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MODELING OF CRUDE DISTILLATION UNIT (CDU)

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MODELING OF CRUDE DISTILLATION UNIT (CDU)

MUHAMMAD SAFWAN BIN TAHARIM

A research report submitted in fulfillment of the requirements
for the award of.the degree of
Bachelor of Chemical Engineering

Faculty of Chemical and Natural Resources Engineering
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Special Dedication of This Grateful Feeling…

To my beloved mother, late father, brothers, and sisters
Understanding and helpful supervisor;
Last but not least my lovely friends.

Thank you for your supporting.

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ABSTRACT

Crude distillation unit (CDU) is a complex process in the field of separation which produces wide range of products at different stages under different conditions. The products of the process were heavy naphtha, kerosene, diesel, atmospheric gas oil and reduced crude. However, the dynamic and multivariable nature with strict quality was makes it difficult to operate the process units steadily. More, the dynamics of CDU are complex due to its complex vapor-liquid equilibrium relationships. It is necessary to predict the new steady-state values for any changes in the operating conditions. This research aims to develop a steady-state model for CDU based on the fundamental modeling approach. The simulation was carried out in Aspen Plus. The effect of feed flow rate, feed composition and steam flow rate on product compositions and tray temperatures were studied. The results were compared with the data available in the literature and the accuracy of the model has been proved.

ABSTRAK

Unit penyulingan mentah (CDU) adalah satu proses yang kompleks dalam bidang pemisahan yang menghasilkan pelbagai jenis produk pada peringkat yang berbeza di bawah keadaan yang berbeza. Produk-produk hasil daripada pemisahan ini adalah naphtha berat, minyak tanah, diesel, minyak gas atmosfera dan lebihan minyak mentah. Walau bagaimanapun, ciri-ciri yang dinamik dan berbilang dengan kualiti yang ketat adalah sukar untuk mengendalikan unit-unit proses ini. Dinamik CDU adalah kompleks disebabkan oleh hubungan keseimbangan wap-cecair yang kompleks. Ia perlu untuk meramalkan nilai baru keadaan yang seimbang bagi apa-apa perubahan dalam keadaan operasi. Kajian ini bertujuan untuk membangunkan model keadaan yang seimbang bagi CDU yang berdasarkan pendekatan asas model. Simulasi telah dijalankan di Aspen Plus. Kesan kadar aliran suapan, komposisi suapan dan kadar aliran stim pada komposisi produk dan suhu telah di ulang dikaji. Keputusan dibandingkan dengan data yang ada dalam kesusasteraan dan ketepatan model yang telah terbukti.

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LIST OF SYMBOLS

V_i	Mole flow of vapor from stage i
V_{i+1}	Mole flow of vapor entering the stage
L_i	Mole flow of liquid from stage i
L_{i-1}	Mole flow of liquid entering the stage
x, y, f	Mole friction
Q_m	Heat of mixing
Q_s	External of heat source
Q_{loss}	Heat losses
h_i , h_{i-1} , h_{i+1} , h_f	Molar enthalpies of corresponding stream
w_i	Liquid holdup on the stage.
ρ_{Li}	Density of liquid at stage i
A_{Ti}	Active surface area of stage
A_{Di}	Active surface area of down-comer

LIST OF ABBREVIATIONS

CDU	Crude Distillation Unit
ADU	Atmospheric Distillation Unit
ASTM	American Society for Testing and Materials
TBP	True Boiling Point
IBP	Initial Boiling Point
FBP	Final Boiling Point
SRK	Soave-Redlich-Kwong
PR	Peng-Robinson
NRTL	Non-Random Two Liquid
GS	Grayson-Streed
BK10	Braun K10
HNAPHTHA	Heavy Naphtha
AGO	Atmospheric Gas Oil
RED-CRD	Reduced Crude

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Crude distillation is the first process in the refining sequence and it is important to gain the refinery operations due to the highly complex and integrated process of petroleum in the field of separation process. The crude oil or petroleum is a mixture of different hydrocarbon components that are called fractions and need to be separated to get many useful products. That why CDU is the most important processing unit in refineries which produces wide range of products such as heavy naphtha, kerosene, diesel, atmospheric gas oil and reduced crude. However, the dynamic and multivariable nature with strict quality was makes it difficult to operate the process units steadily.

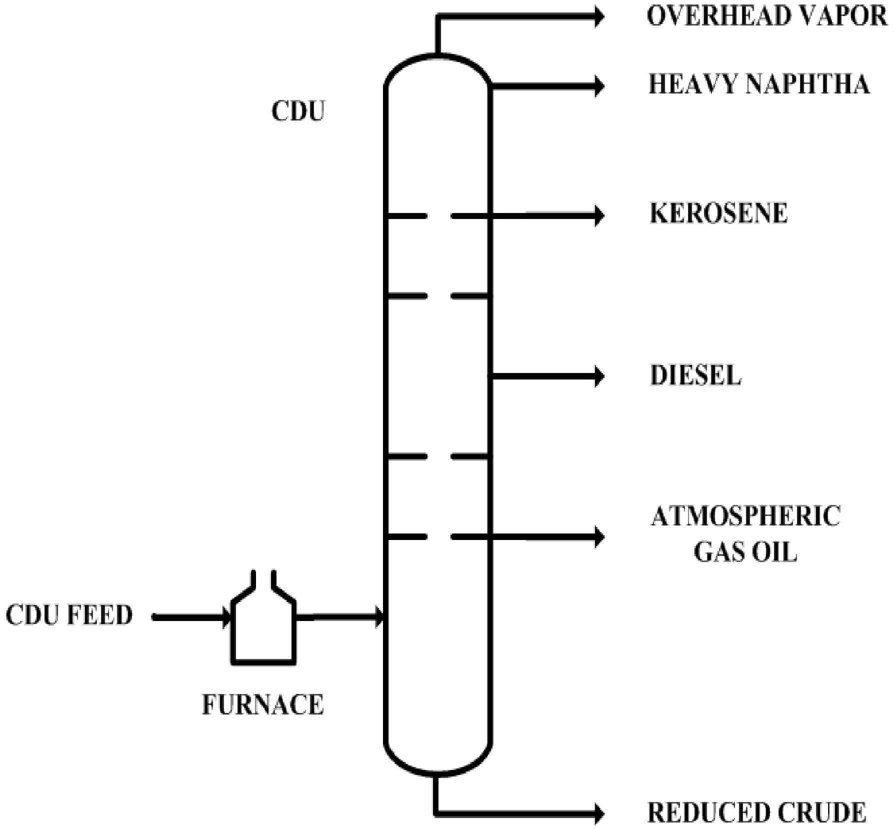


Figure 1.1: Schematic Diagram of CDU

Referring to the figure 1.1 for a full explanation of the process of the present invention, the crude oil at 200 ^{0}C to 280 ^{0}C is preheated by the bottoms furnace for further preheated and partially vaporized of the outlet of the furnace. The crude oil will heated up further between 330 ^{0}C to 370 ^{0}C before it sent to the CDU feed and the crude oil will be separated into number of fraction at different boiling range. The furnaces operates at 24.18 psia and provides an over flash of 3% in the tower. The outlet of the furnace enters the feed of CDU on certain stage of the main fractionators. The CDU is modeled with equilibrium stages and pressure drop where the heavy naphtha product at about 60 ^{0}C to 100 ^{0}C boiling range is yield at desired flow rate. A total condenser that operates at certain pressure with pressure drop is applied and the CDU has pumps around circuits and side strippers for kerosene, diesel and atmospheric gas oil (DeGraff R.R. 1978).

At about 350 ^{0}C, most of the crude oil fraction will vaporize and rise up through the column. During the rise, the fraction will lose heat and will be separate at certain temperature based on the characteristic of its own fraction characteristics (Montgomery D.P. *et al*. 1986). The vaporize fraction will condense and change back to liquid when it touch tray where the temperature is just below its own boiling point. The evaporation and condensing operation is repeated many times until the desired degree of product purity is reach. Hence, a continuous liquid phase is flowing by gravity through 'down-comer'. So, the different fractions are separated each other on different tray of the CDU.

The output from the top of CDU, the overhead of vapor product will leave through a pipe and routed to condenser. The outlet of the overhead condenser at about 40 ^{0}C contain the existed of liquid naphtha and mixture of gas which will transfer to heavy naphtha line for further process (Gomez R.A.M. *et al* 2005). In order to provide a driving force for separation between light and heavy fractions the CDU needs a flow of condensing liquid downward. However, a lot of heat will loss and to prevent this is done by apply the circulating reflux of the column which the objective is to recover heat from condensing vapors (Ronald F. *et al*. 2009).

At boiling range 160 ^{0}C to 280 ^{0}C, kerosene which is lightest side will draw of from the CDU and falls down into a side stripper through a pipe. The stripper is just like small column with certain stages which function for providing contact between vapor and liquid. The main objective of the stripper is to remove very light hydrocarbons by using steam injection or an external heater called 'reboiler'. The boiling range of diesel at 250 ^{0}C to 350 ^{0}C and atmospheric gas oil at 200 ^{0}C to 400 ^{0}C also will draw of from the CDU then falls down into side stripper before being routed to further treating units (Fahim M.A. *et al.*2010). Lastly, the reduced crude oil which is heavy, brown or black color fraction is drawn off at the bottom of CDU.

1.2 PROBLEM STATEMENT

The CDU is the most important processing unit in refineries which produces wide range of products. The dynamics of CDU are complex due to its complex vapor-liquid equilibrium relationships. Whenever there are changes in feed flow rate or feed composition, it is necessary to know the new steady state points of tray temperatures and product compositions. So, accurate steady state model is necessary to predict new steady state values.

1.3 RESEARCH OBJECTIVES

The objectives of this research:

1. To develop steady state model for CDU based on the first principles.
2. To validate the model results by comparing with plant data using Aspen Plus simulation.

1.4 SCOPE OF RESEARCH

The main objective of this study is to develop an appropriate steady state model for the CDU that will guide to accurate steady state model which is necessary to predict new steady state values.

To achieve the objectives, scopes have been identified to this research. The scopes of this research are:

1. To develop model based on following equations
    - Overall material balance
    - Component material balance
    - Liquid and vapor summation equation
    - Enthalpy balance

    This equation had been developed in the simulation of the CDU model based on the fundamental model. The number of trays and products had been considered in order to develop the model equation. All the properties of the crude oil and the data of CDU column also had been considered to full fill the Aspen Plus simulation requirement.

2. Compare the model results and plant data in the literature to validate the model. The success model results had been compared with plant data in literature to validate the model. The result was compared based on the product flow rate, ASTM percentage and others.

1.5 RATIONAL AND SIGNIFICANCE

This study aimed to obtain the steady state model of crude distillation unit which will be helpful to know the new steady state points of tray temperatures and product composition. As from the introduction, crude distillation was very complicated process which will produce several products at different stages. This overhead product must be produced at certain temperature, so in order to maintain the temperature by not affect others parameters is very difficult to achieve it. That is why the efficiency of the product will be less than the desired. To overcome this problem, an accurate steady state model is necessary to predict the new steady state value. Understanding the steady state of crude distillation unit is essential to develop good control strategy. Once the research is successful, it will help to proceed in the dynamics simulation.

The reason in using white box model for the modeling is because white box model contains complete data process rather than black and white box model.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Models are very important and widely used in science and technology. The application of models in engineering can be found in *Research and Development*, *Process Design*, *Planning and Scheduling*, *Process optimization* and *Prediction and control*. A model is an image from the real process or system which has limit to present the complete of the reality (Brian R *et al.*, 2006).

The crude distillation processes are highly complex and integrated in nature, where a large number of variables are required to be controlled. It is necessary to study the performance impact of the individual units and consequently the whole plant, and allow user to predict the behavior of the process and also assist in evaluation or design of the control strategies (Benzo *et al.*, 2004). These processes are significantly interactive and often provide unique challenge to the plant personnel. The interactive nature the control of these processes is difficult task due to the excessive settling time (Sampath Y, 2004). So, the process models are becoming key tools to improve unit yields, plant stability, safety and controllability.

2.2 MODEL CATEGORIES

When using a model to help in the design process, it is important that the right type of model is used. Using the wrong type of model can waste computing power and time, and either provide too little detail or far too much. So, there are three categories in modeling which black box model, grey box model and white box model.

A **white box** model contains as much detail as the simulation model can provide and no approximations are made using any bulk parameters. Fundamental models, also called first-principles models or white box models are based on the underlying physics of the system. These models are developed by applying mass and energy balances over the components or states and may also include a description of the fluid flow and transport processes that occur in the system. The main advantage of fundamental model is that they are highly constrained with respect to their structure and parameter. Also, these models provide physical interpretation of all the variables involved in the model and require less data for development. The model parameters can be estimated from laboratory experiments and routine operating data. As long as the underlying assumptions remain valid, fundamental models can be expected to extrapolate at operating regions which are not represented in the data set used for the model development (Henson, 1998). A major point of attraction is that a model obtained on the basis of fundamental principles is usually more accurate, and provide more complete process understanding. However, the fundamental model is too complex for controller design and the process characteristics for the fundamental models development are based on assumptions and sometimes these assumption may be wrong (Pearson, 1995). These models can already be developed when the process does not yet exist. The dynamic equations are supplemented with algebraic equations describing heat and mass transfer, kinetics, etc. Developing this model is much timed consuming (Brian R *et al.*, 2006).

In a pure **black box** model the internal workings of a device are not described, and the model simply solves a numerical problem without reference to any underlying physics. This usually takes the form of a set of transfer parameters or empirical rules that relate the output of the model to a set of inputs. There are no process understanding is required. This model also called empirical model which do not describe the physical phenomena of the process, they are based on input/output data and only describe the relationship between the measured input and output data of the process. These models are useful when limited time is available for model development and/or when there is insufficient physical understanding of the process (Brian R *et al.*, 2006).

In a **grey box** model, some or all of the mechanisms describing the behavior of a device are known, but are not all fully represented in the model. In a grey box model, certain elements within the model can be approximated by rules. If we continue our transistor model analogy, then a grey box model of a transistor would be more complex, and would model some of the internal transistor operation. The grey box models also are the combination of white and black box model (Zalizawati A *et al*. 2007)

2.3 STEADY STATE MODEL OF RESEARCH

This research project was proceeds with simulation by Aspen Plus to solve the steady state model on CDU. The model equation for an ordinary differential equation of this CDU is commonly use in Mass balance, Equilibrium, Summation and Enthalpy balance equation. All of these fundamental equations are available in many different nomenclatures and variable definition. So, before proceed to any further, a practical view point should be stated to present the feed crude oil or the products was in terms of actual component flow rates or mole fraction since crude oil is a mixture of several hundred constituent which are not easy to analyze. Generally, the composition of crude will be in term of pseudo-component in fact of complex mixture of hydrocarbons with a range of boiling points (Thirta *et al.,* 2003). The pseudo-component will characterized by an average boiling point and an average specific gravity. The method of solution involves solving simultaneously the system of nonlinear equation which use the component mass conservation, energy conservation and the summation equation. Traditionally, the nonlinear algebraic method will be solves by using the Newton-Raphson method. In this method, the nonlinear equations are linearized at iteration. If the number of nonlinear equation is large, then the result will become ill-conditioned leading to slow convergence or non-convergence. The modified Newton-Rahpson method may be applied to overcome the convergence problem (Thirta *et al.,* 2003). The equation solver has been specially developed for the sparse matrix system present in the model to enhance the efficiency of the solution.

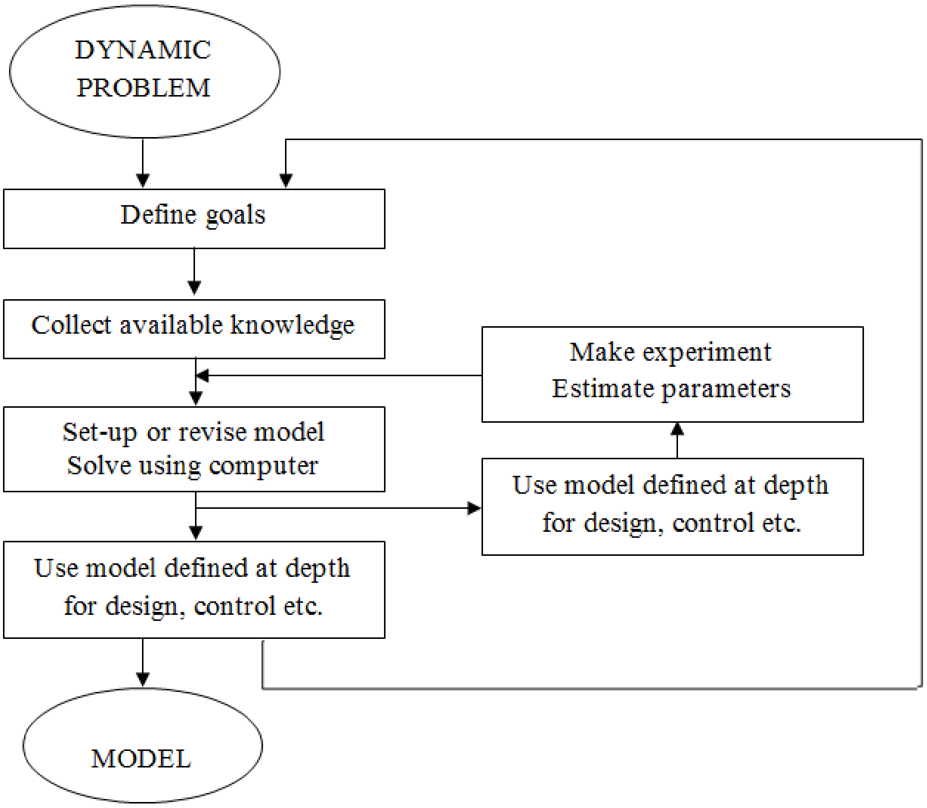
However, the Aspen Plus also had been used in develop the steady state model of CDU. The simulation was carried out in steady state form first where the specification of crude oil and CDU was designed (Juma H. *et al*. 2009). The simulation was begin with defining the crude oil feed where defining the component, assay data for crude oils, blending the crude oils to produce the crude feed, generate the pseudo-components for the blend and defined the Assay Data Analysis. After the blending crude and its fractions steps, the simulation was proceeds to add an atmospheric crude distillation unit in the simulation flow-sheet. The additional feed stream, product stream and other stream had been specified. Once the simulation run was successes, the steady state simulation had been exported to the Aspen Dynamic where the dynamic characteristic had been full fill and it was run in the Aspen Plus without any error. After this simulation, the result of product flow rate and the ASTM value had been study and discussed about it changes at any manipulation data (Juma H. *et al* 2009). So, the conclusion here is, the steady state equation must be determine first.

2.4 BASIC METHODOLOGY OF MODELING

Based on the reference of Chemical Engineering Dynamics; An Introduction to Modeling and Computer Simulation, the steps in model building had been applied. One of the more important features of modeling is the basic theory which is the physical model, and the mathematical equations, representing the physical model which is mathematical model, in order to achieve agreement, between the model prediction and actual process behavior (experimental data) (J. Ingham *et al.,* 2007).

Based on the reference the following stages in the modeling procedure can be identified:

1. The first involves the proper definition of the problem and hence the goals and objectives of the study.
2. All the available knowledge concerning the understanding of the problem must be assessed in combination with any practical experience, and perhaps alternative physical models may need to be developed and examined.
3. The problem description must then be formulated in mathematical terms and the mathematical model solved by computer simulation.
4. The validity of the computer prediction must be checked. After agreeing sufficiently well with available knowledge, experiments must then be designed to further check its validity and to estimate parameter values. Steps (1) to (4) will often need to be revised at frequent intervals.
5. The model may now be used at the defined depth of development for design, control and for other purposes.



