ENERGY SAVING FOR CLOSE BOILING MIXTURE

By

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AHMEDABAD-382481

MAY 2016

ENERGY SAVING FOR CLOSE BOILING MIXTURE

Major Project Report

Submitted in partial fulfillment of the requirements

For the Degree of

Master of Technology in Chemical Engineering

(Energy System)

By

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DEPARTMENT OF CHEMICAL ENGINEERING

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MAY 2016

Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Energy System at Nirma University and has not been submitted elsewhere for a degree or diploma.

2. Due acknowledgement has been made in the text to all other material used.

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I, **Malina Rani Paul**, Roll. No. **14M**CHN02, give undertaking that the Major Project entitled "**Energy Saving for close Boiling Mixture** " submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Chemical Engineering (Energy System)** of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project Report entitled "**Energy Saving for close Boiling Mixture**" submitted by **Malina Rani Paul (14MCHN02)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Technology in Chemical Engineering (Energy System)** of Institute of Technology, Nirma University, Ahmadabad is the record of work carried out by her under our supervision and guidance. To the best of my knowledge, the submitted work has reached a level required for being accepted for examination.The result embodied in this report, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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Acknowledgments

Without hard work and intelligent efforts it is not possible to achieve any heights in the respective fields but it is equally important for an individual to get the opportunity for the same. I would like to express my gratitude to PG Co-ordinator Dr.Parin Shah & Prof. S.S.Patel, HOD of Chemical Engineering Department, Institute of Technology, Nirma University for giving us opportunity to work on the topic as a part of curriculum. I wish to thank Prof. Millind Joshipura, Chemical Engineering Department, Institute of Technology, Nirma University for guiding me to do this project. I'm grateful to the institute of technology, Nirma University for giving the opportunity to be part of it.

I am also thankful to all the supporting staff of Chemical Engineering Department for their constant support during Aspen Hysys simulation.

I am very thankful to Dr P N Tekwani (Director, IT, NU) and all the faculty members of Chemical Engineering Department who have directly or indirectly helped me during this dissertation work.

At the end I am thankful to my family and collegues who have directly or indirectly helped me during this dissertation work and for their encouragement.

MALINA RANI PAUL

Abstract

We have simulated close Boiling Mixture using Aspen Hysys 2004.2 version software.As we know separation of close boiling mixture by conventional distillation consumes lot of energy. To reduce the load on the reboiler and for energy saving as well as total annual cost saving energy efficient technologies like MVRHP, BFHP, Double effect feed forward and Feed split distillation technologies have been used for binary mixture as well as Multicomponent close boiling mixture of propane, isobutene, n-butane, C4olefins, Neopentane, Iso-pentane and n-pentane have been performed. Separation of this mixture by i-butane/n-butane fractionator requires many stages and large amount of energy to meet stringent product purity specifications. Mechanical vapor recompression heat pumps (MVRHPs) can recycle the energy of the vapor and can thus be used in such distillation processes to save steam cost and total annual cost of this separation task. Three different distillation schemes, conventional distillation, top MVRHP distillation, and bottom-flashing MVRHP distillation, were simulated for the separation of the above mixture using Aspen HYSYS software to determine the energy savings. The research result indicates that, compared to conventional distillation, energy savings for BFHP case and MVRHP case are respectively 62.65% and 57.36%. Other than this energy saving in case of double effect feed split distillation and feed forward distillation was compared with single column distillation.

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Nomenclature

D	Diameter of the Column
H	Height of the Column
MVRHP	Mechanical Vapour Recompression Heat Pump
BFHP	Bottom Flush Heat Pump
N	Number of stages
U	Overall heat transfer coefficient
FC	Fixed Capital Investment
C_v	Process Variable costs
S_R	Heat Transfer Area of the Reboiler
S_C	Heat Transfer Area of the condenser
Q_C	Heat Duty of Condenser (kW
Q_R	Heat Duty of Reboiler(kW)
TAC	Total Annual Cost
A	Area
U	Overall Heat Transfer Coefficient
HP	High Pressure Column
LP	Low Pressure column
K	Compressor
E	Exchanger
AC	Air Cooler

