Taguchi's Parametric Design Approach for Determining the Significant Decision Variables in a Crude Distillation Unit (CDU)

by

Muhammad Rajhan Bin Mohd Rosidi

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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(CHEMICAL ENGINEERING)

Approved by,

____

(Dr. Noor Yusmiza Bin Yusoff)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

(MUHAMMAD RAJHAN BIN MOHD ROSIDI)

ABSTRACT

The purpose of this study is to conduct a research on the implementation of Taguchi's parametric design approach in selecting the appropriate variable for optimization for crude distillation unit (CDU). The main aspect that that will focusing in this study is on the maximizing the profit based on different case studies.
A dynamic CDU model is developed using HYSYS environment in order to test the case study. 13 variable and 3 level is chosen to be used in this project. This variable is selected due to their function as manipulated variable in controlling the process. Each sequence of variable is tested simultaneously in HYSYS. The validation process on result is done by comparing the optimum value through a experiment in HYSYS. On the other hand, the analysis of mean and variance, ANOM and ANOVA is conducted to find the most valuable and profitable sequence of variable. The result obtain is in term of profit which is the highest profit is 1.7 million RM/day with the optimum configuration is $A_1B_3C_1D_3E_3F_1G_1H_1I_1J_1K_3L_1M_1N_3O_{1.}$

ACKNOWLEDGEMENT

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CHAPTER 1
INTRODUCTION

1. INTRODUCTION

1.1 Background of study

Crude distillation unit also known as CDU is one of the units in petroleum refining industries. Crude distillation is used to separate the hydrocarbons in crude oil into fractions based on their boiling points. The separation is done at atmospheric distillation column. The distillation column consists of a number of trays where hydrocarbon gases and liquids interact. The gases will move to the top of the column and the liquid component will be moving down due to atmospheric condition. The light component such as butane and naphtha are removed in the upper part of column and the heavier component such as distillate and residue oil will withdraw from the lower section. The practical goal such a kind of unit is to achieve a higher production rate beside the lower cost relate to economic consideration. On the other hand, the objective is to perform a process optimization including high production rate with required low operating cost by searching an optimal operating condition (Sea, Oh, & Lee, 2000). In crude distillation unit, a lot of equipment and technologies have been implemented. There are heat exchanger, preflash column, furnace, desalter and etc. All this equipment is connect with each other in order to produce the high quality product. However, along the journey of producing the high demand product, the crude market price automatically increases drastically. With this phenomenon, the researcher and engineer in various disciplines try to find the alternative way to increase the production of selling product by regulating the variable at the maximum optimization. However, the concern about the environment resulted in stricter regulations on the emission of greenhouse gases.

The current study is based on Aspen HYSYS simulation model which is on crude distillation unit (CDU). By selecting the control and optimization control systematically can ensure the effectiveness RTO implementation (Yusoff, N. et al., 2011). Among various type of optimization study, Taguchi method has been chosen. Throughout the year, a lot of successful result have been reported regarding the implementation of the Taguchi's parametric design approach by selecting the appropriate optimization variables. Orthogonal array technique was developing the list of factor with different level in order to select the best possible combination of variable to optimize the plant. This project aims to use L27 with nine variables and number of level is three. The most significant variable can be determined by conducting the analysis of mean and variance.

1.2 Problem Statement

Crude distillation unit is the higher profitable unit in industry. Because of that, a lot of study has been conducted in order to make sure the technology and the efficiency of the crude distillation unit at the higher level. Plus, the nature of crude distillation can be accessible directly and in directly in order to maximize the efficiency of the plant. Due to the vast range of optimization study on crude distillation unit, specific research has to be done to address a most suitable combination of variable to use in order to optimize the operating condition and to increase the production.

This project aims to develop an experiment that can be used to find the best combination of variable to optimize the plant. Due to problem state above, the Taguchi Method is chosen to be implemented along with the simulation model. An experiment of the variable combination will be use along the journey.

1.3 Objective

To maximize profit at Crude Distillation Unit (CDU) based on the selection of 13 control variable. The project will be conducted by following the method of Taguchi's approach in selection of the control and optimization variable which are significant towards the process optimization.

1.4 Scope of Study

1.4.1 Basic Process Flow of Crude Distillation Unit (CDU)

Crude distillation unit (CDU) is designed to separate raw crude petroleum from the rig into valuable product such as diesel, naphtha, kerosene and residue. For this project, Crude Distillation Unit (CDU) will be the main focus from the beginning to the end. The study on how to increasing the business profit by regulating selected control variable will be conducted at curtain units with supporting from Taguchi method.

Output from running these experiment is performed from an objective function as stated below (Yusoff, N. et al., 2011):

$$P = \sum R - \sum E$$

P = Profit

R = Revenues

E = Expenses (Utilities)

The profit is calculated based on revenues minus by an expenses. The revenues is refined as product that produce from crude distillation unit and vacuum distillation unit. On the other hand, the expenses is referred to the cost of utilities such as electrical and steam consumption.

1.5 Relevancy of Project

Since the number of petroleum refinery plant has increase drastically, with proper research and knowledge coupled with new technology, the crude distillation unit can be optimized to the most efficient and profitable. This will help to save the operating cost by reducing the utilities and at the same time increasing the production.

1.6 Feasibility of Project

This project will be done in two semesters which basically includes three basic areas which are experiment, variable testing using CDU model and run the result analysis. This project will be utilized the current model of CDU to find the tune of perfect combination of variable. Based on the description above, it is very clear that this project will be feasible to be carried out within the time frame.

CHAPTER 2
LITERATURE REVIEW

2. LITERITURE REVIEW

2.1 Crude Distillation Unit

Crude Distillation Unit or known as CDU is the most important unit in petroleum refinery. CDU comprises four sections which is crude preheat section, crude distillation section, LPG recovery unit and chemical injection section. Refineries are the largest energy consumers in the chemical industries. Despite, 2% amount of fuels from the total crude processed required for these plant to operate (M. Bagajewicz, S.Ji, 2001). Thus, finding the ways to increase the energy efficiency for the existing plant becomes a serious matter nowadays.

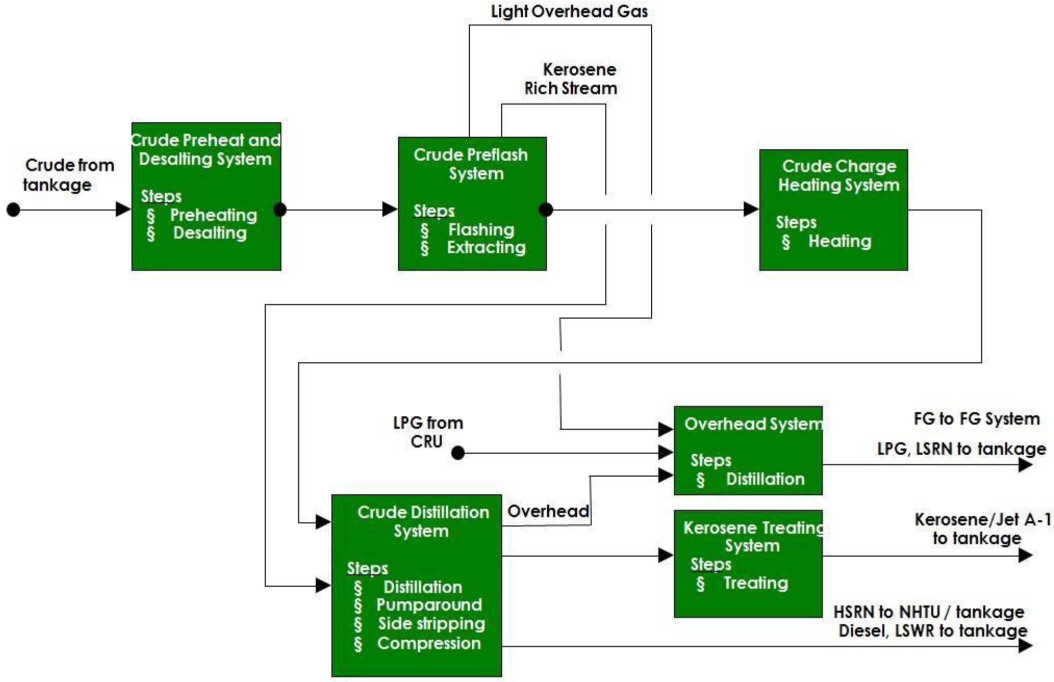


Figure 1 CDU Process flow diagram (real existing plant)

Early 1940, crude distillation unit was running officially in this world. After that, in 80's Pinch method becomes one of the famous strategies for energy recovery between process fluids (B. Linnohff, E. Hindmarsh, 1983). Furthermore, CDU produce several products from various temperature cut point. The table below shows the products from the specific temperature.

Table 1 Crude product cut point temperature (PPTSB Manual Book, 2010)

Product	Temperature
LPG	TBP
Light Naphtha	65-70^{o}C
Heavy Naphtha	70-172 ^{o}C
Kerosene	172-214 ^{o}C
Diesel	214-354 ^{o}C
LSWR (residue)	>354 ^{o}C

On the other hand, furnace in CDU become main leader in providing 50% of energy required in an oil refinery plant (Y. Kansha, A. Kishimoto, A. Tsutsumi, 2012). For that, energy saving process and technology need to be apply in order to minimize the energy consumption and at the same time increase the production profit.

Crude separation process involves many complex phenomena which have to be controlled in its best placement. Regarding (S. Motlaghi, F. Jalali & M. Nili, 2008) the input variable of crude distillation column are usually energy supply inputs, reflux ratios and product flow rates, while the output variable are the oil production, system operating performance and plant profit. However, to maintain the plant at only curtain condition is very difficult. This is because the non-linear interaction between the operating input and output variables. Plus, if the production not meets the client specification, this will cause some problem to plant management.

