Journal of Scientific Research and Development 2 (10): 20-24, 2015
Available online at www.jsrad.org
ISSN 1115-7569

Statistical process control of debutanizer column

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Abstract: Distillation process in distillation column is a challenging process as it is subjected to disturbances and interruptions that sometime cannot be controlled or predicted. The main concern in any distillation column or process is the quality of the main product produced. To control and monitor the quality of the main product also proves as a challenge. Therefore, Statistical Process Control (SPC) is introduced with the aim to identify the variations affecting the process, thus controlling and monitoring the quality of the end product of distillation column. The debutanizer column at PETRONAS Penapisan Terengganu Sdn Bhd (PPTSB), an oil refinery plant will be the subject for this SPC research. The methodology to implement SPC is constructed and Individual Control Charts will be used to determine the state of the process.

Key words: Statistical Process Control; Debutanizer column

1. Introduction

Distillation is a separation process that separates a mixture based on differences in volatility of components in a boiling liquid mixture. The components in a liquid solution are separated by distillation with regards to the components distribution in vapor and liquid phase (Geankoplis, 2003). It is a physical separation process which is different than a chemical process that using chemical reactions. Distillation is used in many applications for separation but found its widest application in oil and gas and petrochemical industries. In petroleum/oil refineries for example, crude oil as the feedstock of the refineries is separate to various fractions to produce petroleum products and other using vapor-liquid separation process in a distillation column/tower.

The distillation column is definitely the most important component in distillation unit. The separation process between mixtures happens inside the distillation column and produces two type of product, which are the top product and bottom product. Most of the time, the top product will be the main product of the separation and the bottom product will undergo another separation to obtained another desired product. However, some of the aforementioned products will be recycled back into the column as reflux. This is where the distillation process in distillation column gets complicated (Mohamed Ramli, 2014).

Distillation process in refinery plant is usually operated in continuous steady state. In continuous steady state operation, the amount of product being distilled is normally will be the same with the amount of feed being added. This will be different if there are interruptions in the process such as changes in the feed, heat, pressure, or temperature. This will affect the separation process inside the distillation column.

It is not easy to maintain the stability in the process and definitely same goes to the quality of the product as it is correlated. The separation process in distillation column proves to be complicated and difficult to be handled as it is complex and highly un-predictive in nature. To maintain the stability and desired quality that meets the customers' requirement will be a challenging process. Therefore, the best control strategy is needed to be implemented in the distillation column to manage the stability and the product quality. The process stability can be managed by the process model or corrective actions by the controller. The product quality however proves to be the hardest to control.

In response to the challenges in controlling and monitoring the quality of the end product of the debutanizer column, SPC is introduced as a quality control strategy. In this study, the relationship between the process variables and the top product will be investigated. The effect of this relationship is then compared to the process in order to identify if it has an impact toward the process. The process can be either in control or out of control.

2. Objectives

The objectives of the project are as follows:

- To implement Statistical Process Control techniques/tools to analyse the debutanizer column top product quality.
- To investigate the relationship between the process variables and the top product compositions.

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• To analyse the variables using control chart

3. Literature review

3.1. Statistical process control

Statistical Process Control (SPC) has been widely used since the World War II both in the United Kingdom (UK) and the United States of America (USA) but as industries converted to peacetime production, SPC lost its importance in the industries (Wetherill & Brown, 1991). However, when taught to the Japanese by W. E. Deming in the 1950s, they have applied it to their industry widely and prove that SPC saves money and attracts customers. Competition between industries becomes bigger since the application of SPC in Japan and it has forced UK and USA to introduce it to their industries in order to compete with the Japanese. Up until now, SPC have gained the interest in industries for quality control and improvements.

