CHAPTER 4 RESULTS AND DISCUSSION

4.1 Steady State Model

This section describes the development and tuning of the simulation model of the pilot distillation column using Aspen Plus 2006.5. This includes the necessary input data for streams and units, simulation results and comparisons between the test run data and the simulation results.

4.1.1 Model Development

The feed stream (FEED) which consists of Benzene and Toluene mixture is introduced to the column above the packed section. This system is used to study the separation of Benzene in the overhead stream (OVHD) from the mixture of Benzene-Toluene. The pilot distillation column is represented by RADFRAC model in Aspen plus and operated with the operating conditions. The simulation model from Aspen Plus is shown in Figure 4.1 below.

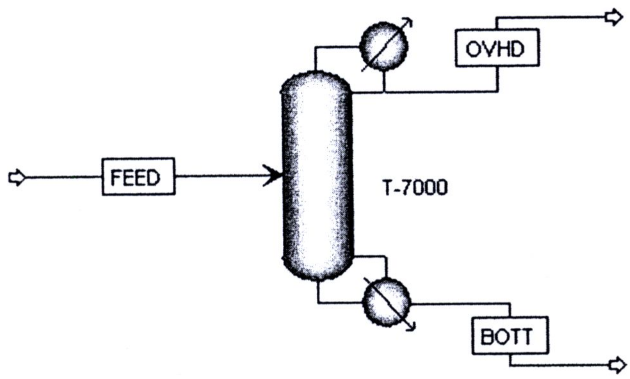

Figure 4.1 The steady state model from Aspen Plus

From the actual configurations of the pilot distillation column, the heater submerged at a bottom of a column is a heat source. The Sulzer packing are arranged along the column as a contactor to enhance the separation efficiency of the column. In addition, the reflux which is cooled from the condenser is subcooled reflux. However, the RADFRAC model in this simulation uses a reboiler as a heat source and the plate column instead the heater and the packing, respectively. One of the important data is the number of stage but in the actual configuration of pilot distillation column is packed by Sulzer packing. Therefore, it is important to convert the height equivalent to a theoretical stage (HETP) from the packing to the number of the theoretical stage from equation (2.4) in Chapter 2. The calculation of number of the theoretical stages is shown in Appendix B. The necessary data which is required for the Aspen Plus simulation is divided into two main parts which are stream data and equipment data and shown in Table 4.1 and 4.2, respectively.

Table 4.1 The required stream input data of the pilot distillation column

Parameters	**FEED**
Temperature (°C)	30
Pressure (atm)	1.036
Total flow (kg/hr)	1.724
Mass fraction	
- Benzene	0.503
- Toluene	0.497

Table 4.2 The required equipment data of the pilot distillation column (T-7000)

T-7000	**Value**
Number of stages	52
Condenser (Total)	N/A
Reboiler (Kettle)	N/A
Distillate rate (kg/hr)	0.9
Reflux rate (kg/hr)	6.465
Feed stages	27
Condenser pressure (atm)	1
Column pressure drop (atm)	0.07
Subcooled reflux temperature (°C)	30

4.1.2 Model Tuning

In order to ensure that the model can predict the process operation correctly, the model accuracy should be determined. The model accuracy is assessed by comparing the simulation results with the test run data. In this project, the model accuracy is acceptable when the differences in the stream composition between the simulation results and the test run data are less than or equal 5% whereas the difference in temperature profile of the column (A-E) between the simulation results and the test run data must be less than 2 °C. However, the temperature profile of the column (A- E) can be determined by the average temperature between the stages as shown in Table 4.3.

Table 4.3 Temperature profile of the column (A-E) of the pilot distillation column

T-7000	Average Temperature
TA (°C)	Stages 6 - 7
TB (°C)	Stages 16 - 17
TC (°C)	Stages 26 - 27
TD (°C)	Stages 36 - 37
TE (°C)	Stages 46 - 47

From Table 4.2 above, the number of the theoretical stages has 52 stages which are 50 stages for the section of packing (A-E) and 2 stages for reboiler and condenser. Therefore, each packing consists of 10 stages arranged in the column. The temperature of each packing is located along the column and shown in Table 4.3.

Table 4.4 The simulation results from Aspen Plus before tuning with the Murphree efficiency of case 1

T-7000	Test run	Simulation	ΔT (°C)	%Diff
TA (°C)	86.77	99.67	12.90	NA
TB (°C)	106.68	107.85	1.17	NA
TC (°C)	107.12	108.32	1.20	NA
TD (°C)	111.58	112.36	0.78	NA
TE (°C)	111.97	112.82	0.86	NA
Mass fraction of Benzene in the OVHD stream (Xbz)	0.962	0.964	NA	0.27

The simulation results from the Aspen Plus at the normal operation before tuning of case 1, reflux rate 6.465 kg/hr, feed location pack C and distillate rate 0.9 kg/hr, are shown in Table 4.4. The results from this table show that the mass fraction of Benzene in the overhead stream (Xbz) and the temperature profile along the column fit well with the test run data except the temperature of packing A (TA) because its delta temperature is 12.90 °C which is higher than 2 °C.

Table 4.5 The model tuning results with the Murphree efficiency

Section	Stages	Murphree Efficiency
Packing A	2 - 11	0.6
Packing B	12 - 21	1
Packing C	22 – 31	1
Packing D	32 – 41	1
Packing E	42 - 51	1

Therefore, this model must be tuned with the Murphree efficiency in order to match the packing A temperatute (TA) with the test run data. The model tuning after tuning with the Murphree efficiency is shown in Table 4.5. From this table, the Murphree efficiency of all packing is 1 except the Murphree efficiency of packing A (stages 2-11) which is only 0.6.

Table 4.6 The operating conditions of the pilot distillation column (T-7000) of 3 cases

Parameters	Case 1	Case 2	Case 3
Reflux rate (kg/hr)	6.465	6.465	7.758
Feed location	C	D	B
Distillate rate (kg/hr)	0.9	0.9	0.88

After the model is tuned with the Murphree efficiency, the simulation results are validated with 3 cases of ROC's pilot test run data to ensure that the model is correct and reliable. Three cases of the test run data have the difference operating conditions such as the feed location, reflux rate and the distillate rate as shown in Table 4.6. The diferrence between case 1 and case 2 is the feed location. For case 3, all of these parameters (reflux rate, feed location and distillate rate) are different from previous 2 cases.

Table 4.7 The simulation results from Aspen Plus after tuning of 3 cases

Parameters	TA (°C)	TB (°C)	TC (°C)	TD (°C)	TE (°C)	Xbz
			Case 1			
Test run	86.77	106.68	107.12	111.58	111.97	0.962
Simulation	86.60	107.43	108.04	112.36	112.82	0.964
ΔT (°C)	0.17	0.75	0.93	0.78	0.86	NA
%Diff	NA	NA	NA	NA	NA	0.27
			Case 2			
Test run	86.10	107.57	108.22	108.49	111.46	0.962
Simulation	86.60	107.43	108.04	108.50	112.82	0.964
ΔT (°C)	0.50	0.14	0.18	0.01	1.36	NA
%Diff	NA	NA	NA	NA	NA	0.27
			Case 3			
Test run	83.98	108.60	112.20	112.42	112.72	0.997
Simulation	83.01	107.74	111.89	112.36	112.82	0.986
ΔT (°C)	0.97	0.86	0.31	0.06	0.10	NA
%Diff	NA	NA	NA	NA	NA	1.12

The simulation results from Aspen Plus after tuning with the Murphree efficiency of 3 case studies are shown in Table 4.7. The results show that the difference temperature profile of the column (A-E) of all 3 case studied is less than 2°C. In addition, the percentage difference between the test run data and the simulation results of all 3 case studies is less than 5 % which is an acceptable value. Therefore, this simulation model is good enough for describing the process operation of the ROC's pilot distillation column. Moreover, it can be used for predicting the output parameters such as the mass fraction of benzene in the overhead stream and the temperature profile of the column (A-E) when the operating conditions such as reflux rate, distillate rate and feed location are changed. Furthermore, it can be used for describe process operation of the pilot distillation column when it uses for separating the other components.

From the Aspen Plus results, the ROC's pilot distillation column is matched well by the 50 theoretical stages with 0.6 Murphree efficiency of packing A. From the theory of the packing as mention in Chapter 2, the height equivalent to the theoretical stages (HETP) can be determined by the ratio of the section pack height and the number of the theoretical stages. The HETP of each packing (A-E) is concluded and shown in Table 4.8.

Table 4.8 The HETP value of packing (A-E) of the column

Section	Section packed height (m)	Number of the theoretical stages	HETP (m)
Packing A	0.4	6	0.067
Packing B	0.4	10	0.04
Packing C	0.4	10	0.04
Packing D	0.4	10	0.04
Packing E	0.4	10	0.04

Table 4.8 shows the HETP value of each packing (A-E) of ROC's pilot distillation column. From this Table, the section packed height of all packing (A-E) is equal 0.4 m. The number of the theoretical stages can be achieved from the Aspen Plus program. The numbers of theoretical stages are equal to 10 stages for packing B-E and 6 stages for packing A. This value is calculated from the Murphree efficiency multiply by the ideal number of the theoretical stages. Therefore, the HETP value of packing A is 0.067 m which is higher than the others. The high HETP will show that the lower efficiency of packing in the column as mention above in theoretical part. The pack efficiency of packing A is degraded because it is located at the overhead of the column where the L/V ratio is high. Finally, the actual number of the theoretical stages of ROC's pilot distillation column is 46 stages.

4.2 Dynamic Model

After the steady state model from Aspen Plus is already completed, the dynamic model will be created from Aspen Dynamics. The steady state model is used for describing the process behavior when reaching a steady state. However, the response of the process cannot be observed before it reaches a steady state. Therefore, the dynamic model is generated for observing the response of the output parameter when the operating conditions are changed before it reaches the steady state condition. Moreover, the dynamic model is also used for generating the start-up procedure of pilot distillation column operation as mention above.

4.2.1 Model Development

The dynamic model from Aspen Dynamics is shown in Figure 4.2. This model has also same configuration with the steady state model from Aspen Plus. In this model, the distillate and bottom rate of the tower is kept as constant value. In fact, level of the pilot distillation column (T-7000) can be controlled by adjusting the heat duty of the heater manually. Therefore, the dynamic model has not the controller which control the level in the tower as same as the actual operation.