Chapter 1

Introduction

1.1 Background of the work

Distillation is the main separation technology in refineries and the chemical process industry. Distillation processes are major industrial energy consumers, requiring significant amount of heat in the reboiler and rejecting a large amount of heat from the condenser. This is the major drawback of this system. Reports have shown that about (40-60)% of the energy used by the chemical and refining industry for the separation of products by distillation. Various techniques, such as heat integration, heat pumps, thermal couplings and others have been employed to achieve energy reductions. Nowadays different types of assisted heat pump distillation systems exist and have found practical applications in the industries. The most commonly used are the mechanical heat pump (MHP). The MHP is categorized into three types, the vapor recompression heat pump (VRHP) and bottom flash heat pump (BFHP). Of the aforementioned types, the VRHP has gained more recognition due to its outstanding performance. This technology pressurizes vapor of a low grade heat to a higher grade by using mechanical power and then the pressurized vapor provides a heating effect when condensing benefits.

1.2 Process Design and Objective

The main aim of this project was to reducing energy consumption for the separation of close boiling mixture and minimize capital investment as well as achieving environmental benefits by integrating different processes. Two different case studies were investigated here. One for binary mixture as a feed to the column and the other one for multi-component feed mixture. The performances of heat pump in distillation column were investigated.

For binary system we have chosen isobutane and normal butane separation by fractionating column and for multi-component system we have chosen feed containing species

Propane, Isobutane, n-Butane, C4 olefins, Neopentane, Isopentane, and n-Pentane. To find out the best alternative to the conventional distillation we have simulated the conventional distillation column, distillation column with top vapour recompression heat pump and bottom flashing heat pump case.

Energy requirement of the conventional process was compared with the distillation column with the top vapour recompression heat pump case and Distillation column with bottom flashing heat pump case to find out the best suitable technology for energy saving. We were using Aspen HYSYS model version 2004.2 under license from Aspentech.

Chapter 2

Literature Review

Distillatillation of close boiling mixture require huge amount of energy input in the reboiler reboiler to perform the separation task. At the same time, a similar amount of heat at lower temperature is rejected in the condenser. Several heat pump concepts have been proposed to upgrade that discharged energy and thus reduce theconsumption of valuable utilities.Mechanical vapour recompression and BFHP technology are used to save energy for close boiling Mixtures. . G.P. Quadri used vapour recompression heat pump for P-P splitter, Hydrocarbon Processing 60 (1981) 147-151 and he got energy saving upto35[1]. O. Annakou, P. Mizsey have done rigorous investigation of heat pump assisted distillation, Heat Recovery Systems & CHP 15 (1995) 241-247 and the result is annual cost can be reduced by 37%[2].Ferre., F. Castells, J. Flores worked on optimization of a distillation column with direct vapor recompression heat pump and the result was reduced energy cosumption 40% [3].[4]Distillation has a relatively low thermodynamic efficiency,requiring the input of high quality energy in the reboiler to perform the separation task [4]. At the same time, a similar amount of heat at lower temperature is rejected in the condenser. Several heat pump concepts have been proposed to upgrade that discharged energy and thus reduce the consumption of valuable utilities. Heat Pumping is an economic way to conserve energy when the temp difference between the overhead and the bottom of the column is small and the heat load is high. There are many types of heat pumps used in the industry, such as electrically driven heat pump types and absorption heat pumps. Ranade & Chao have presented guidelines of where and when to use the different kind of heat pumps. W.F. Davidson and W.V.L. Campagne worked on energy saving for hydrocarbon mixture using absorption heat pump and suggested thatabsorption refrigeration system needs to be redesigned for use at temperatures entirely above ambient [5].

