**Petroleum Research**

Petroleum Research 2018(June-July), Vol. 28, No. 99. 43-48

**DOI: 10.22078/pr.2017.2652.2305**

# Investigating the Foaming Phenomenon in the Absorption Tower of Gas Refinery Using Response Surface Methodology and Determining the Effective Antifoam

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Received: July/29/2017 Accepted: December/09/2017

## Abstract

Foaming phenomenon is one of the main problems in the gas refining process. Antifoams can be used for solving this undesirable problem. The current study was carried out with the aim of determining the optimum amount of effective parameters on foaming phenomenon in the absorption tower of Ilam gas refinery. An experimental design was used to quantify the effects of variables, including the amine concentration, the gas flow rate, and temperature, on amount of foam as response. The experiments were carried out using MDEA and foam measuring apparatus. A quadratic model was developed to correlate the relationship between variables and the response. The results demonstrated the accuracy of the model and show that the foaming strongly depended on temperature. The optimum operating condition with the less amount of foam can be obtained with an amine concentration of 35.19 (wt.%), gas flow rate of 1.63 (L/min), and temperature of 40.21 (°C). The best antifoam was determined among four different kind of antifoam i.e., silicon based (SAG 7133 and SAG 220) and alcohol based (KX-1415 and PN-30) in the optimum operating condition. SAG 7133 was chosen as the most effective antifoam.

**Keywords:** Foaming, Antifoam, Adsorption Process, Response Surface Methodology, Amine.

## Introduction

Foaming phenomenon is one of the main problems in the gas refining process. Foaming can be occurred due to the present of suspense solids, liquid hydrocarbons, low amine temperature, low inlet gas temperature, and so on [1, 2]. Foaming phenomenon can be reduced by filtering, control of hydrocarbons pollution and reduction of fouling in heat exchangers [3]. However, none of these solutions cannot be effective more than using antifoam. Antifoams can be used for solving this undesirable problem. The current study was carried out with the aim of determining the optimum amount of effective parameters on foaming phenomenon in the absorption tower of Ilam gas refinery. Operation parameters such as amine concentration, gas flow rate, and temperature were chosen as variables. In addition, selecting these variables was carried out based on foaming phenomenon in absorption tower. A quadratic model was developed to correlate the relationship between variables and the response. The optimum operating conditions with the less amount of foam were obtained. At last, the best antifoam was determined among four different kind of antifoams.

## Methodology

### Foam Measuring Apparatus

Foaming measurement experiments were carried out using SCAVINI (Twin- unit Faming Test Apparatus). 300 mL of Dyethanolamine (DMEA) solution was used for each experiment. After obtaining optimum condition, the experiments were continued for determining the appropriate antifoam. The properties of used antifoams are shown in Table 1.

**Table 1: properties of antifoams.**

| Antifoam base | Antifoam | Concentration(wt.%) |
|---|---|---|
| silicon | SAG 7133 | 20% |
| | SAG 220 | |
| Alcohol | KX -1415 | 2.5% |
| | PN -30 | |

### Experimental Design

RSM is a combination of mathematical and statistical techniques. It has four steps: experimental design, model fitting, model validation, and optimization [4]. The experimental design was carried out using Design Expert software version 7.0.1. The Box Behnken design with a quadratic model was employed to correlate the three independent variables. The relation between response and variables can be expressed by a second order polynomial function that consists of linear, quadratic and interactive components, as follows:

$$Y = A_0 + \sum A_i X_i + \sum A_i X_i^2 + \sum A_i X_i X_j \quad (1)$$

where, Y, X, $A_0$, $A_i$, $A_{ii}$ are the response variable, independent variables, intercept, linear, quadratic, and interaction constant coefficients, respectively. Analysis of variance (ANOVA) has been used to check and justify the significance of the model. The F-value and Prob.>F were employed to determine the statistical significance of the model. A significant model should have a high F-value and a Prob>F below 0.05. The $R^2$ and $R^2_{adj}$ show a measure of the variability in the response values and the fraction of variation of the response explained by the model adjusted for degrees of freedom, respectively [4, 5].

The variables with the coded and actual values are shown in Table 2. 17 experiments were conducted at different combinations of variable factors by using the Box-Behnken design (Table 3).