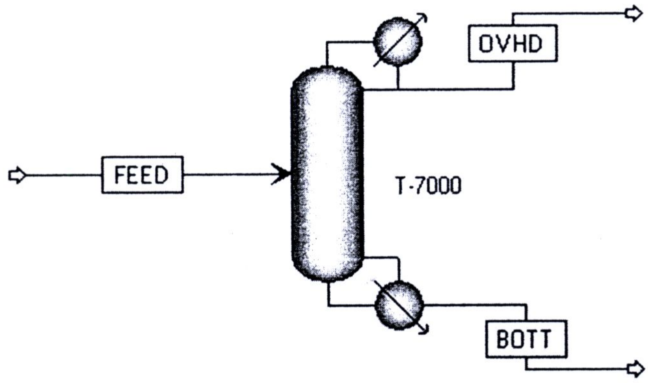

Figure 4.2 The dynamic model of ROC's pilot distillation column

Before the dynamic model is generated, the necessary data which is the configuration of the pilot distillation is needed such as the medium temperature, diameter and length of the pilot distillation and the reflux drum, the height equivalent to a theoretical stage (HETP) of the packing and the initial liquid volume fraction of reflux drum and sump. These necessary data are shown in Table 4.9.

Table 4.9 The required data of the pilot distillation column for Aspen Dynamics

T-7000	Type	Value
Condenser	Constant medium temperature (°C)	15
Reboiler	Constant duty	NA
Reflux drum	Vertical, Hemispherical head	NA
	Diameter (m)	0.224
	Length (m)	0.63
	Initial liquid volume fraction	0.14
Sump	Flat head	NA
	Diameter (m)	0.305
	Height (m)	0.475
	Initial liquid volume fraction	0.716
Hydraulics	HETP for packing A (m)	0.067
	HETP for packing B-E (m)	0.04
	Diameter (m)	0.078
	Initial liquid volume fraction	0.05
	Section packed height (m)	2

4.2.2 Dynamic Responses

In this topic, the dynamic responses of the process are concerned. The dynamic responses are interested in term of the temperature profile of the column (A-E), level in the reflux drum and sump and the mass fraction of Benzene in the overhead stream (Xbz) when the operating conditions which are feed location and reflux rate are changed. The dynamic responses of the simulation model will be verified to compare with the responses from test run data in order to ensure that the dynamic model is correctly.

Table 4.10 The 3 steps operation of the pilot distillation column (T-7000)

Operation	**Feed location**	**Reflux rate (kg/hr)**	**Time (hr)**
Base case	C	6.465	1.00 – 4.00
Step 1	D	6.465	4.00 – 6.30
Step 2	D	6.982	6.30 – 8.30

In this work, the dynamic responses are concerned in 2 steps which are shown in Table 4.10. The feed is fed at packing C with 6.465 kg/hr of the reflux rate and then the feed location is changed to packing D while kept the reflux rate constant in step 1. In step 2, the reflux rate is increased from 6.465 kg/hr to 6.982 kg/hr (Reflux ratio from 7.183 to 7.758) by keeping the feed location at location D. Moreover, the time which each step takes is also shown in Table 4.10. The output parameters which are the temperature profile of the column (A-E) and level in reflux drum and sump are observed from the pilot's test run data and shown in Figure 4.3 and 4.4, respectively.

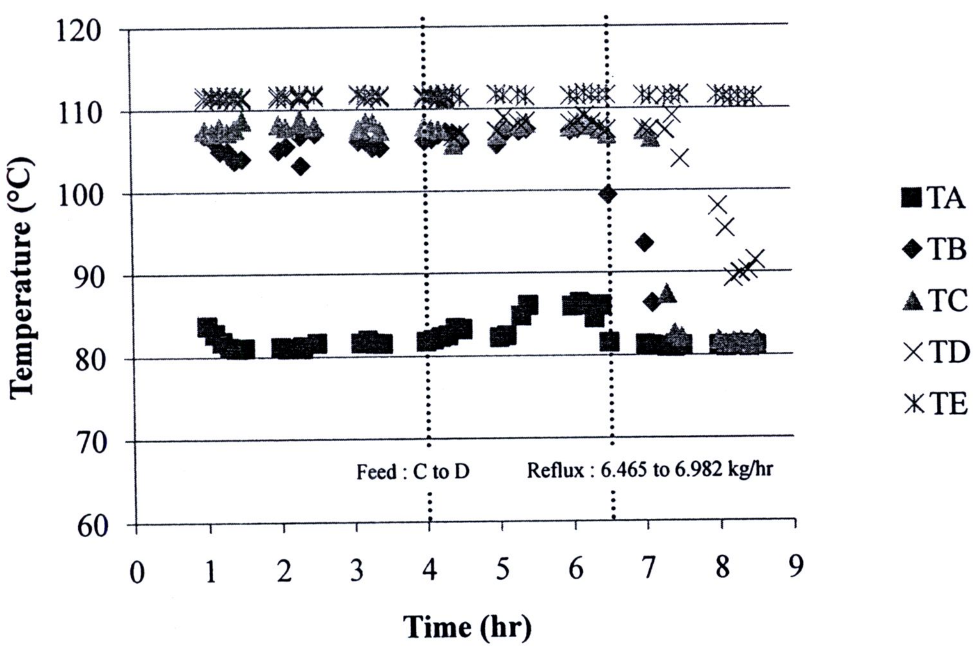

Figure 4.3 Response of the temperature profile of the column (Test run data)

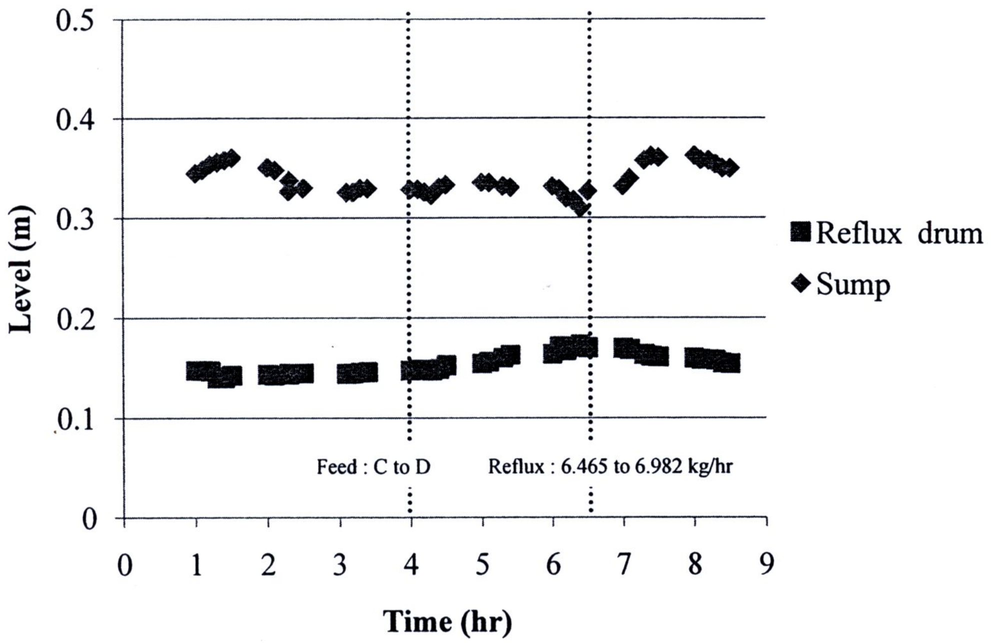

Figure4.4 Response of level in reflux drum and sump (Test run data)

The feed location is changed from packing C to packing D at 4.00 hours. The response of temperature profile of the column (A-E) from the ROC's pilot data is shown in Figure 4.3. The liquid is more introduced to the column at packing D. Therefore, the temperature at packing D is decreased while the others are quite constant. When the reflux rate is increased from 6.465 to 6.982 kg/hr (around 8%) at 6.30 hours, the temperature profile of the column (A-E) is suddenly dropped because more liquid flows to the column except temperature at packing E. Most of Benzene is vaporized in the column before it goes down to bottom at packing E so the temperature profile at packing E is quite constant.

The responses of the level of the reflux drum and sump from ROC's pilot test run data are shown in Figure 4.4. When the feed location is changed from packing C to D, the level of both reflux drum and sump are quite constant. In case the reflux rate is increased from 6.465 to 6.982 kg/hr, the level of both reflux drum and sump are also quite different. In the actual operation, the sump level is controlled by manually adjusting the heat input of the heater. In case the reflux rate is increased, the heat duty of the heater is also increased to maintain the sump level of the column.

When the feed location and the reflux rate are changed from step 1 and step 2, the dynamic responses of the temperature profile of the column (A-E) and the level of reflux drum and sump from the dynamic model are obtained and shown in Figure 4.5 and 4.6, respectively.

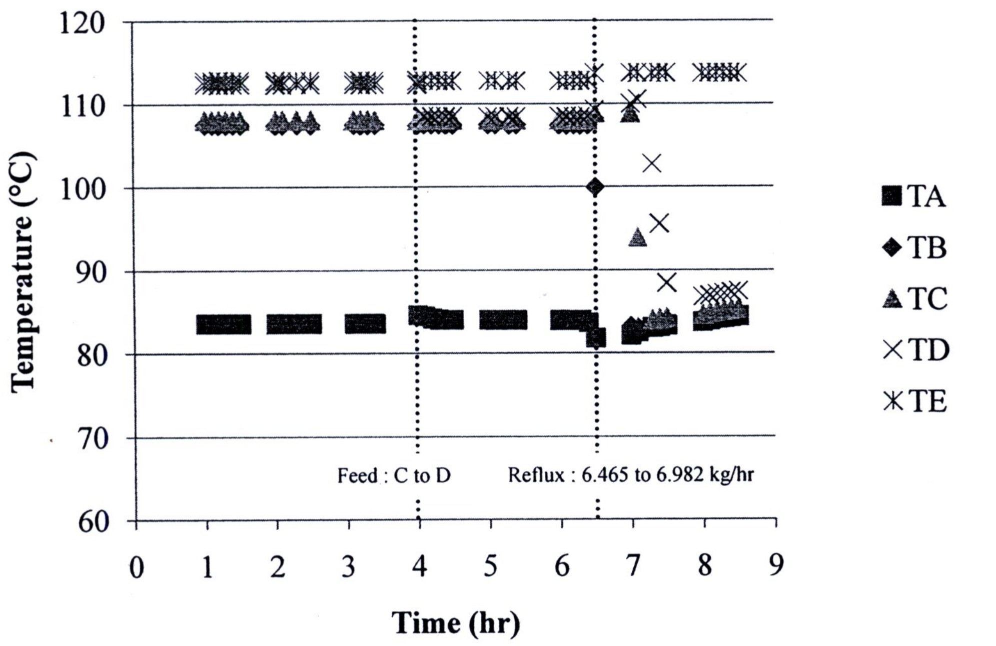

Figure 4.5 Response of the temperature profile of the column (Simulation)