Technology	Performance Information	Referrences
Heat Pump	40% energy saving could be reached.	[6]
Vapour Compression and Mechanical Vapour Recompression and Bottom Flashing Heat Pump.	MVR allows higher energy & cost savings (50% lower TAC) than column integrated schemes but its capex are almost twice. Vapour Compression savings are similar to Mechanical Vapour Recompression gave 36% energy savings from column integration	[7]
Mechanical Vapour Recompression and Absorption Heat Pump	Mechanical Vapour Recompression yields 33% energy savings and 9% less Total annual Cost. Absorption Heat Pump was incorrectly implemented. Both compared to conventional distillation	[8]
Heat Integrated Distillation Column & Mechanical Vapour Recompression	MVR Industrial implementation gives Co-efficient of Performance7.4 and 37% TAC savings against conventional column . Heat integrated Distillation Column case study yielded Co-efficient of performanceequal to10 and 25% Total Annual cost savings against Mechanical Vapour Recompression with ΔTb =10.9 K.	[9]
Mechanical Vapour Recompression	Optimal column top pressure of 658,6 kPa.	[10]
Towards energy efficient	20% Total Annual Cost.	[11]
Mechanical Vapour Recompression and Absorption Heat Pump Technology	1-MVR yields COP 6.44 and 29% savings in utilities requirements in case 1. AHP yields COPw1.87 and 41% utilities savings. AHP lowest PBT. 2-MVR yields COP 2.63 and AHP yields COP 1.67. None gives utilities saving. PBT is negative for all cases	[12]
Vapour Compression	VC resulted 10% reduction in Total Annual Cost Saving	[13]

Chapter 3

Case Study of Energy saving for Binary Mixture

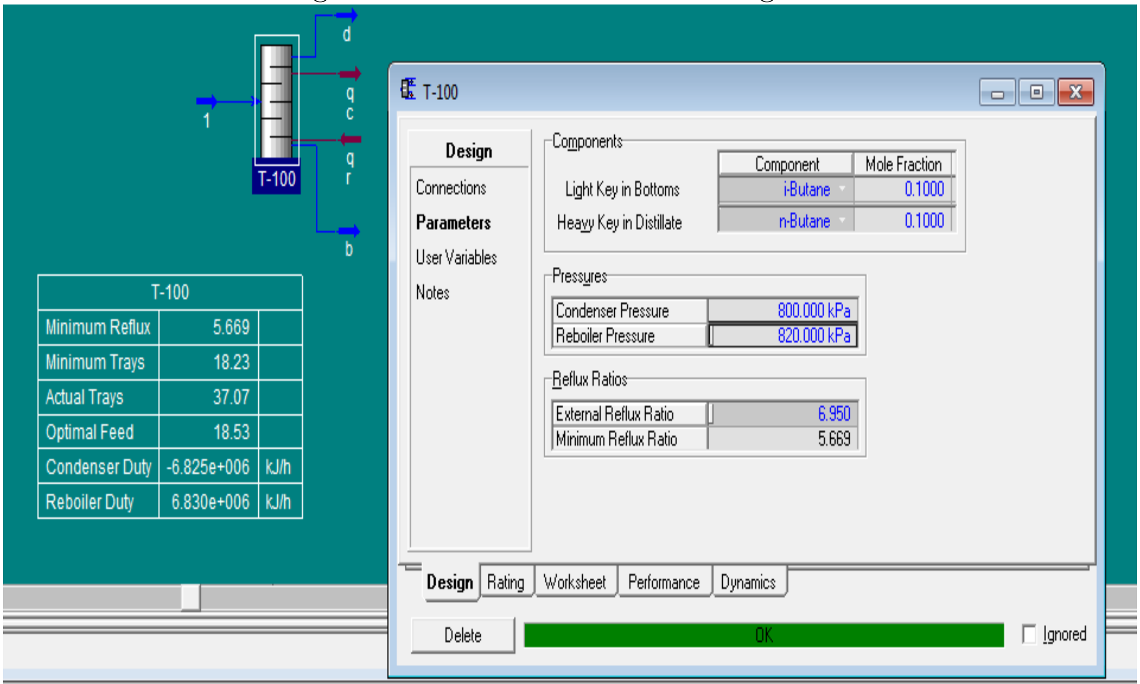
3.1 Property package for Hysys

For hysys simulation we have selected Peng Robinson Property package. It was suitable for n-butane and iso-butane hydrocarbon mixture.