Last two decades, the researcher, engineer and industrial practitioners has an awareness that operability issue need to be consider explicitly at the early stage of plant design. Mizoguchi (1995) says that the researcher in recent year have been focused on the process control and optimization. Currently, the optimal condition of variable of distillation unit process was controlled by expert operators according to the input characteristic of crude. Thus, if the condition is vice versa, the optimal process cannot be reached due to false decision by the inexperience operator. Therefore, support from the optimum operating information from the study is quite essential to maintain a proper management of the crude operation.

In refinery operation, there are many different operating units that are used to separate the fraction, improve the quality and increase the production of the product like liquefied petroleum gas (LPG), naphtha, kerosene, diesel and residue oil. The function of this unit is to separate the raw crude into the several kind of product.

Further, the input variable can be oil properties likes flow rate and the temperature is the control variable. On the other hand, the output variable can be the flow rate of the product such as naphtha and diesel. If one of this parameter changes, it will affect the other condition and parameter on control variable. The model that has been developing can be used by express the relationship between operating condition and the product flow rate.

Typically, the crude oil is brought up to the feed temperature required by the crude column by being passed through a series of hot oil heat exchangers and then being heated in a gas or oil fired heater. For example, the crude oil wills first heated by the circulating naphtha stream which is produced by the crude column. Next the crude oil will be heated by the product kerosene which is leaving the crude column. After that, the hot crude oil may then be passed into the desalter which removes the salt and other water soluble from the hot crude. In desalter, the function is using electrostatic. The desalted hot crude may be further heated by then and picking up heat in another series of heat exchanger. After several heat exchanges in heat exchanger, the crude is passing through to the preflash column where the light product (LPG) is separate first. By doing so, the duty at the distillation column will be reduce.

Normally, the high crude oil pressure causes the crude oil to be passes through the tube of heat exchanger bundles in the heat exchanger sequence since the crude oil is at a pressure which is higher than the pressure of hot stream with which it is being heated. After coming out from the preflash the crude oil is then flow thought the furnace before entering the distillation column.

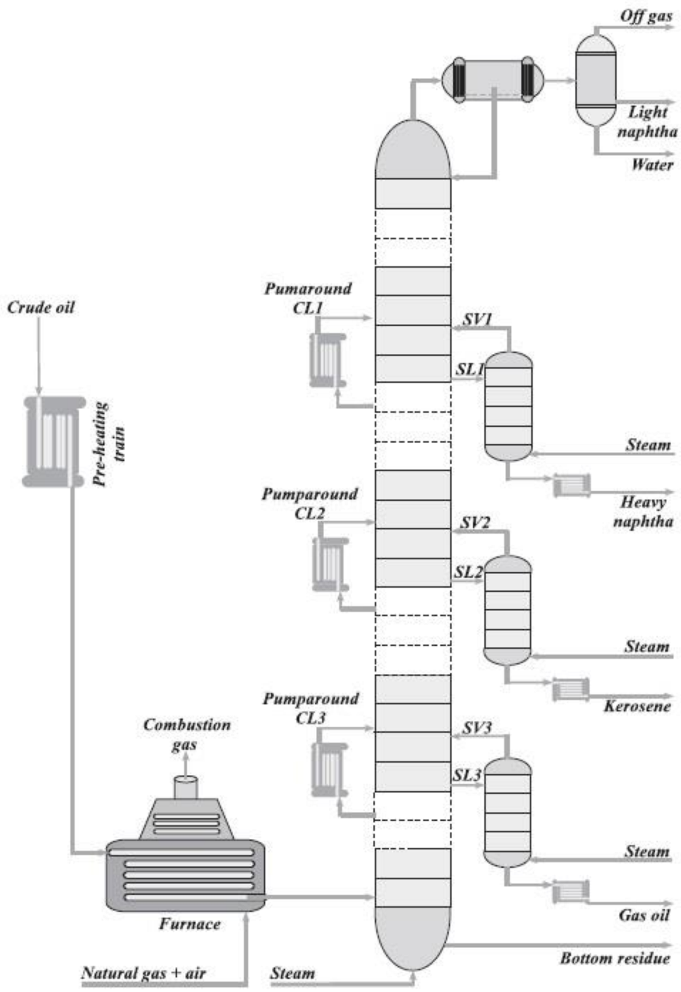


Figure 2 Crude Distillation tower (atmospheric)

2.2 Optimization

Modern optimization technique have challenged the most of the organization to think deeply the way how they running the company internally and externally. In term of oil and gas refining industries, CDU plant is one of the popular plants for the researcher and engineer to do an optimization. Optimization can be done in several ways physically and chemically. However, optimization with chemical something becomes complicated when dealing with complex reaction. In real life industries, changing the temperature and pressure is the most common thing. This is because, changing the volume of an equipment can be so expensive and the limitation of the space area of current equipment.

Model Predictive Control (MPC) is the standard control algorithm in process industries. Five thousand application was reported in 1999 with increasing demand around 80% in continues years (S.J Qin, T.A Badgwell, 2003). Rossitier (2003) says that the MPC algorithm utilized an obvious process model in order to optimized the open loop performance by the time constrains over a future horizon based on current and future inputs (J.A. Rossitier, 2003).

MPC application was used the linear progression in order to develop the model (S.J Qin, T.A Badgwell, 2003). On the other hand, dynamic modeling was developing to cooperate all variable at the same time; hence the effect of the intermediate variable and disturbances can be justified immediately.

Back to 70s, energy crisis have attracted the plant management to republish their plants that designed before 1970 in order to improving energy recovery and lowering the capital cost (M. Errico, G. Tola, M. Mascia, 2009). As discuss above, 50% of energy is come from the furnace. Thus, implementation of the preflash help to reduce the energy consumption of the furnace by remove the light product before transfer it into the distillation column. There have two main approaches for the preflash execution which is impact of preflash to the heat exchanger network and impact on the main column performance. (W.D. Harbert, 1978), (H.M. Feintuch, et al., 1985) and (R.Yahyaabadi, 2006) have given some familiarization of the problem solving regarding the behavior of the system. The location of preflash drum just downstream of the desalter can reduce the heat exchange between the furnace and flash drum. By doing so, energy can be save without using the new equipment or technology in the whole heat exchanger network. Bagajewicz, (2002) and S.W. Golden, (1997) state that the lightest compound of the crude which called carrier-effect will improve the separation of gas oil fraction to produce highly accurate differentiate the carrier gas by implement the preflash column. However, preflash column can be much higher performance compare to preflash drum (M. Errico, G. Tola, M. Mascia, 2009).

2.3 Taguchi method

In the nutshell, the need and scope for optimization is so huge in refinery that it is essential to use software tools not only to done a best plan, but also to evaluate quickly the new optimum and the most efficient route to optimizing the plant.

Moreover, by using simulation software, the data that we provide to the system will be generate the almost the same result as the real plant.

To do so, Taguchi method has been selected before using the simulation software. Taguchi method is a statistical technique to optimize the process design problem in many engineering disciplines. Basically, Taguchi method use by the combination of factors that get from an experiment to obtain the list of number of test to be performed. On the other hand, Taguchi method is considered as the off-line optimization method to design the system from the parameters involved (S.F. Ali, N. Yusoff, 2012). Further, parametric design is defines the ideal state due to the design factors at a specific point.

Taguchi method was used in the manufacturing industries to allocate the most economical way of building equipment with the best performance. But after this method is successfully shown the good result, Taguchi method have been implied in process industry to characterize the performance of an operation (S.F. Ali, N. Yusoff, 2012). Further, Taguchi's technique proposes experimental plan in term of orthogonal array that give the different grouping of parameter and their level of each experiment (S. Kamaruddin, et al., 2004). After finish with an experiment, the Analysis of variance (ANOVA) was conducted based on average output value in order to determine which process parameter is much suitable to proceed (S. Kamaruddin, et al., 2004).

Moreover, K. Palanikumar (2008) refer that Taguchi method is an interactive study regarding the interaction between the parameters and also provide powerful design experiment tool in determining the optimal parameter in curtain case study. In this case, the author have done with optimizing the cutting parameter in machining of glass fiber reinforced plastic (GFRP).

In CDU, some of the cases used Taguchi experiment to determine the optimal cut point temperature. Because of that, the system will generate the octagonal array based on number of factors and levels involved. Moreover, degree of freedom is defined as the number of comparisons between process parameter that needed to determine the level of significant (S. Kamaruddin, et al., 2004). In orthogonal array, the degree of freedom should be greater or equal to process parameter.

The design and selection of factor levels is conducted before test at the CDU model. The experiment was designed by following Design of Experiment (DOE) method. In full factorial experiment for nine factors with three levels the number of experiment will be 3^9 = 19683. To reduce the number of experiment that needed to be conducted the experiment were design by using Taguchi approach by conduction an orthogonal array technique. Below is the example of the orthogonal array table (nine factors with four levels).

Table 2 Example of L9 orthogonal array (S. Kamaruddin, Z.A. Khan, K.S. Wam, 2004)

PARAMETER/LEVEL				
Exp. No	**A**	**B**	**C**	**D**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The analysis of data is conducted straightaway the experiment is done. The obtained response for each trial at different loading condition is analyzed to get the result for the formulated problem. In optimization, MRSN or Multi Response Signal to Noise was calculated from the total loss function by using the equation below.

$$MRSN = -10\log(TL_f) \qquad \text{equation 2}$$

This technique apply in order to determine the optimal level of combination for the obtain MRSN ratio corresponding to the assigned weight factor. The variance of MRSN ratio is analyzed thought the analysis of variance (ANOVA).

