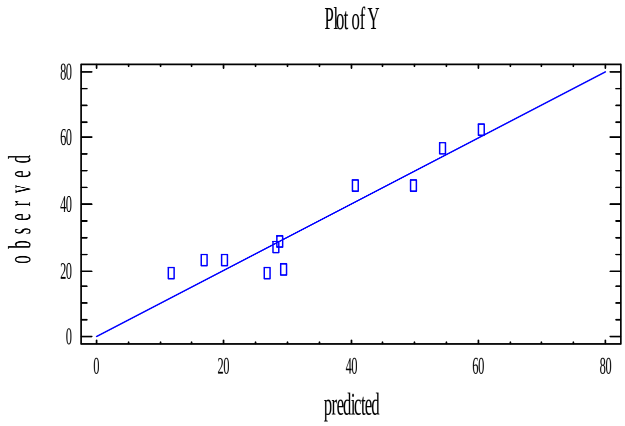

Fig. 11 Predicted removal efficiency (Y) versus observed removal efficiency (Y) for nozzle N6

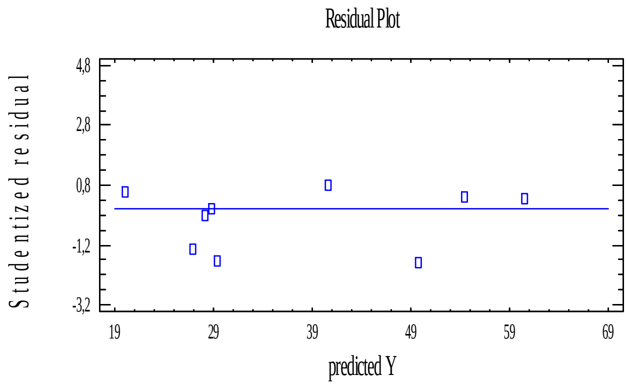

Fig. 12 Residual plot for nozzle N6

Nozzle N7 with no. of orifice 5

TABLE XIV
Estimation Results for nozzle N7

Parameter	Estimate	Asymptotic Standard Error	Confidence Interval Asymptotic 95.0%	
b1	17.4129	17.0439	-20.5635	55.3892
b2	166.782	82.0164	-15.962	349.527
b11	-0.923805	3.77345	-9.33159	7.48398
b22	-88.6827	92.8142	-295.486	118.121
b12	-19.0502	14.3113	-50.9379	12.8375

TABLE XV
Analysis of Variance for nozzle N7

Source	Sum of Squares	Df	Mean Square
Model	64257.3	5	12851.5
Residual	10632.7	10	1063.27
Total	74890.1	15	
Total (Corr.)	7155.6	14	

TABLE XVI
Results of statistical tests for nozzle N7

R-Squared	-48.5931 %
R-Squared (adjusted for d.f.)	0.0 %
Standard Error of Est.	32.6079
Mean absolute error	17.9461
Durbin-Watson statistic	1.67242

TABLE XVII
Residual Analysis for nozzle N7

Estimation	Validation
N	15
MSE	1063.27
MAE	17.9461
MAPE	43.8221
ME	4.7561
MPE	-14.4586

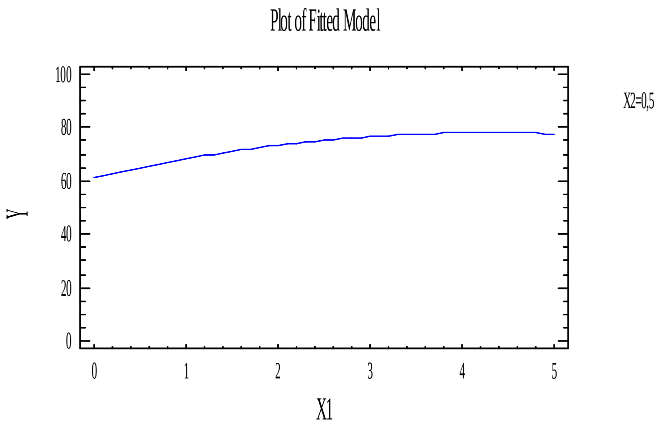

Fig. 13 : Removal efficiency (Y) versus gas concentration (X_1) for constant liquid concentration ($X_2 = 0.4$) for nozzle N7