3.2 Simulation of Shortcut column

First we solved short-cut column to know the actual number of trays required and calculate the needed reflux ratio for the conventional column. Here we took an eqimolar binary mixture of i-butane and n-butane as feed to the column.. Feed flowrate was 100 kmol/hr. Feed was introduced into the column at various pressures. Mole fraction of i-butane in the feed was 0.9 and mole fraction of n-butane in the bottom product was 0.9. steps for short cut column distillation are given below.

Figure 3.1: Short Cut column Design for case 1



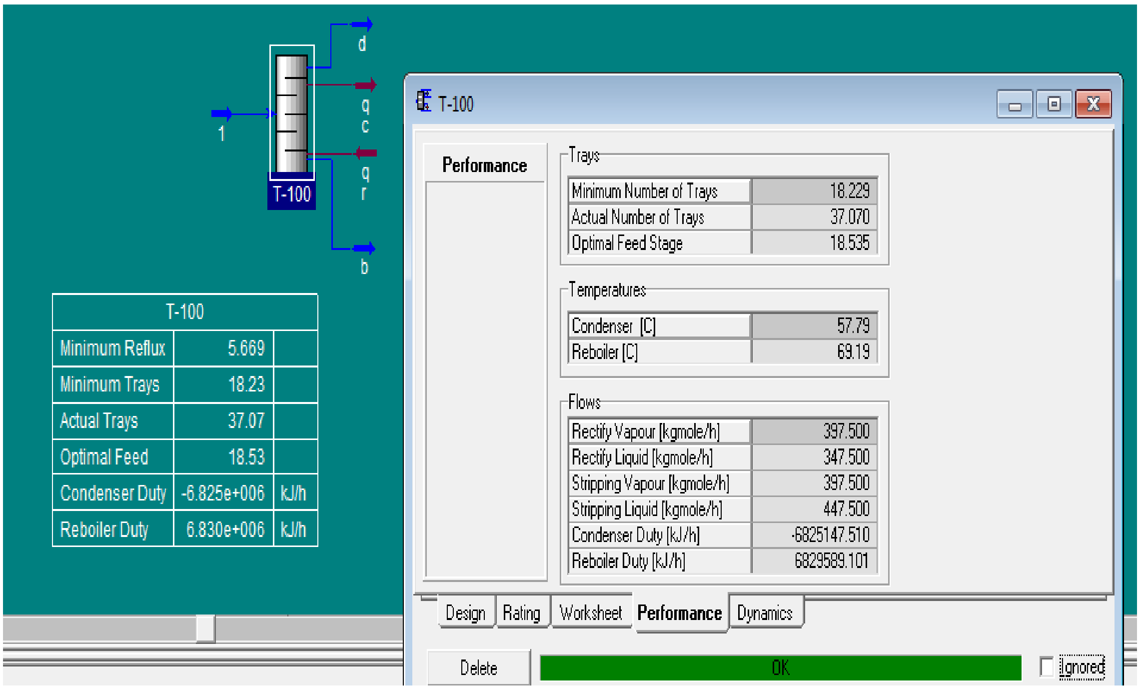


Figure 3.2: Performance data of the Short Cut Column

3.3 Simulation of Conventional Column

We have simulated the conventional column for various pressure conditions and the flow diagrams for the same are given below in the figures$Fig3.3 - Fig3.6$

3.3.1 Simulation Procedure

For solving the conventional column, first we defined the feed stream. Then we placed a distillation column. By double clicking in the column we opened the design page.There we connected the feed stream and inserted column name, condenser energy stream, reboiler energy stream, actual number of trays, reboiler pressure and condenser pressure. We added specifications like reflux ratio or top product rate or sometimes both to converge the column successfully. Next we double clicked in the converged column and entered into the column environment to get the flow diagram with reflux and boilup stream . We performed this simulation at different pressure conditions like 500 kPa, 600 kPa, 700 kPa, 800 kPa, 900 kPa and 1000 kPa.