Anova is the static method used to interpret experimental data and made the necessary decisions. The equation for total variability of the MRSM ratio is measured by the sums of square of MRSN ratio by using equation below:

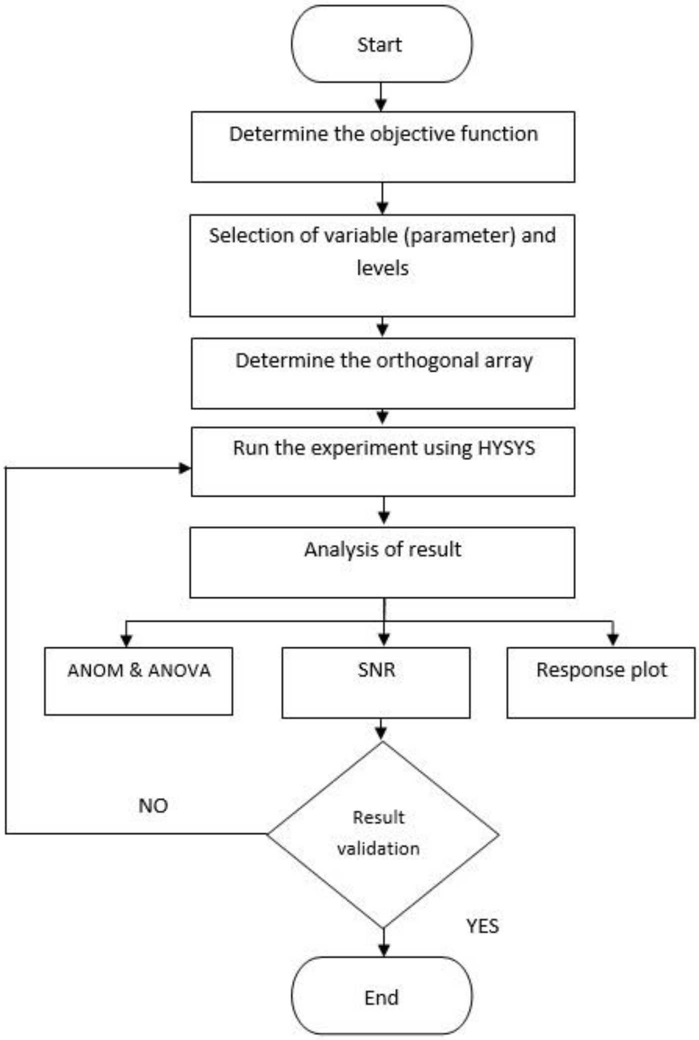
$$SS_T = [\ \sum y_i^2\ ] - T^2/N \qquad \text{equation 3}$$

CHAPTER 3
METHODOLOGY

3. METHODOLOGY

3.1 Research Methodology and Project Activities

The methodology for conducting this research project is exploration and discovery. As this project is mainly an empirical research, the results obtained from this research can be used to compare with the real life plant. Besides, the result obtained from this project is currently setup at steady state condition. The results can hence further enhance the research and development of CDU optimization at another high level. This project activity in this research is mainly simulation work by varying the variable by using Taguchi method.



3.2 Simulation Software

In this project, there is basically running fully with HYSYS simulation software. HYSYS is a powerful engineering simulation tool, has been uniquely created with respect to the program architecture, interface design, engineering capabilities, and interactive operation. The integrated steady state and dynamic modelling capabilities, the process simulation can be evaluated from either perspective with full sharing of process information.

3.2.1 Factor and Level

Table 3 Factor and Level

	Factor	Level 1	Level 2	Level 3	
1	CUT POINT - NAPHTHA	152.8728553	154.8728553	156.8728553	oC
2	CUT POINT - KERO	208.3211615	210.3211615	212.3211615	oC
3	CUT POINT - DIESEL	342.1619006	344.1619006	346.1619006	oC
4	CUT POINT - AGO	394.7421909	396.7421909	398.7421909	oC
5	CUT POINT - LVGO	286.7135944	288.7135944	290.7135944	oC
6	CUT POINT - HVGO	370.842059	372.842059	374.842059	oC
7	VACUUM FEED TEMPERATURE	375.6220853	377.6220853	379.6220853	oC
8	KERO REBOILER DUTY	6797197.536	7552441.707	8307685.878	kJ/h
9	COT TEMPERATURE	380.4021117	382.4021117	384.4021117	oC
10	VACUUM STEAM FLOWRATE	1376.647602	1720.809503	2064.971403	kg/h
11	BOTTOM STEAM FLOWRATE	2600.33436	3250.41795	3900.50154	kg/h
12	DIESEL STEAM FLOWRATE	1032.485702	1290.607127	1548.728553	kg/h
13	AGO STEAM FLOWRATE	879.524857	1099.406071	1319.287286	kg/h

3.2.2 Orthogonal Array

The experiment is conducted under L27 array with 13 control variable and 3 levels for each control variable. The basic arrangement of the orthogonal array can be refer in appendix.

3.2.3 Noise factor

Two noise factor is selected with three level in this study. The noise factor are:

- Crude flow rate
- Crude price

3.2.4 CDU Model

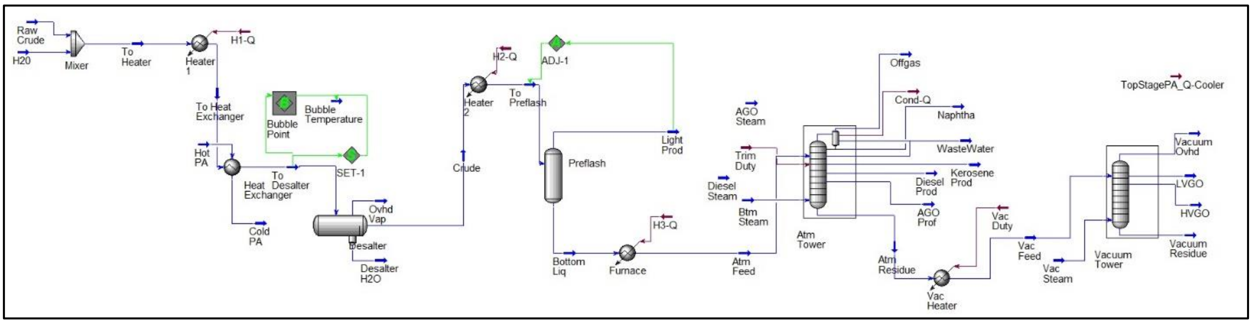


Figure 3 CDU model in HYSYS

3.3 Key Milestone

Problem Statement and Objective of the project

Identify the purpose of this research.

⇩

Literature Review

Understanding the fundamental theories and concepts by gathering much information as possible from various sources.

⇩

Simulation Procedure

Conduct an experiment using CDU model in HYSYS and record all data (result).

⇩

Analysis of Result

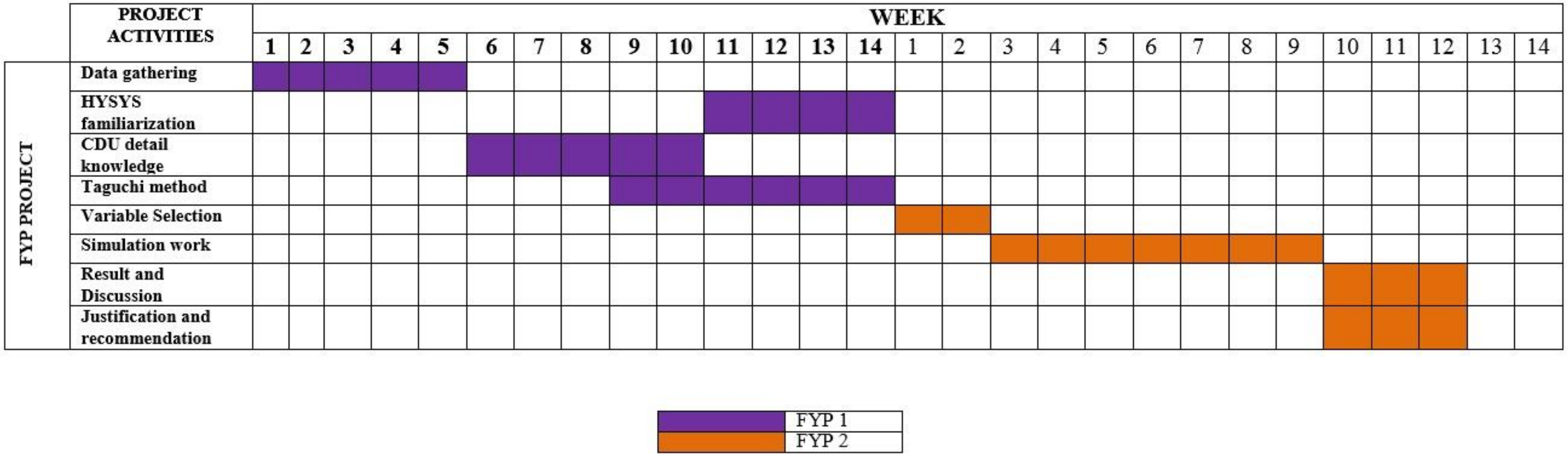
The collected data will be analyze and interpreted precisely using SNR, ANOM, ANOVA and response plot to determine the most profitable configuration.

⇩

Documentation and Reporting

The research study will be documented and the future improvement in the future will be discussed.

3.4 Gantt Chart



CHAPTER 4
RESULT AND DISCUSSION

4. Result and Discussion

By using the current model that has been develop by the lecturer, the development of the variable selection is done. The CDU model is develop by using Aspen HYSYS simulation software. In this model, it has two main units which are atmospheric tower and vacuum tower.