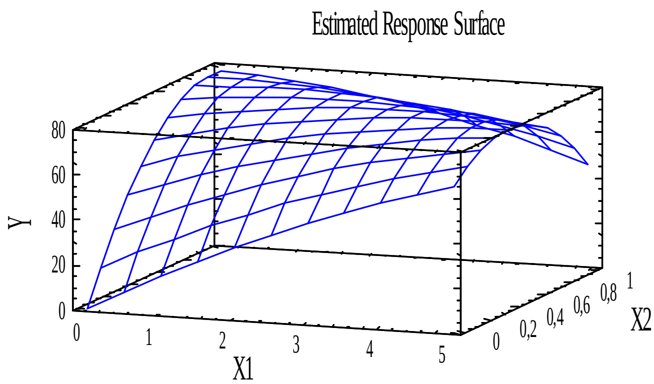

Fig. 14: Removal efficiency (Y) response surface versus gas concentration (X_1) and liquid concentration (X_2) for nozzle N7

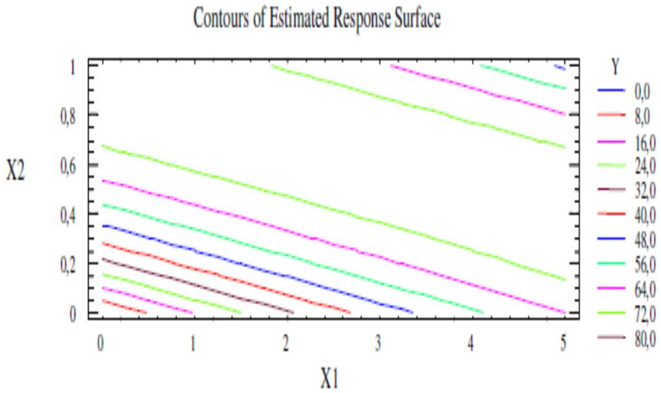

Fig. 15: Contour plot for removal efficiency (Y) for nozzle N7

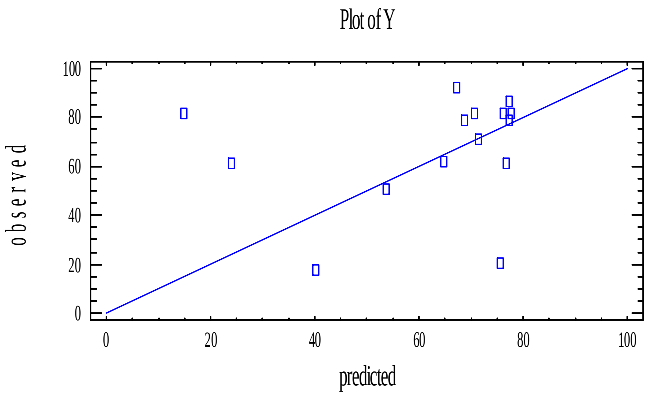

Fig. 16: Predicted removal efficiency (Y) versus observed removal efficiency (Y) for nozzle N7

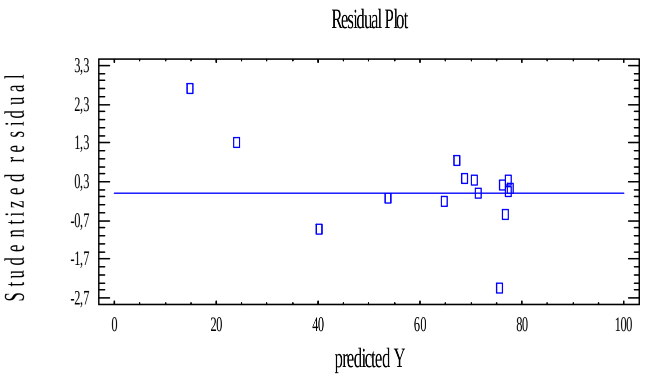

Fig. 17: Residual plot for nozzle N7

B. Interpretation of the results of statistical analysis in STATGRAPHICS Plus 4 for different nozzles

The results of fitted model, R-squared test, R-squared (adjusted for d.f.) test, standard error of estimates, mean absolute error and Durbin-Watson statistic test are summarized in Table 18 and may be interpreted as follow.

- The R-Squared statistic indicates that the model as fitted explains 86.55 %, 88.27% and 48.59% of the variability in Y for N5, N6 and N7 respectively.
- The adjusted R-Squared statistic which is more suitable for comparing models with different numbers of independent variables are 78.86%, 80.46% and 0.0% for , N5, N6 and N7 respectively
- The standard error of the estimate shows the standard deviation of the residuals to be 7.69, 7.08 and 32.60 for N5, N6 and N7 respectively. This value can be used to construct prediction limits for new observations.
- The mean absolute error (MAE) of 5.15, 4.43 and 17.94 is the average value of the residuals for N5, N6 and N7 respectively
- The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur. Similarly, since, the DW value is greater than 1.4 for N5, N6, N7 there is probably not any serious autocorrelation in the residuals.
- The output also shows asymptotic 95.0% confidence intervals for each of the unknown parameters.