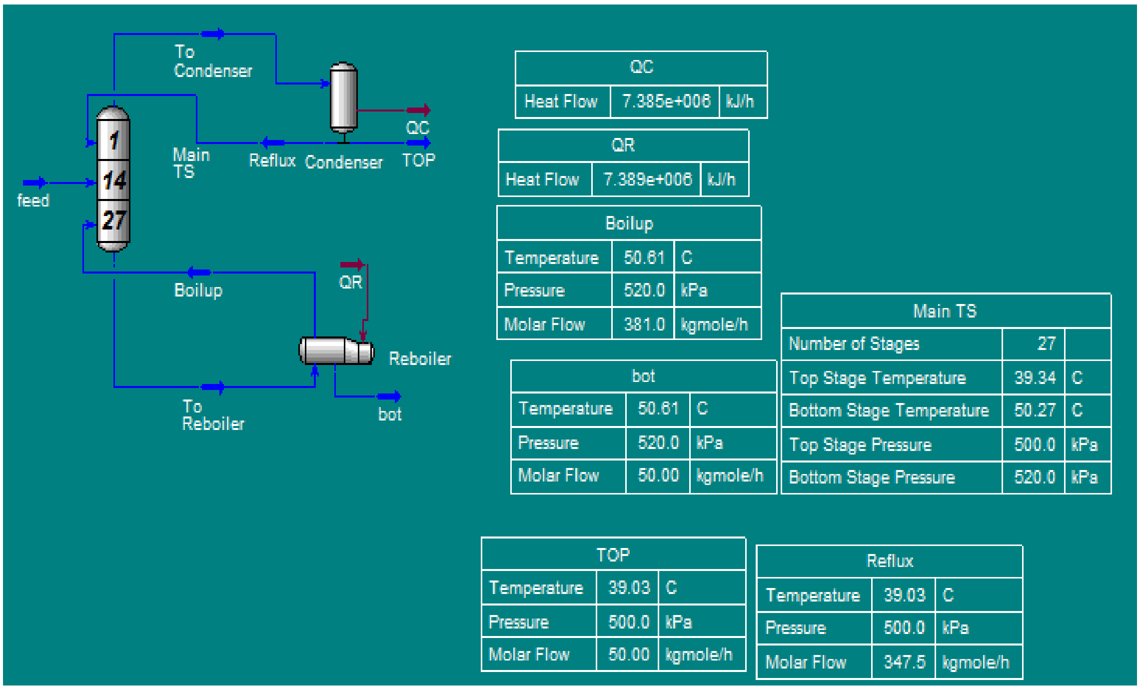


Figure 3.3: Column Environment of the Conventional Column at 500 kPa

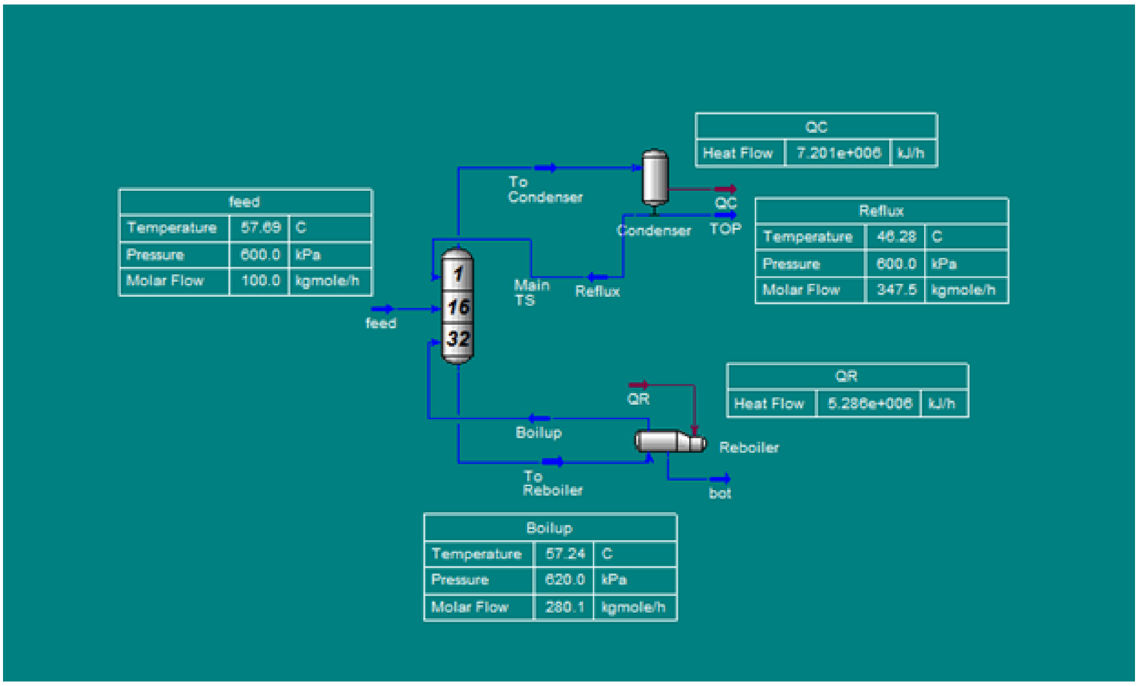


Figure 3.4: Column Environment of the Conventional Column at 600 kPa