Flow Chart 2.1: Step in Model

Sources: J. Ingham *et al.* (2007)

2.5 ASSUMPTIONS AND SIMPLIFICATIONS

Assumption is very important where not to complicate the matters which is unnecessarily. But for the greater part, they are generally applicable to distillation column. By the way, there are few specifically defined for the column and the mixture concerned (Brian R *et al.*, 2006).

Based on the reference, the assumptions and simplifications can be identified (Brian R *et al.*, 2006):

1. Convenient to take the physical properties as being dependent on the molar composition. No general valid relationships are known, the relationship must be established experimentally.
2. In the stationary situation the vapor and the liquid phase at a tray are uniform, coexisting at the same temperature and pressure, and having a certain interrelated composition. This assumes an ideal heat rate balancing in the absence of interface resistance.
3. Compared to the liquid mass, the vapor mass at tray is negligible.
4. The energy content of the vapor mass at tray is neglected.
5. The equilibrium temperature is considered to be dependent variable.
6. The tray vapor rate and the liquid hold-up have no effect on the heat transfer.
7. The heat of mixing is negligible.
8. The component dynamics of condenser and evaporator are neglected.
9. The reflux consists of liquid approximately at boiling point.

2.6 PETROLEUM FRACTIONS

The mole fractions or compositions is really important in chemical industry but it different with petroleum refining where the boiling point ranges would be applied. For example, the sample of heating oil would be used and had been placed in a heated container. The temperature would be categorized by initial boiling point which starts at 0% to final boiling point where the sample had completely vaporized. The normal percentage measured was at 5% and 95% where the percent of the sample has vaporized. This is very similar to the dew point of a mixture of specific chemical components (Ji S. *et al*. 2002).

By the way, there are three types of boiling point analysis which are ASTM-D86 (Engler), ASTM-D158 (Saybolt) and TBP. The first and second very similar to the boiling of vapor as described before. In the third, the vapor from the container passes into a packed distillation column and some specified amount is refluxed. Thus the third analyses exhibit some fraction, whiles the first and second are just single-stage separations. The ASTM analysis is easier and faster to run but the TBP analysis gives more detailed information about the contents of crude. For the Aspen Plus, the method for performing quantitative calculations with petroleum fraction is to break them into pseudo-components and generates the pseudo-components into given "assay" information like table 2.1 an example for crude oil (William L. *et al*. 2006).

Table 2.1: An Example of Comparison for Boiling Point Methods for Crude Oil

Vol% Distilled	ASTM D86	TBP
IBP	5	- 99
5	146	97
10	227	196
30	408	403
50	554	569
70	742	772
90	1021	1143
95	1169	1331
FBP	1317	1563

Source: William L. *et al*. (2006)

2.7 PROPERTY METHOD SYSTEM

Method system in Aspen Plus simulation is the requirement to run the simulation and usually after the defining of components which to be used. The important of thermodynamic methods is to calculate the quantities for the simulation like to calculate enthalpy, entropy, K-values, density, transport properties and others. The selection of thermodynamic methods is very important for running the Aspen Plus simulation and the wrong selection will give meaningless results (Eric C.C. 1996). The following table 2.2 had been showed the example of thermodynamic methods and its keyword.

Table 2.2: Property Methods Keyword and Uses

Keyword	Uses
SRK	Suitable for hydrocarbon systems in gas and refinery processing.
PR	Suitable for hydrocarbon systems in gas and refinery processing.
NRTL	Used with mixtures, this can form two immiscible liquid phases.
GS	For the calculation of K-values.
BK10	Primarily for refinery crude and vacuum columns which is operating near or at atmospheric pressure.

Source: Aspen Tech, Inc., (2001)

For this research, the simulation was proceeding to BK10 method as long as it suitable for crude and vacuum columns and more the CDU was operated at and near to atmospheric pressure. The BK10 property method uses the Braun K-10 K-value correlation which for real components and oil fractions. Furthermore, the proprietary methods were developed to cover the heavier oil fractions and the boiling ranges 450 – 700 K. The real components also had included 70 hydrocarbons and light gases. The BK10 property method is suited for vacuum and low pressure applications which may up to several atm. The high pressures petroleum-tuned equations of state are best suited. The temperature range in K10 chart is 133 – 800 K and may be used up to 1100 K (Aspen Tech, Inc., 2001).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will show how to develop steady state model on CDU based on the fundamental model or white box model. The developed model equation had been solved in Aspen Plus. The methods and procedure for developing the model of CDU also had been summarized in the flow chart type. By doing this, the progress for the modeling can be smooth because it was showed in steps.

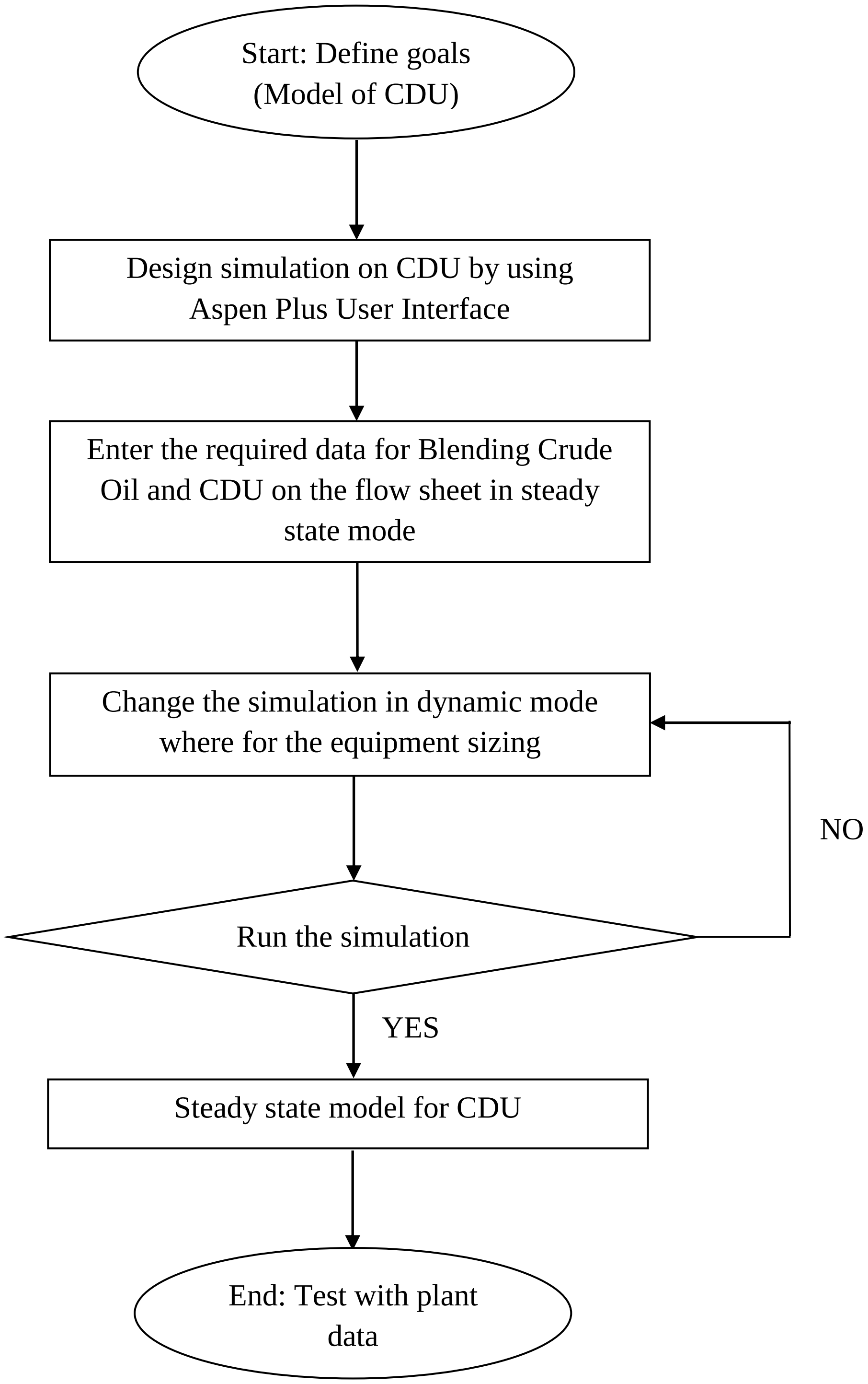
The selection data from literature also was very important to validate the equation develop from the fundamental model. The composition of the crude oil, number of stages, type of method used in simulation or the temperature value at each separations point are the example of the required data for the simulation step and to validate the equation too.

3.2 METHODS AND PROCEDURES

The first step of modeling is to define goals which the goal is steady state modeling. The second step followed by built up steady state equation for overall, composition and enthalpy equation. In order to build the steady state equation, the steady state equation must be determined. Once the steady state equation was developed, it will be implement by using fundamental equation which is Ordinary Differential Equation (ODE) or Algebraic Equations.

The steps in develop the steady state model of CDU also had been studied by using the Aspen Plus simulation which start with steady state simulation. The required data for the blending crude must be put into the simulation as the first step of simulation. The blending crude or the feed component is very important to determine the result of the simulation once it completed. Once the simulation on steady state successful, the simulation may be proceed to Aspen Plus Dynamic for next step of model.

The steps of modeling had been simplified by flow chart 3.1 which start with the define goal and ended by validate with any plant data. The flow charts were explaining the steps in modeling of CDU by using Aspen Plus.



Flow Chart 3.2: Steady State Model Process Flow Chart for Aspen Plus Environment

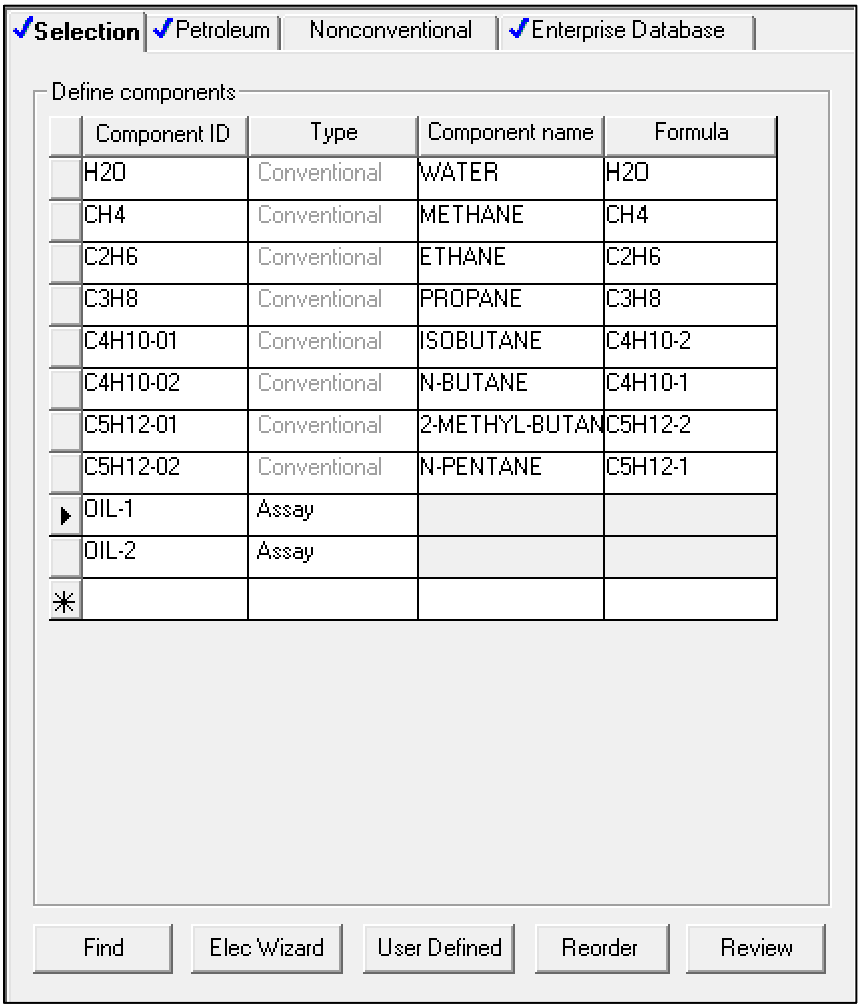
3.3 ASPEN PLUS STEADY STATE SIMULATION

The CDU had been modeled in Aspen Plus simulation environment where the first step is to run the simulation in steady state. All this steady state simulation had been completed by model study of Aspen Plus literature. This simulation was run in petroleum with English unit with the run type is Assay Data Analysis. The components had been specified to the components IDs like the following table 3.1. The figure 3.1 showed how the specified component entered into the Aspen Plus.

Table 3.1: Component ID and Name

Component ID	Component Name
H20	WATER
C1	METHANE
C2	ETHANE
C3	PROPANE
IC4	ISOBUTANE
NC4	N-BUTANE
IC5	2-METHYL-BUTANE
NC5	N-PENTANE

Sources: Aspen Tech, Inc., (2006)



	Component ID	Type	Component name	Formula
	H2O	Conventional	WATER	H2O
	CH4	Conventional	METHANE	CH4
	C2H6	Conventional	ETHANE	C2H6
	C3H8	Conventional	PROPANE	C3H8
	C4H10-01	Conventional	ISOBUTANE	C4H10-2
	C4H10-02	Conventional	N-BUTANE	C4H10-1
	C5H12-01	Conventional	2-METHYL-BUTAN	C5H12-2
	C5H12-02	Conventional	N-PENTANE	C5H12-1
▶	OIL-1	Assay		
	OIL-2	Assay		
✳				

Figure 3.1: Component Specification

After the components IDs was specified, the step was proceed by entering the assay data which specified into distillation curve, light ends data and API Gravity data like in the table 1 and 2 for OIL 1 and Oil 2. The step in specified the distillation curve, light ends and API gravity into Aspen Plus simulation had been showed in figure 3.2, 3.3 and 3.4. Then the step was proceeding for blending the oil which name MIXOIL.

The simulation followed with blending crude and petroleum fraction. This part is very important in simulation which to define the components, entering assay data for two crude oils, blend the crude oils into a single process feed and generate pseudo-components for the blend. Step for the entering data had been showed in figure 3.5 where the process feed, consisting of a blend of two crude oils can be defined in table

3.2 and 3.3. The fraction of assay blending should be specified in order to complete the assay requirement where the fraction had been entered for OIL-1 0.2 and OIL-2 0.8. Generating pseudo-components is the last step in blending the crude oil and the MIXOIL had been selected for the pseudo-components.

Table 3.2: OIL-1 (API = 31.4)

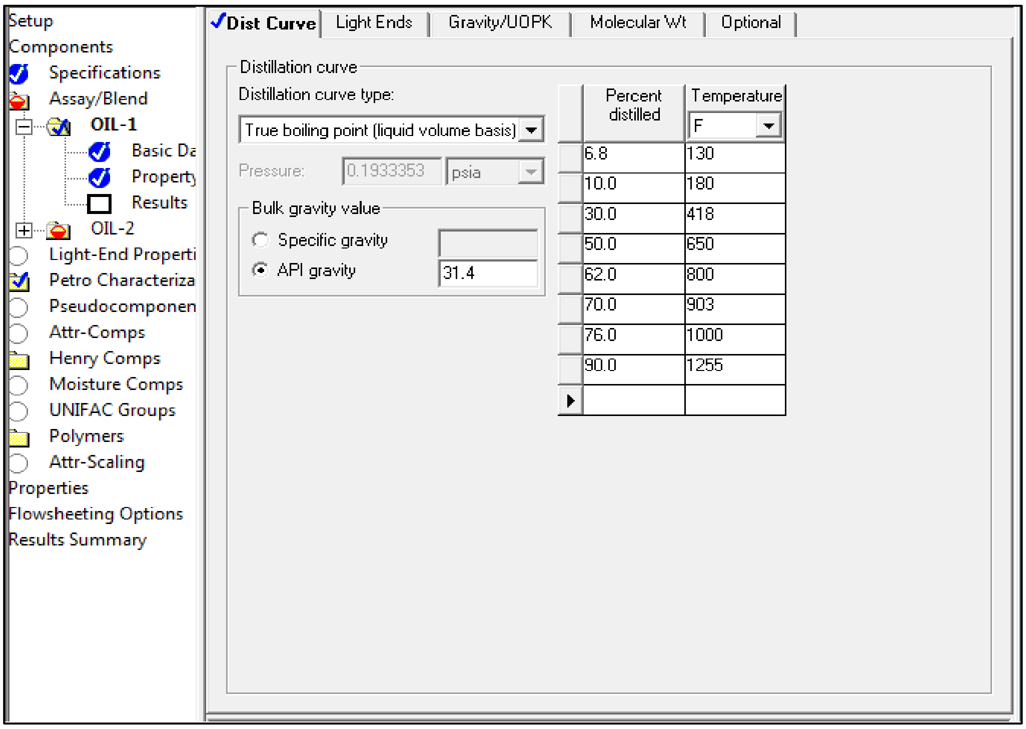
TBP Distillation		Light Ends Analysis		API Gravity Curve	
Liq. Vol. %	Temp. (F)	Component	Liq. Vol. Frac.	Mid. Vol. %	Gravity
6.8	130.0	Methane	0.001	5.0	90.0
10.0	180.0	Ethane	0.0015	10.0	68.0
30.0	418.0	Propane	0.009	15.0	59.7
50.0	650.0	Isobutane	0.004	20.0	52.0
62.0	800.0	N-Butane	0.016	30.0	42.0
70.0	903.0	2-Methyl-Butane	0.012	40.0	35.0
76.0	1000.0	N-Pentane	0.017	45.0	32.0
90.0	1255.0			50.0	28.5
				60.0	23.0
				70.0	18.0
				80.0	13.5

Sources: Aspen Tech, Inc., (2006)

Table 3.3: OIL-2 (API = 34.8)

TBP	Distillation	Light Ends	Analysis	API Gravity	Curve
Liq. Vol. %	Temp. (F)	Component	Liq. Vol. Frac.	Mid. Vol. %	Gravity
6.5	120.0	Water	0.001	2.0	150.0
10.0	200.0	Methane	0.002	5.0	95.0
20.0	300.0	Ethane	0.005	10.0	65.0
30.0	400.0	Propane	0.005	20.0	45.0
40.0	470.0	Isobutane	0.010	30.0	40.0
50.0	550.0	N-Butane	0.010	40.0	38.0
60.0	650.0	2-Methyl-Butane	0.005	50.0	33.0
70.0	750.0	N-Pentane	0.025	60.0	30.0
80.0	850.0			70.0	25.0
90.0	1100.0			80.0	20.0
95.0	1300.0			90.0	15.0
98.0	1475.0			95.0	10.0
100.0	1670.0			98.0	5.0

Sources: Aspen Tech, Inc., (2006)



Distillation curve

Distillation curve type: True boiling point (liquid volume basis)