Interpretation of figures (graphs)

For each set of experiment a mathematical model describing the effect of related variables on removal efficiency were derived and plotted in the Figures 3 to 17.These figures may be analyzed as follows:

Figures 4, 9 and 14 show the response surfaces for the removal of chlorine with variation in initial gas concentration and the scrubbing liquid concentration. The response surface shows removal efficiency varies from 50% to maximum value of 95%. It is observed that the effect of liquid concentration is greater than the gas concentration on RE.

Dependency of removal efficiency (RE) on gas concentration ($C_{Ag,in}$) and on initial concentration of liquid (C_{B0})

Figures 3, 8 and 13 are demonstrative curve of the fitted model showing the effect of $C_{Ag,in}$ on $\%RE$ at constant C_{B0}.The similar curve may be obtained and plotted for other value of C_{B0}.

Figures 5, 10 and 15 show the contours of estimated response surface for nozzle N5, N6 and N7 respectively. The presentation of contours is for visualization of the best region where $\% RE$ is maximum.

A common trend (except small variation for nozzle N6) may be observed that at higher concentration of C_{B0} there is decrease of $\%RE$ with increase in initial concentration of $C_{Ag,in}$. But a reverse trend is observed at lower C_{B0} i.e. $\%RE$ is increasing with increase in $C_{Ag,in}$. The reason for this behavior is that at higher C_{B0} the viscosity of liquid increases. The higher viscosity has adverse effect on diffusivity and physical solubility. And this effect becomes more appreciable at higher $C_{Ag,in}$ because of higher scrubbing load due to higher initial concentration of A ($C_{Ag,in} - C_{Ag,out}$).

TABLE XVIII
Summary of statically results

Nozzle no.	Fitted Model	R-Squared	R-Squared (adjusted for d.f.)	Standard Error of Est.	Mean absolute error	Durbin-Watson statistic
N5	$Y = 20.6505X_1 + 263.417X_2 - 4.09009X_1X_1 \pm 293.901X_2X_2 \pm 16.134X_1X_2$	86.5528 %	78.8687 %	7.69463	5.15937	1.95717
N6	$Y = 67.9698X_1 - 99.2834X_2 - 15.4581X_1X_1 + 95.9406X_2X_2 \pm 17.0609X_1X_2$	88.2783 %	80.4638 %	7.08676	4.43336	2.20699
N7	$Y = 17.4129X_1 + 166.782X_2 - 0.923805X_1X_1 \pm 88.6827X_2X_2 \pm 19.0502X_1X_2$	48.5931 %	0.0 %	32.6079	17.9461	1.67242

TABLE XIX
Summary of analysis of contours for removal efficiency

Nozzle No.	Best region $C_{Ag,in}$	Best region C_{B0}	Maximum efficiency achievable
N5	0.9 – 3.3 0.9 – 3.3	0.02 -0 0.8 – 0.75	72
N6	0.9 – 1.2 2.5 – 3.3	0.3 – 0.8 0.8 – 0.25	82
N7	0 – 2.00	0.2 – 0	80

Observed versus Predicted %RE

The Figures 6, 11 and 16 show the observed versus predicted plot for N5, N6 and N7 respectively. The Y axis shows the observed value of $\%RE$ and X axis show the predicted value by fitted model of $\%RE$. It may be observed that the points are randomly scattered around the diagonal line indicating that model fits well. It may also be observed that the plot is straight line having no curve that means no need to try for higher order polynomial.

Residuals versus Predicted

The Figures 7, 12 and 17 show of the residual analysis. The Y axis shows Studentized residual and X axis shows the predicted $\%RE$ from the fitted models. It may be observed that there is uniformity in variability with change in mean value shown by line in the center.

V. CONCLUSION

The models developed as shown in Table 4 for nozzles N5, N6 and N7 to predict $\%RE$ by using STATGRAPHICS considering variation with respect to $C_{Ag,in}$ and C_{B0} are well fitted.

Statistical analysis showed that both factors C_{B0} and $C_{Ag,in}$ have significant effect on removal efficiency (RE) but the liquid concentration is more significant between two.

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