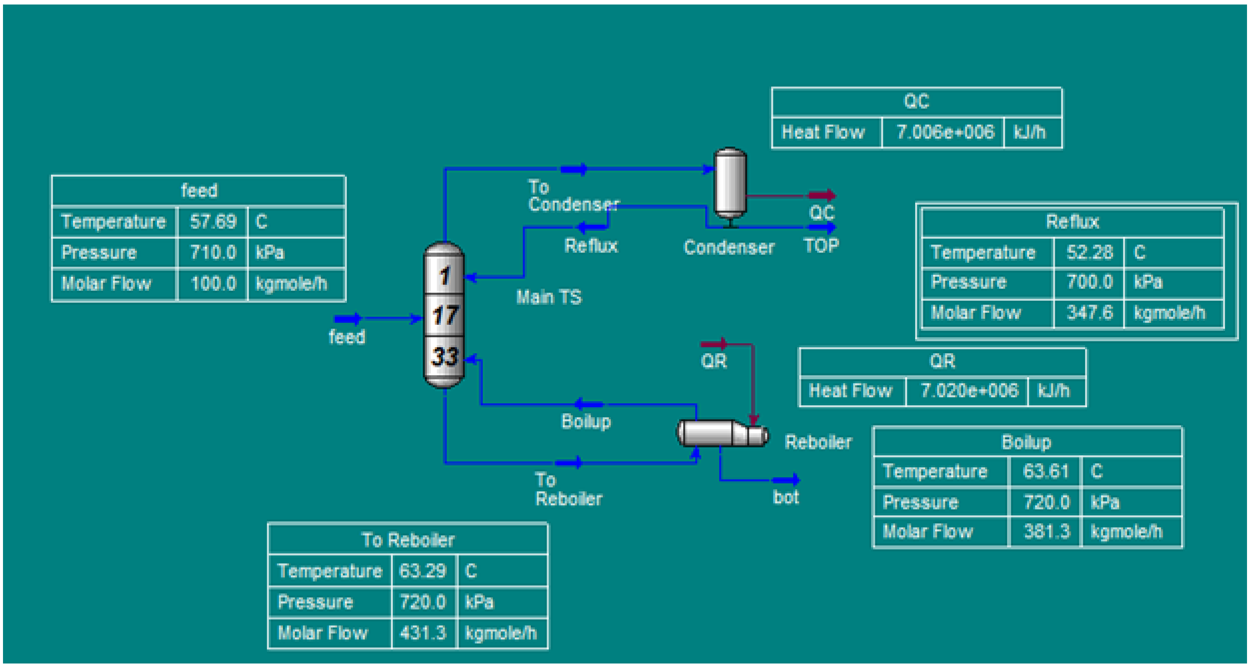


Figure 3.5: Column Environment of the Conventional Column at 700 kPa

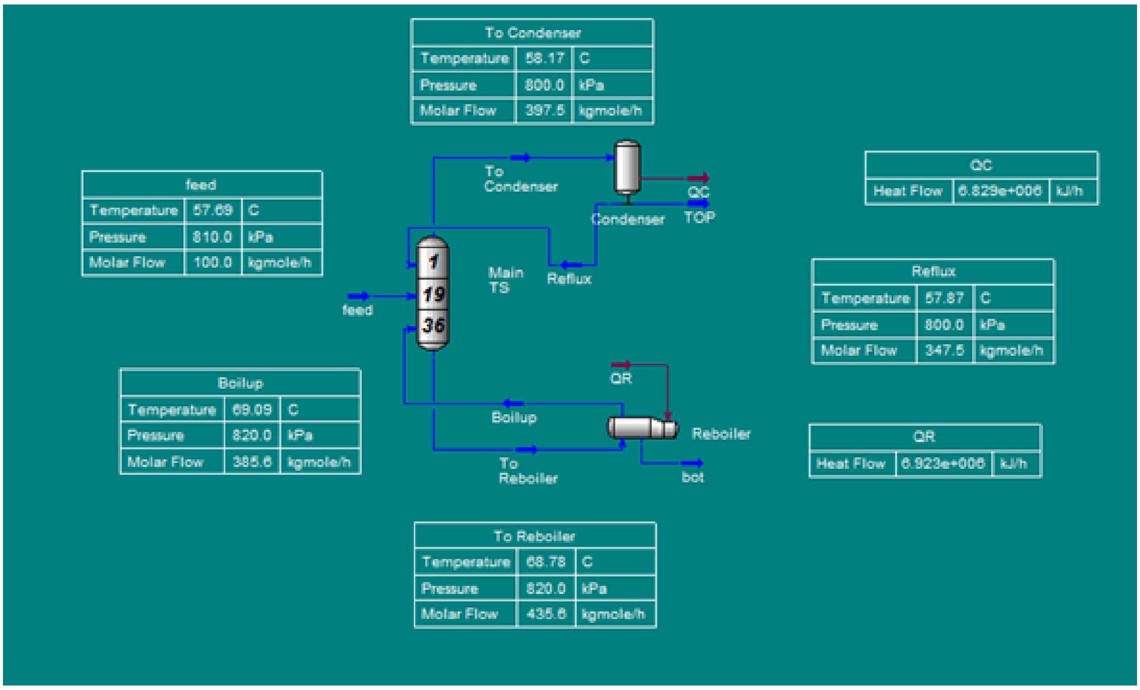


Figure 3.6: Column Environment of the Conventional Column at 800 kPa