By referring to the figure 3, the crude will go through one heater and one heat exchanger before entering the desalter. The main function of desalter is to remove salts, water and sediment present in the crude feed by electrostatic coalescence, whereby a high voltage of current with 415 volts and 11 ampere is passing through inside the desalter with layer plate. The crude after desalter is expected to minimize the fouling in the preheat train exchanger and crude furnace. The water and sediment is discharge to the oily water sewer. In real case for example, PETRONAS PENAPISAN TERENGGANU SDN BHD (PPTSB) use four heat exchangers (see appendix A) whereas the crude oil is exchange with the end product like naphtha, kerosene, diesel and residue oil. Next, crude without salt and impurities is travel along the pipeline to the preflash column. Before reach at preflash the crude will be heater once more. This is to ensure the crude gain the heat energy before entering the preflash. The purpose of preflash is to remove light naphtha, mixed naphtha and light hydrocarbon gassed from crude oil. The balance of the heavier part of crude oil is then sent to crude tower for further fractionation. The preflash tower bottom is pumped to the furnace. In this furnace, the heat required to obtain sufficient vaporization of the crude in the flash zone of crude distillation column. Regarding the hysys data, the crude temperature enter the furnace is around 178 ^{o}C. Then the crude will further heated by gas and / or oil burners, before leaving the crude heater at approximately around 400 ^{o}C (from hysys).

From the model used, the crude distillation unit consists of two types, atmospheric and vacuum. In atmospheric tower, the tower equipped with 29 trays. On the other hand, the pump around was setup to increase the efficiency of the product cut point. The function of pump around is to maintain the tray temperature and stabilize the tower temperature. Thus, the specific product can be extracted more.

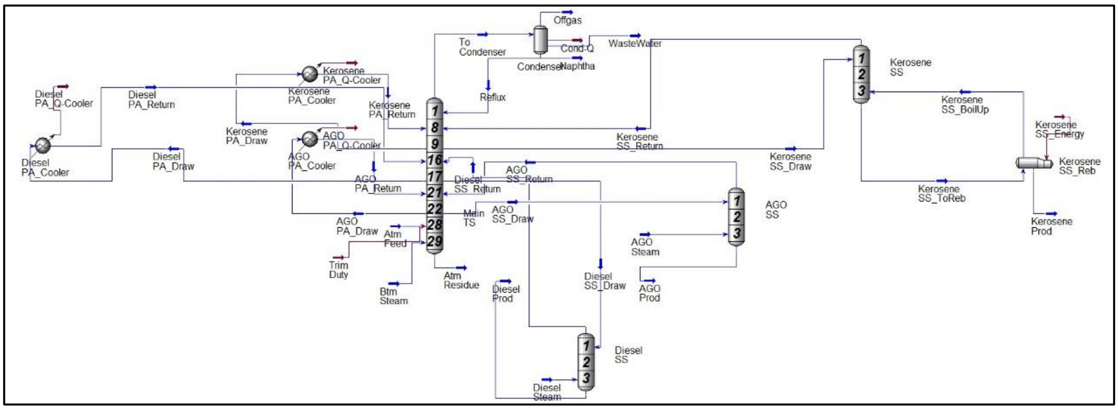


Figure 4 Atmospheric tower

Vacuum distillation is used to safely recover higher boiling point crude. The maximum temperature of the distillation unit's heater has been set the limit. There is where the temperature at which a flammable or combustible material can ignite by the temperature only, this is called the auto ignition temperature. Vacuum distillation lowers the boiling point of the product in order to allow the recovery within the heaters. Vacuum distillation should not be used on the crude with boiling point below 93.3 ^{o}C.

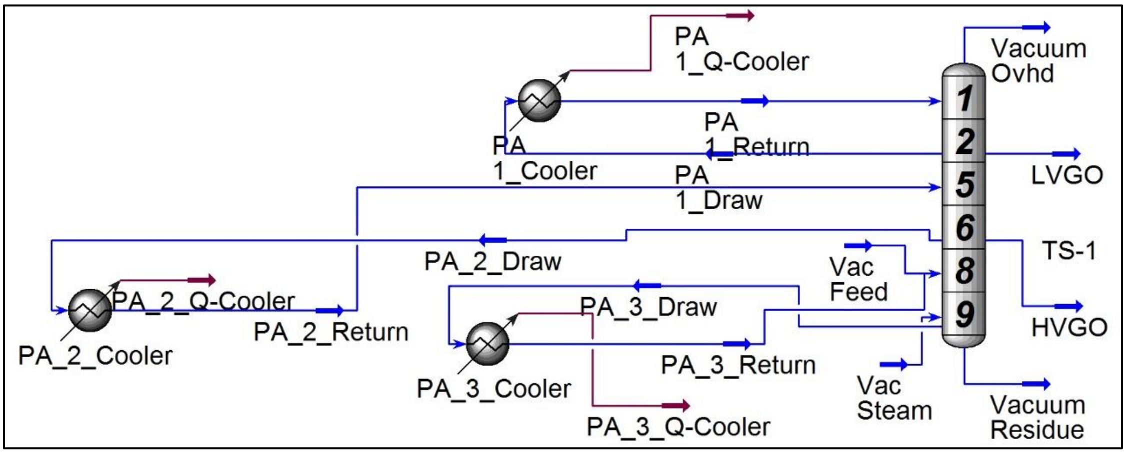


Figure 5 Vacuum tower

Taguchi method has been used in this project. Taguchi design is the statistical technique to optimize the process design problem in different engineering discipline. Currently the flow of the study on the developing the Taguchi procedure is almost done. First of all, the objective function has been developing which is profit as shown below.

Profit = Product sales – crude cost – energy cost – steam cost

The factor (level) for an experiment has been chosen which three is:

- Upper bound
- Lower bound
- Middle

Below shown the controlled variable that is used in this project.

Table 4 Controlled variable

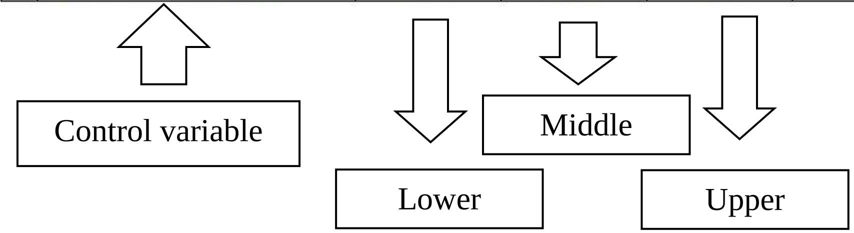
CUT POINT - NAPHTHA	oC
CUT POINT - KERO	oC
CUT POINT - DIESEL	oC
CUT POINT - AGO	oC
CUT POINT - LVGO	oC
CUT POINT - HVGO	oC
VACUUM FEED TEMPERATURE	oC
KERO REBOILER DUTY	kJ/h
COT TEMPERATURE	oC
VACUUM STEAM FLOWRATE	kg/h
BOTTOM STEAM FLOWRATE	kg/h
DIESEL STEAM FLOWRATE	kg/h
AGO STEAM FLOWRATE	kg/h

Table 5 Noise factor

Noise factor	
Crude Flow rate	m^3/h
Crude Price	RM

Table 6 Upper, middle and lower bound for case study variable

	Crude Flowrate		651.9				681.9				711.9	
1	**CUT POINT - NAPHTHA**	153	155	157		160	162	164		167	169	171
2	**CUT POINT - KERO**	208	210	212		218	220	222		228	230	232
3	**CUT POINT - DIESEL**	342	344	346		358	360	362		374	376	378
4	**CUT POINT - AGO**	395	397	399		413	415	417		431	433	435
5	**CUT POINT - LVGO**	287	289	291		300	302	304		313	315	317
6	**CUT POINT - HVGO**	371	373	375		388	390	392		405	407	409
7	**VACUUM FEED TEMPERATURE**	376	378	380		393	395	397		410	412	414
8	**KERO REBOILER DUTY**	6797198	7552442	8307686		7110000	7900000	8690000		7422802	8247558	9072314
9	**COT TEMPERATURE**	380	382	384		398	400	402		416	418	420
10	**VACUUM STEAM FLOWRATE**	1377	1721	2065		1440	1800	2160		1503	1879	2255
11	**BOTTOM STEAM FLOWRATE**	2600	3250	3901		2720	3400	4080		2840	3550	4259
12	**DIESEL STEAM FLOWRATE**	1032	1291	1549		1080	1350	1620		1128	1409	1691
13	**AGO STEAM FLOWRATE**	880	1099	1319		920	1150	1380		960	1201	1441



All experiment are conducted using CDU and VDU steady state model under HYSYS simulation software. All the case study that shown in table above is run separately using different file to avoid miss conduct while inserting the data. The profit is then calculated directly by using spreadsheet setting inside HYSYS software. All required detail as need by the above objective function formula was filled as shown below:

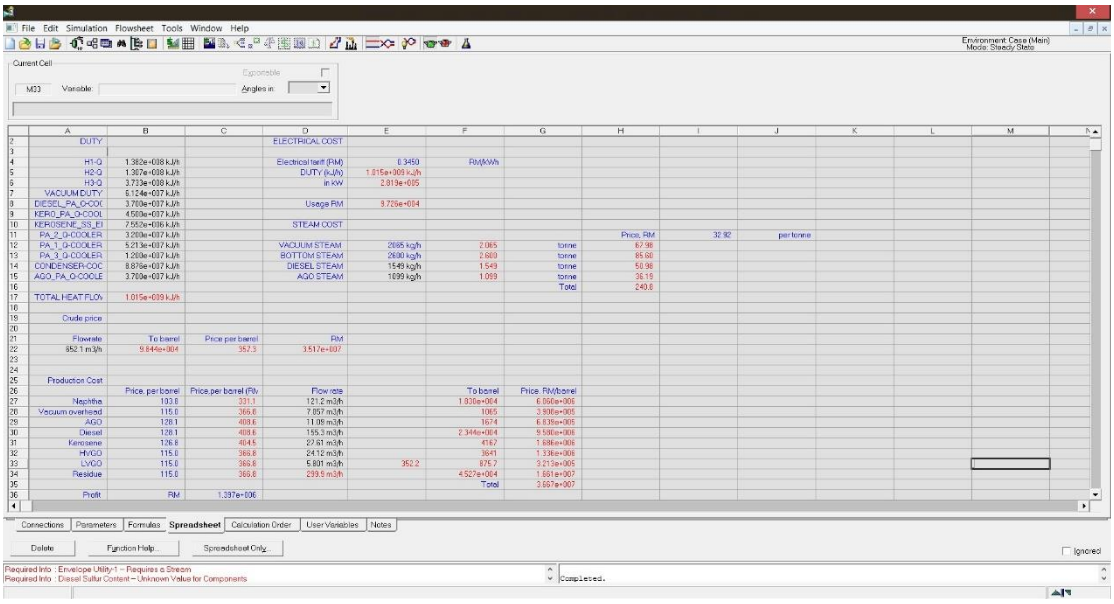


Figure 6 HYSYS spreadsheet

The changes of variable is done simultaneously for each case study. Therefore, only one profit value is obtain for each run. After the selection has been done, the L27 table is constructed. The constructed table for this experiment is stated at the appendix B. The major result are presented in table below. The profit is denoted as X_j where (j = 1-9). On the other hand, the profit is divide into three group. This group is segregate regarding the configuration of noise factor. This sequence also including the similarity of crude feed price.