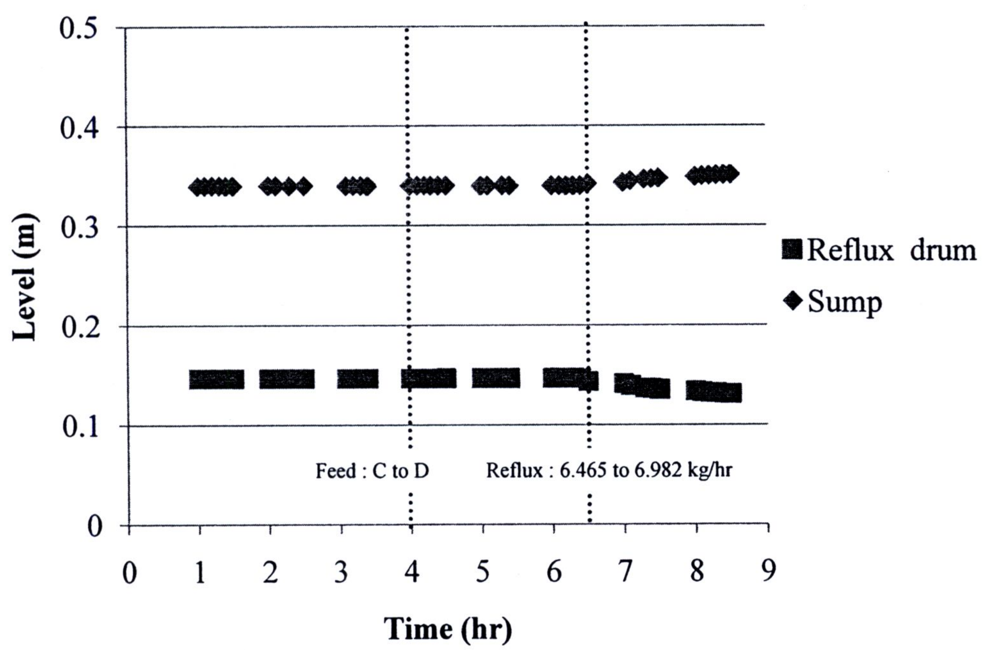

Figure 4.6 Response of level in reflux drum and sump (Simulation)

The response of temperature profile of the column (A-E) from the simulation results is shown in Figure 4.5. When the feed location is changed from packing C to D, the trend of temperature profile of the column (A-E) is quite similar with the test run data. When the reflux rate is from 6.465 to 6.982 kg/hr (around 8%) at 6.30 hours, the temperature profile of the column (A-E) is suddenly dropped more than the test run data. However, the trend of the temperature profile (A-E) of the column is also quite similar with the test run data. At the same way, the trends of the reflux drum and sump level are quite constant when the 2 steps are already changed. To ensure that the dynamic model is correctly, the comparison of both temperature profile of the column (A-E) and the level of the reflux drum and sump between the test run data and dynamic model must be compared and separated in each graph in the section below.

4.2.2.1 Dynamic Responses of Changing Feed Location

The dynamic responses of the process when the feed location is changed from packing C to packing D are shown in section below.

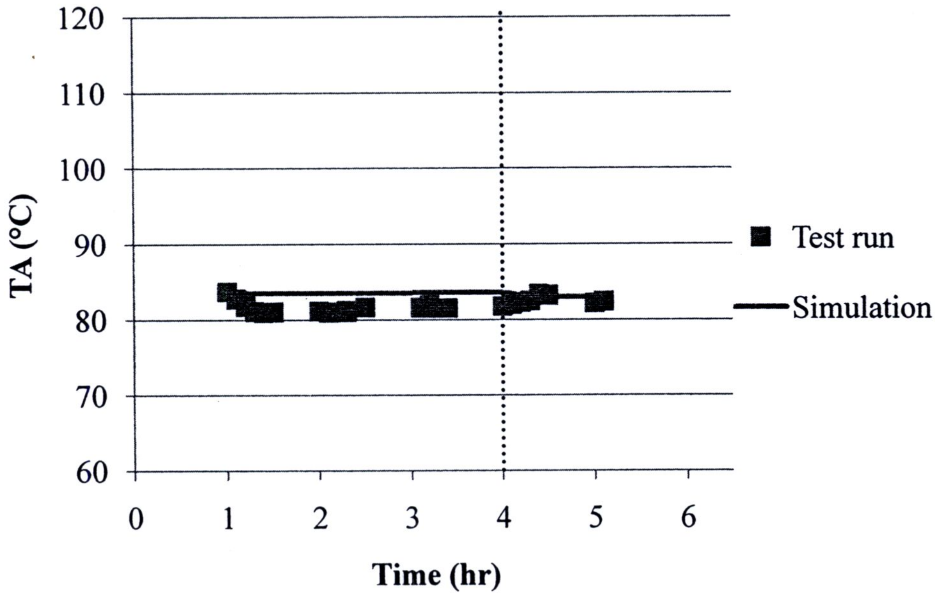

Figure 4.7 Comparison of packing A temperature (TA) between test run data and simulation result when the feed location is changed

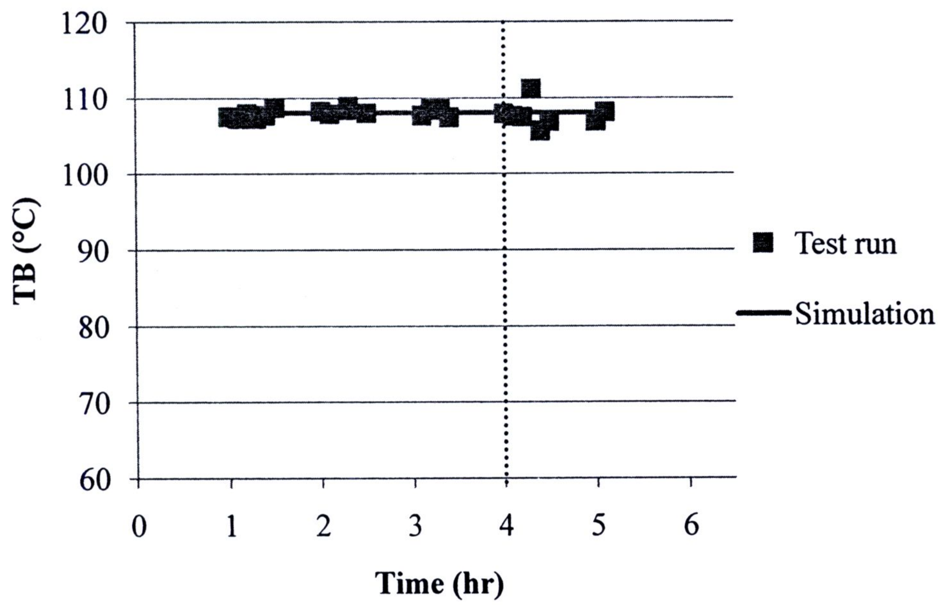

Figure 4.8 Comparison of packing B temperature (TB) between test run data and simulation result when the feed location is changed

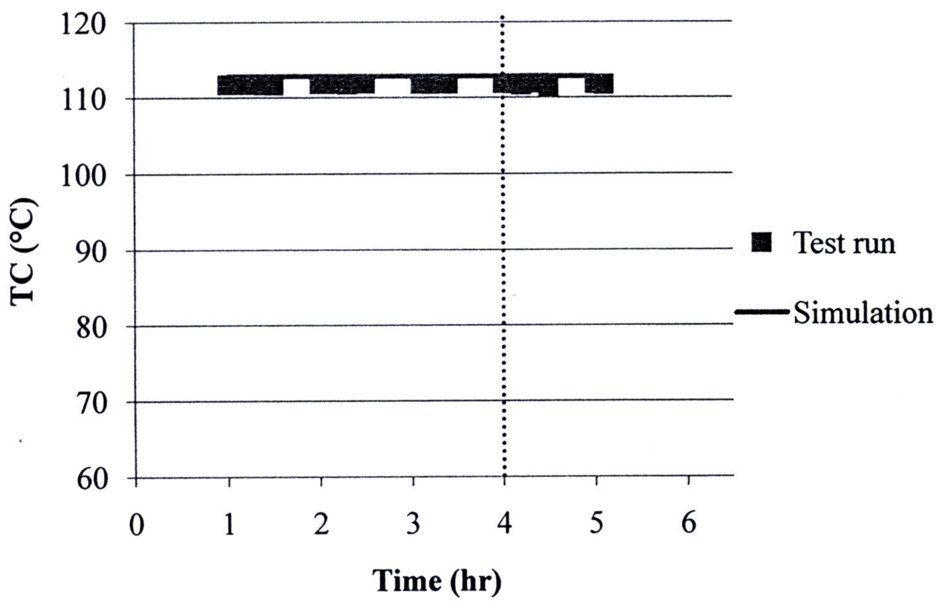

Figure 4.9 Comparison of packing C temperature (TC) between test run data and simulation result when the feed location is changed