Pressure: 0.1933353 psia

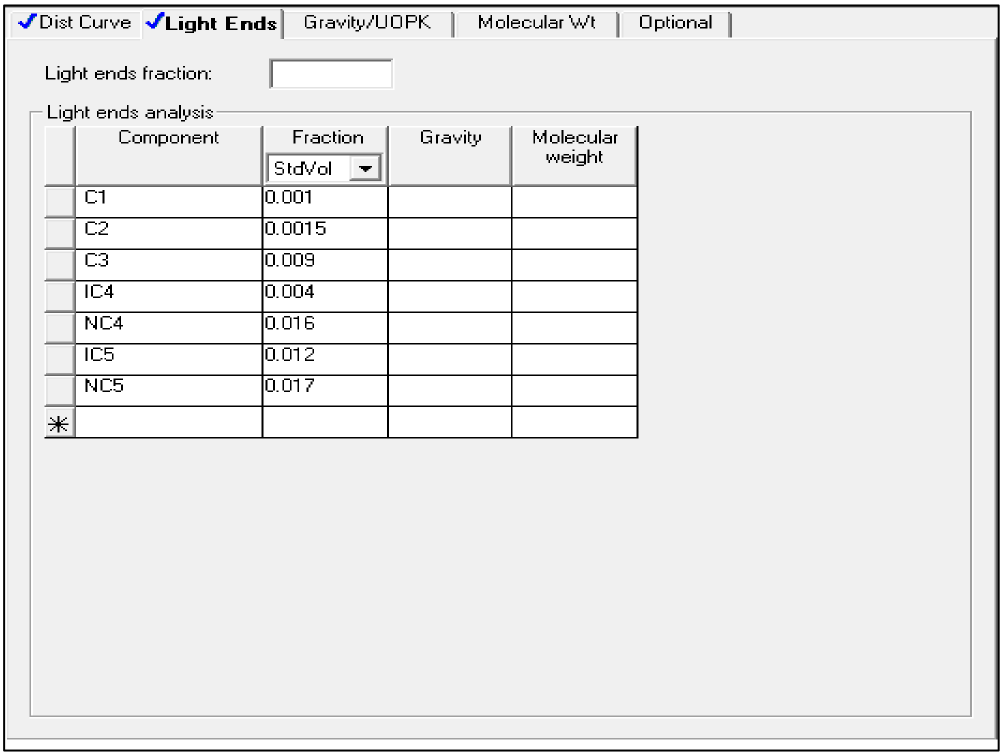
Bulk gravity value

○ Specific gravity

● API gravity 31.4

Percent distilled	Temperature F
6.8	130
10.0	180
30.0	418
50.0	650
62.0	800
70.0	903
76.0	1000
90.0	1255

Figure 3.2: Distillation Curve Specification

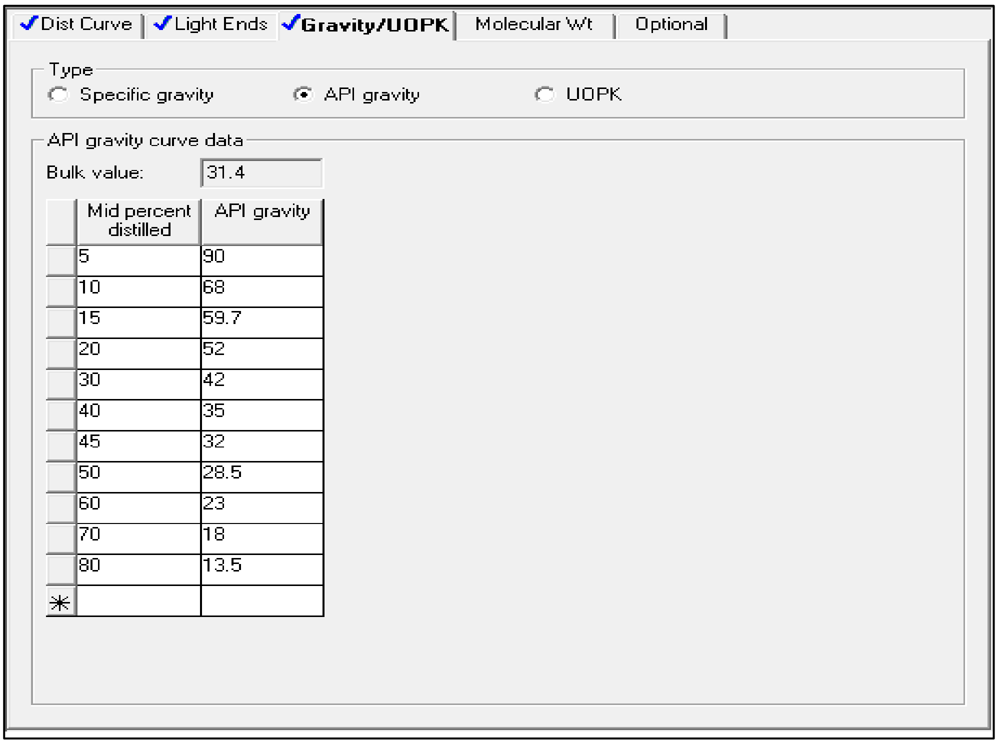


Light ends fraction:

Light ends analysis

Component	Fraction StdVol	Gravity	Molecular weight
C1	0.001		
C2	0.0015		
C3	0.009		
IC4	0.004		
NC4	0.016		
IC5	0.012		
NC5	0.017		

Figure 3.3: Light Ends Specification



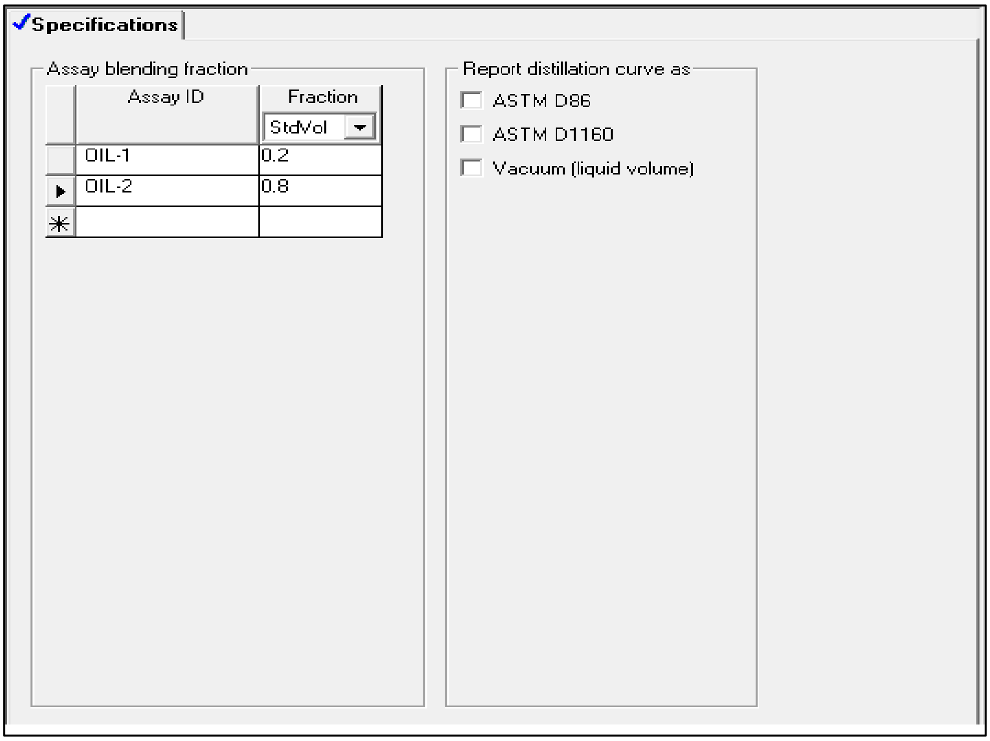
Type
○ Specific gravity ● API gravity ○ UOPK

API gravity curve data

Bulk value: 31.4

Mid percent distilled	API gravity
5	90
10	68
15	59.7
20	52
30	42
40	35
45	32
50	28.5
60	23
70	18
80	13.5

Figure 3.4: API Gravity Data



Assay blending fraction

Assay ID	Fraction StdVol
OIL-1	0.2
OIL-2	0.8

Report distillation curve as
☐ ASTM D86
☐ ASTM D1160
☐ Vacuum (liquid volume)

Figure 3.5: Assay Blending Fraction

Once the components had been specified by blending the Crude Oil, the step was proceeding by adding an atmospheric crude distillation unit and the specification of the column had been entered. The column model was using a single PetroFrac block named as CDU10F which consist a total condenser, 3 coupled side strippers and two pump-around circuits. The simulated furnace was operates at a pressure of 24.18 psia and provides over flash of 3 % in the column. The column has been modeled with 25 stages with the heavy naphtha product flow is estimated at 13 000 bbl/day and is manipulated to achieve an ASTM 95 % temperature of 375 ^{0}F. The feed of the column was at stage 22 and it pressure drop was 4 psi. The condenser of the column was operates at 15.7 psia with 5 psi of pressure drop.

The pump-around circuits, side strippers and it steam used for stripping had been summarize in table 3.4, 3.5 and 3.6.

Table 3.4: Pump-around location and specifications

Pump-around	Location	Specifications
1	From stage 8 to 6	Flow: 49 000 bbl/day Duty: -40 MMbtu/hr
2	From stage 14 to 13	Flow: 11 000 bbl/day Duty: -15 MMbtu/hr

Sources: Aspen Tech, Inc., (2006)

Table 3.5: Stripper location and specifications

Stripper	Location	Specifications
KEROSENE	Liquid draw from stage 6 Vapor return to stage 5	Product rate: 11 700 bbl/day Steam stripping (CU-STM1) 4 equilibrium stages
DIESEL	Liquid draw from stage 13 Vapor return to stage 12	Product rate: 16 500 bbl/day Steam stripping (CU-STM2) 3 equilibrium stages
AGO	Liquid draw from stage 18 Vapor return to stage 17	Product rate: 8 500 bbl/day Steam stripping (CU-STM3) 2 equilibrium stages

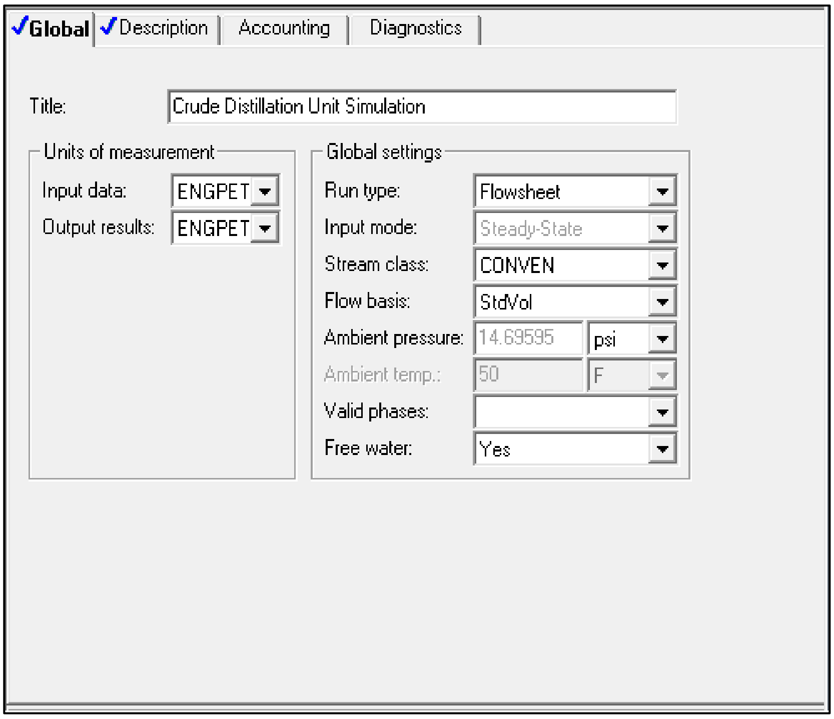
Sources: Aspen Tech, Inc., (2006)

Table 3.6: Stripper and main fractionators use steam for stripping

Stream	Location	Conditions and Flow
CU-STEAM	Main Tower	400 ^{0}F, 60 psia, 12 000 lb/hr
CU-STM1	Kerosene stripper	400 ^{0}F, 60 psia, 3 300 lb/hr
CU-STM2	Diesel stripper	400 ^{0}F, 60 psia, 1 000 lb/hr
CU-STM3	AGO stripper	400 ^{0}F, 60 psia, 800 lb/hr

Sources: Aspen Tech, Inc., (2006)

Before proceed to further simulation of CDU by the data required like discussed before, the specification of simulation had been setting up first where the run type must be in flow sheet. This data can be change at global link at setup specification where the tittle of the simulation should be stated too. The unit measurement of data had been used as ENGPET and the figure 3.6 showed how the step was.



Title: Crude Distillation Unit Simulation

Input data: ENGPET

Output results: ENGPET

Run type: Flowsheet

Input mode: Steady-State

Stream class: CONVEN

Flow basis: StdVol

Ambient pressure: 14.69595 psi

Ambient temp.: 50 F

Valid phases:

Free water: Yes

Figure 3.6: Setup Specification of the Simulation

Like the explanation that the column was choose from the PetroFrac where the CDU10F as the CDU column. The figure 3.7 had showed the choosing of CDU10F and figure 3.8 showed the model of the column.

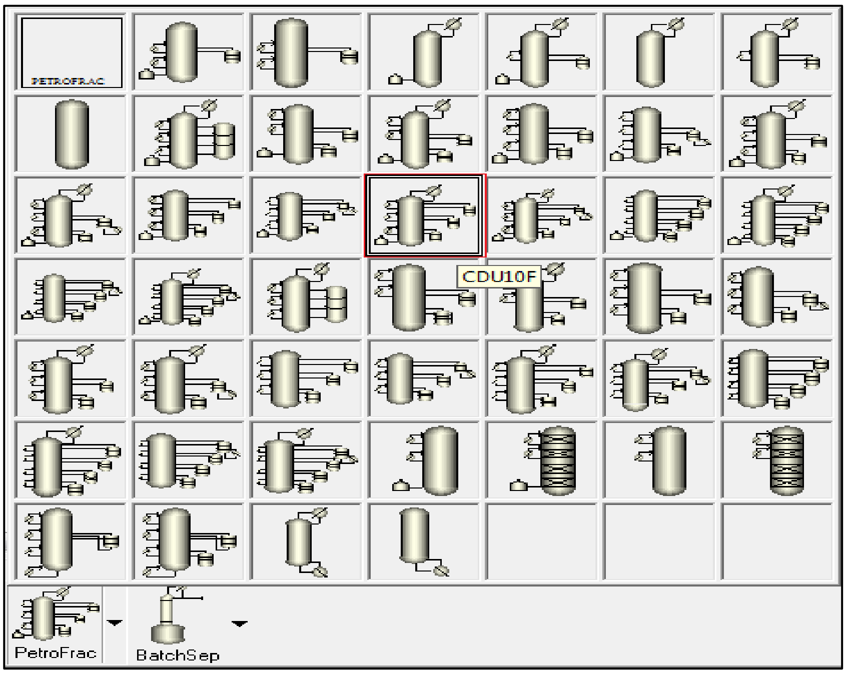


Figure 3.7: CDU10F Column in PetroFrac

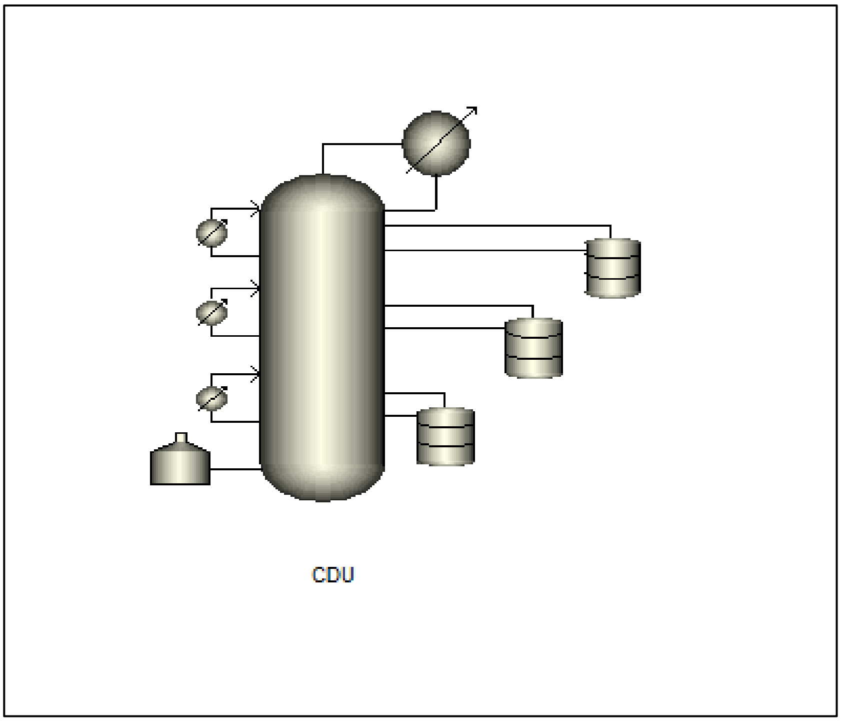


Figure 3.8: CDU Model for CDU10F Type

The connection, moved and named of the stream had been specified at the column flow sheet and it was been simplified in the table 3.7 and had been showed in figure 3.9 for Aspen Plus flow sheet. The next step was followed by specifying steam feeds to the tower with the specification for this steam from the table before. Figure 3.10 were showed the CU-STEAM specification where the water/steam flow rate had been stated.

Table 3.7: Connection, Moved and Named of Streams

Stream ID	Port Name
CDU-FEED	Main Column Feed
CU-STEAM	Main Column Feed
CU-STM1	Stripper Steam Feeds
CU-STM2	Stripper Steam Feeds
CU-STM3	Stripper Steam Feeds
CU-WATER	Condenser Water Decant for Main Column
HNAPHTHA	Liquid Distillate from Main Column
KEROSENE	Bottoms Product from Stripper
DIESEL	Bottoms Product from Stripper
AGO	Bottoms Product from Stripper
RED-CRD	Bottoms Product from Main Column

Sources: Aspen Tech, Inc., (2006)

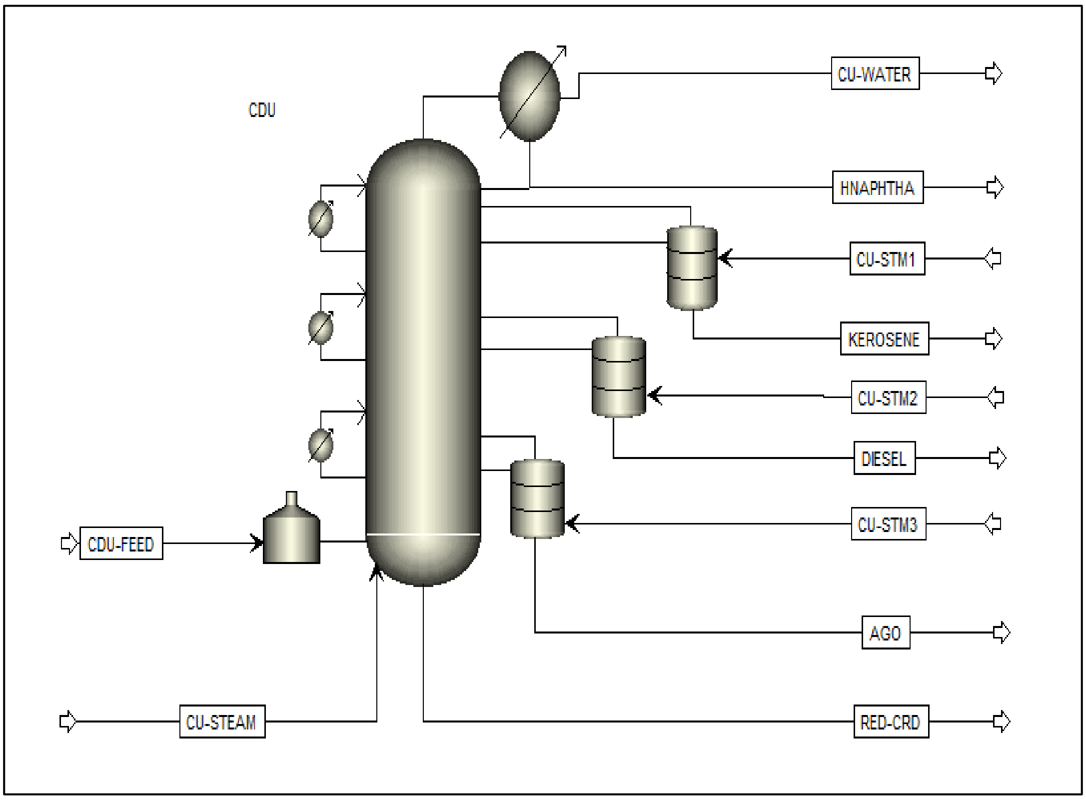
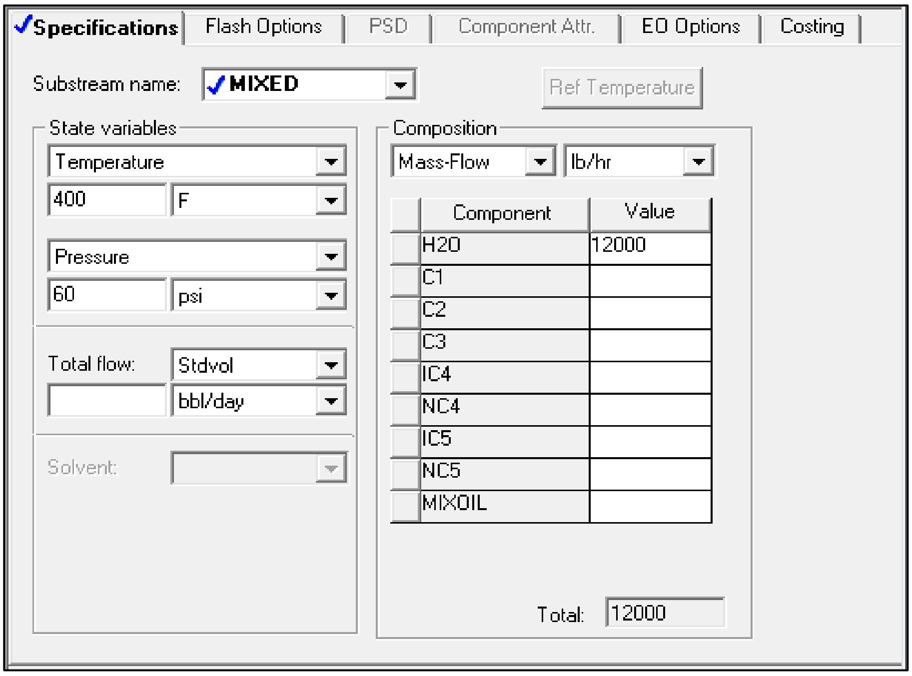