Table 7 External array profit

Noise factor		Group 1			Group 2			Group 3		
Feed flowrate	m3/h	651.9	651.9	651.9	681.9	681.9	681.9	711.9	711.9	711.9
Feed Price	$/barrel	112	114	116	112	114	116	112	114	116
	RM/barrel	357.28	363.66	370.04	357.28	363.66	370.04	357.28	363.66	370.04
		Profit (RM/day)								
	Run	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**
	1	1501121.87	1501121.92	245048.85	1466109.71	809164.13	152218.74	1698002.59	1012154.01	326280.63
	2	1498318.36	1498318.36	242224.25	1462350.70	805402.63	148457.99	1693969.31	1008120.73	322271.06
	3	1496262.24	1496262.25	240161.10	1459493.89	802545.96	145602.70	1691225.29	1005376.71	319528.19
	4	1511904.04	1511899.18	255803.74	1480024.36	823057.65	166151.53	1703779.15	1017930.57	332081.85
	5	1500959.76	1500958.77	244865.96	1470550.88	813602.63	156650.74	1688777.60	1002929.02	317080.11
	6	1512883.64	1512884.44	256789.46	1482007.88	825062.37	168113.86	1705633.05	1019784.47	333935.94
	7	1511061.07	1511129.45	254967.16	1492270.87	835272.24	178368.21	1702657.65	1016809.07	330960.66
	8	1523073.65	1523107.54	266979.65	1504499.58	847551.70	190603.51	1718162.96	1032314.38	346466.06
	9	1511503.32	1511503.25	255409.27	1493289.98	836344.12	179389.15	1704682.51	1018833.93	332985.50
	10	1474544.49	1474544.12	218450.30	1470464.46	813515.99	156568.99	1686975.52	1001126.94	315278.45
	11	1483258.69	1483271.34	227164.60	1478944.70	821995.03	165048.48	1696453.62	1010605.04	324756.35
	12	1491804.26	1491804.98	235710.25	1488216.90	831271.66	174316.52	1707423.37	1021574.79	335726.12
	13	1458519.31	1458518.83	202413.11	1440469.50	783519.83	126563.16	1683185.05	997336.47	311487.88
	14	1436062.99	1436064.34	179968.59	1416544.44	759597.52	102645.35	1660888.75	975040.17	289191.39
	15	1453852.69	1453852.69	197758.61	1435956.15	779008.76	122062.29	1675358.87	989510.29	303661.71
	16	1474654.57	1474657.45	218564.94	1461150.84	804192.99	147263.64	1691082.98	1005234.39	319386.18
	17	1490674.73	1490684.42	234593.79	1478640.18	821691.95	164744.93	1706426.03	1020577.45	334728.72
	18	1464181.78	1464181.72	208088.02	1450648.15	793699.21	136747.93	1680066.01	994217.43	308368.77
	19	1407784.76	1407784.61	151691.06	1429711.43	772759.67	115815.69	1647602.55	961753.97	275905.49
	20	1417767.29	1417766.97	161673.44	1439782.12	782832.47	125886.27	1660063.06	974214.48	288365.90
	21	1425893.49	1425893.64	169800.22	1448560.18	791607.87	134663.18	1668686.88	982838.30	296989.71
	22	1451801.03	1451800.44	195706.48	1484966.51	828019.25	171081.41	1688344.61	1002496.03	316647.67
	23	1426464.93	1426482.37	170379.43	1461384.25	804436.58	147487.34	1663089.27	977240.69	291392.12
	24	1443483.34	1443502.84	187404.95	1479001.38	822055.09	165106.47	1679214.72	993366.14	307517.62
	25	1404968.53	1404974.63	148872.49	1423599.25	766652.37	109701.58	1652252.53	966403.95	280555.41
	26	1419757.17	1419752.65	163673.34	1440683.02	783735.66	126785.60	1664390.60	978542.02	292693.03
	27	1397226.62	1397226.82	141132.56	1416766.13	759818.23	102868.90	1642437.44	956588.85	270740.01
	Mean	1466288.47	1466294.44	210196.13	1461336.57	804385.69	147441.27	1683734.52	997885.94	312036.39

4.1 Effect of noise factor

In group one, the mean is 1466288.47, 1466294.44 and 210196.13 in unit of Ringgit Malaysia (RM/day) for case 1 until 3. For cases 4 to 5 which is in group two, the global mean is stated at 1461336.57, 804385.69 and 147441.27 RM/day. Therefore for last group, cases 6-9, the respective value are 1683734.52, 997885.94 and 312036.39 RM/day. The different among the global mean each group is quick huge is about 200000 RM/day. This value is caused by the present of noise factor (crude feed flow rate). The amount of crude feed flow rate increase the amount of plant production. Thus, the CDU and VDU profit due to substantial additional production sales of light gas, naphtha, diesel, AGO, diesel and residue. However, along the analysis the result did not shown as that way. Increasing crude flow rate will not ensure that the plant will give maximum profit. The sequence of selected variable also play the important role in this project.

Similarly, the effect crude price as second noise factor can be seen clearly. The highest value of average profit is stated for group one is at second level with 1466294.44 RM/day. For group two, the respective average value is lay on first level which is at 1461336.57 RM/day and 1683734.52 RM/day for group three (level 1).

4.2 Average profit analysis

The analysis of mean (ANOM) is performed to determine the ranking of factors. The significant variable will be review after this test is conducted. In this project, the average profit value is calculate or each case row by row basis. This method is follow the basis of Taguchi implementation by taking the average value as a deal.

Table 8 ANOM and ANOVA for average profit analysis

AVERAGE

ANOM	A	B	C	D	E	F	G	H	I	J	K	L	M
Level	CUT POINT - NAPHTHA	CUT POINT - KERO	CUT POINT - DIESEL	CUT POINT - AGO	CUT POINT - LVGO	CUT POINT - HVGO	VACUUM FEED TEMPERATURE	KERO REBOILER DUTY	COT TEMPERATURE	VACUUM STEAM FLOWRATE	BOTTOM STEAM FLOWRATE	DIESEL STEAM FLOWRATE	AGO STEAM FLOWRATE
1	975227.324	949531.171	955137.4857	934678.4232	949835.4899	950162.2578	950469.2109	953429.6911	951297.999	950692.0717	941273.8581	952853.6844	952790.8249
2	951222.2704	949691.5352	949749.6048	949868.4761	949945.1053	949983.0843	949843.1013	949675.7718	950154.7064	949845.9472	950317.5074	949672.9217	949834.8248
3	923416.877	950643.7653	944979.381	965319.5722	950085.8762	949721.1293	949554.1593	946761.0086	948413.766	949328.4526	958275.1059	947339.8654	947240.8217
Mean	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905	949955.4905
Effect	51810.44699	1112.594324	10158.10469	30641.14898	250.3862883	441.1285367	915.0515778	6668.682495	2884.233052	1363.619066	17001.24778	5513.819047	5550.003275
Rank	1	10	4	2	13	12	11	5	8	9	3	7	6

ANOVA

Factor	CUT POINT - NAPHTHA	CUT POINT - KERO	CUT POINT - DIESEL	CUT POINT - AGO	CUT POINT - LVGO	CUT POINT - HVGO	VACUUM FEED TEMPERATURE	KERO REBOILER DUTY	COT TEMPERATURE	VACUUM STEAM FLOWRATE	BOTTOM STEAM FLOWRATE	DIESEL STEAM FLOWRATE	AGO STEAM FLOWRATE	
1	638665570	180047.06	26853074.19	233388785.6	14400.13518	42752.7321	263908.6319	12070069.69	1802329.238	542551.8329	75370740.51	8399528.001	8039121.478	
2	1604731.393	69672.38568	42388.9193	7571.50008	107.8515861	761.4211367	12631.32963	78242.53498	39686.98613	11999.73274	131056.271	79845.12314	14560.19603	
3	704298004.5	473722.1975	24761665.74	236055005.7	17000.4373	54925.1714	161066.7279	10204714.69	2376914.404	393176.5119	69216000.67	6841494.804	7369426.796	
Sum	1344568306	723441.6432	51657128.85	469451362.8	31508.42407	98439.32463	437606.6894	22353026.91	4218930.628	947728.0775	144717797.4	15320867.93	15423108.47	
Sk	36303344259	19532924.37	1394742479	12675186795	850727.4498	2657861.765	11815380.61	603531726.6	113911127	25588658.09	3907380531	413663434.1	416423928.7	
DOF	2	2	2	2	2	2	2	2	2	2	2	2	2	
Vk	18151672129	9766462.183	697371239.5	6337593398	425363.7249	1328930.883	5907690.307	301765863.3	56955563.48	12794329.05	1953690266	206831717	208211964.3	2.794E+10
Ck	64.95658306	0.034949728	2.495574651	22.67936579	0.001522183	0.00475564	0.021140938	1.079882846	0.203818071	0.045785088	6.991369341	0.740156693	0.74509597	100
Rank	1	10	4	2	13	12	11	5	8	9	3	7	6	

The ANOM analysis have been conducted to determine the ranking of control variable. From table above, the deviation of effect value is use to determine the ranking. Factor that carry highest value of effect value will be at the highest ranking. In this study, among 13 controllable factors that affect plant profit is arranged by the descending order of importance which is ADKCHMLIJBGFE as refer to above table of ANOM analysis. In this case, the factor A is the most significant while the factor E is the least significant.