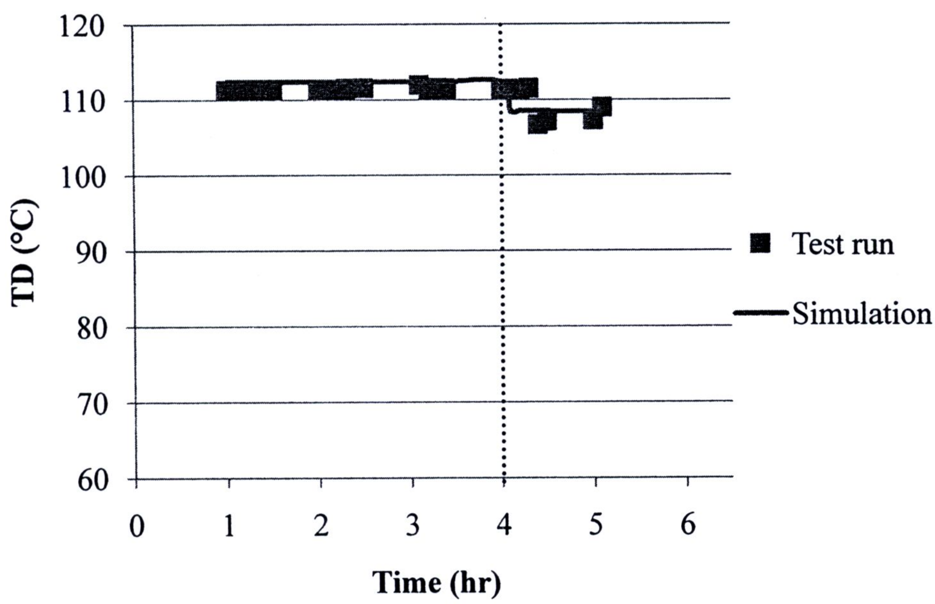

Figure 4.10 Comparison of packing D temperature (TD) between test run data and simulation result when the feed location is changed

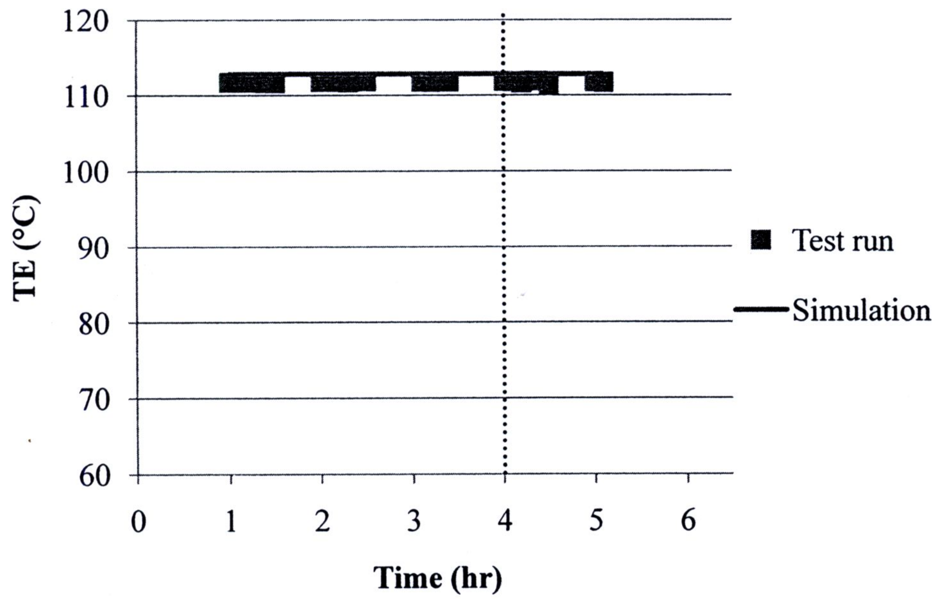

Figure 4.11 Comparison of packing E temperature (TE) between test run data and simulation result when the feed location is changed

The response of the temperature profile of the column (A-E) when the feed location is changed from packing C to packing D are shown in Figure 4.7 – 4.11. After the feed location is changed at 4 hours, the temperature profile of the column (A-E) is quite constant except the packing D temperature. It obviously decreased because more liquid which has the lower temperature is introduced to the packing D column.

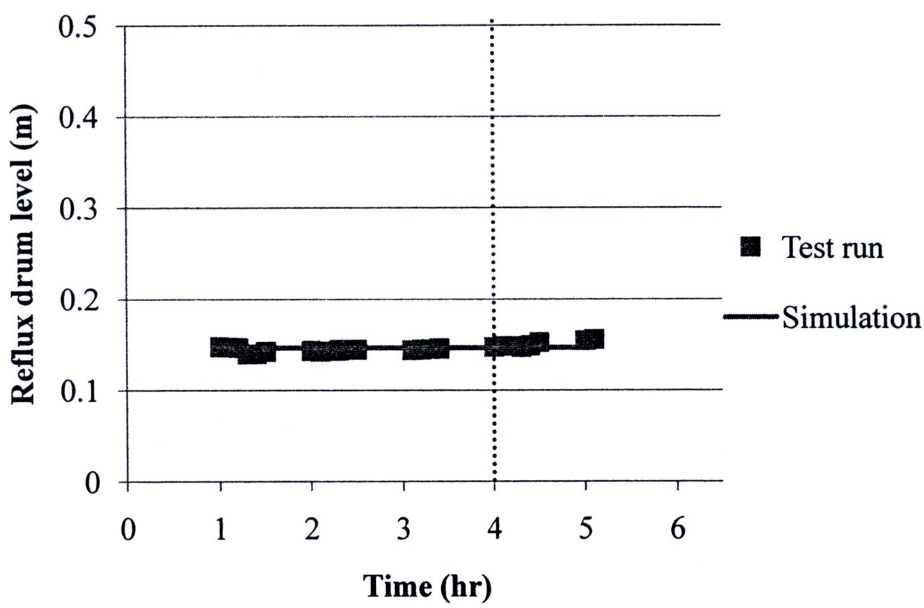

Figure 4.12 Comparison of reflux drum level between test run data and simulation result when the feed location is changed

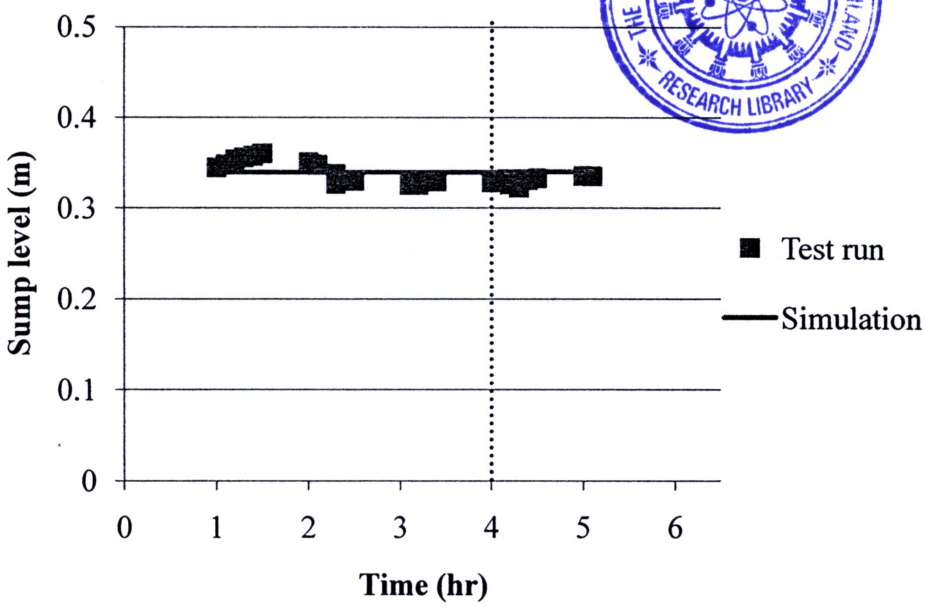

Figure 4.13 Comparison of sump level between test run data and simulation result when the feed location is changed

The responses of the reflux drum and sump level are shown in Figure 4.12 and 4.13, respectively. Changing the feed location has slightly effect on the sump and reflux drum level. Furthermore, the sump level of the column is controlled by adjusting the temperature of the heater manually. Therefore, the liquid level in sump is rather constant as same as the level in the reflux drum. However, the comparison of the test run data and simulation results must be performed. The percentage difference of each parameter between the simulation model and the pilot test run data must be less than 5% as and the acceptable value. The difference of each parameter when the feed location is changed from packing C to packing D is shown in Table 4.11.

Table 4.11 The percentage difference of parameters between the test run data and simulation results when the feed location is changed

Parameters	**Average (Test sun)**	**Average (Simulation)**	**Percentage difference**
TA (°C)	81.92	83.44	1.86
TB (°C)	107.45	107.45	0.00
TC (°C)	108.06	108.06	0.00
TD (°C)	111.18	111.18	0.00
TE (°C)	112.81	112.81	0.00
Reflux drum level (m)	0.146	0.146	0.19
Sump level (m)	0.338	0.340	0.73

The percentage difference of each parameter can be determined by the difference of the average value of test run data and the simulation model. From Table 4.11, all of these parameters have the percentage difference lower than 5%. Therefore, it can be concluded that the trend of dynamic model has quite similar with the trend of the test run data when the feed location is changed from packing C to packing D.

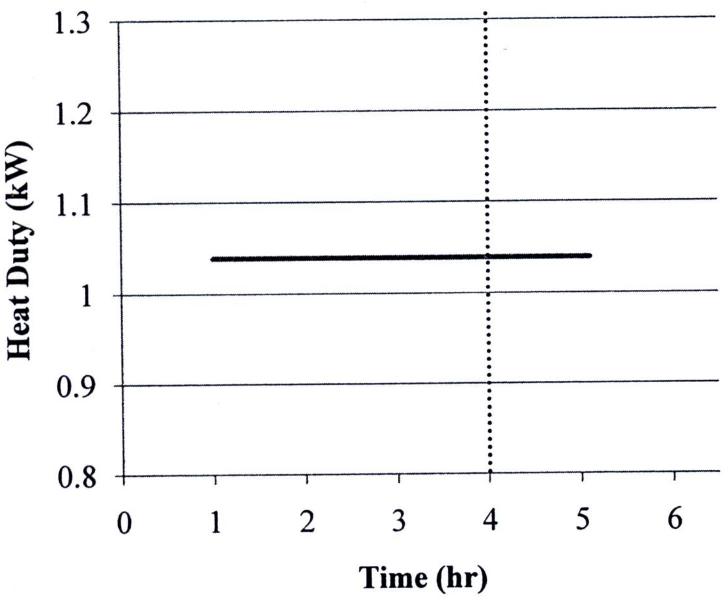

Figure 4.14 Response of the heat duty from the dynamic simulation when the feed location is changed

One of the other results obtained from the dynamic model is the energy consumption of the pilot distillation column that shows in Figure 4.14. Normally, the energy consumption of this tower is the heat duty of the heater which can be adjusted by adjusting the temperature of the bottom tower. Before the feed location is changed, the heat duty of the heater at the normal operation is 1.04 kW. When the feed location is changed from packing C to packing D, the heat duty is not changed because it depends on liquid load of the column. Therefore, it can be concluded that the heat duty of this column is not changed when the feed location is changed.