SPC in general is a quality control technique which uses the statistical method. Control Chart is commonly used as SPC tools to monitor and controlling the process. It helps to monitor and control the variations in the process that eventually affects the quality of the product. However, according to (Oakland, 2008), SPC is not really about statistics or control, it is about competitiveness. Quality, delivery and price are the three main issues that always revolve around the competition between industries. If the quality is right, the delivery and price performance will be competitive (Oakland, 2008). Therefore, there is a relationship between the SPC methods and the result or quality of the desired product.

3.2. The SPC and its applications

Control chart is proven as the most prominent SPC tools when it comes to monitoring and controlling variations (Driesen, 2004). Control chart enable visual and statistical analysis of a data for practitioner in descriptive and inferential tools. As descriptive tool, the control chart help practitioner to see and visualize the patterns in production process, whereas as inferential tools, control chart established baseline and applying probability test to distinguish special cause variations from common cause variations. Control Chart will be further discussed later in this chapter.

The application of SPC has been used in many industries nowadays but not limited only to production or manufacturing industries. SPC also widely used in healthcare and at some point, in an organization for better performances.

The Application of Statistical Process Control' to show how control chart is used to find the causes of the quality changes of the concentrates and examines if the process is 'in control' or otherwise (Ipek et al., 1999). The finding using control chart shows that the process is 'in control' but found also few causes that contribute to the poor quality of the concentrates. A suggestion based on the findings using control chart to increase the quality (Ipek et al., 1999).

The SPC also can be used in monitoring and improving the outcomes of cardiac surgery performances (Smith et al., 2013). In his article entitle 'Use of Graphical Statistical Process Control Tools to Monitor and Improve Outcomes in Cardiac Surgery' concluded that the use of SPC tools such as the Cumulative Sum (CUSUM) charts, Exponentially Weighted Moving Average (EWMA) charts and Funnel Plots, facilitate near "real-time" performance monitoring by allowing early detection and intervention in altered performance. This proves that SPC is working effectively even though it was outside of the common use in manufacturing.

SPC is proven to be effective in monitoring, controlling and improving the quality of the desired outcome especially using the control chart and other statistical methods. SPC is not a theory anymore as it has been proven time after time (Wheeler, 2010).

4. Methodology

This project is using a real plant data consisting the process variables and compositions. These data were obtained from PETRONAS Penapisan Terengganu Sdn Bhd (PPTSB) debutanizer column as inputs for SPC analysis. The data will be analyzed in inferential analysis, and control charts with the aid of Microsoft Excel and Statistical Package for the Social Science (SPSS) software. The data distribution will be displayed using the histogram to describe it.

For inferential analysis, the multivariable data will be analyzed using various statistical methods in order to come out with an inference or conclusion from the data. Statistical methods such as Paired t-Test, Analysis of Variance (ANOVA) and Chi-square test will be used. Last but not least, the last statistical method is the control charts. Individual chart is chosen as control chart as the data exhibits only one-time set of data

5. Results and discussion

5.1. Histogram

Histogram is the one of the best way to illustrate the descriptive statistic of the data analyzed especially the frequency distribution. The histograms are discussed based on the skewness and kurtosis.

Fig. 1 shows the histogram of the debutanizer top product compositions. It can be seen that all the compositions have a positive skewness. Propane (C3), i-Butane (iC4), n-Butane (nC4), i-Pentane (iC5) and n-Pentane (nC5) has skewness of 0.817, 0.566, 0.893, 1.271 and 1.012 respectively. As a result, all the histogram of the compositions is skewed to the right and creating an asymmetrical distribution. As the skewness value getting higher, the distribution will have a long 'tail' to the right as indicated by iC5 and nC5 histogram.