The ANOM is then verified with the analysis of variance (ANOVA). This test is to make sure the ANOM analysis is done correctly. The sum of square factor k shown the significant contribution of particular factor. If the value is approaching zero, the factor is can be conclude as unimportant factor. The degree of freedom is two for all cases. Hence, the variance of factor k, V_k can be determined. The ranking that shown in ANOVA is identical with the result that obtain from ANOM. The ranking is arrange descending order of importance from 13 variables is ADKCHMLIJBGFE.

Factor A (naphtha cut point) is a major contributor in this study with 65%. This factor is used to control the temperature at naphtha condenser that could effluent the amount of the production. Increasing the cut point will increase the tendency to recover all naphtha inside the raw crude feed. Contribution of factor D (AGO cut point) at 22.7% is influent at AGO side stripper column. This will affect the efficiency of side stripper column. On the other hand, by regulating the AGO cut point, the steam inlet will be fluctuated. Increasing steam will increasing the utilities cost as well as reducing the plant profit. The factor K (bottom steam flow rate) is slightly significant 7% contribution toward plant optimization. Supply sufficient amount of heat can increase the column efficiency. This action is contribute to a present of factor A.

Diesel cut point (factor C) is also significant with 2.5% contribution. Diesel side stripper temperature is the major contribution in factor C. Similarly with naphtha side stripper function. Increasing the temperature will increase the efficiency to extract all diesel inside the raw crude feed. Contribution of factor H (kerosene reboiler duty) is minor at 1.1%. This factor controlled the kerosene side stripper column temperature. Increasing the reboiler duty will promote more kerosene product. Hence, the profit can be increased significantly. The other 8 factor is can be assume did not affect the plant optimization. Almost 98% optimization is develop by using only 5 controlled variables.

4.3 Signal-to-noise ratio (SNR) analysis

Table 9 ANOM and ANOVA for SNR

SNR

ANOM	A	B	C	D	E	F	G	H	I	J	K	L	M
Level	CUT POINT - NAPHTHA	CUT POINT - KERO	CUT POINT - DIESEL	CUT POINT - AGO	CUT POINT - LVGO	CUT POINT - HVGO	VACUUM FEED TEMPERATURE	KERO REBOILER DUTY	COT TEMPERATURE	VACUUM STEAM FLOWRATE	BOTTOM STEAM FLOWRATE	DIESEL STEAM FLOWRATE	AGO STEAM FLOWRATE
1	91.21084106	89.81141561	77.55971802	89.03818538	87.07829463	88.06820105	94.87988956	93.56500235	92.33793035	85.74390242	87.46165953	91.32326033	88.28784198
2	85.33466255	84.66449982	95.2173674	89.90500854	88.26219081	84.42083327	91.22321271	88.83100016	86.99562042	90.09236738	88.85870084	89.92281313	87.18226728
3	90.70578369	92.77537187	94.47420188	88.30809338	91.91080186	94.76225298	81.14818503	84.8552848	87.91773653	91.41501751	90.93092694	86.00521385	91.78117804
Mean	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243	89.08376243
Effect	5.876178517	8.110872049	17.65764938	1.59691516	4.832507225	10.34141972	13.73170453	8.709717548	5.342309934	5.671115081	3.469267412	5.318046485	4.598910761
Rank	6	5	1	13	10	3	2	4	8	7	12	9	11

ANOVA

Factor	CUT POINT - NAPHTHA	CUT POINT - KERO	CUT POINT - DIESEL	CUT POINT - AGO	CUT POINT - LVGO	CUT POINT - HVGO	VACUUM FEED TEMPERATURE	KERO REBOILER DUTY	COT TEMPERATURE	VACUUM STEAM FLOWRATE	BOTTOM STEAM FLOWRATE	DIESEL STEAM FLOWRATE	AGO STEAM FLOWRATE	
1	4.524463497	0.529479146	132.8035996	0.002077268	4.0219011	1.031364917	33.59508967	20.08151117	10.58960885	11.15466489	2.63121785	5.015350828	0.633489369	
2	14.05574997	19.52988204	37.62110993	0.674445168	0.674979933	21.74290842	4.577247476	0.06388877	4.360337075	1.017283926	0.050652721	0.704006063	3.615683818	
3	2.630952961	13.62798023	29.0568374	0.601662481	7.992151906	32.24525491	62.97338869	17.8800231	1.35961641	5.434750204	3.4120167	9.47746141	7.276050958	
Sum	21.21116642	33.68734141	199.481547	1.278184916	12.68903294	55.01952825	101.1457258	38.02542304	16.30956233	17.60669902	6.09388727	15.1968183	11.52522414	
Sk	572.7014935	909.5582182	5386.001768	34.51099273	342.6038893	1485.527263	2730.934598	1026.686422	440.358183	475.3808736	164.5349563	410.3140941	311.1810519	
DOF	2	2	2	2	2	2	2	2	2	2	2	2	2	
Vk	286.3507467	454.7791091	2693.000884	17.25549637	171.3019447	742.7636314	1365.467299	513.343211	220.1790915	237.6904368	82.26747815	205.1570471	155.590526	7145.1463
Ck	4.007625745	6.364867166	37.68993026	0.241499533	2.397458681	10.39535844	19.11041603	7.184501846	3.08151945	3.32659972	1.151375602	2.871278224	2.177569308	
Rank	6	5	1	13	10	3	2	4	8	7	12	9	11	

In this section, the significant variable is conducted using signal-to-noise ratio (SNR) analysis. The principle selected is in the form of ‘the-higher-the-better’. An external array is conducted at $L_{9,}$ which mean that each experiment need to be repeated 9 times under different configuration of external array. The noise factor is a major factor in configure the external array. The low value of SNR indicate the high effect of noise factor on the outputs. 13 controlled variables in descending order of importance is CGFHBAJILEMKD as stated in table above. Factor C is the most important factor compare to factor D which is the least importance factor.

The analysis of mean and variance must be conducted in order to interpret of result from SNR analysis. The same procedure to calculate the ANOM is shown in previous case of averaged profit analysis. The order of importance variable same for ANOM and ANOVA which is CGFHBAJILEMKD. The diesel cut point (factor C) become the first variable that is the most important in this study. On the other hand, the factor G (vacuum feed temperature) with 19% is the second most important in minimizing effects of noise factor through SNR analysis. Vacuum feed temperature is responsible to maintain the temperature inside vacuum distillation column. Maintaining the temperature will help increase the efficiency of the vacuum column. Hence, the cut point of product inside vacuum tower can be thoroughly follow its specification. Factor F (HVGO cut point) is the third minimizing effect of noise factor with 10.4%. The other factor which is factor H, B, A, J, I, L, E, M, K and D are respectively at 7.2%,6.4%, 4%, 3.3%, 3.1%, 2.9%, 2.4%, 2.2%, 1.2% and 0.2%. Hence the cut point AGO can say that the least minimizing effect of noise factor.

Besides determining the significant of factors to stabilizing the disturbance, the optimal configuration also can be determine by using SNR. The optimal configuration of factor that can maximizing the profit can be located. From all 9 cases, the result in case 7 in 8 run shown the highest profit with a value of 1718162.96 RM/day. The configuration for this is $A_1B_3C_3D_3E_2F_2G_2H_1I_1J_1K_3L_3M_3$. On the other hand, the low profit configuration is $A_2B_2C_3D_1E_2F_3G_1H_3I_1J_2K_1L_2M_3$ with value of 102645.35 RM/day. In general, the result confirm that the study is comply in order to find the highest profit value.

4.4 Validation

The last event is to validate the result. The configuration of the highest profit is then compare to the individual ANOM result. The optimal configuration can be display in term of response plot based on the average profit and the SNR analysis.