Figure 3.9: Connection, Moved and Named of Streams



Substream name: ✓MIXED

State variables

Temperature: 400 F

Pressure: 60 psi

Total flow: Stdvol, bbl/day

Solvent:

Composition: Mass-Flow, lb/hr

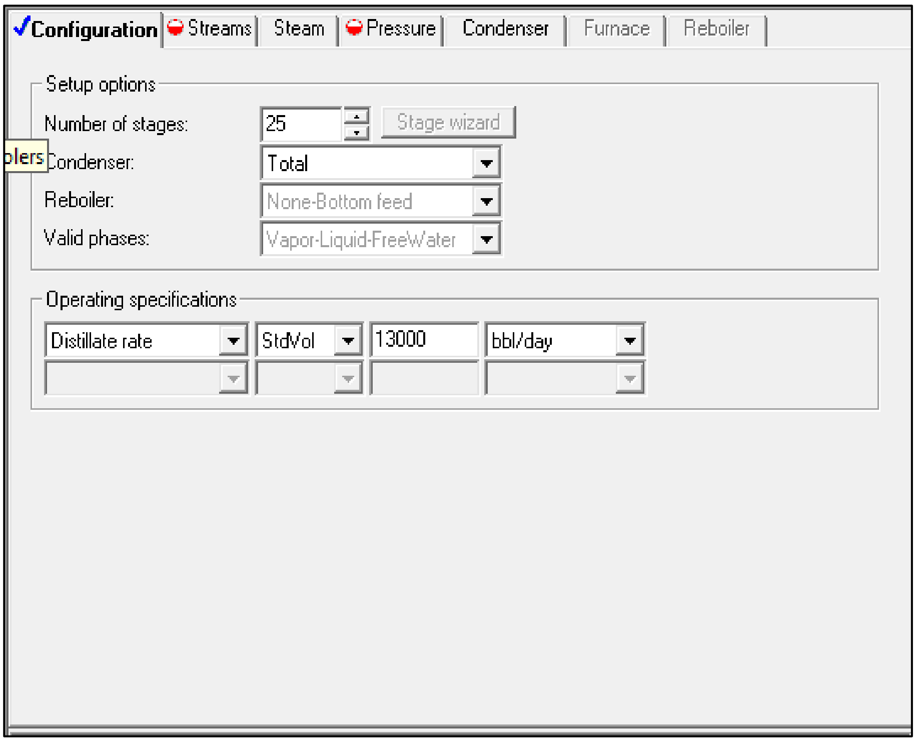
Component	Value
H2O	12000
C1	
C2	
C3	
IC4	
NC4	
IC5	
NC5	
MIXOIL	

Total: 12000

Figure 3.10: CU-STEAM Specification

Once, the stream feed specification was entered, the data for the CDU had been entered into the simulation. All the data had been summarized in the table before and the flow of the CDU simulation in Aspen Plus was recorded by figures below. The figure 3.11 was starting to show the CDU configuration where the specific trays must be entered and followed by distillate rate. The figure 3.12 was showed the streams connection and the CU-Steam was connected at stage 25. The CDU pressures were explain in figure 3.13 where the bottom stage pressure is 24.7 psi. The last consideration in CDU was the furnace where the furnace type is single stage flash like in figure 3.14.

The specification for the stripper had been showed in figure 3.15 which same like stripper 2 and 3. The pump-around specification had been showed in figure 3.16 for P-1 and P-2 with the same procedure.



Setup options

Number of stages: 25

Condenser: Total

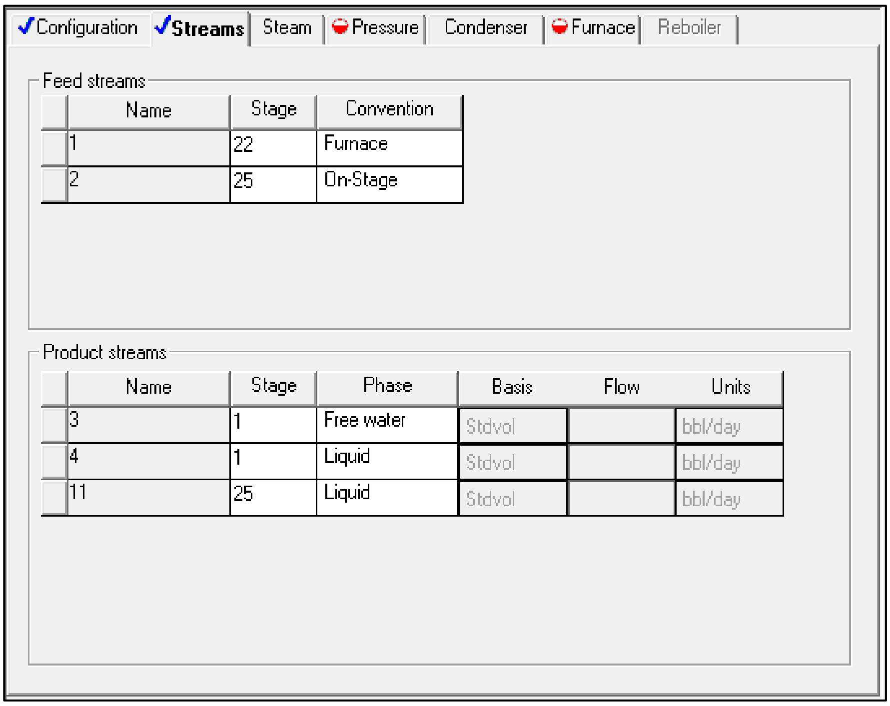
Reboiler: None-Bottom feed

Valid phases: Vapor-Liquid-FreeWater

Operating specifications

Distillate rate StdVol 13000 bbl/day

Figure 3.11: CDU Configuration



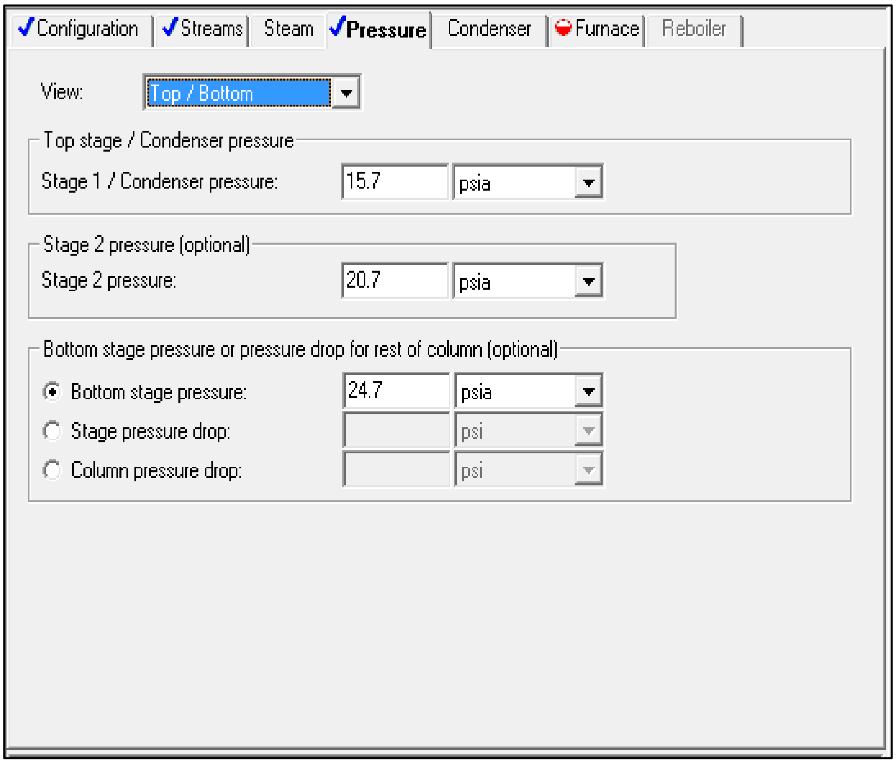
Feed streams

Name	Stage	Convention
1	22	Furnace
2	25	On-Stage

Product streams

Name	Stage	Phase	Basis	Flow	Units
3	1	Free water	Stdvol		bbl/day
4	1	Liquid	Stdvol		bbl/day
11	25	Liquid	Stdvol		bbl/day

Figure 3.12: CDU Streams



View: Top / Bottom

Top stage / Condenser pressure

Stage 1 / Condenser pressure: 15.7 psia

Stage 2 pressure (optional)

Stage 2 pressure: 20.7 psia

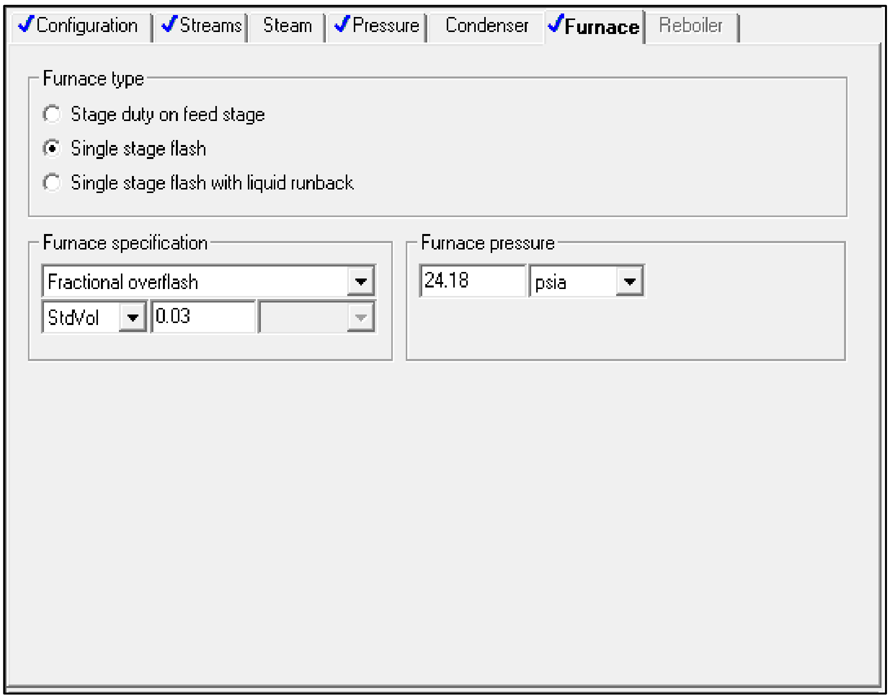
Bottom stage pressure or pressure drop for rest of column (optional)

● Bottom stage pressure: 24.7 psia

○ Stage pressure drop: psi

○ Column pressure drop: psi

Figure 3.13: CDU Pressures

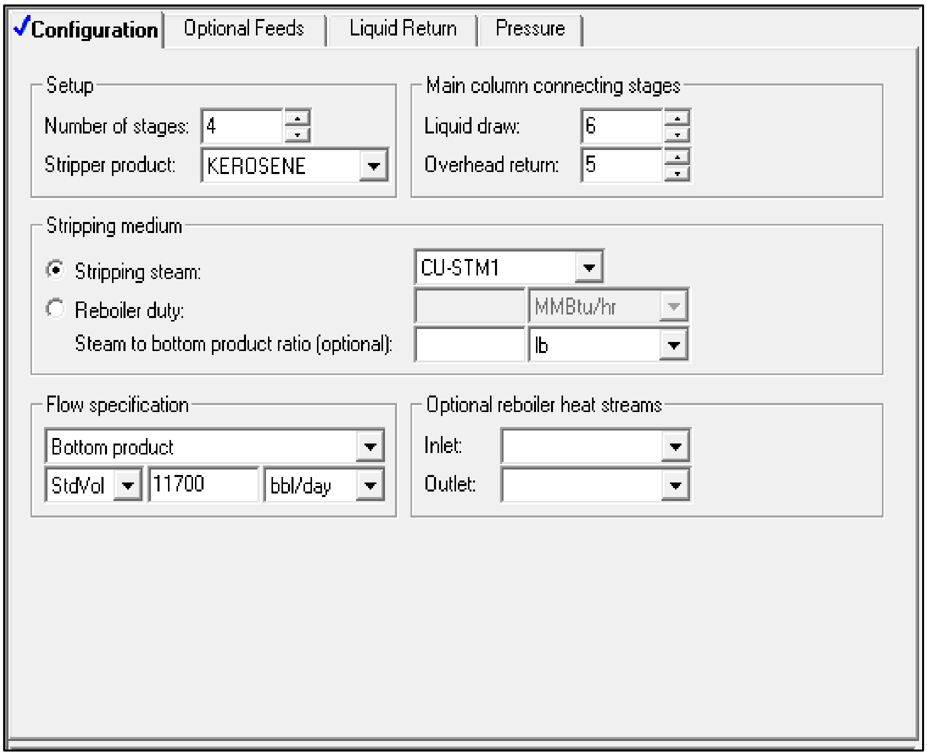


Furnace type
○ Stage duty on feed stage
● Single stage flash
○ Single stage flash with liquid runback

Furnace specification
Fractional overflash
StdVol 0.03

Furnace pressure
24.18 psia

Figure 3.14: CDU Furnace



Setup
Number of stages: 4
Stripper product: KEROSENE

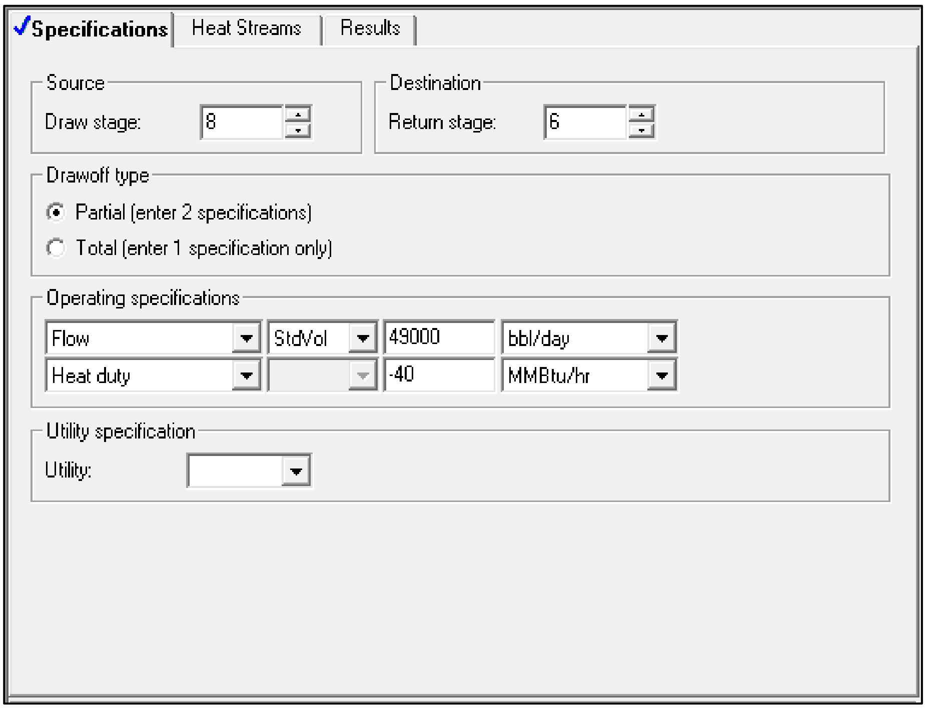
Main column connecting stages
Liquid draw: 6
Overhead return: 5

Stripping medium
● Stripping steam: CU-STM1
○ Reboiler duty: MMBtu/hr
Steam to bottom product ratio (optional): lb

Flow specification
Bottom product
StdVol 11700 bbl/day

Optional reboiler heat streams
Inlet:
Outlet:

Figure 3.15: Side-Stripper Specification



Source

Draw stage: 8

Destination

Return stage: 6

Drawoff type

● Partial (enter 2 specifications)

○ Total (enter 1 specification only)

Operating specifications

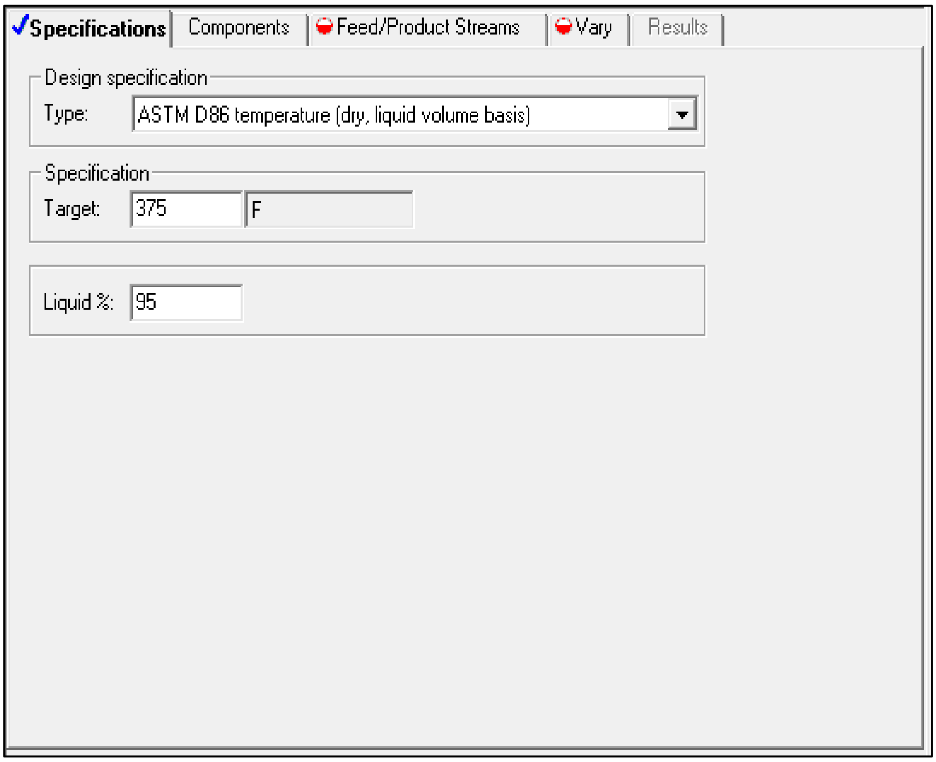
Flow	StdVol	49000	bbl/day
Heat duty		-40	MMBtu/hr

Utility specification

Utility:

Figure 3.16: Pump-Around Specification

Lastly, the design specification had been entered which to specify the ASTM 95 % temperature for HNAPHTA, DIESEL or KEROSENE. All the data had been showed in figured 3.17 until 3.19. After all the required data was entered, the simulation was ready to run and steady state simulation of the CDU was completed.