The mass fraction of Benzene in the overhead stream from the dynamic model is shown in Figure 4.15. The feed location is changed from packing C to packing D at 4 hours. The result shows that the Benzene purity in the overhead stream is quite constant value at 0.964. In this system, it contains two components which have clarified the difference of the boiling point temperature. Most of Benzene is separated in the overhead stream of the pilot distillation column. Therefore, the purity of Benzene in the overhead stream only depends on the distillate rate as shown the calculation in Appendix C.

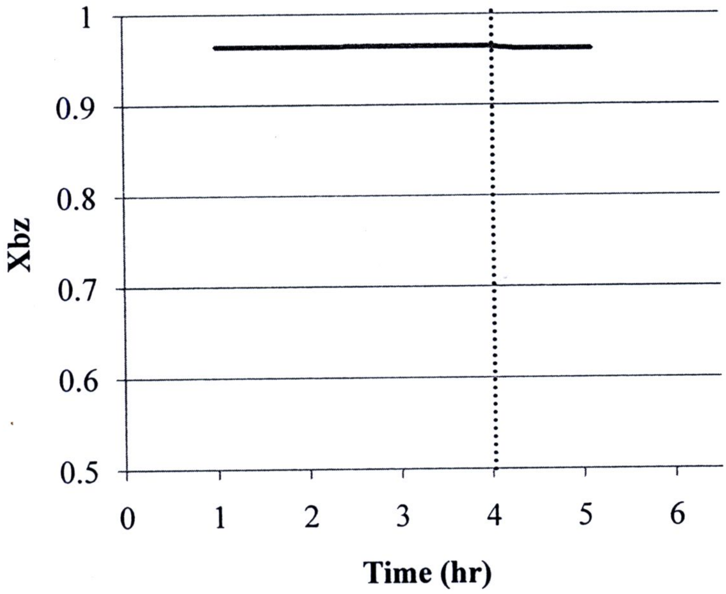

Figure 4.15 Response of the mass fraction of Benzene in the overhead stream from the dynamic simulation when the feed location is changed

4.2.2.2 Dynamic Responses of Increasing Reflux Rate

The dynamic responses of the process when the reflux rate is increased from 6.465 to 6.982 kg/hr or increased around 8 % are shown in section below.

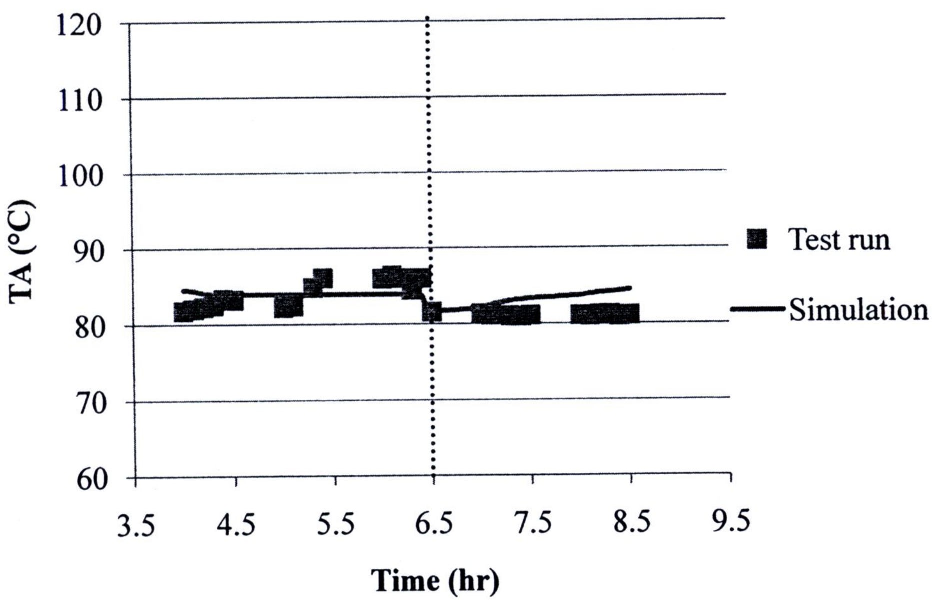

Figure 4.16 Comparison of packing A temperature (TA) between test run data and simulation result when the reflux rate is increased

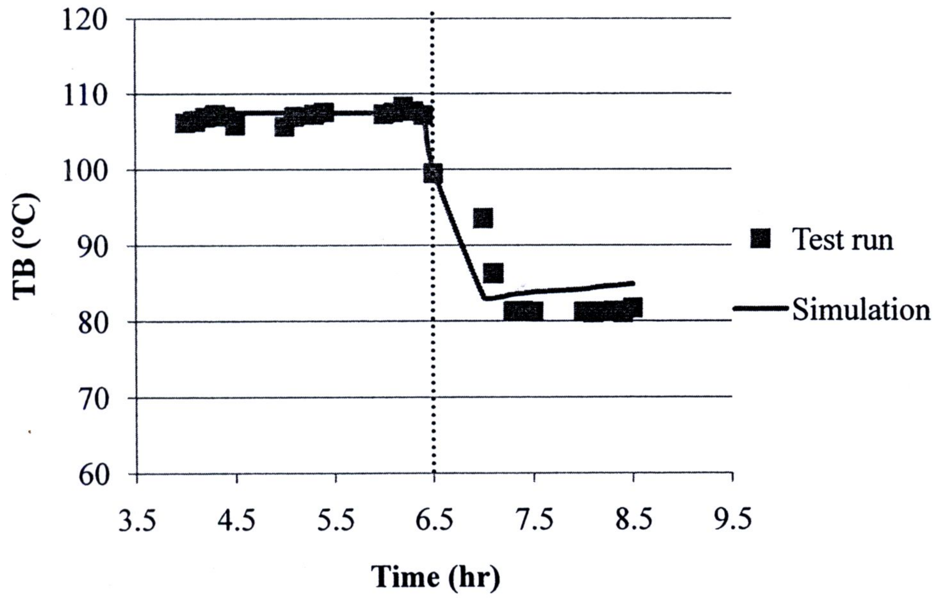

Figure 4.17 Comparison of packing B temperature (TB) between test run data and simulation result when the reflux rate is increased

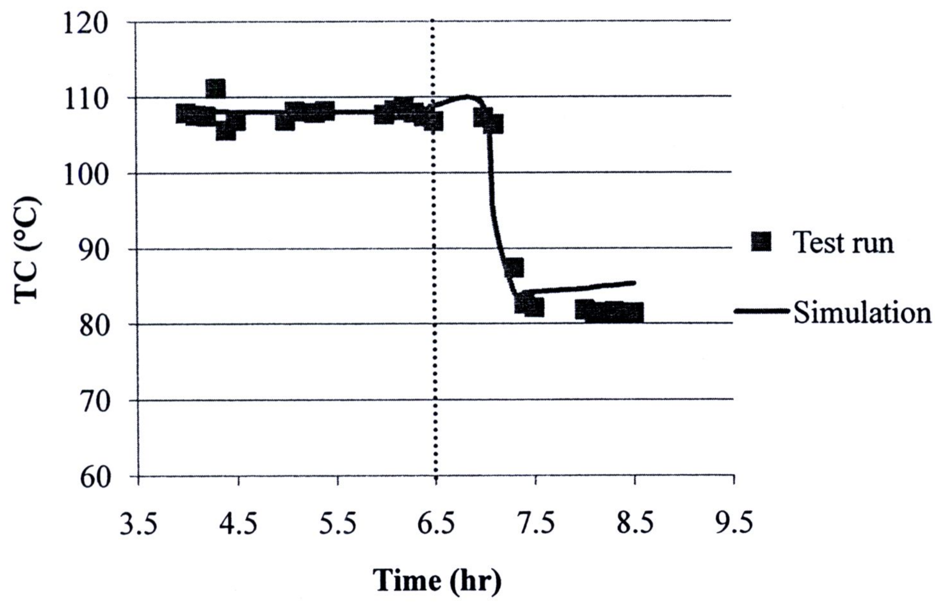

Figure 4.18 Comparison of packing C temperature (TC) between test run data and simulation result when the reflux rate is increased

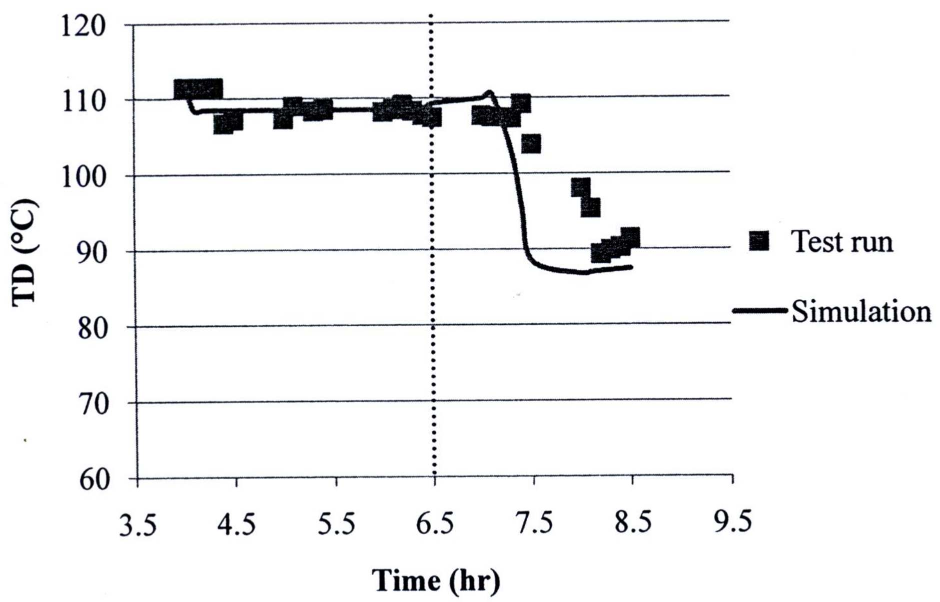

Figure 4.19 Comparison of packing D temperature (TD) between test run data and simulation result when the reflux rate is increased