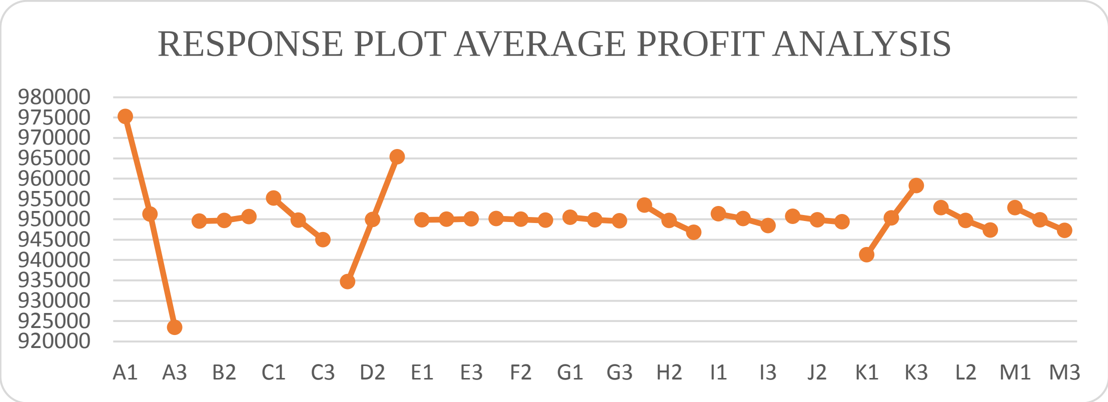


Figure 7 Response plot average profit analysis

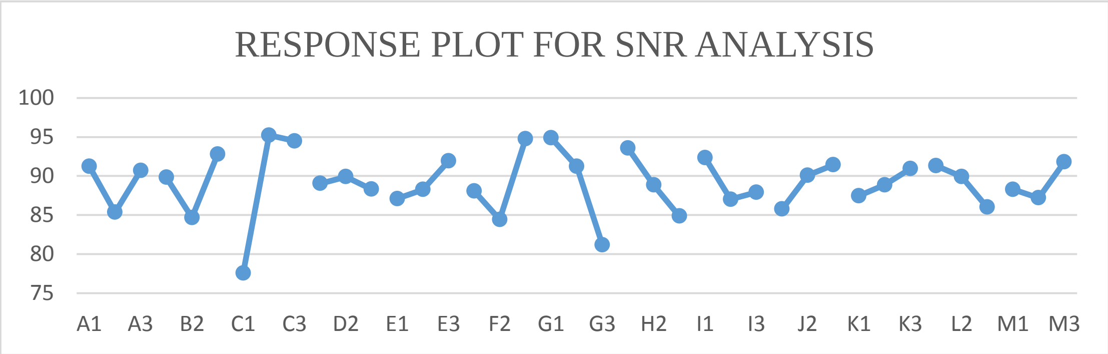


Figure 8 Response plot for SNR analysis

From response plot above, the steeper the slope shown the most significant factor. In the analysis that uses averaged value of profit, the maximum profit configuration can be see clearly from the graph above. The configuration is $A_1B_3C_1D_3E_3F_1G_1H_1I_1J_1K_3L_1M_1$. With this optimal configuration, it then set to the HYSYS simulation environment. The profit is calculated automatically inside the build-in spreadsheet. The profit value can be seen in the table below:

Table 10 Profit value from HYSYS and Taguchi method ANOM at optimal condition

Case	HYSYS (RM/day)	ANOM (RM/day)	Deviation(%)
1	1543195.29	1545768.77	0.17
2	1543182.81	1545793.20	0.17
3	287088.62	289695.55	0.91
4	1526230.52	1528802.84	0.17
5	869276.56	871853.27	0.30
6	212345.07	214909.45	1.21
7	1736443.04	1737668.98	0.07
8	1050594.46	1051820.40	0.12
9	364746.15	365958.38	0.33

From table above, the deviation value is less than 1% is obtain from all cases. This situation shown that the optimal configuration of controllable factor for all cases have been found. As stated earlier, the lowest global mean is at 102645.35 RM/day is obtain with noise factor configuration of (crude feed flow rate = N , crude price = O) N_2O_3. This lower value is stated at case study 6. While, with the configuration of N_3O_1 the maximum profit collected is at 1642437.44 RM/day. From this situation, it shown that the most optimum configuration of noise factor have been found in case 7. The combination of configuration for all including the noise factor, the optimum configuration is at $A_1B_3C_1D_3E_3F_1G_1H_1I_1J_1K_3L_1M_1$ N_3O_1. When the validation test is conducted in HYSYS, with this configuration the profit is at 1736443.04 RM/day. Further, the deviation value is 0.07% confirming that this configuration is the optimum.

CHAPTER 5

CONCLUSION

5. Conclusion

Significant of 13 controlled variable with 2 noise factor that effecting the plant profit is studied by conducting an experiment under Taguchi orthogonal array set up. Five controlled variable is rank at the top among the others. This combination of 5 variable completely neglected the other 8 controlled variable. This is because the selection of cut point as the controlled variable is complicated. The cut point can caused the product purity problem.

In industry, customer will decide the product specification before they buy it. In this case, the product purity is fluctuated cause by the changing of cutting point. Even though the changes $2^{o}C$ can cause the different in mass flow production of curtain product. This is almost 200 barrel/day the differences can be detected. Higher load (crude feed flow rate) is more significant compare to crude feed price. The combination of low, medium and high level that selected from the response plot of average profit values. Last but not least, all the configuration is validate with the minimum factorial configuration.

For future recommendation, the selection variable must be conducted more precise with different combination. Test run experiment is a must before take that variable as the controlled variable for this project. On the other hand, the detail of simulation model needed in order to make sure easy flow in determining and regulating the variable.

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APPENDICES

Table 11 Orthogonal array arrangement

Run	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Table 12 Variable distribution inside orthogonal array for 651.9 m^3/h

651.9

	CUT POINT - NAPHTHA	CUT POINT - KERO	CUT POINT - DIESEL	CUT POINT - AGO	CUT POINT - LVGC	CUT POINT - HVGC	VACUUM FEED TEMPERATURE	KERO REBOILER DUTY	COT TEMPERATURE	VACUUM STEAM FLOWRATE	BOTTOM STEAM FLOWRATE	DIESEL STEAM FLOWRATE	AGO STEAM FLOWRATE
	X4	X5	X6	X7	X8	X9	X10	X12	X14	X15	X16	X18	X20
Run	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**
1	152.8728553	208.3211615	342.1619006	394.7421909	286.7135944	370.842059	375.6220853	6797197.536	377.4021117	1376.647602	2600.33436	1032.485702	879.524857
2	152.8728553	208.3211615	342.1619006	394.7421909	288.7135944	372.842059	377.6220853	7552441.707	382.4021117	1720.809503	3250.41795	1290.607127	1099.406071
3	152.8728553	208.3211615	342.1619006	394.7421909	290.7135944	374.842059	379.6220853	8307685.878	387.4021117	2064.971403	3900.50154	1548.728553	1319.287286
4	152.8728553	210.3211615	344.1619006	396.7421909	286.7135944	370.842059	375.6220853	7552441.707	382.4021117	1720.809503	3900.50154	1548.728553	1319.287286
5	152.8728553	210.3211615	344.1619006	396.7421909	288.7135944	372.842059	377.6220853	8307685.878	387.4021117	2064.971403	2600.33436	1032.485702	879.524857
6	152.8728553	210.3211615	344.1619006	396.7421909	290.7135944	374.842059	379.6220853	6797197.536	377.4021117	1376.647602	3250.41795	1290.607127	1099.406071
7	152.8728553	212.3211615	346.1619006	398.7421909	286.7135944	370.842059	375.6220853	8307685.878	387.4021117	2064.971403	3250.41795	1290.607127	1099.406071
8	152.8728553	212.3211615	346.1619006	398.7421909	288.7135944	372.842059	377.6220853	6797197.536	377.4021117	1376.647602	3900.50154	1548.728553	1319.287286
9	152.8728553	212.3211615	346.1619006	398.7421909	290.7135944	374.842059	379.6220853	7552441.707	382.4021117	1720.809503	2600.33436	1032.485702	879.524857
10	154.8728553	208.3211615	344.1619006	398.7421909	286.7135944	372.842059	379.6220853	6797197.536	382.4021117	2064.971403	2600.33436	1290.607127	1319.287286
11	154.8728553	208.3211615	344.1619006	398.7421909	288.7135944	374.842059	375.6220853	7552441.707	387.4021117	1376.647602	3250.41795	1548.728553	879.524857
12	154.8728553	208.3211615	344.1619006	398.7421909	290.7135944	370.842059	377.6220853	8307685.878	377.4021117	1720.809503	3900.50154	1032.485702	1099.406071
13	154.8728553	210.3211615	346.1619006	394.7421909	286.7135944	372.842059	379.6220853	7552441.707	387.4021117	1376.647602	3900.50154	1032.485702	1099.406071
14	154.8728553	210.3211615	346.1619006	394.7421909	288.7135944	374.842059	375.6220853	8307685.878	377.4021117	1720.809503	2600.33436	1290.607127	1319.287286
15	154.8728553	210.3211615	346.1619006	394.7421909	290.7135944	370.842059	377.6220853	6797197.536	382.4021117	2064.971403	3250.41795	1548.728553	879.524857
16	154.8728553	212.3211615	342.1619006	396.7421909	286.7135944	372.842059	379.6220853	8307685.878	377.4021117	1720.809503	3250.41795	1548.728553	879.524857
17	154.8728553	212.3211615	342.1619006	396.7421909	288.7135944	374.842059	375.6220853	6797197.536	382.4021117	2064.971403	3900.50154	1032.485702	1099.406071
18	154.8728553	212.3211615	342.1619006	396.7421909	290.7135944	370.842059	377.6220853	7552441.707	387.4021117	1376.647602	2600.33436	1290.607127	1319.287286
19	156.8728553	208.3211615	346.1619006	396.7421909	286.7135944	374.842059	377.6220853	6797197.536	387.4021117	1720.809503	2600.33436	1548.728553	1099.406071
20	156.8728553	208.3211615	346.1619006	396.7421909	288.7135944	370.842059	379.6220853	7552441.707	377.4021117	2064.971403	3250.41795	1032.485702	1319.287286
21	156.8728553	208.3211615	346.1619006	396.7421909	290.7135944	372.842059	375.6220853	8307685.878	382.4021117	1376.647602	3900.50154	1290.607127	879.524857
22	156.8728553	210.3211615	342.1619006	398.7421909	286.7135944	374.842059	377.6220853	7552441.707	377.4021117	2064.971403	3900.50154	1290.607127	879.524857
23	156.8728553	210.3211615	342.1619006	398.7421909	288.7135944	370.842059	379.6220853	8307685.878	382.4021117	1376.647602	2600.33436	1548.728553	1099.406071
24	156.8728553	210.3211615	342.1619006	398.7421909	290.7135944	372.842059	375.6220853	6797197.536	387.4021117	1720.809503	3250.41795	1032.485702	1319.287286
25	156.8728553	212.3211615	344.1619006	394.7421909	286.7135944	374.842059	377.6220853	8307685.878	382.4021117	1376.647602	3250.41795	1032.485702	1319.287286
26	156.8728553	212.3211615	344.1619006	394.7421909	288.7135944	370.842059	379.6220853	6797197.536	387.4021117	1720.809503	3900.50154	1290.607127	879.524857
27	156.8728553	212.3211615	344.1619006	394.7421909	290.7135944	372.842059	375.6220853	7552441.707	377.4021117	2064.971403	2600.33436	1548.728553	1099.406071