**Table 2: Levels and codes of the Box- Behnken experimental design.**

| Variable Factor | Code Level | | |
|---|---|---|---|
| | -1 | 0 | +1 |
| A: amine concentarion(% .wt) | 35 | 40 | 45 |
| B: gas flow rate (L/min) | 1.5 | 2 | 2.5 |
| C: temperature (°C) | 40 | 50 | 60 |

**Table 3: Experimental values of the Box-Behnken design.**

| Runs | Variable | | | Foam volume (mL) |
|---|---|---|---|---|
| | C | B | A | |
| 1 | 0 | +1 | +1 | 150 |
| 2 | 0 | 0 | 0 | 170 |
| 3 | 0 | 0 | 0 | 165 |
| 4 | 0 | -1 | -1 | 130 |
| 5 | -1 | 0 | +1 | 90 |
| 6 | +1 | 0 | +1 | 170 |
| 7 | -1 | 0 | -1 | 65 |
| 8 | 0 | -1 | +1 | 150 |
| 9 | -1 | -1 | 0 | 95 |
| 10 | +1 | +1 | 0 | 230 |
| 11 | 0 | 0 | 0 | 175 |
| 12 | +1 | 0 | -1 | 180 |
| 13 | +1 | -1 | 0 | 165 |
| 14 | -1 | +1 | 0 | 115 |
| 15 | 0 | +1 | -1 | 165 |
| 16 | 0 | 0 | 0 | 165 |
| 17 | 0 | 0 | 0 | 170 |

## Discussion and Results

### Experimental Design and Model Fitting

The final regression equations based on amine concentration (A), gas flow rate (B) and temperature (C) in term of coded form was obtained as follows:

$$V=169+2.5A+15B+47.5C-8.78\,AB-8.75\,AC+11.25\,BC-22.62\,A^2+2.37\,B^2-20.13\,C^2 \quad (2)$$

The statistical significance of foam model terms was examined via ANOVA and regression analysis. The fitting results of equation model is shown in Table 4. The reliability of the fitted model can be confirmed by the high values of F and the very low values of probability. Furthermore, the values of $R^2$ and $R^2_{adj}$, are close to 1. Also, the very small difference between $R^2$ and $R^2_{adj}$ shows the accuracy of the models. The model did not explain only 1.16% of the total variance. The values of lack of fit confirm the significance of the developed model (P-value > 0.05).

The normal probability versus residual is shown in Fig. 1. A residual distribution close to a straight line is an indicator of the accuracy of the model.

**Table 4: Analysis of variance for the regressive model.**

| P-Value Prob>F | F- Value | MS | SS | DF | Source |
|---|---|---|---|---|---|
| 0.3849 | 0.86 | 50 | 50 | 1 | A |
| 0.0009 | 30.92 | 1800 | 1800 | 1 | B |
| 0.0001> | 310.06 | 18050 | 18050 | 1 | C |
| 0.0555 | 5.26 | 306.25 | 306.25 | 1 | AB |
| 0.0555 | 5.26 | 306.25 | 306.25 | 1 | AC |
| 0.0214 | 8.70 | 506.25 | 506.25 | 1 | BC |
| 0.0005 | 37.02 | 2155.33 | 2155.33 | 1 | $A^2$ |
| 0.5433 | 0.41 | 23.75 | 23.75 | 1 | $B^2$ |
| 0.0010 | 29.29 | 1705.33 | 1705.33 | 1 | $C^2$ |
| 0.0001> | 47.89 | 2788.06 | 25092.50 | 9 | Model |
| 0.0520 | 6.43 | 112.50 | 337.50 | 3 | Lack of fot |
| $R^2$ =0.9840 | | | $R^2_{adj}$ =0.9635 | | |

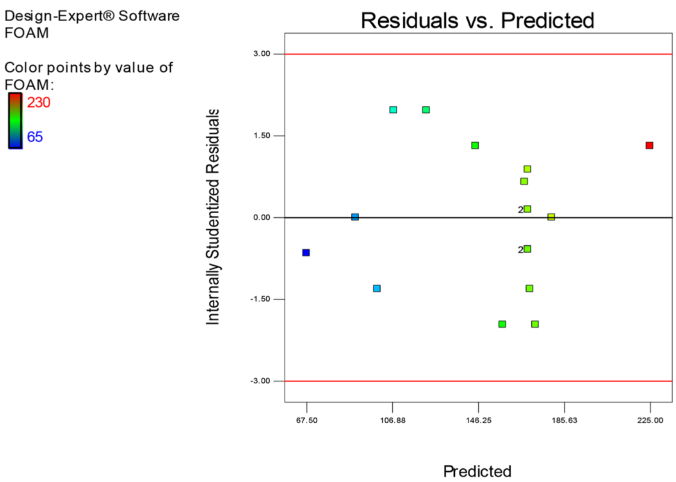


**Fig. 1: Plot of stundarzied residual vs. predicte.**

If the residuals fall near a straight line, the errors are evenly distributed, which supports the adequacy of the least-square fit [4, 5]. As can be seen in Fig. 1, the residuals distribute normally close to a straight line. The plot of the actual responses vs. the predicted values is presented in Fig. 2. As shown, the points are close to the diagonal. This shows a high correlation between experimental and predicted values and confirms the reliability of the foaming model.

### Effects of Variables on Foaming

The shapes of the interaction and contour plots can show the nature of the interactions between variables and factors. Elliptical and circular shapes of the contour plots indicate prominent and negligible interactions, respectively [4]. The interaction graphs of obtained model are shown in Fig. 3

### Optimum Conditions

The optimum operating condition with the less amount of foam can be obtained with an amine concentration of 35.19 (wt.%), gas flow rate of 1.63 lit/min, and temperature of 40.21°C.