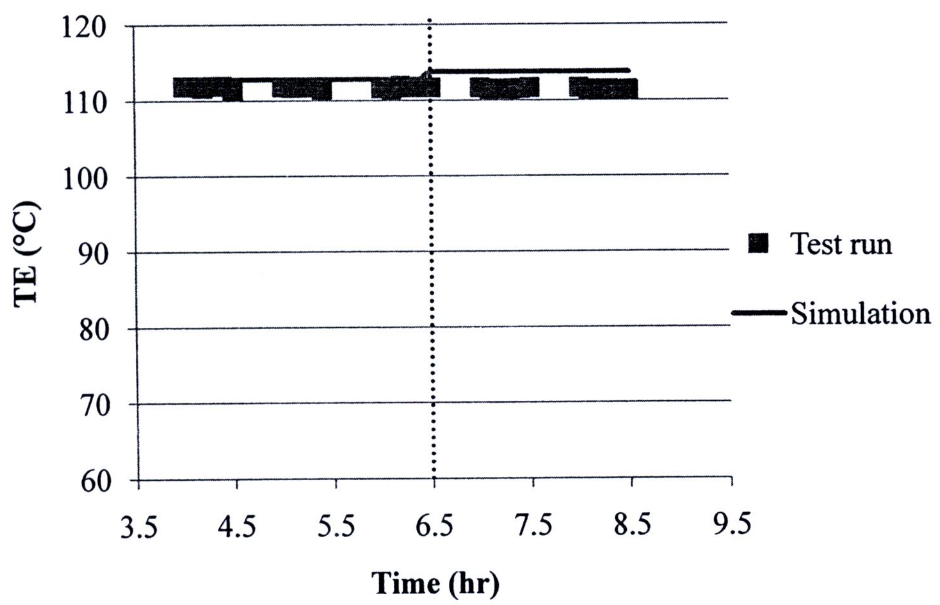

Figure 4.20 Comparison of packing E temperature (TE) between test run data and simulation result when the reflux rate is increased

The responses of the temperature profile of the column (A-E) when the reflux rate is increased from 6.465 to 6.982 kg/hr are shown in Figure 4.16 – 4.20. The results show that the trend of the temperature profile of the column (A-E) from the simulation model is quite similar with the test run data except the temperature profile of packing D. When the reflux rate is increased at 6.50 hours, trends of the temperature profile of the column (A-E) become lower than the previous condition because the liquid reflux is flowed to the column more than the previous condition.

Normally when the reflux rate is changed, the actual process will respond with the time delay depends on the location of the packing temperature. The temperature at the top of the column (TA) will respond faster than the other temperature as shown in the test run data of each packing temperature. However, this dynamic model is generated without time delay controller to control the process of the pilot distillation column. Consequently, the trend of the temperature profile of the column from the dynamic model is not same as the test run data especially the temperature of the packing D. From Figure 4.15, the packing D temperature from the dynamic model is suddenly decreased which is different from the test run data due to the effect of the time delay controller.

Furthermore, trend of the temperature of all packing will decrease to the new steady state except the packing E temperature. The packing E temperature (TE) is measured at the lower packing of the pilot distillation column. The temperature at the bottom of the column is higher than the top of the column. Most of Benzene component is vaporized before entering to the packing E. Therefore, this packing mostly consists of Toluene component as a major component. Thus, the packing E temperature is almost constant value that is equal to the normal boiling point temperature of the Toluene.

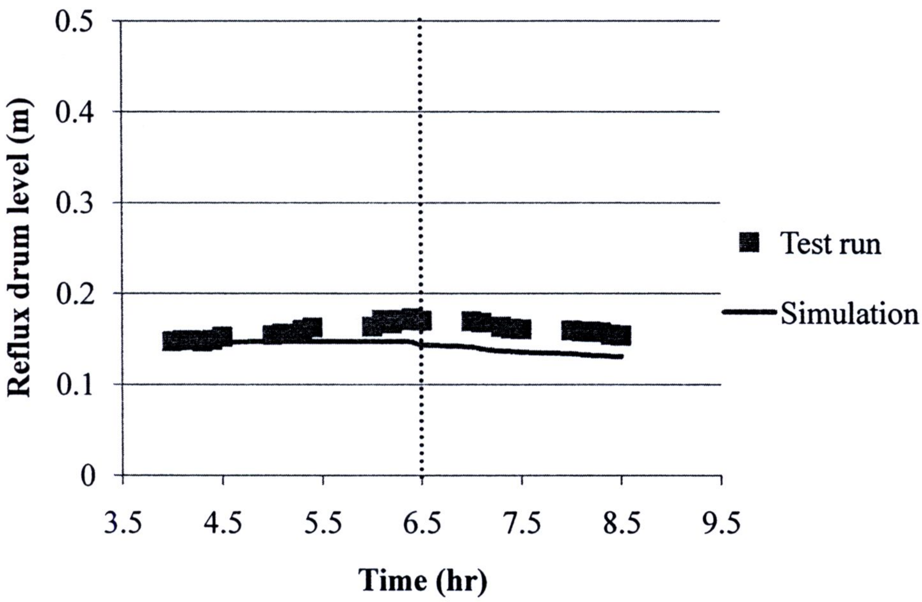

Figure 4.21 Comparison of reflux drum level between test run data and simulation result when the reflux rate is increased

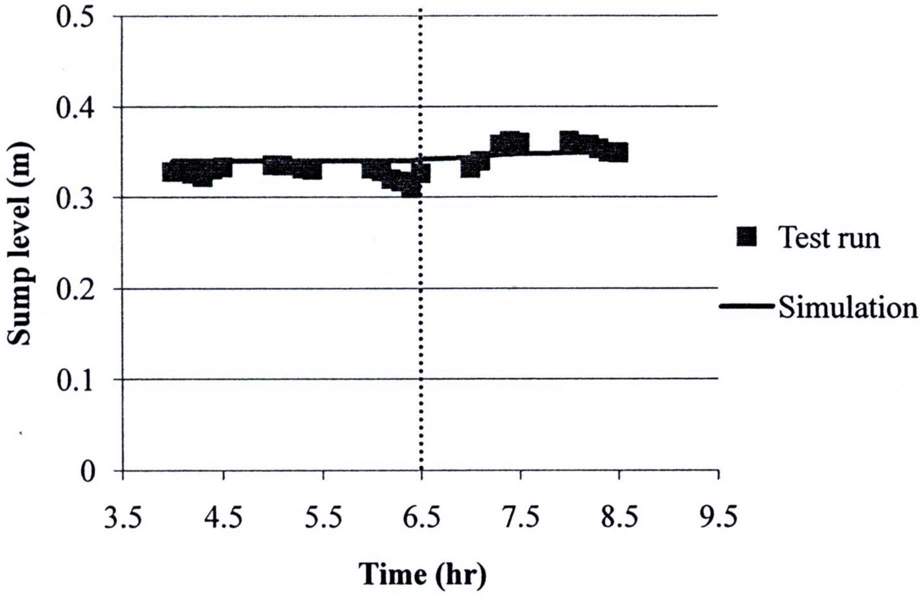

Figure 4.22 Comparison of sump level between test run data and simulation result when the reflux rate is increased

The responses of the reflux drum and sump level are shown in Figure 4.21 and 4.22, respectively. Although the reflux rate is more introduced to the column, the sump level is controlled by manual adjusting the temperature of the heater. From the normal operation, the heat duty of the heater is around 1.04 kW. This value must be increased due to the increasing of the reflux rate in order to maintain the sump level. As the same way, the reflux drum level is also constant with the new heat duty. The percentage difference of each parameter between the simulation model and the pilot test run data must be less than 5% as and the acceptable value. The difference of each parameter when the reflux rate is increased from 6.465 to 6.982 is shown in Table 4.12.

Table 4.12 The percentage difference of parameters between the test run data and simulation results when the reflux rate is increased

Parameters	**Average (Test sun)**	**Average (Simulation)**	**Percentage difference**
TA (°C)	82.72	83.77	1.26
TB (°C)	96.89	97.65	0.79
TC (°C)	99.24	99.82	0.58
TD (°C)	104.88	102.60	2.17
TE (°C)	111.60	113.18	1.42
Reflux drum level (m)	0.144	0.142	1.78
Sump level (m)	0.338	0.344	1.71

The percentage difference of each parameter can be determined by the difference of the average value of test run data and the simulation model. From Table 4.12, all of these parameters have the percentage difference lower than 5%. Therefore, it can be concluded that the trend of dynamic model is quite similar with the trend of the test run data when reflux rate is increased from 6.465 to 6.982 kg/hr.

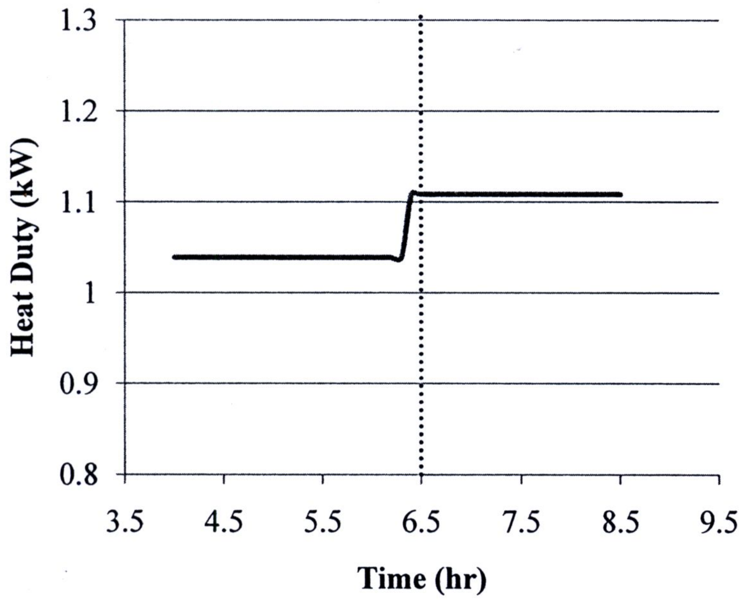

Figure 4.23 Response of the heat duty from the dynamic simulation when the reflux rate is increased

The other results which are obtained from the dynamic simulation are the heat duty of the heater and the mass fraction of Benzene in the overhead stream. In term of the heat duty, when the reflux rate is increased from 6.465 to 6.982 kg/hr, it must be increased from 1.04 to 1.11 kW to maintain the level of sump and reflux drum as shown in Figure 4.23. This result can be concluded that when the reflux rate is increased around 8%, the heat duty will be increased around 6.73 %, or the heater temperature must be increased around 5°C.