Table 13 Variable distribution inside orthogonal array for 681.9 m3/h

681.9

	CUT POINT - NAPHTHA	CUT POINT - KERO	CUT POINT - DIESEL	CUT POINT - AGO	CUT POINT - LVGC	CUT POINT - HVGC	VACUUM FEED TEMPERATURE	KERO REBOILER DUTY	COT TEMPERATURE	VACUUM STEAM FLOWRATE	BOTTOM STEAM FLOWRATE	DIESEL STEAM FLOWRATE	AGO STEAM FLOWRATE
	X4	X5	X6	X7	X8	X9	X10	X12	X14	X15	X16	X18	X20
Run	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**
1	160	218	358	413	300	388	393	7110000	395	1440	2720	1080	920
2	160	218	358	413	302	390	395	7.90E+06	400	1800	3400	1350	1150
3	160	218	358	413	304	392	397	8690000	405	2160	4080	1620	1380
4	160	220	360	415	300	388	393	7.90E+06	400	1800	4080	1620	1380
5	160	220	360	415	302	390	395	8690000	405	2160	2720	1080	920
6	160	220	360	415	304	392	397	7110000	395	1440	3400	1350	1150
7	160	222	362	417	300	388	393	8690000	405	2160	3400	1350	1150
8	160	222	362	417	302	390	395	7110000	395	1440	4080	1620	1380
9	160	222	362	417	304	392	397	7.90E+06	400	1800	2720	1080	920
10	162	218	360	417	300	390	397	7110000	400	2160	2720	1350	1380
11	162	218	360	417	302	392	393	7.90E+06	405	1440	3400	1620	920
12	162	218	360	417	304	388	395	8690000	395	1800	4080	1080	1150
13	162	220	362	413	300	390	397	7.90E+06	405	1440	4080	1080	1150
14	162	220	362	413	302	392	393	8690000	395	1800	2720	1350	1380
15	162	220	362	413	304	388	395	7110000	400	2160	3400	1620	920
16	162	222	358	415	300	390	397	8690000	395	1800	3400	1620	920
17	162	222	358	415	302	392	393	7110000	400	2160	4080	1080	1150
18	162	222	358	415	304	388	395	7.90E+06	405	1440	2720	1350	1380
19	164	218	362	415	300	392	395	7110000	405	1800	2720	1620	1150
20	164	218	362	415	302	388	397	7.90E+06	395	2160	3400	1080	1380
21	164	218	362	415	304	390	393	8690000	400	1440	4080	1350	920
22	164	220	358	417	300	392	395	8690000	395	2160	4080	1350	920
23	164	220	358	417	302	388	397	8690000	400	1440	2720	1620	1150
24	164	220	358	417	304	390	393	7110000	405	1800	3400	1080	1380
25	164	222	360	413	300	392	395	8690000	400	1440	3400	1080	1380
26	164	222	360	413	302	388	397	7110000	405	1800	4080	1350	920
27	164	222	360	413	304	390	393	7.90E+06	395	2160	2720	1620	1150

Table 14 Variable distribution inside orthogonal array for 711.9 m3/h

711.9

	CUT POINT - NAPHTHA	CUT POINT - KERO	CUT POINT - DIESEL	CUT POINT - AGO	CUT POINT - LVGC	CUT POINT - HVGC	VACUUM FEED TEMPERATURE	KERO REBOILER DUTY	COT TEMPERATURE	VACUUM STEAM FLOWRATE	BOTTOM STEAM FLOWRATE	DIESEL STEAM FLOWRATE	AGO STEAM FLOWRATE
	X4	X5	X6	X7	X8	X9	X10	X12	X14	X15	X16	X18	X20
Run	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**
1	167.1271447	227.6788385	373.8380994	431.2578091	313.2864056	405.157941	410.3779147	7422802.464	412.5978883	1503.352398	2839.66564	1127.514298	960.475143
2	167.1271447	227.6788385	373.8380994	431.2578091	315.2864056	407.157941	412.3779147	8247558.293	417.5978883	1879.190497	3549.58205	1409.392873	1200.593929
3	167.1271447	227.6788385	373.8380994	431.2578091	317.2864056	409.157941	414.3779147	9072314.122	422.5978883	2255.028597	4259.49846	1691.271447	1440.712714
4	167.1271447	229.6788385	375.8380994	433.2578091	313.2864056	405.157941	410.3779147	8247558.293	417.5978883	1879.190497	4259.49846	1691.271447	1440.712714
5	167.1271447	229.6788385	375.8380994	433.2578091	315.2864056	407.157941	412.3779147	9072314.122	422.5978883	2255.028597	2839.66564	1127.514298	960.475143
6	167.1271447	229.6788385	375.8380994	433.2578091	317.2864056	409.157941	414.3779147	7422802.464	412.5978883	1503.352398	3549.58205	1409.392873	1200.593929
7	167.1271447	231.6788385	377.8380994	435.2578091	313.2864056	405.157941	410.3779147	9072314.122	422.5978883	2255.028597	3549.58205	1409.392873	1200.593929
8	167.1271447	231.6788385	377.8380994	435.2578091	315.2864056	407.157941	412.3779147	7422802.464	412.5978883	1503.352398	4259.49846	1691.271447	1440.712714
9	167.1271447	231.6788385	377.8380994	435.2578091	317.2864056	409.157941	414.3779147	8247558.293	417.5978883	1879.190497	2839.66564	1127.514298	960.475143
10	169.1271447	227.6788385	375.8380994	435.2578091	313.2864056	407.157941	414.3779147	7422802.464	417.5978883	2255.028597	2839.66564	1409.392873	1440.712714
11	169.1271447	227.6788385	375.8380994	435.2578091	315.2864056	409.157941	410.3779147	8247558.293	422.5978883	1503.352398	3549.58205	1691.271447	960.475143
12	169.1271447	227.6788385	375.8380994	435.2578091	317.2864056	405.157941	412.3779147	9072314.122	412.5978883	1879.190497	4259.49846	1127.514298	1200.593929
13	169.1271447	229.6788385	377.8380994	431.2578091	313.2864056	407.157941	414.3779147	8247558.293	422.5978883	1503.352398	4259.49846	1127.514298	1200.593929
14	169.1271447	229.6788385	377.8380994	431.2578091	315.2864056	409.157941	410.3779147	9072314.122	412.5978883	1879.190497	2839.66564	1409.392873	1440.712714
15	169.1271447	229.6788385	377.8380994	431.2578091	317.2864056	405.157941	412.3779147	7422802.464	417.5978883	2255.028597	3549.58205	1691.271447	960.475143
16	169.1271447	231.6788385	373.8380994	433.2578091	313.2864056	407.157941	414.3779147	9072314.122	412.5978883	1879.190497	3549.58205	1691.271447	960.475143
17	169.1271447	231.6788385	373.8380994	433.2578091	315.2864056	409.157941	410.3779147	7422802.464	417.5978883	2255.028597	4259.49846	1127.514298	1200.593929
18	169.1271447	231.6788385	373.8380994	433.2578091	317.2864056	405.157941	412.3779147	8247558.293	422.5978883	1503.352398	2839.66564	1409.392873	1440.712714
19	171.1271447	227.6788385	377.8380994	433.2578091	313.2864056	409.157941	412.3779147	7422802.464	422.5978883	1879.190497	2839.66564	1691.271447	1200.593929
20	171.1271447	227.6788385	377.8380994	433.2578091	315.2864056	405.157941	414.3779147	8247558.293	412.5978883	2255.028597	3549.58205	1127.514298	1440.712714
21	171.1271447	227.6788385	377.8380994	433.2578091	317.2864056	407.157941	410.3779147	9072314.122	417.5978883	1503.352398	4259.49846	1409.392873	960.475143
22	171.1271447	229.6788385	373.8380994	435.2578091	313.2864056	409.157941	412.3779147	8247558.293	412.5978883	2255.028597	4259.49846	1409.392873	960.475143
23	171.1271447	229.6788385	373.8380994	435.2578091	315.2864056	405.157941	414.3779147	9072314.122	417.5978883	1503.352398	2839.66564	1691.271447	1200.593929
24	171.1271447	229.6788385	373.8380994	435.2578091	317.2864056	407.157941	410.3779147	7422802.464	422.5978883	1879.190497	3549.58205	1127.514298	1440.712714
25	171.1271447	231.6788385	375.8380994	431.2578091	313.2864056	409.157941	412.3779147	9072314.122	417.5978883	1503.352398	3549.58205	1127.514298	1440.712714
26	171.1271447	231.6788385	375.8380994	431.2578091	315.2864056	405.157941	414.3779147	7422802.464	422.5978883	1879.190497	4259.49846	1409.392873	960.475143
27	171.1271447	231.6788385	375.8380994	431.2578091	317.2864056	407.157941	410.3779147	8247558.293	412.5978883	2255.028597	2839.66564	1691.271447	1200.593929