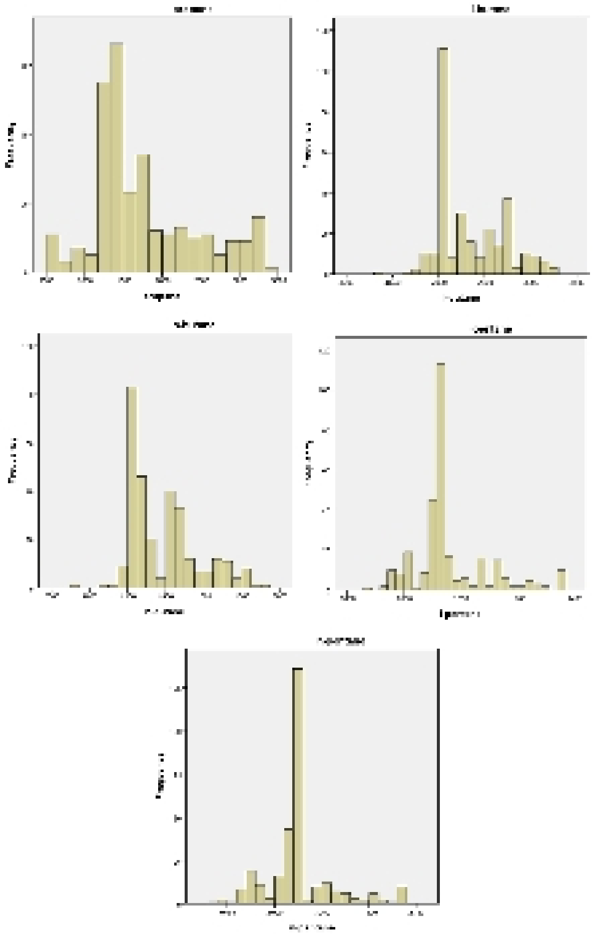

Fig. 1: Histogram of the compositions

However, C3 and iC4 have a negative kurtosis while nC4, iC5 and nC5 have a positive kurtosis. Negative kurtosis suggests that the data have a 'flat' distribution, while positive kurtosis suggests that the data have a 'peaked' distribution.

Fig. 2 and 3 shows the histogram of the manipulated variables which are the Feed flow rates, Reboiler flow rates, and Reflux flow rates. All three histogram have negative Kurtosis which indicates flat distribution among the data.

5.2. Statistical analysis

There are few statistical methods used for the statistical analysis on the data provided. The other hand, t-Test and Analysis of Variance (ANOVA) used to test the significant of the relationship. Last but not least, individual chart is used as control chart to observe the state of the data especially on the top product compositions

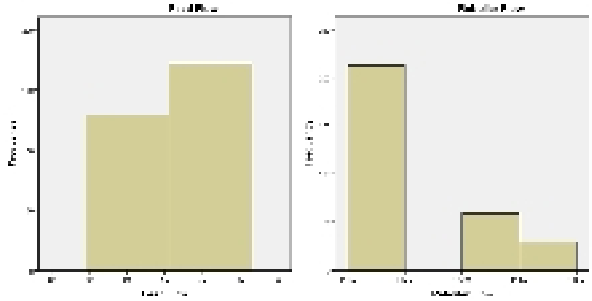

Fig. 2: Histogram of the feed flow and reboiler flow

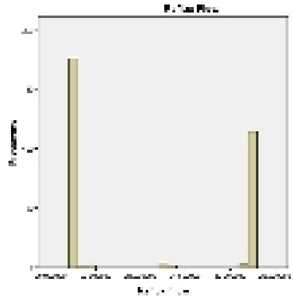

Fig. 3: Histogram of the reflux flow

5.3. Paired t-test and analysis of variance (ANOVA)

Paired t-test and ANOVA is used to test the significant of the relationship between the process variables and the compositions on mean basis.

The t-Test is used to determine whether there is a significant difference between the two variables investigated. The null hypothesis is there is no significant difference between the two variables. Based on the t-test, it can be seen that the p value is less than 0.05 for all case; therefore the null hypothesis is rejected. This indicates that there is a significant difference between the two variables.