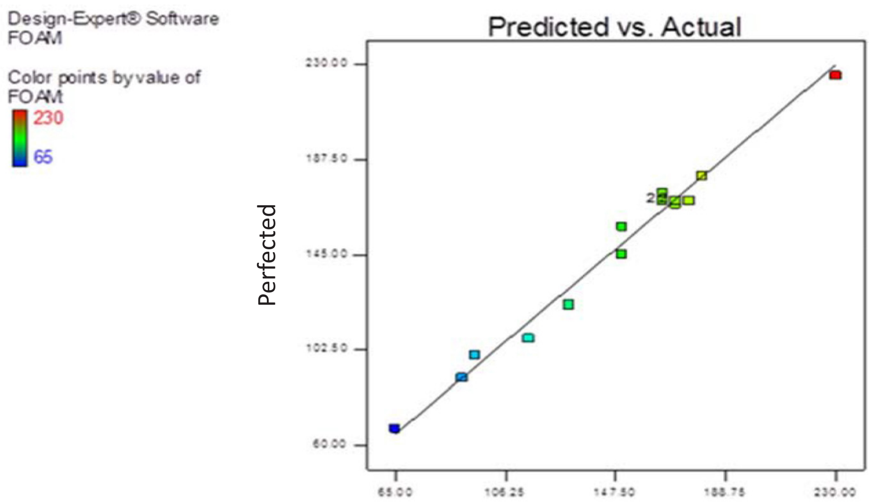


**Fig. 2: Plot of predicted values vs. actual responses.**

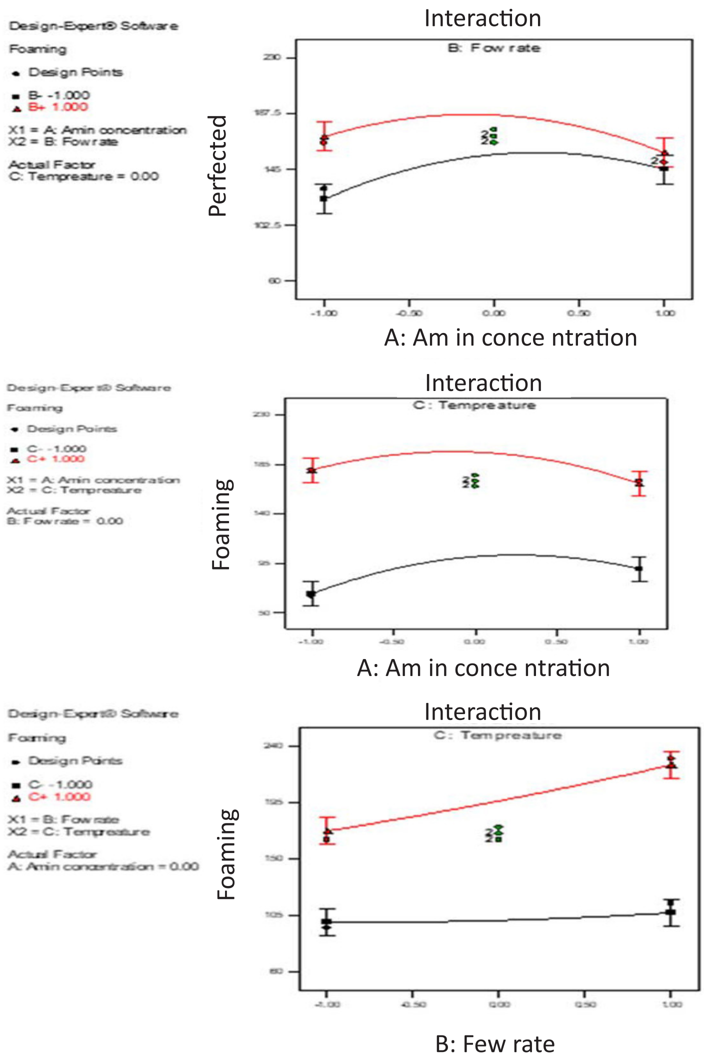


**Fig. 3: Interaction graphs of model.**

### Effective Antifoam

The best antifoam was determined among four different kind of antifoams (silicon based (SAG 7133 and SAG 220) and alcohol based (KX-1415 and PN-30)) in the optimum operating condition. SAG 7133 was chosen as the most effective antifoam.

## Conclusion

Foaming is one of the main problems in the gas refining process. Antifoams can be used for solving this undesirable problem. The effects of variable parameters on the foaming in the absorption tower of Ilam gas refinery were studied. An experimental design was used to quantify the effects of variables including the amine concentration, gas flow rate, and temperature, on amount of foam as response. it shows that the foaming is strongly depended on temperature. The optimum operating condition with the less amount of foam can be obtained with an amine concentration of 35.19 (wt.%), flow rate of 1.63 L/min, and temperature of 40.21°C .SAG 7133 was chosen as the most effective antifoam

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