The mass fraction of Benzene in the overhead stream from the dynamic model is shown in Figure 4.24. The reflux rate is increased from 6.465 to 6.982 kg/hr at 6.50 hours. The result shows that the purity of Benzene in the overhead stream is almost constant value at the 0.964 because the purity of benzene in the overhead stream only depends on the distillate rate as shown in Appendix C. In this system, it is used to separate the two components which have the different boiling point temperature. The increasing of the reflux rate does not affect on the purity. The purity of the component only depend on the distillate rate.

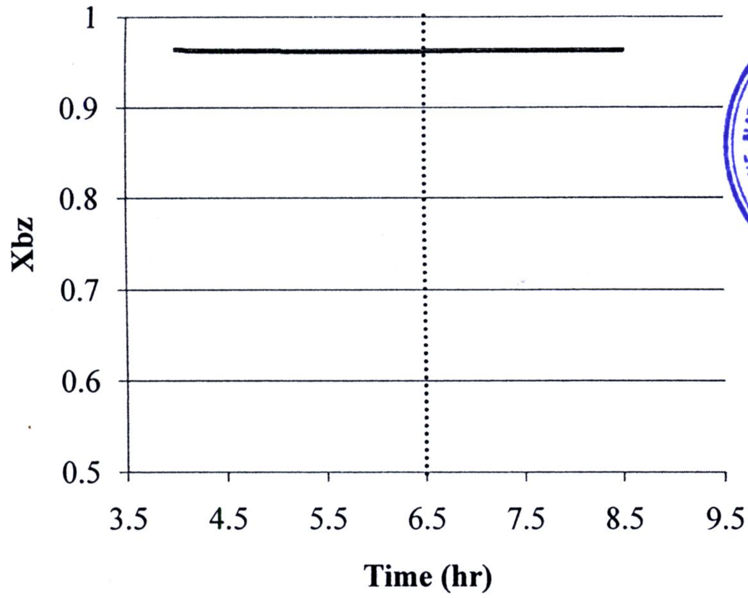

Figure 4.24 Response of the mass fraction of Benzene in the overhead stream from the dynamic simulation when the reflux rate is increased

4.3 Start-up procedure

In the actual operation, the start-up procedure has not exactly method but operating by the operator's experience. After the reflux is totally introduced to the column, the sequence for adjusting the parameters must be concerned. The start-up procedure is concerned about the adjusting sequence of three parameters which are the distillate rate, reflux rate and bottom rate. The adjusting sequence of this parameter for the actual operation is distillate, reflux and bottom rate, respectively. The purpose of the start-up procedure is to generate the best start-up operation which takes the shortest time to reach a steady state. The scenarios for start-up procedure are concerned in 6 scenarios as shown in Table 4.13. The target value of the distillate rate, reflux rate and bottom rate of each scenario are 0.9, 6.465 and 0.824, respectively.

Table 4.13 Case study for start-up operation

Scenario	Procedure
1	Distillate >> Reflux >> Bottom
2	Distillate >> Bottom >> Reflux
3	Bottom >> Distillate >> Reflux
4	Bottom >> Reflux >> Distillate
5	Reflux >> Distillate >> Bottom
6	Reflux >> Bottom >> Distillate

The results from the Aspen Dynamic simulation are shown in this section below. The main objective of this work is to find the best scenario for the start-up procedure which takes a shortest time to reach a steady state. However, the comparison of each scenario is occurred when the criteria is generated. This criterion is the mass fraction of Benzene in the overhead stream which is controlled at the range between 0.89-0.91.

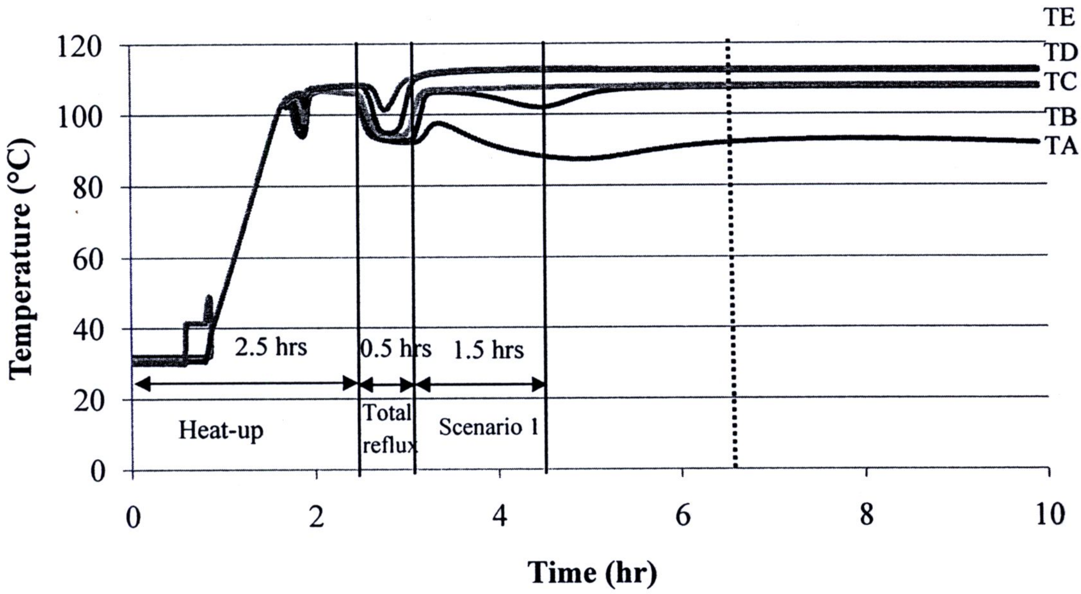

Figure 4.25 Temperature profile of the column (A-E) of scenario 1

From the scenario 1, the adjustment sequence is the distillate rate, reflux rate and bottom rate, respectively. This scenario is the same as the actual start-up operation of ROC's pilot distillation column. From Figure 4.25, the column is heated gradually by the heater of the column from 0 hours to 2.5 hours until the temperature profile of the column (A-E) is reached to a steady state. Then, the liquid from the reflux drum is totally flowed to the column for about 0.5 hours. Therefore, the temperature profile of the column (A-E) is suddenly dropped in the second step. In the last step, the sequence of scenario 1 must be performed from 3 hours to 4.5 hours. From this step, it takes 1.5 hours for adjusting three parameters which are distillate rate, reflux rate and bottom rate, respectively. In this step, the temperature profile of the column (A-E) is adjusted to reach a steady state condition. Furthermore, the time to reach a steady state for scenario 1 is about 6.50 hours as shown in dash line.

From the scenario 2, the adjustment sequence is the distillate rate, bottom rate and reflux rate, respectively. From Figure 4.26, the step 1 and 2 which is heat-up the column and flow totally reflux is also same as the scenario 1. The trend of the temperature profile of the column (A-E) for step 1 and 2 is quite similar with the scenario 1. However, the adjustment sequence of step 3 is changed from the scenario 1 by adjusting the bottom rate before the reflux rate. The results from the simulation show that the temperature profile of packing B and C is quite smoothly. Finally, this step just takes 6 hours of time to reach a steady state.