Design specification

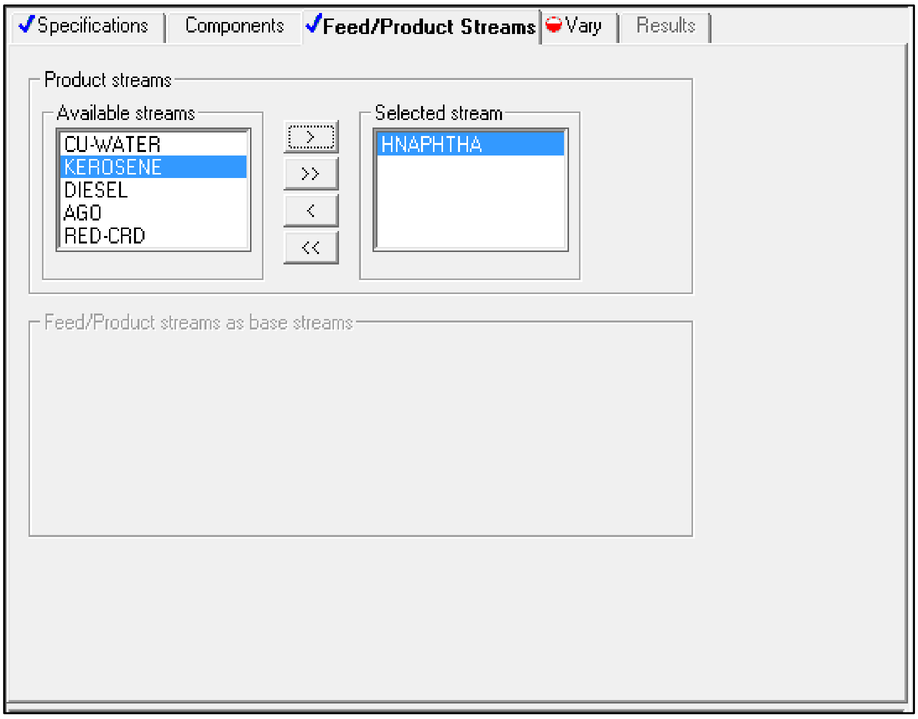
Type: ASTM D86 temperature (dry, liquid volume basis)

Specification

Target: 375 F

Liquid %: 95

Figure 3.17: ‘Design Spec’ Specification



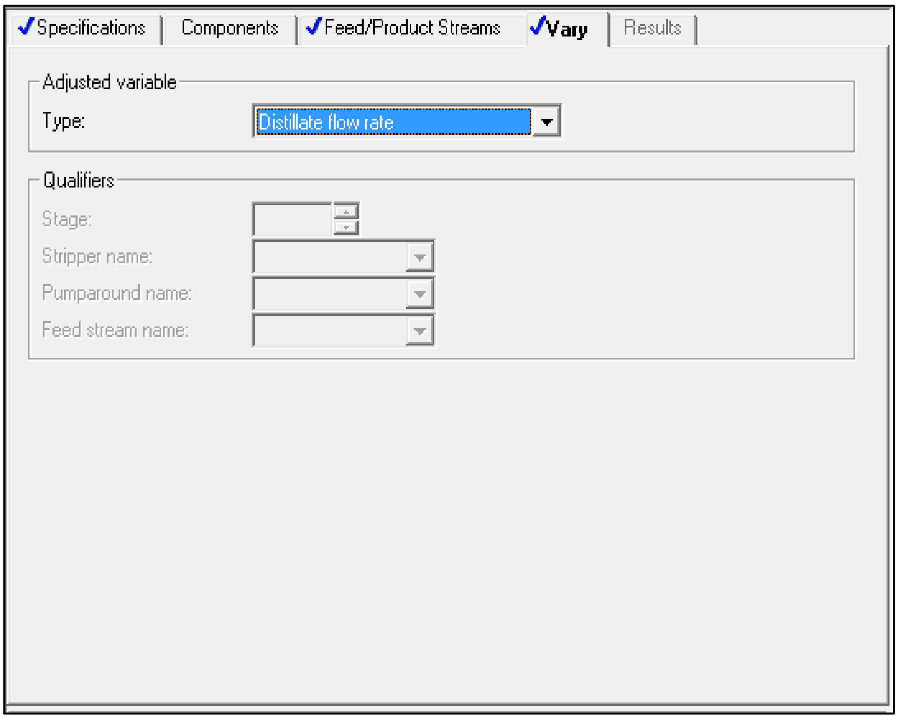
Product streams

Available streams:
- CU-WATER
- KEROSENE
- DIESEL
- AGO
- RED-CRD

Selected stream:
- HNAPHTHA

Feed/Product streams as base streams

Figure 3.18: ‘Design Spec’ Feed / Product Stream



Adjusted variable
Type: Distillate flow rate

Figure 3.19: 'Design Spec' of the Adjusted Variable

3.4 ASPEN PLUS STEADY STATE SIMULATION WITH EQUIPMENT SIZING

The steady state simulation with equipment sizing had been proceeding once the steady state process was completed or done. By the way, the pressure unit like valves or pump should been specified in dynamic model which not important in steady state simulation (Juma H. *et al*. 2009). Figure 3.20 showed how the valves had been put at every stream. The complete connection may lead to the next step in dynamic simulation. The steady state simulation with equipment sizing had been started by clicking the dynamic button like figure 3.21. Once the clicking button was checked, the dynamic simulation requirement will be appeared. The data in table 3.8 had been used for the dynamic requirements which is sizing of the equipment.

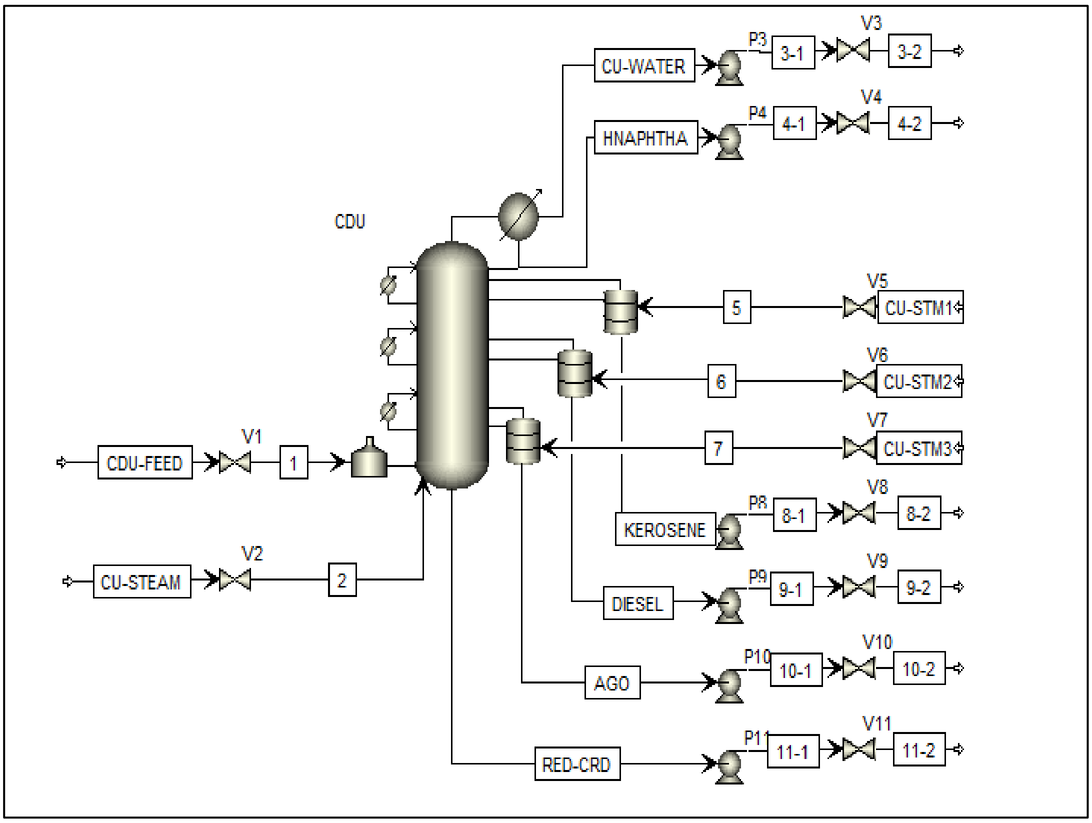


Figure 3.20: Connection, Moved and Named of Streams Included Valves

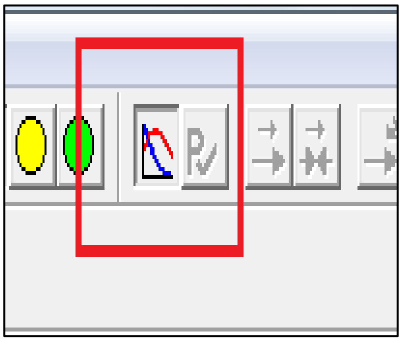
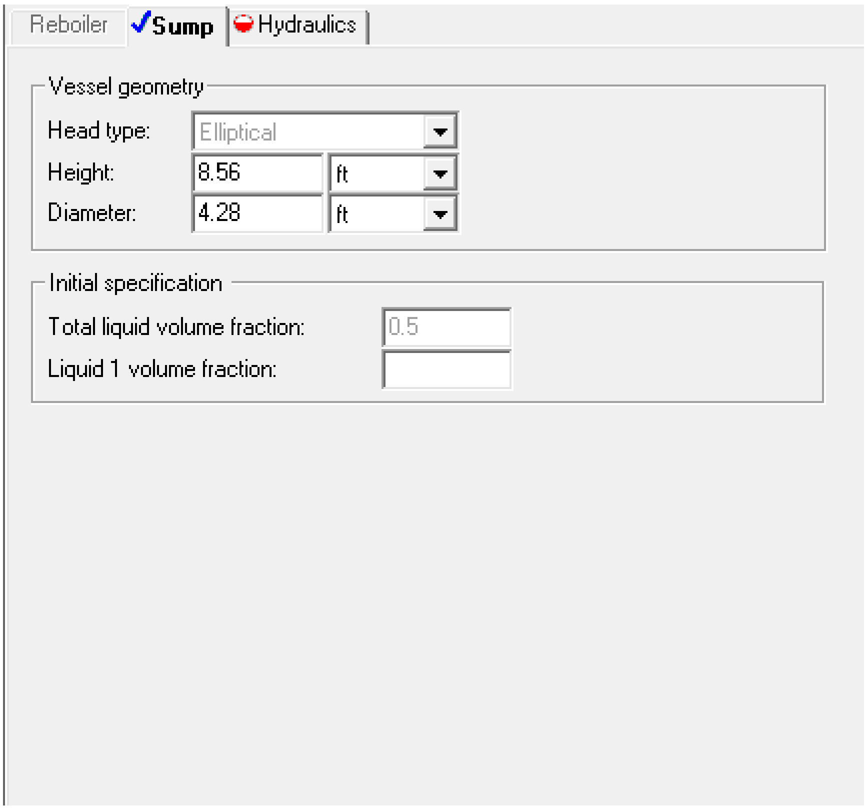


Figure 3.21: Dynamic Button

Table 3.8: Dynamic Simulation Requirement

Parameter	CDU	Stripper 1	Stripper 2	Stripper 3
Number of Tray	49	4	3	2
Sump diameter, ft.	12.3	4.28	4.98	3.98
Sump height, ft.	33.64	8.56	9.96	7.96
Reflux Drum height, ft.	12.18	-	-	-
Reflux Drum diameter, ft.	6.10	-	-	-

The requirements for the column geometry will appeared for the stripper and CDU sizing of the column. The sump diameter, sump height, reflux drum height and reflux drum diameter were the requirement for the column geometry. Figure 3.22 was showed how the specification requirement for sump vessel geometry of side-stripper. The hydraulics of the stripper was referring to the tray used in the simulation. The simple tray had been used in this simulation with tray geometry was based on the number of side-stripper tray. Figure 3.23 was showed the tray geometry for side stripper. The entire specification requirement for S-1, S-2 and S-3 was same like the figure 3.22 and 3.23. The completed requirement of side-stripper was lead to the requirement of the CDU geometry. The figure 3.24 to 3.26 was showed the requirement of reflux drum vessel geometry, sump vessel geometry and tray geometry of the CDU.



Vessel geometry

Head type: Elliptical

Height: 8.56 ft

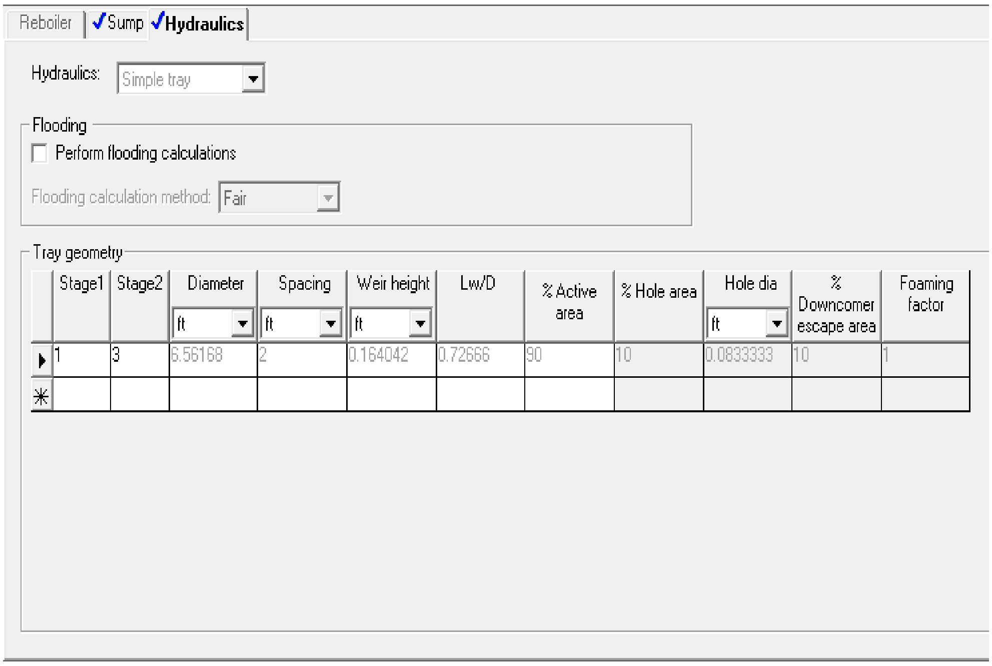
Diameter: 4.28 ft

Initial specification

Total liquid volume fraction: 0.5

Liquid 1 volume fraction:

Figure 3.22: Sump Vessel Geometry for Side Stripper



Hydraulics: Simple tray

Flooding

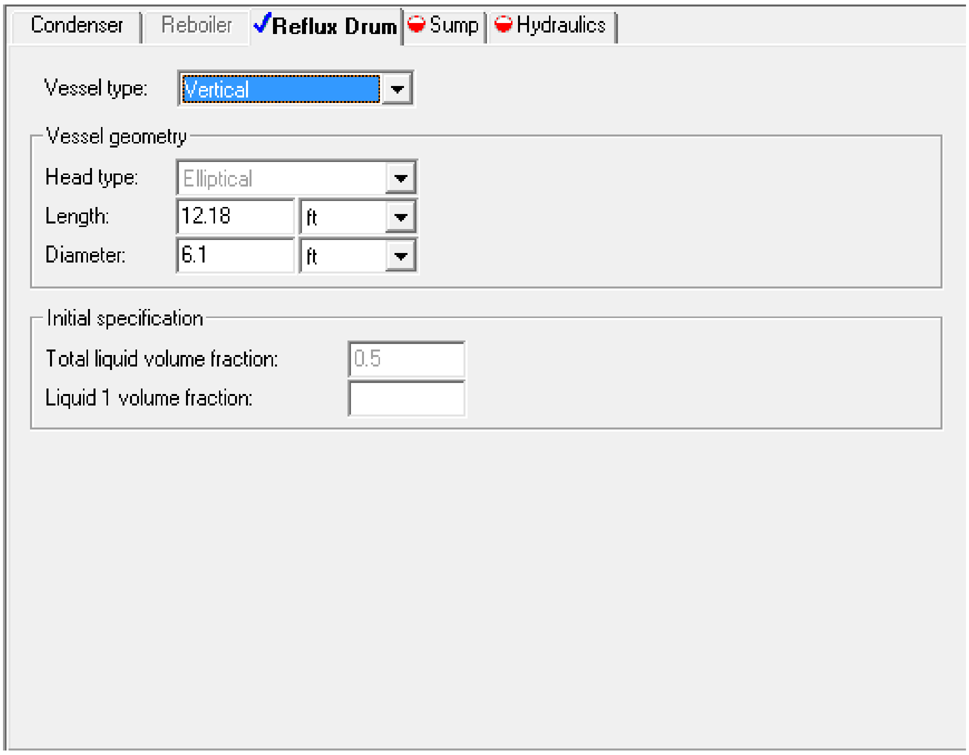
☐ Perform flooding calculations

Flooding calculation method: Fair

Tray geometry

Stage1	Stage2	Diameter	Spacing	Weir height	Lw/D	% Active area	% Hole area	Hole dia	% Downcomer escape area	Foaming factor
		ft	ft	ft				ft		
1	3	6.56168	2	0.164042	0.72666	90	10	0.0833333	10	1

Figure 3.23: Tray Geometry for Side Stripper



Vessel type: Vertical

Head type: Elliptical

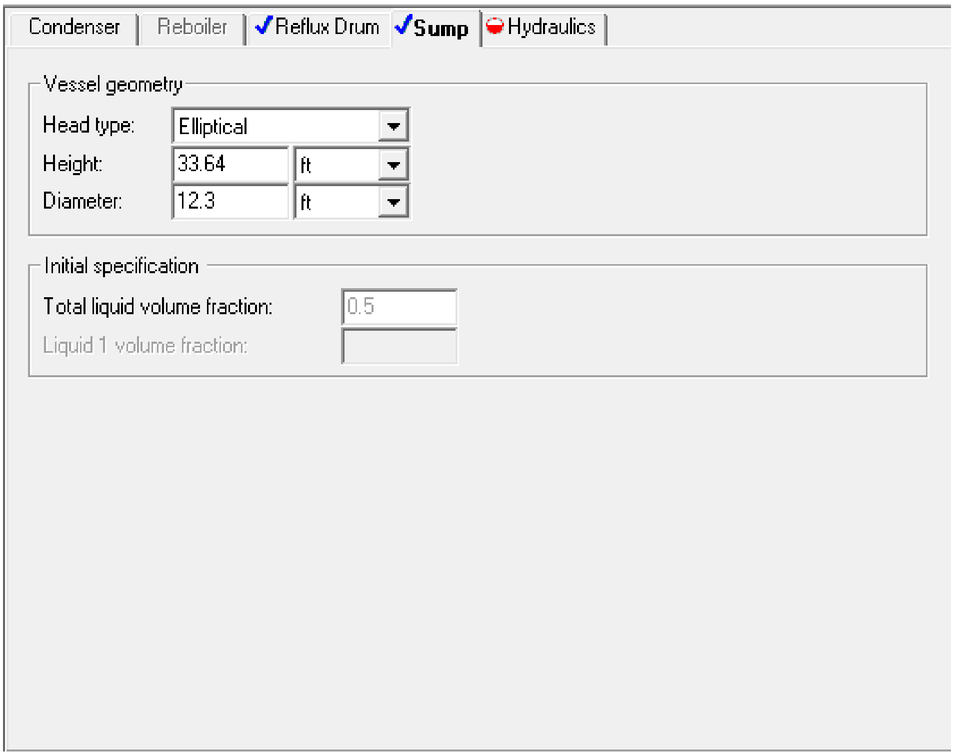
Length: 12.18 ft

Diameter: 6.1 ft

Total liquid volume fraction: 0.5

Liquid 1 volume fraction:

Figure 3.24: Reflux Drum Vessel Geometry for CDU



Head type: Elliptical

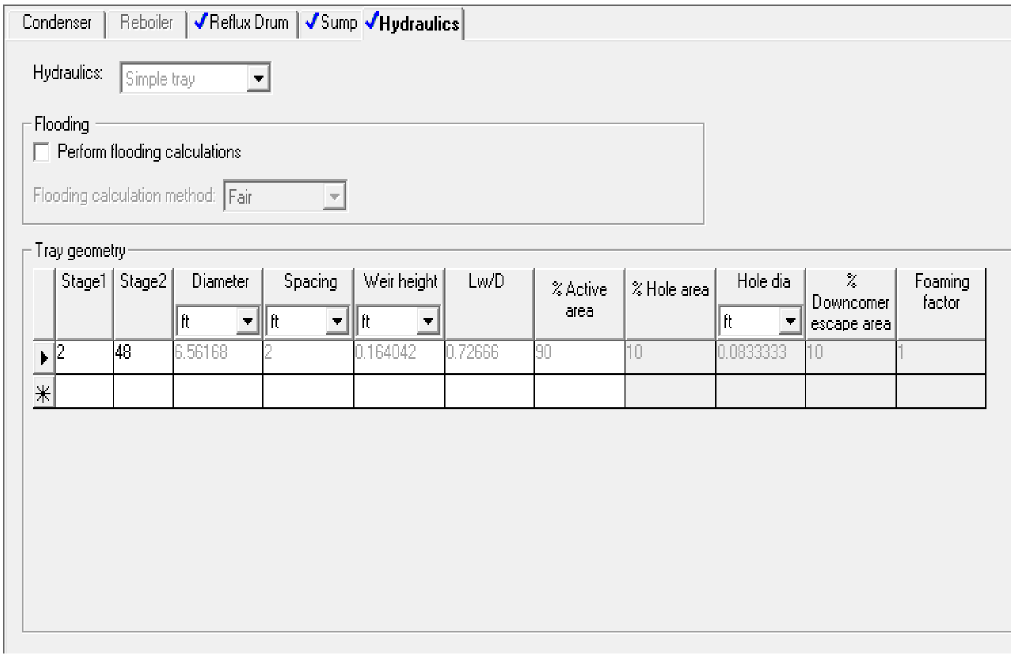
Height: 33.64 ft

Diameter: 12.3 ft

Total liquid volume fraction: 0.5

Liquid 1 volume fraction:

Figure 3.25: Sump Vessel Geometry for CDU



Hydraulics: Simple tray

Flooding

☐ Perform flooding calculations

Flooding calculation method: Fair

Tray geometry

Stage1	Stage2	Diameter ft	Spacing ft	Weir height ft	Lw/D	% Active area	% Hole area	Hole dia ft	% Downcomer escape area	Foaming factor
2	48	6.56168	2	0.164042	0.72666	90	10	0.0833333	10	1

Figure 3.26: Tray Geometry for CDU

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

The study of modeling on CDU was started by developed the fundamental equation which based on the physical and chemical laws of conversation, such as mass balance, component balance and energy balance (Brian R *et al.*, 2006).

The developed equations are steady state equation for overall mass balance, component mass balance and enthalpy balance. The modeling of CDU was proceeding by using ASPEN Plus where the steady state model had been developed for the simulation validated. The steady state model with equipment sizing was developed in ASPEN Plus where the parameters required for equipment sizing was entered.

4.2 FUNDAMENTAL EQUATIONS

The fundamental equation was developed based on the fundamental model or other named is white box model. The steady state equation was developed first for overall mass balance, component mass balance and enthalpy balance. The steady state equation is very important for developing unsteady state equation where the liquid hold up with time had been considered.

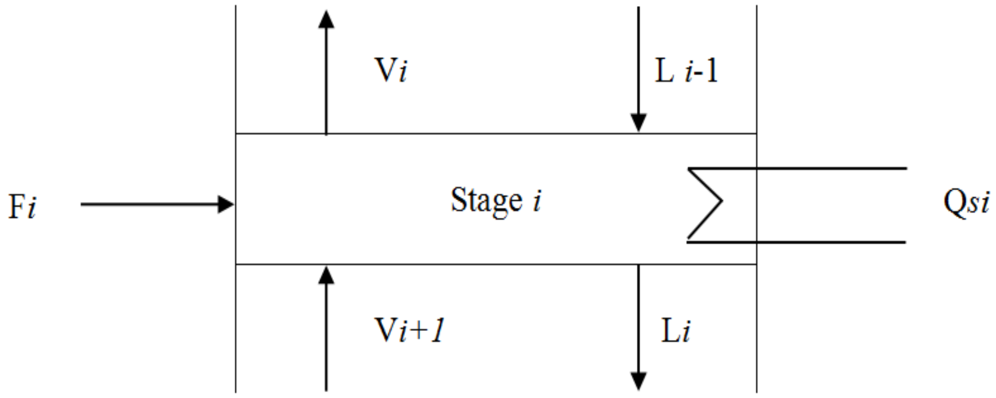


Figure 4.1: Column stage overview

4.2.1 Steady State Equation

Overall Mass Balance (Feed):

$$(L_{i-1} * x_{i-1,j}) + (V_{i+1} * y_{i+1,j}) + (F_i * f_{i,j}) - (L_{i,j} * x_{i,j}) - (V_i * y_{i,j}) = 0$$

Overall Mass Balance (Any stage):

$$(L_{i-1} * x_{i-1,j}) + (V_{i+1} * y_{i+1,j}) - (L_{i,j} * x_{i,j}) - (V_i * y_{i,j}) = 0$$

The equation is same with the feed mass balance as long as it is equation at any stage; the ‘Feed’ part will be removing from the equation

Component Mass Balance (Feed):

$$(x_{i-1,j}) + (y_{i+1,j}) + (f_{i,j}) - (x_{i,j}) - (y_{i,j}) = 0$$

Component Mass Balance (Any stage):

$$(x_{i-1,j}) + (y_{i+1,j}) - (x_{i,j}) - (y_{i,j}) = 0$$

Enthalpy Balance (Feed):

$$(L_{i-1} * h_{i-1}) + (V_{i+1} * h_{i+1}) + (F_i * h_{f\,i}) - (L_i * h_i) - (V_i * h_i) + Q_m - Q_s - Q_{loss} = 0$$

Enthalpy Balance (Any Stage):

$$(L_{i-1} * h_{i-1}) + (V_{i+1} * h_{i+1}) - (L_i * h_i) - (V_i * h_i) + Q_m - Q_s - Q_{loss} = 0$$

4.2.2 Unsteady state equation (Dynamic Equation)

Overall Mass Balance (Feed):

$$(L_{i-1} * x_{i-1,j}) + (V_{i+1} * y_{i+1,j}) + (F_i * f_{i,j}) - (L_{i,j} * x_{i,j}) - (V_i * y_{i,j}) = d (w_{\mathrm{i}} * x_{\mathrm{i,\,j}}) / dt$$

The equation is no longer equal to zero, but represent accumulation of mass on the stage.

Where;

$$w_i = (\rho_{\mathrm{Li}} * A_{\mathrm{Ti}} * h_{\mathrm{Ti}}) + (\rho_{\mathrm{Li}} * A_{\mathrm{Di}} * h_{\mathrm{Di}})$$

Overall Mass Balance (Any stage):

$$(L_{i-1} * x_{i-1,j}) + (V_{i+1} * y_{i+1,j}) - (L_{i,j} * x_{i,j}) - (V_i * y_{i,j}) = d (w_{\mathrm{i}} * x_{\mathrm{i,\,j}}) / dt$$

Component Mass Balance (Feed):

$$(x_{i-1,j}) + (y_{i+1,j}) + (f_{i,j}) - (x_{i,j}) - (y_{i,j}) = d (w_{\mathrm{i}} * x_{\mathrm{i,\,j}}) / dt$$

Component Mass Balance (Any stage):

$$(x_{i-1,j}) + (y_{i+1,j}) - (x_{i,j}) - (y_{i,j}) = d (w_{\mathrm{i}} * x_{\mathrm{i,\,j}}) / dt$$

Enthalpy Balance (Feed):

$$(L_{i-1} * h_{i-1}) + (V_{i+1} * h_{i+1}) + (F_i * h_{f\,i}) - (L_i * h_i) - (V_i * h_i) + Q_m - Q_s - Q_{loss} = d (w_{\mathrm{i}} * x_{\mathrm{i,\,j}}) / dt$$

Enthalpy Balance (Any Stage):

$$(L_{i-1} * h_{i-1}) + (V_{i+1} * h_{i+1}) - (L_i * h_i) - (V_i * h_i) + Q_m - Q_s - Q_{loss}$$
$$= d (w_i * x_{i,j}) / dt$$

4.3 MODEL VALIDATED

The model had been validated based on by performing the literature data into the model. In this model, the CDU specification and components specification had been entered into the model simulation. The feed flow rate of the crude oil was 1 080.2 m^3 / h. The validated model had been compared based on the product composition, boiling range temperature at ASTM-D86 10 % and ASTM-D86 90 %. So, from the data, we can see that there are different between simulation with the literature which slightly different with no accurate value. From the product flow rate, the heavy naphtha, kerosene and atmospheric gas oil was compared which the accuracy of the heavy naphtha and kerosene at most 30% error but the AGO has low accuracy which 55% error. The boiling range at ASTM-D86 90% showed good accuracy which the three products was low than 30%. The HNAPHTHA accuracy was at the 7% error, KEROSENE 4% error and AGO at 15% error. The detail data had been showed in table 4.1a. The changes of effect for the CDU model had been studied since the accuracy of the model has low error for the product flow rate and boiling temperature range.

By the way, the model also had been validated by using other data from a thesis where the crude oil of Masila and Dubai crude had been used. From the thesis the feed flow rate of the crude was 2000 m^3 / h. The compositions of the crude oil are ethane, propane, isobutene and n-butane where the friction of the crude is 75% for Masila Crude and 25% for Dubai Crude (Sampath Y, 2004). The result had been showed in table 4.1b where the accuracy of KEROSENE and AGO is less than 30%. But the comparison of the HNAPHTHA was really high which more than 50%. Regarding the referred of the literature, the Peng Robinson method had been used as the base method rather than this research which is BK-10 method. The simulation used also is different where the Aspen HYSYS was applied in the literature. So, the model had been proceed to see the effect of changes the variable and had been discussed in chapter 4.

Table 4.1a: Validated Data Comparison

Data and Results	Steady State Simulation	Literature Data	Error %
Feed Flow rate, m^3 / h	1080.2	1080.2	
Product Flow Rate, m^3 / h			
HNAPHTHA	287.82	199.20	30.79
KEROSENE	92.86	128.00	27.45
AGO	73.07	32.40	55.66
ASTM-D86 5%, K			
HNAPHTHA	305.59	399.65	23.54
KEROSENE	485.01	438.15	9.66
AGO	603.39	588.62	2.45
ASTM-D86 95%, K			
HNAPHTHA	452.19	421.15	6.86
KEROSENE	509.01	488.15	4.10
AGO	659.75	776.27	15.01

Source: Chatterjee T. *et al.* (2003)

Table 4.1b: Validated Data Comparison

Data and Results	Steady State Simulation	Literature Data	Error %
Feed Flow rate, m^3 / h	2000	2000	
Product Flow Rate, m^3 / h			
HNAPHTHA	214.72	27.51	87.19
KEROSENE	78.71	98.57	20.15
AGO	105.01	106.03	0.96

Source: (Sampath Y, 2004)

4.4 Aspen Plus Steady State Simulation Based on The Literature

The steady state simulation in ASPEN Plus had been preceding which to see the effects on the feed flow rate, product composition and steam flow rate. The pressure units which are valves had been specified in this simulation. By the way, the simulation needs the sizing of equipment which is the required criteria in finished the steady state simulation with the equipment sizing (Indra L. *et al.* (2009). Below are the data and criteria for the steady state simulation with equipment sizing and the specified data for the simulation criteria in table 4.2. The sizing of this data had been referring to the literature and had been assuming that the data of the double up for this simulation since the number of the tray in the CDU was double up too.

1. The CDU column diameter and high
2. Tray spacing
3. Weir length and height
4. Reflux drum diameter and high
5. Sump diameter and high

Table 4.2: Specified Data for Steady State Simulation

Parameter	CDU	Stripper 1	Stripper 2	Stripper 3
Number of Tray	49	4	3	2
Sump diameter, ft.	12.3	4.28	4.98	3.98
Sump height, ft.	33.64	8.56	9.96	7.96
Reflux Drum height, ft.	12.18	-	-	-
Reflux Drum diameter, ft.	6.1	-	-	-

Sources: Indra L. *et al.* (2009) and Chatterjee T. *et al.* (2003)

4.4.1 Effect of Changes in Feed Flow Rate

The effect of the steady state simulation had been studied further which based on the variation of the feed flow rate. The result had been compared based on the product flow rate result based on the different flow rate. The first operating observation was at the normal operating at 100 000 bbl / day. The observation followed by the decreasing and increasing of the operating flow rates. The table 4.3 below is the data for the effect of the changing observation.

Table 4.3: Specified Data for the Effect of Feed Flow Rate

Observation 1	CDU Operating: Normal Operating Feed flow rate : 100 000 bbl / day
Observation 2	CDU Operating: Decreased Feed, Feed flow rate : 55 000 bbl / day
Observation 3	CDU Operating: Increase Feed, Feed flow rate : 200 000 bbl / day

Based on these three observations, the feed flow rate would affect the production of the crude products even in dynamics mode. The increasing of feed flow at double normal operating flow rate showed that the HNAPHTHA product flow rate also will increase double. By the way RED-CRD product flow rate had showed really high value means that the waste is really high. The value from these 3 observations, the value of the AGO and KEROSENE does not showed significances changes. The DIESEL product flow rate had showed that the increasing of feed flow rate would affect the product flow rate which if it too low feed flow, the product will not appear. The result for these 3 observations had been showed in table 4.4 to 4.6. The detail comparison for the observation for ASTM-D86 5%, 95% and product flow rate had been shown by plotting graph in figure 4.2 to 4.4.

Observation 1: Feed flow rate at 100 000 bbl / day

Table 4.4: Feed flow rate at 100 000 bbl / day

Products	Temperature, ^{0}F	Pressure, psia	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow Rate, lb / hr
HNAPHTHA	-83.9	15.7	11.70	375.00	314 686.2
KEROSENE	385.7	21.6	410.80	492.20	141 800.8
DIESEL	510.6	22.5	489.60	640.00	204 889.5
AGO	600.0	23.0	595.20	768.30	110 759.4
RED-CRD	629.7	24.7	690.40	1 363.7	472 050.1

Observation 2: Feed flow rate at 55 000 bbl / day

Table 4.5: Feed flow rate at 55 000 bbl / day

Products	Temperature, ^{0}F	Pressure, psia	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow Rate, lb / hr
HNAPHTHA	-83.6	15.7	12.60	375.00	174 085.7
KEROSENE	406.1	21.6	433.00	558.80	143 497.6
DIESEL	523.7	22.5	560. 40	640.00	34 366.5
AGO	610.0	23.0	602.30	784.00	110 934.9
RED-CRD	645.8	24.7	732.90	1 382.90	221 434.8

Observation 3: Feed flow rate at 200 000 bbl / day

Table 4.6: Feed flow rate at 200 000 bbl / day

Products	Temperature, ^{0}F	Pressure, psia	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow Rate, lb / hr
HNAPHTHA	-84.5	15.7	10.10	375.00	622 198.8
KEROSENE	370.5	21.6	395.90	459.10	141 085.9
DIESEL	487.9	22.5	444.70	640.00	532 839.3
AGO	582.4	23.0	576.60	745.80	110 313.1
RED-CRD	610.0	24.7	638.50	1 344.60	1 081 881.2