The null hypothesis for ANOVA is also the same with t-test. However, some of the result did not reject the null hypothesis which indicates that there is a significant difference between the two variables. The failure to reject the null hypothesis ($p>0.05$) is because ANOVA take account on the possibility of a linear relationship between the variables. Although almost all scatter plots of process variables vs compositions showing a nonlinear relationship, ANOVA detected a possible linear relationship (medium relationship as observed in the correlations analysis) between the two variables investigated. In regression analysis also, it is observed that linear equation is possible for the relationship based on the ANOVA significant result ($p<0.05$).

Table 1: ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.	
Model	Regression	.035	1	.035	7.911	.005b
	Residual	1.340	299	.004		
	Total	1.375	300			

5.4. Chi-square test

Chi-square test can be used to convey the existence or nonexistence of the relationships between the variables investigated. However, it cannot determine the strength of the relationship.

The process variables and compositions were subjected to Chi-square test. However it did not give correct results as it violates the assumption for conducting a chi-square test. As seen in Table 2, 98.7% of the data have counts less than 5. In order to do the chi-square test, the counts must be more than 5 and none less than 1 (minimum expected count is 0.43). Therefore chi-square test is not suitable to be used.

Table 2: Chi-Square Tests C3 and Feed Flow

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	158.156[a]	158	.482
Likelihood Ratio	213.224	158	.002
Linear-by-Linear Association	7.367	1	.007
N of Valid Cases	301		
a. 314 cells (98.7%) have expected count less than 5. The minimum expected count is .43.			

5.5. Control charts (Individual charts)

Individual chart is selected as control chart because the data obtained is just a one-time data. It is the simplest variable chart which has Upper Control Limit (UCL) and Lower Control Limit (LCL). The control limit is placed three standard deviations (from the Centerline (CL). The CL can be the mean or target value of the variable.

Based to the data used, the manipulated variables (MVs) are manipulated few times to see the changes on the compositions and other process variables. As the values of the MVs changing, the values of other variables also changing accordingly. The Individual Chart explain the state of the variable either in control (within UCL and LCL) or out of control (out of UCL and LCL) after the changes.

According to all the individual charts, all the compositions variables are not in control since many of the values are exceeding the UCL and LCL as indicate by the red dots. The red dots are showing the value that is in violation with the control chart. This happened when the value are exceeding the three sigma or the control limit (UCL and LCL). The green dots indicate that there is no violation and the values are inside the control limits.

Propane, i-Butane and n-Butane individual charts showing a similar trend. Many of the values are outside of the control limits, and at some point, it stabilizes along the CL. Individual charts for i-Pentane and n-Pentane also showing a similar trends but different than the other three charts aforementioned. The charts have fewer points outside the control limits compare to the other three charts. At some point also, the values are stabilizing along the CL. The violations might be because of the changes made on the manipulated variable. It causes sudden changes on the compositions. The compositions then slowly stabilizing inside the control limits. It might be because of the corrective action taken by the controller to bring the process under the control.

As the MVs changes, this requires the compositions to react based on the changes. From the individual charts, it can be seen that Propane, i-Butane, and n-Butane is highly affected by the changes in the MVs compare to i-Pentane and n-Pentane.

When the process is out of control, it is best to take action to bring back the process in control.