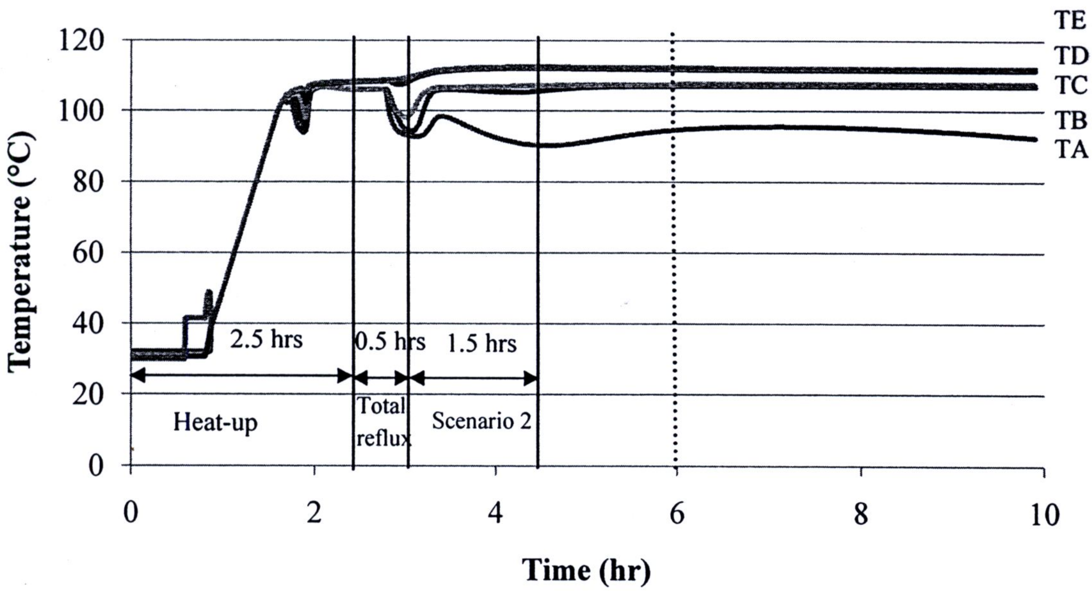

Figure 4.26 Temperature profile of the column (A-E) of scenario 2

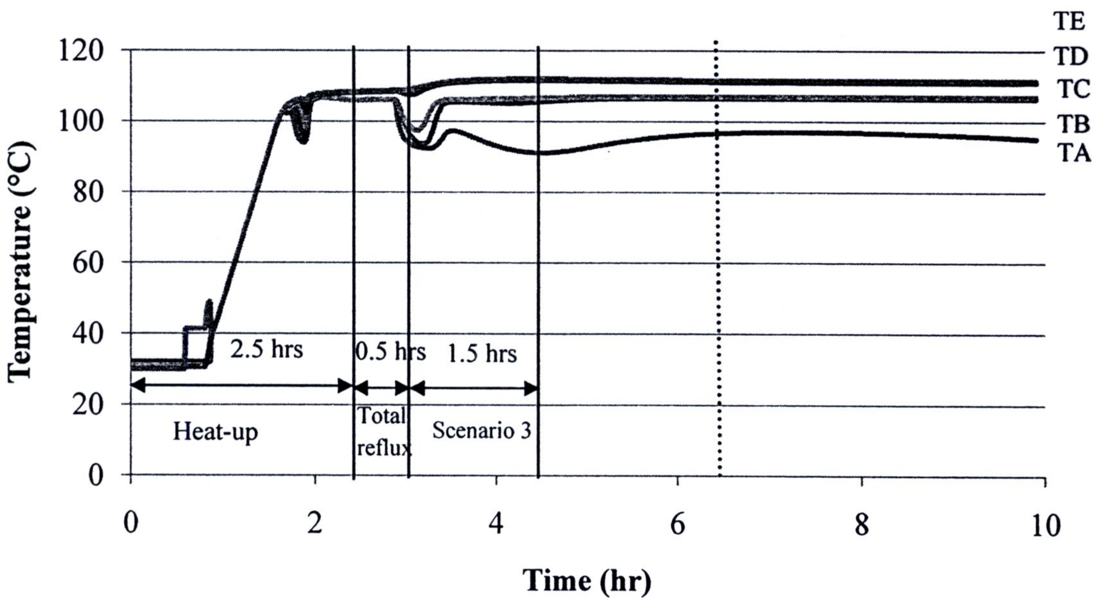

Figure 4.27 Temperature profile of the column (A-E) of scenario 3

From the scenario 3, the adjustment sequence is the bottom rate, distillate rate and reflux rate, respectively. From Figure 4.27, the step 1 and 2 which is heat-up the column and flow totally reflux is also same as the scenario 1 and 2. In this step, the bottom rate is adjusted firstly to 0.824 kg/hr. Then, the distillate rate is adjusted to 0.9 kg/hr that is the distillate product flowrate. Finally, the reflux rate is also reduced from the total reflux to 6.465 kg/hr. From this scenario, the time to reach a steady state is about 6.20 hours as shown in dash line.

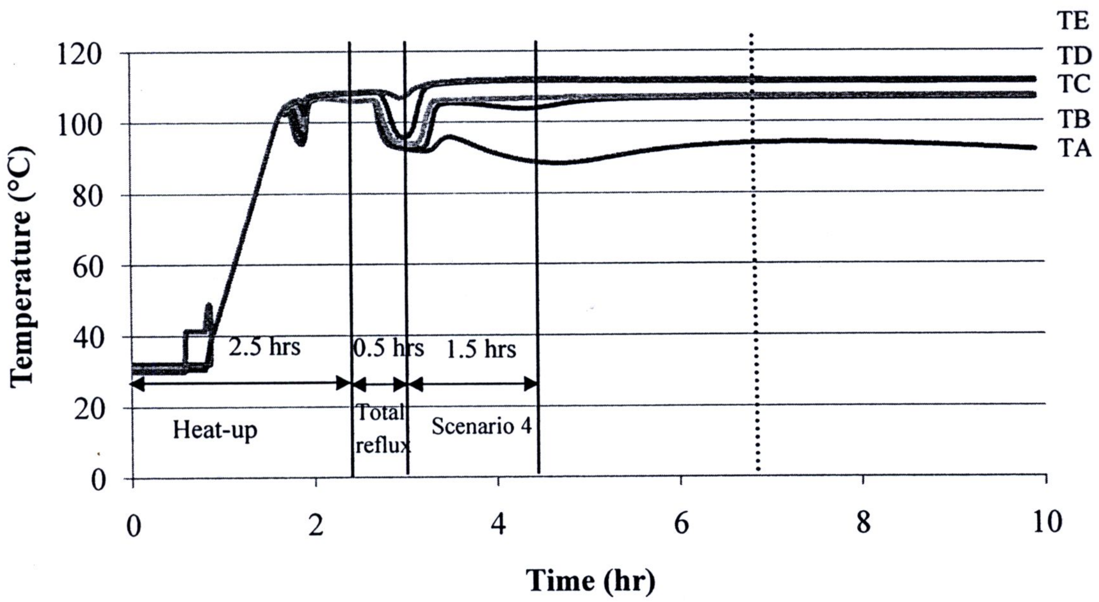

Figure 4.28 Temperature profile of the column (A-E) of scenario 4

From the scenario 4, the adjustment sequence is changed from the scenario 3 with the reflux rate is adjusted before the distillate rate. The trend of the temperature profile of 3 steps is quite similar with the scenario 3. In the scenario 4, it takes 6.70 hours of time to reach a steady state. However, this scenario takes a longer time than scenario 3 but this scenario will obtain the higher purity of Benzene in the overhead stream as shown in the lower temperature of packing A.

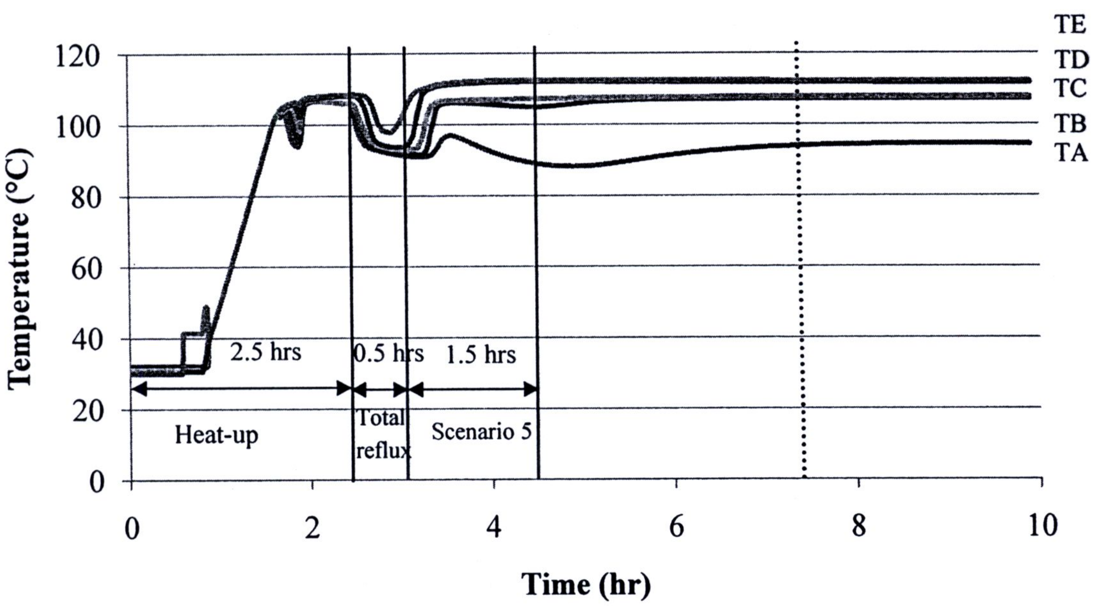

Figure 4.29 Temperature profile of the column (A-E) of scenario 5

From the scenario 5, the adjustment sequence is the reflux rate, distillate rate and bottom rate, respectively. The temperature profile of the column (A-E) is shown in Figure 4.29. The column is heated at the bottom in step 1 and then the reflux is totally flowed in step 2. The trend of the temperature profile of 3 steps is quite similar with the scenarios above. In the scenario 5, it takes 7.40 hours of time to reach a steady state

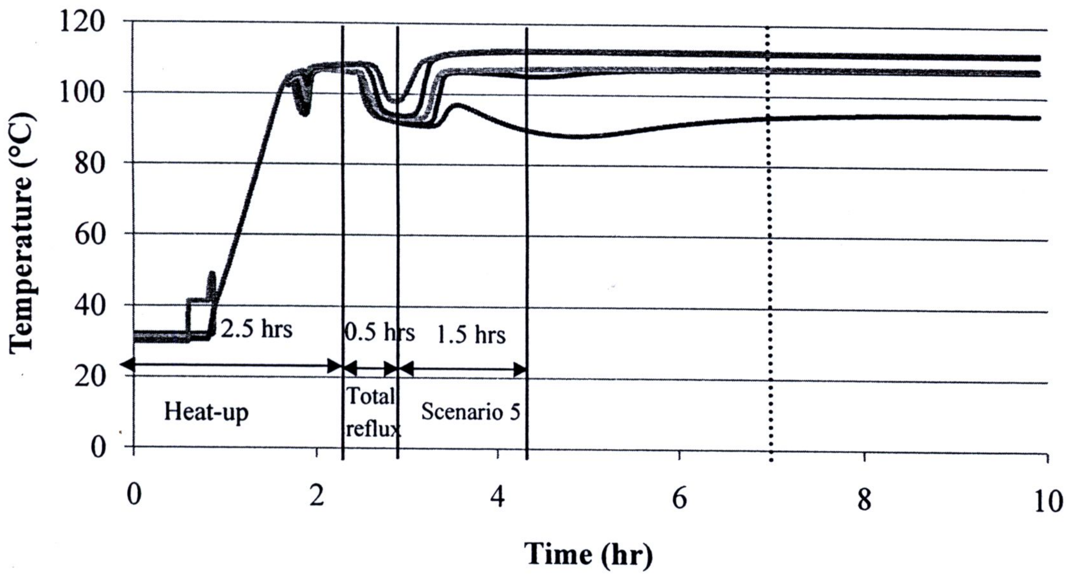

Figure 4.30 Temperature profile of the column (A-E) of scenario 6

From the scenario 6, the adjustment sequence is the reflux rate, distillate rate and bottom rate, respectively. The temperature profile of the column (A-E) is shown in Figure 4.30. This scenario is adjusting the bottom rate before distillate rate. The trend of the temperature profile of 3 steps is quite similar with the scenarios above. In the scenario 6, it takes 7.40 hours of time to reach a steady state

Table 4.14 Conclusion of the results of each scenario

Scenario	1	2	3	4	5	6
Tss (hr)	6.50	6.00	6.20	6.70	7.40	7.20
Xbz	0.905	0.90	0.890	0.905	0.907	0.907

The results of the start-up procedure are shown in Table 4.14. These scenarios are simulated by concerning the purity of Benzene in the overhead stream as a constraint. This target is kept between 0.89 – 0.91 in order to compare the results of each scenario. The best scenario is selected by observing time to reach a steady state. The best scenario for the ROC's pilot distillation column start-up procedure is scenario 2 because it takes around 6.00 hours to reach a steady state as shown in temperature profile along the column (A-E) in Figure 4.26. Moreover, the results show that the scenario 5 and 6 are unsuitable for the start-up operation. Because, when they are compared with the other scenarios, they take more time to reach a steady state around 1 hour.