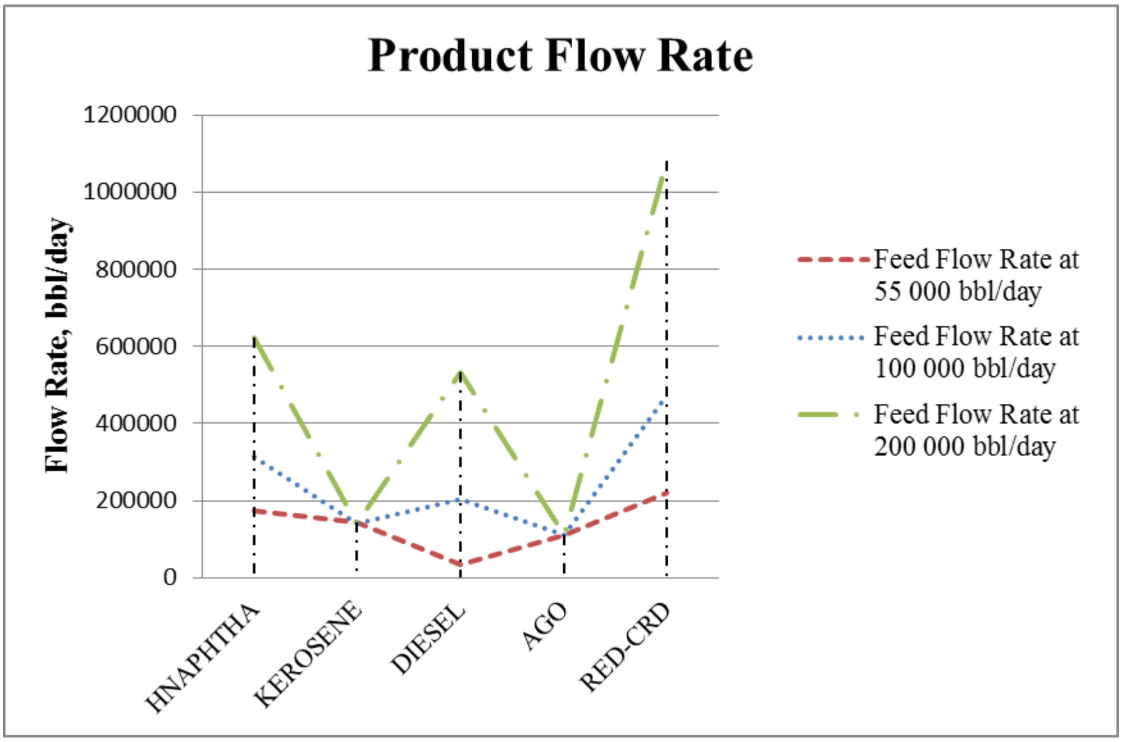


Figure 4.2: Product Flow Rate at Different Feed Flow rate

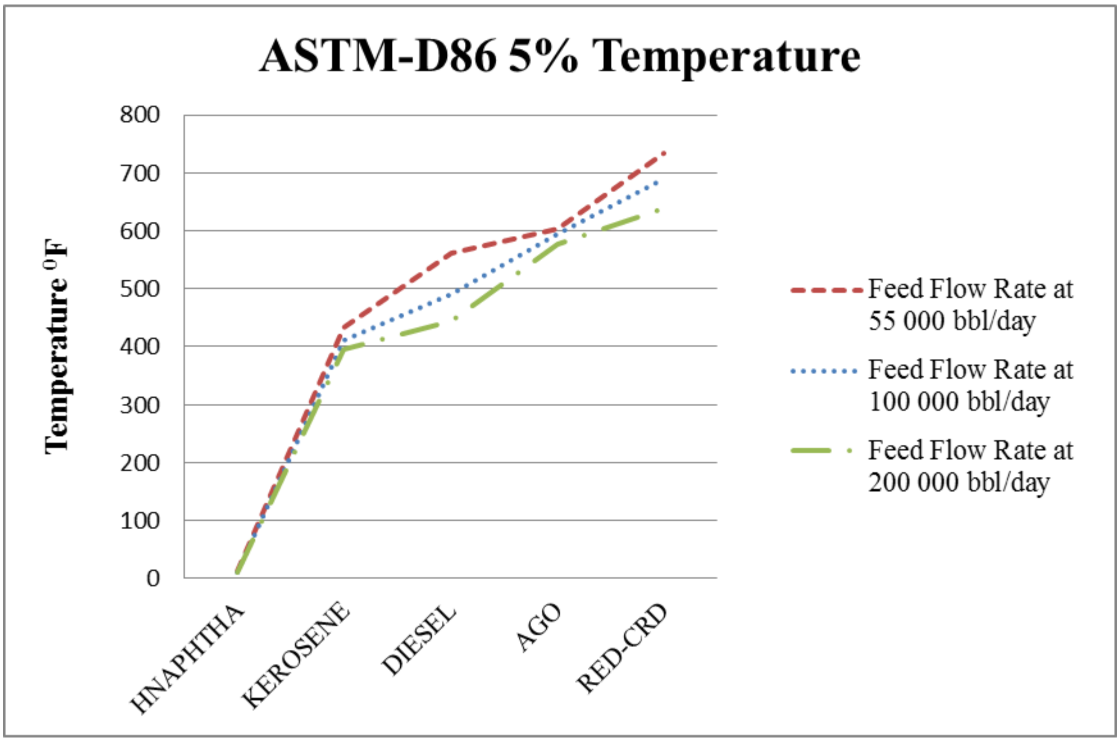


Figure 4.3: ASTM-D86 5% Temperature at Different Feed Flow Rate

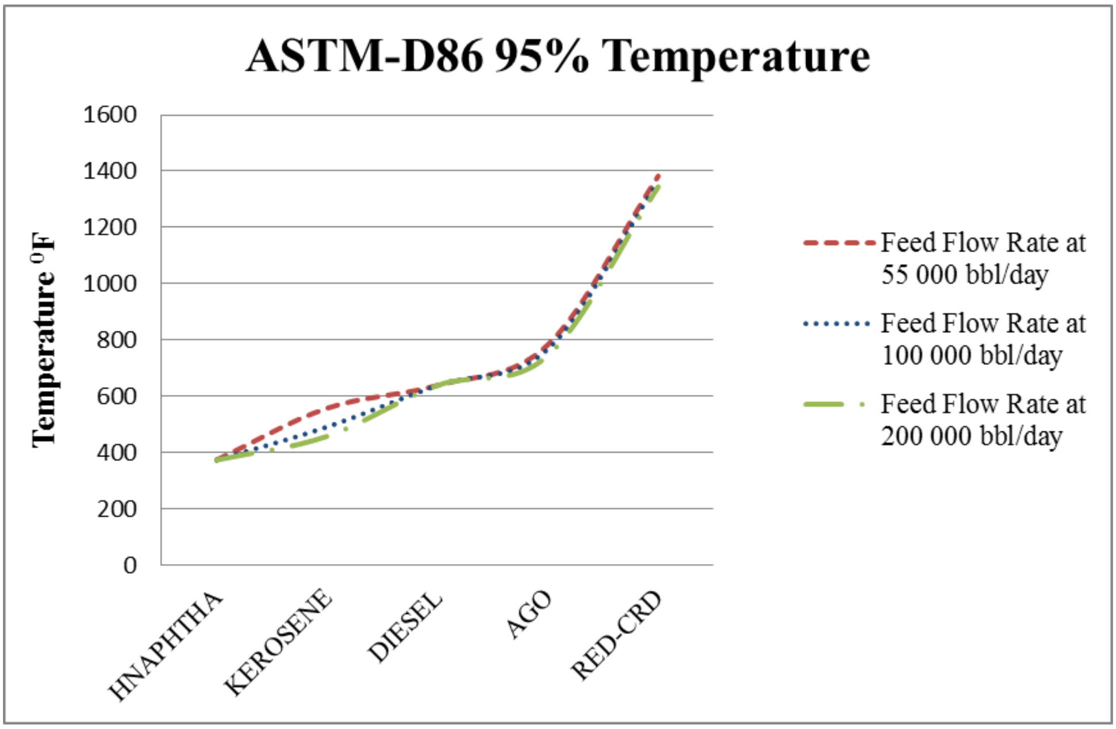


Figure 4.4: ASTM-D86 95% Temperature at Different Feed Flow Rate

4.4.2 Effect of Changes in Feed Composition

The scenario and effect of the steady state simulation had been studied further which based on the variation of the feed composition. The result of each variation had been compared by the value of the product flow rate, feed composition and steam flow rate. The observation was start with the different of flow rate and followed by the decreasing the fraction and followed by increasing the fraction. The table 4.7 below is the data for the effect of the changing observation.

Table 4.7: Specified Data for the Fraction Changes

	Normal Operating:	
	Oil 1	: 0.2
	Oil 2	: 0.8
Observation 1	Decreasing the fraction:	
	Oil 1	: 0.1
	Oil 2	: 0.7
Observation 2	Increasing the fraction:	
	Oil 1	: 0.4
	Oil 2	: 0.9

Observation 1: Decreasing the fraction

Based on the ASTM-D86 plotting figure 4.5, the volume percent versus the temperature showed that the increases of each point. The temperature was increase at each volume percent increase. The specified temperature of HNAPHTHA and DIESEL also was same at the ASTM-D86 95%. The table 4.8 showed that the HNAPHTHA product flow rate was 315 839.8 lb/hr. The trend that we can see when decreasing the fraction numbers, the product flow rate and boiling temperature at ASTM-D86 5% will decrease as long as the fraction was decrease. This is because the composition in the feed was decrease.

Table 4.8: Decreasing the fraction

Products	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow-Rate lb/hr
HNAPHTHA	9.74	350.00	315 839.8
KEROSENE	409.70	491.80	141 785.3
DIESEL	486.40	640.00	213 323.6
AGO	594.10	767.40	110 686.4
RED-CRD	689.80	1 362.50	460 502.3

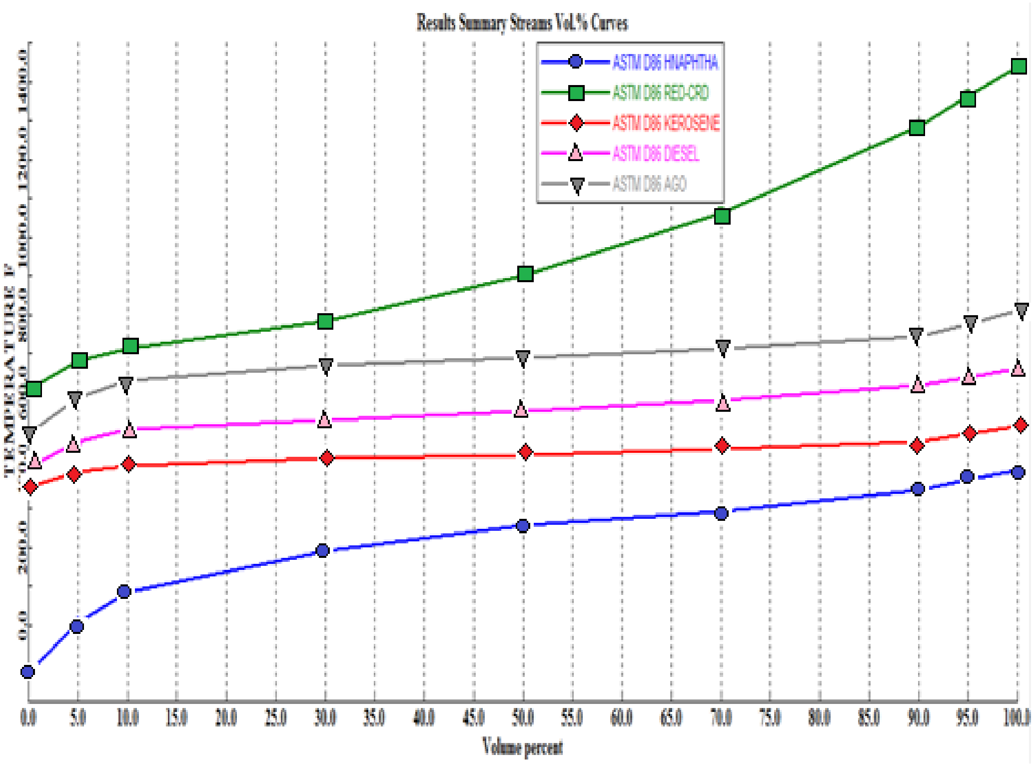


Figure 4.5: ASTM-D86 Plotting Result for Decreasing the Fraction

Observation 2: Increasing the fraction

Based on the ASTM-D86 plotting figure 4.6, the volume percent versus the temperature also showed that the increases of each point. The temperature was increase at each volume percent increase. The specified temperature of HNAPHTHA and DIESEL also was same at the ASTM-D86 95%. The table 4.9 showed that the HNAPHTHA product flow rate was 313 004.7 lb/hr which less than the normal operating. This result showed that the product flow rate will decrease when the specified temperature decrease. The trend that we can see when increasing the fraction numbers, the product flow rate and boiling temperature at ASTM-D86 5% will increase as long as the fraction was increase. This is because the composition in the feed was increase.

Table 4.9: Increasing the fraction

Products	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow-Rate lb/hr
HNAPHTHA	14.80	350.00	313 004.7
KEROSENE	412.40	495.40	141 829.3
DIESEL	494.20	640.00	192 714.4
AGO	596.70	769.80	110 866.6
RED-CRD	691.20	1 365.50	488 712.6

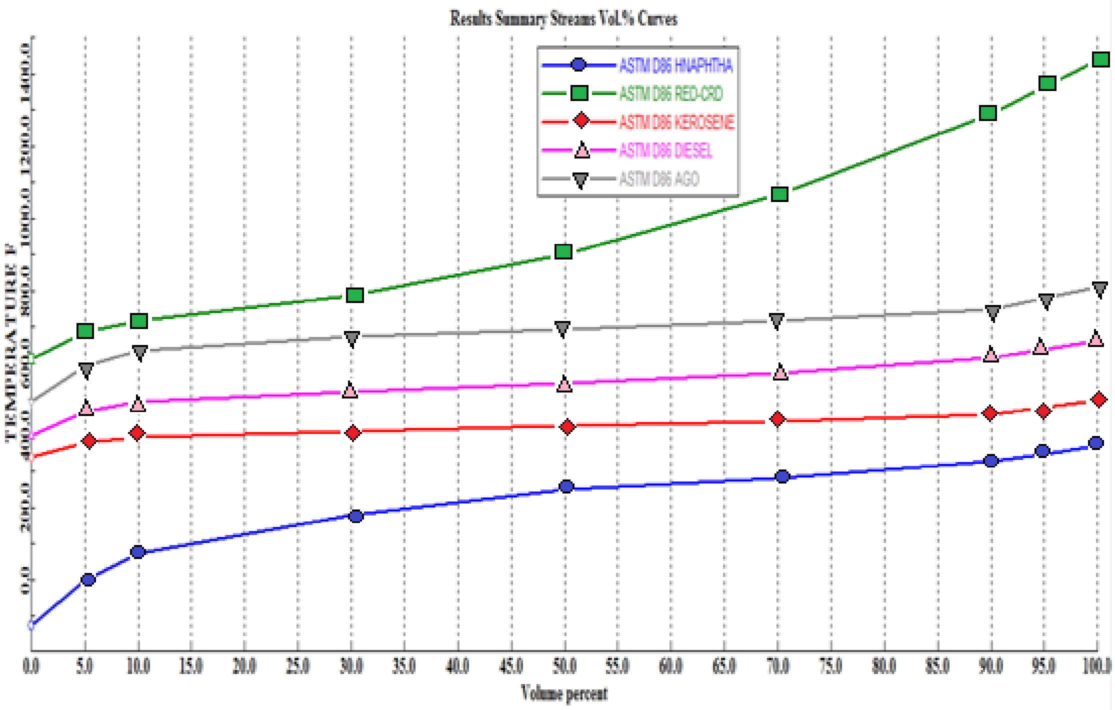


Figure 4.6: ASTM-D86 Plotting Result for Increasing the Fraction

4.4.3 Effect of Changes in Steam Flow Rate

The effect of changing the stripping stream was done by assuming the stripping steam to the top kerosene stripper (S-1) is increased from 11700 to15700 bbl/day. The result of the changes was recorded as below:

- The initial TBP boiling point of kerosene changes from 331.40 to 331.22 ^{0}F.
- The initial ASTM boiling point of kerosene changes from 380.70 to 384.06 ^{0}F.
- The ASTM 5% boiling point changes only from 410.80 to 417.26 ^{0}F.
- The ASTM 95% boiling point changes only from 492. 10 to 517.05 ^{0}F.

So, the result showed that at the initial TBP boiling point, the temperature was drop around 0.20 ^{0}F. The rest of the boiling point was increasing along the operating specification.

4.5 Aspen Plus Steady State Form Based on Geometry Calculation

The steady state simulation with equipment in ASPEN Plus had been proceed by perform the method like discussed in chapter 3. The pressure units which are valves had been specified in this simulation. By the way, the simulation needs the sizing of equipment which is the required criteria in finished the simulation. Below are the data and criteria for the simulation with equipment sizing and the specified data for the in table 4.10. The sizing of this data had been referring to the literature which the step of the calculation (Luyben W. L. *et al.* 2010).

1. The CDU column diameter and high
2. Tray spacing
3. Weir length and height
4. Reflux drum diameter and high
5. Sump diameter and high

Table 4.10: Specified Data for Steady State Simulation for Geometry

Parameter	CDU	Stripper 1	Stripper 2	Stripper 3
Number of Tray	25	4	3	2
Sump diameter, ft.	29.29	4.75	4.65	3.06
Sump height, ft.	2.64	33.79	51.97	62.73
Reflux Drum height, ft.	22.18	-	-	-
Reflux Drum diameter, ft.	11.09	-	-	-

Sources: Luyben W. L. *et al.* (2010)

4.5.1 Effect of Changes in Feed Flow Rate

The effect of the steady state simulation had been studied further which based on the variation of the feed flow rate. The result had been compared based on the product flow rate result based on the different flow rate. The first operating observation was at the normal operating at 100 000 bbl / day. The observation followed by the decreasing and increasing of the operating flow rates. The table 4.11 below is the data for the effect of the changing observation.

Table 4.11: Specified Data for the Effect of Changes in Feed Flow Rate

Observation 1	CDU Operating: Normal Operating Feed flow rate : 100 000 bbl / day
Observation 2	CDU Operating: Decreased Feed, Feed flow rate : 55 000 bbl / day
Observation 3	CDU Operating: Increase Feed, Feed flow rate : 200 000 bbl / day

Based on these three observations, the feed flow rate would affect the production of the crude products even in the steady state mode. The increasing of feed flow at double normal operating flow rate showed that the HNAPHTHA product flow rate also will increase double. Based on the study, the flow rates in a steady state model of a column with constant tray efficiencies will scale directly with the column feed rate (Riggs J. 1992). By the way RED-CRD product flow rate had showed really high value means that the waste is really high. The value from these 3 observations, the value of the AGO and KEROSENE does not showed significances changes. The DIESEL product flow rate had showed that the increasing of feed flow rate would affect the product flow rate which if it too low feed flow, the product will not appear. The result for these 3 observations had been showed in table 4.12 to 4.14. The detail comparison for the observation for ASTM-D86 5%, 95% and product flow rate had been shown by plotting graph in figure 4.7 to 4.9.

Observation 1: Feed flow rate at 100 000 bbl / day

Table 4.12: Feed flow rate at 100 000 bbl / day

Products	Temperature, ^{0}F	Pressure, psia	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow Rate, lb / hr
HNAPHTHA	-86.1	15.7	6.11	375.00	301 372.2
KEROSENE	367.8	21.2	395.22	494.06	141 527.9
DIESEL	497.4	22.4	474.95	640.00	212 620.2
AGO	595.1	23.3	588.32	776.27	110 629.8
RED-CRD	627.2	24.7	682.02	1362.01	478 056.4

Observation 2: Feed flow rate at 55 000 bbl / day

Table 4.13: Feed flow rate at 55 000 bbl / day

Products	Temperature, ^{0}F	Pressure, psia	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow Rate, lb / hr
HNAPHTHA	-85.3	15.7	7.98	375.00	168 292.3
KEROSENE	381.1	21.2	414.05	557.24	143 168.7
DIESEL	495.5	22.4	539. 49	640.00	29 236.6
AGO	595.3	23.3	585.79	782.78	110 468.3
RED-CRD	635.3	24.7	717.74	1 376.83	233 176.2

Observation 3: Feed flow rate at 200 000 bbl / day

Table 4.14: Feed flow rate at 200 000 bbl / day

Products	Temperature, ^{0}F	Pressure, psia	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow Rate, lb / hr
HNAPHTHA	-85.9	15.7	5.81	375.00	601 645.8
KEROSENE	356.8	21.2	383.82	463.85	140 846.8
DIESEL	480.6	22.4	436.92	640.00	549 876.0
AGO	580.8	23.3	574.00	754.72	110 319.1
RED-CRD	609.6	24.7	633.22	1 344.08	1 085 650.5