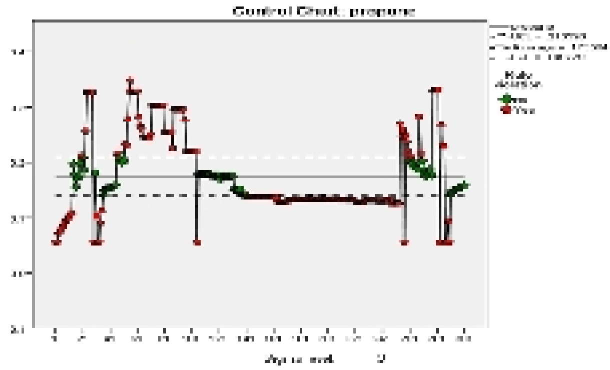

Fig. 4: Propane individual chart

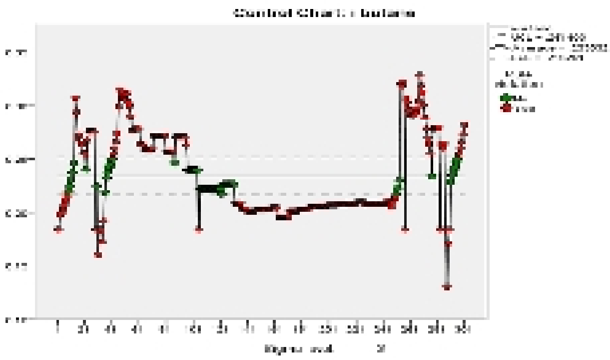

Fig. 5: I-butane individual chart

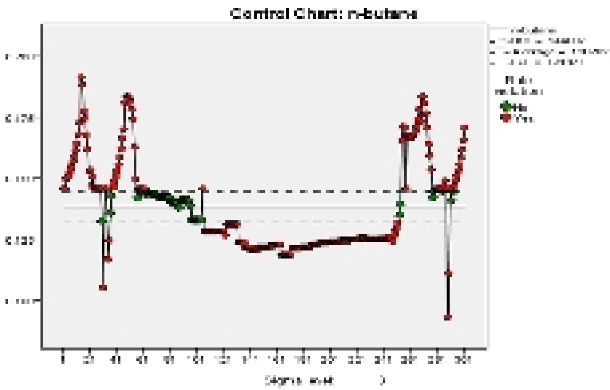

Fig. 6: N-butane individual chart

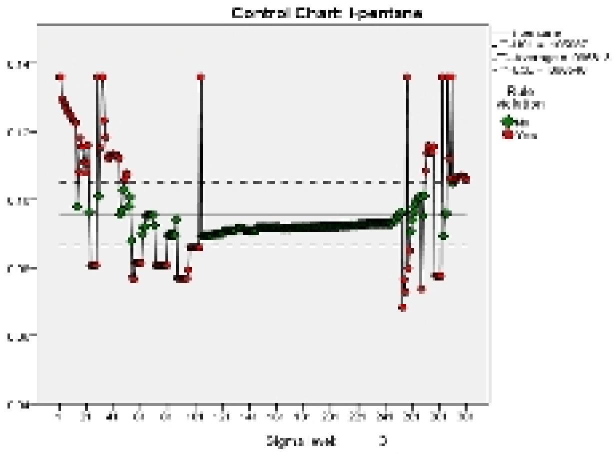

Fig. 7: I-pentane individual chart

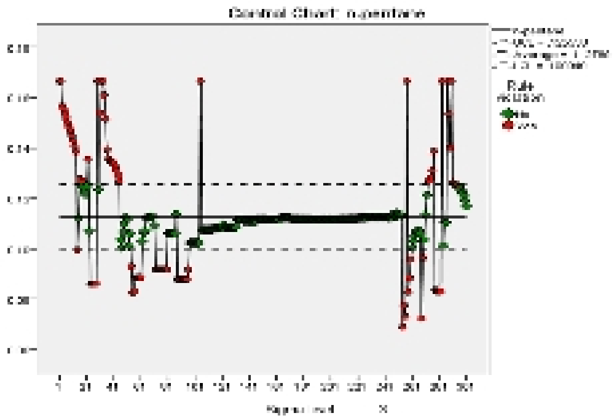

Fig. 8: N-pentane individual chart

6. Conclusion

Statistical Process Control is an interesting and proven method for monitoring, controlling and improving quality of desired product. To apply it in debutanizer column would enable us to see the variations effects on the process using statistical method especially on the relationship between the process variables and the top product compositions. Control charts especially individuals chart is used to observe the state of the process especially on the compositions. From the individual charts, it can be seen that the changes in the manipulated variables haves effects on the compositions.

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