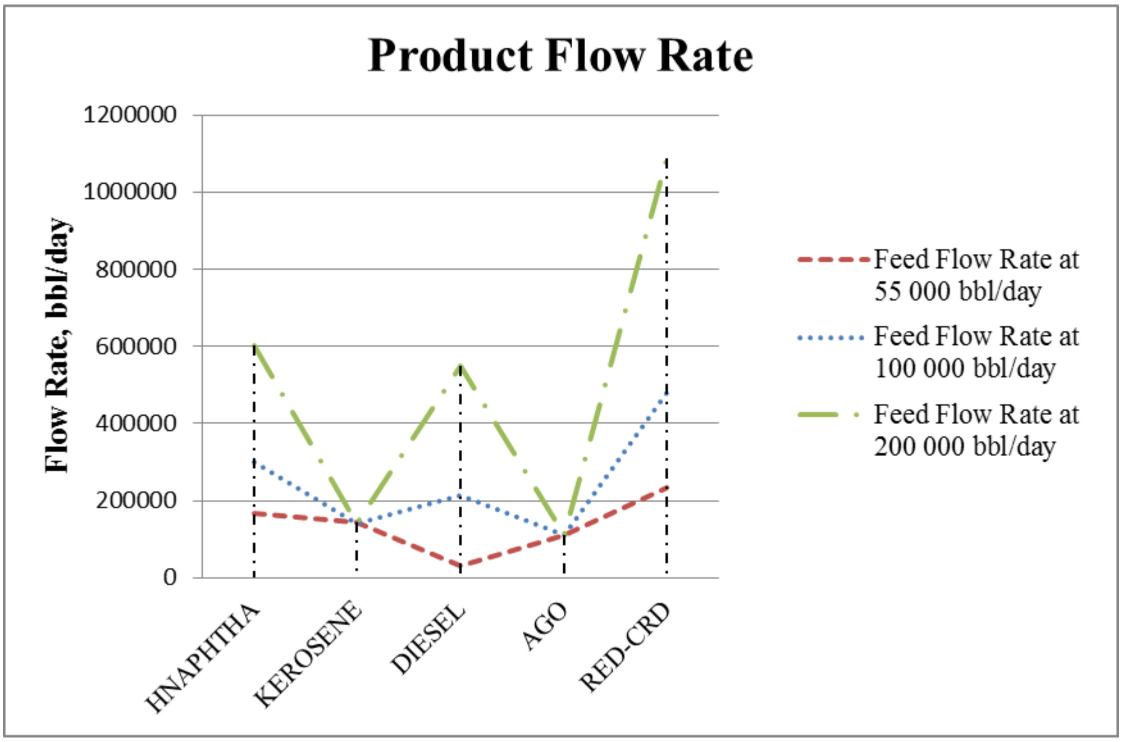


Figure 4.7: Product Flow Rate at Different Feed Flow rate

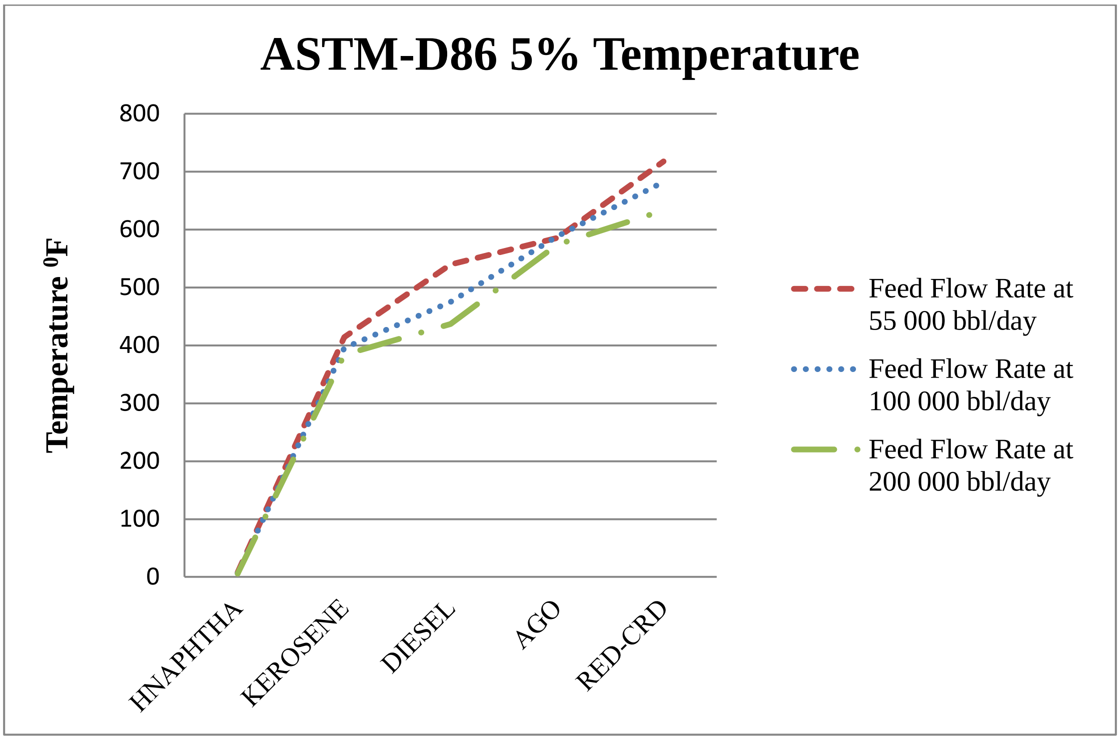


Figure 4.8: ASTM-D86 5% Temperature at Different Feed Flow Rate

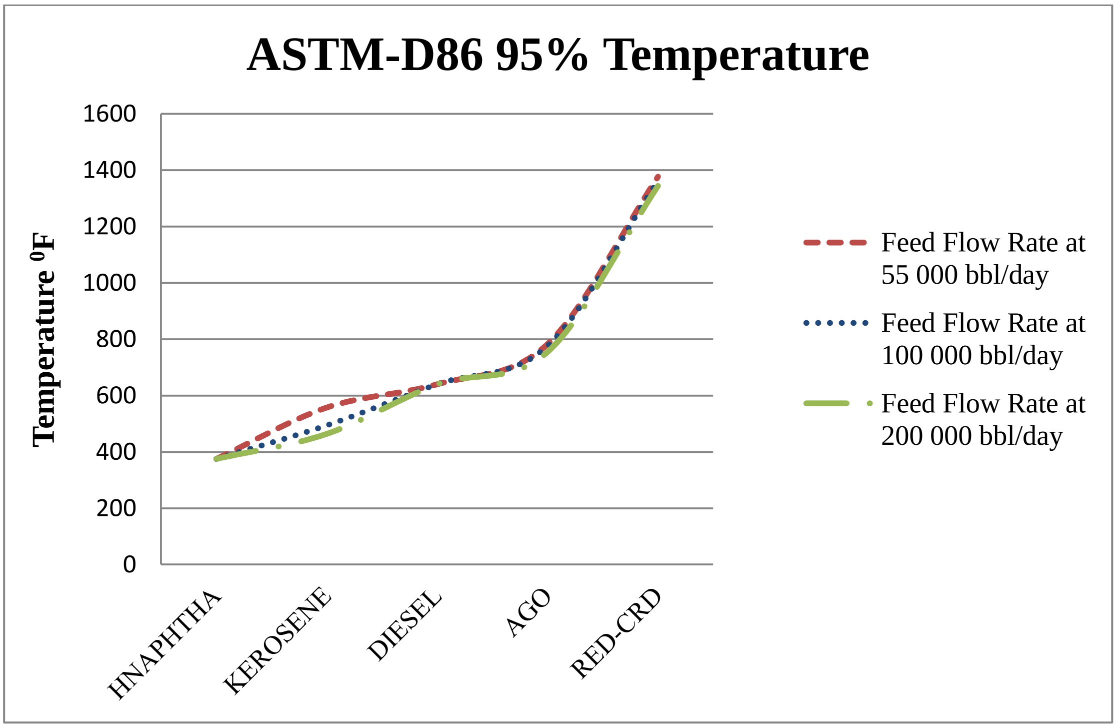


Figure 4.9: ASTM-D86 95% Temperature at Different Feed Flow Rate

4.5.2 Effect of Changes in Feed Composition

The scenario and effect of the steady state simulation had been studied further which based on the variation of the feed composition. The result of each variation had been compared by the value of the product flow rate, feed composition and steam flow rate. The observation was start with the different of flow rate and followed by the decreasing the fraction and followed by increasing the fraction. The table 4.15 below is the data for the effect of the changing observation.

Table 4.15: Specified Data for the Fraction Changes

	Normal Operating:	
	Oil 1	: 0.2
	Oil 2	: 0.8
Observation 1	Decreasing the fraction:	
	Oil 1	: 0.1
	Oil 2	: 0.7
Observation 2	Increasing the fraction:	
	Oil 1	: 0.4
	Oil 2	: 0.9

Observation 1: Decreasing the fraction

Based on the ASTM-D86 plotting figure 4.10, the volume percent versus the temperature showed that the increases of each point. The temperature was increase at each volume percent increase. The specified temperature of HNAPHTHA and DIESEL also was same at the ASTM-D86 95%. The table 4.16 showed that the HNAPHTHA product flow rate was 302 169.1 lb/hr. The trend that we can see when decreasing the fraction numbers, the product flow rate and boiling temperature at ASTM-D86 5% will decrease as long as the fraction was decrease. This is because the composition in the feed was decrease.

Table 4.16: Decreasing the fraction

Products	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow-Rate lb/hr
HNAPHTHA	3.74	350.00	302 169.1
KEROSENE	394.10	492.66	141 538.1
DIESEL	472.12	640.00	221 573.0
AGO	587.44	775.76	110 563.8
RED-CRD	681.70	1360.81	466 314.1

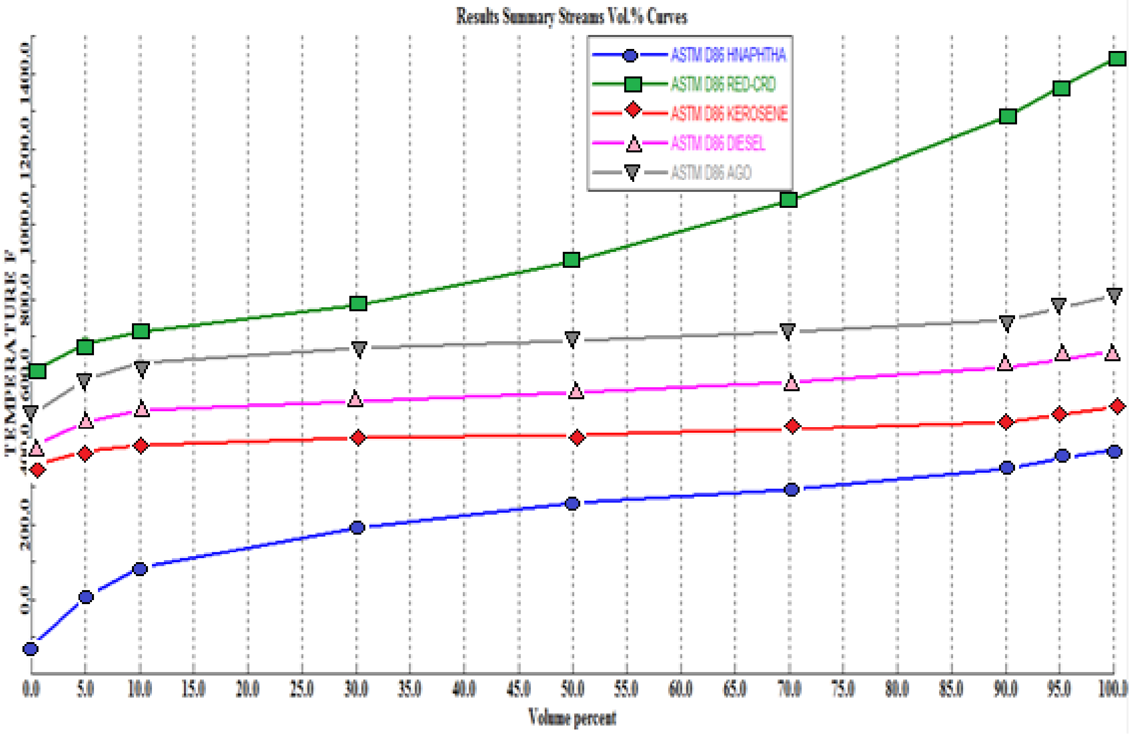


Figure 4.10: ASTM-D86 Plotting Result for Decreasing the Fraction

Observation 2: Increasing the fraction

Based on the ASTM-D86 plotting figure 4.11, the volume percent versus the temperature also showed that the increases of each point. The temperature was increase at each volume percent increase. The specified temperature of HNAPHTHA and DIESEL also was same at the ASTM-D86 95%. The table 4.17 showed that the HNAPHTHA product flow rate was 306 501.4 lb/hr which less than the normal operating. The trend that we can see when increasing the fraction numbers, the product flow rate and boiling temperature at ASTM-D86 5% will increase as long as the fraction was increase. This is because the composition in the feed was increase.

Table 4.17: Increasing the fraction

Products	ASTM-D86 5% Temperature ^{0}F	ASTM-D86 95% Temperature ^{0}F	Product Flow-Rate lb/hr
HNAPHTHA	12.10	350.00	306 501.4
KEROSENE	401.10	501.40	141 678.9
DIESEL	481.90	640.00	191 920.6
AGO	588.60	776.30	110 693.4
RED-CRD	681.90	1363.20	496 349.6

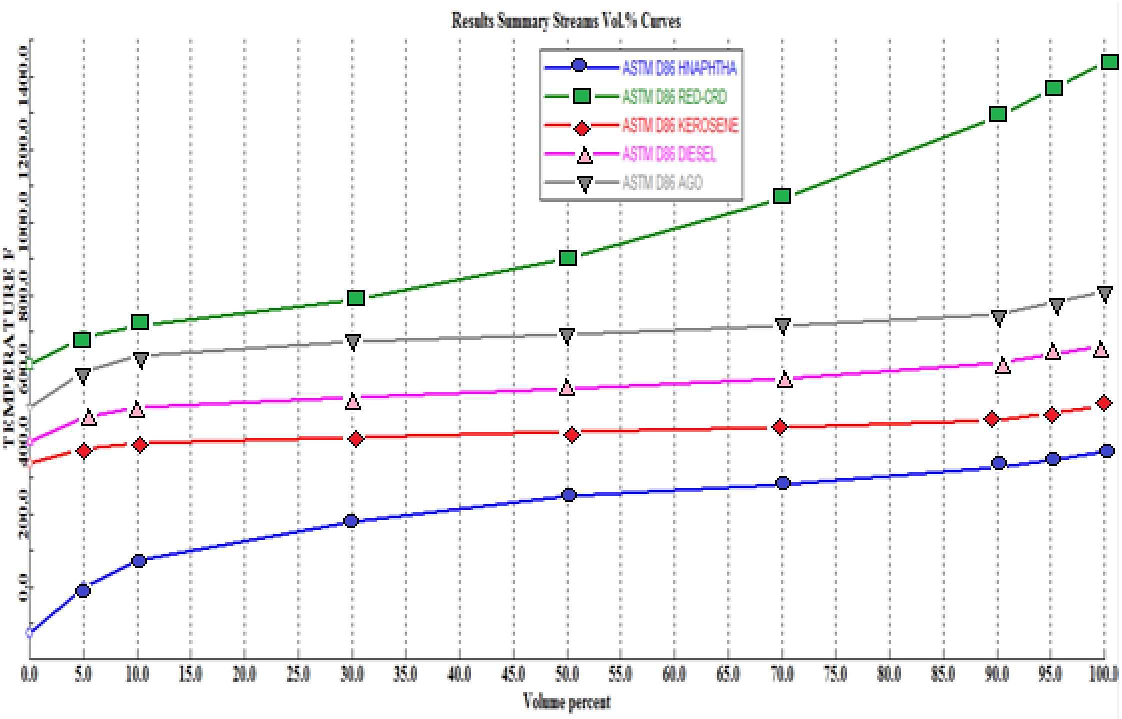


Figure 4.11: ASTM-D86 Plotting Result for Increasing the Fraction

By performing the feed composition changes, it would give effect through the column. Based on the study, feed composition changes will represent a major disturbance for distillation and it really sensitive to configure feed composition upset in control (Riggs J. 1992). So, by performing the steady state model will be useful in observe the changes of feed composition in unsteady state simulation.

4.5.3 Effect of Changes in Steam Flow rate

The effect of changing the stripping stream was done by assuming the stripping steam to the top kerosene stripper (S-1) is increased from 11700 to15700 bbl/day. The result of the changes was recorded as below:

- The initial TBP boiling point of kerosene changes from 300.20 to 297.95 ^{0}F.
- The initial ASTM boiling point of kerosene changes from 355.65 to 356.80 ^{0}F.
- The ASTM 5% boiling point changes only from 395.22 to 400.76 ^{0}F.
- The ASTM 95% boiling point changes only from 494. 06 to 515.68 ^{0}F.

So, the result showed that at the initial TBP boiling point, the temperature was drop around 2.25 ^{0}F. The rest of the boiling point was increasing along the operating specification. Based on the previous study, the flow rate of stripping steam would affect the initial boiling point or the flash point of the cut (Luyben W.L. 2006). The reason is, the heat transfer contact at certain flow rate will affect the heat transfer medium.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The steady-state model of CDU was developed based on mass, energy, component balance equations and summation equations. The Aspen Plus simulation for steady state model was completely based on the basic step in dynamic modeling where defining the goal of model. The simulation was start by using Aspen Plus User Interface and the required data for blending crude oil and the CDU had been entered on the flow sheet in steady state model. The steady state simulation with equipment sizing had been applied in Aspen Plus by changing to flow sheet into dynamic mode. The specification of the dynamic requirement for vessel geometry and tray geometry had been entered. The effect of feed flow rate, feed composition and steam flow rate on product compositions and tray temperatures were studied. From this research, the completed steady state model had been validated with the literature data. The model which applied literature data for different tray at 49 trays give higher HNAPHTHA flow rate which is 199.20 m^3 / h but give low flow rate of KEROSENE which is 128.00 m^3 / h. The results were compared with the data available in the literature and the accuracy of the model has been proved.

5.2 RECOMMENDATIONS

The research in steady state modeling is really important for higher institution and more over in industry sector. The modeling research will give positive impact in the research and development, prediction and control, planning and scheduling, process design and process optimization which mostly was in dynamics. Furthermore the process model also important in process controls application. The implementation of research in modeling by faculty would get full support from other organization.

The completed steady state model should be continuing by using Aspen Dynamics to complete the dynamic simulation. This requirement for the dynamic had been discussed in this research as long as the vessel geometry had been discussed in the report. The model also should be compared by performing other simulation like Aspen HYSYS and also should perform the calculation in MATLAB environment to gain more understanding on modeling.

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APPENDIX A

MANUAL CALCULATION

Determine the Tray Geometry for Sump and Reflux Drum

Assumption:

- 10 minutes of total hold up.
- Reflux drum aspect ratio (length over diameter) H/D of 2.

Information:

- Reflux drum was located top of the column which at the 1st stage.
- Sump was located at the column base which the data of 'volume flow liquid from' was taken at the minus total stage.

Column Geometry

- Sump geometry

  Column Diameter = 29.29 ft. = 8.93 m
  Stage 25 is column base (sump) so, 5.048 m^3/min leave at stage 24

  Volume = (5.048 m^3/min)*(10 min) = 50.48 m^3

  $$\frac{\pi\,(D_c)^2}{4} * H = \frac{\pi\,(8.93)^2}{4} * H = 50.48\,m^3$$

  Height, H = 0.806 m = 2.644 ft.

  So, D = 29.29 ft. H = 2.644 ft.

- Reflux drum geometry

  Stage 1 is reflux drum so, 6.068 m^3/min leave at stage 1

  Volume = (6.068 m^3/min)*(10 min) = 60.68 m^3

  $$\frac{\pi\,(D)^2}{4} * H = \frac{\pi\,(D)^2}{4} * 2D = \frac{\pi\,(D)^3}{2} = 60.68\,m^3$$

  So, D = 3.38 m = 11.09 ft.
  L = 6.76 m = 22.18 ft.

Stripper Geometry

- Stripper 1 sump

  Column Diameter = 4.745 ft. = 1.45 m
  Stage 4 is column base (sump) so, 1.701 m^3/min leave at stage 3

  Volume = (1.701 m^3/min)*(10 min) = 17.01 m^3

  $$\frac{\pi\,(D_c)^2}{4} * H = \frac{\pi\,(1.45)^2}{4} * H = 17.01\,m^3$$

  Height, H = 10.30 m = 33.79 ft.

  So, D = 4.745 ft. H = 33.79 ft.

- Stripper 2 sump

  Column Diameter = 4.646 ft. = 1.42 m
  Stage 3 is column base (sump) so, 2.509 m^3/min leave at stage 2

  Volume = (2.509 m^3/min)*(10 min) = 25.09 m^3

  $$\frac{\pi\,(D_c)^2}{4} * H = \frac{\pi\,(1.42\,)^2}{4} * H = 25.09\,m^3$$

  Height, H = 15.84 m = 51.97 ft.

  So, D = 4.646 ft. H = 51.97 ft.

- Stripper 3 sump

  Column Diameter = 3.057 ft. = 0.93 m
  Stage 2 is column base (sump) so, 1.299 m^3/min leave at stage 1

  Volume = (1.299 m^3/min)*(10 min) = 12.99 m^3

  $$\frac{\pi\,(D_c)^2}{4} * H = \frac{\pi\,(0.93)^2}{4} * H = 12.99\,m^3$$

  Height, H = 19.12 m = 62.73 ft.

  So, D = 3.057 ft. H = 62.73 ft.