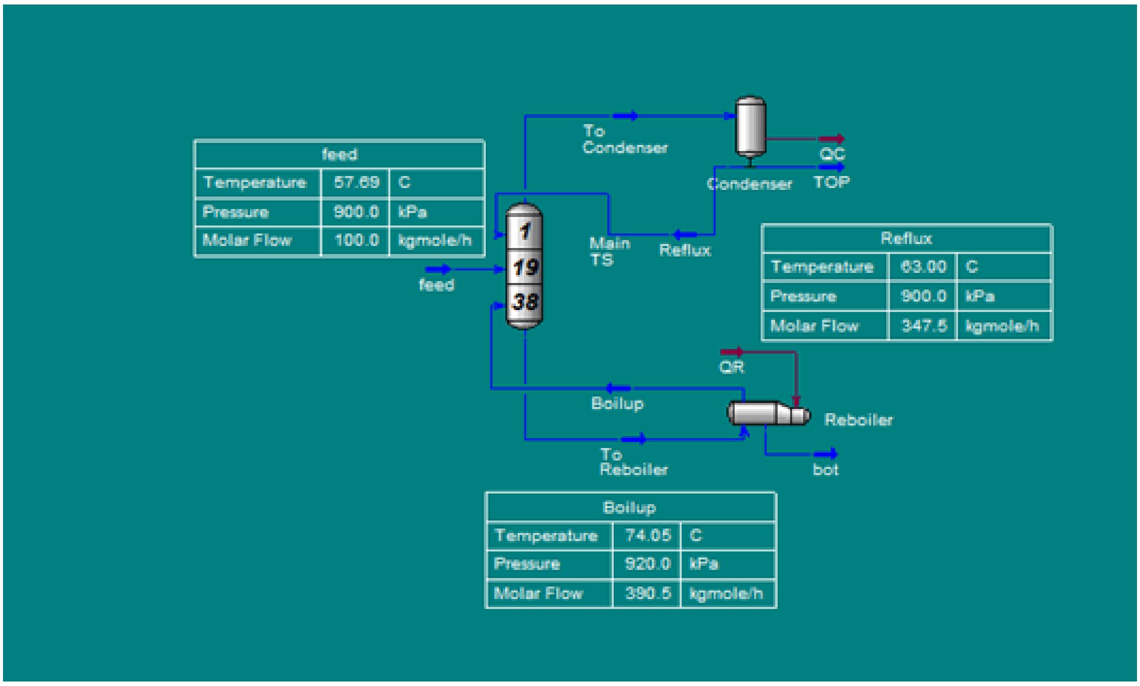


Figure 3.7: Column Environment of the Conventional Column at 900 kPa

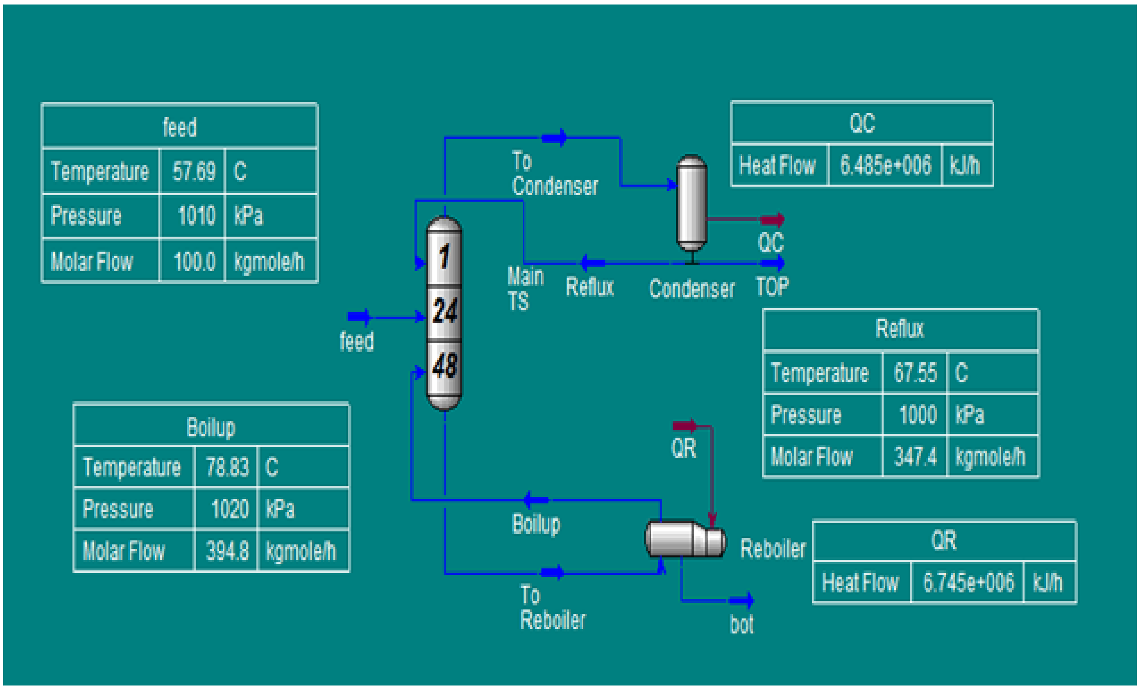


Figure 3.8: Column Environment of the Conventional Column at 1000 kPa

Table 3.1: Simulated Results for Conventional Distillation at Different Pressures

$500kPa$	$700kPa$	$800kPa$	$900kPa$	$1000kpa$
27	33	36	38	48
14	17	18	19	24
1.3	1.3	1.3	1.3	1.3
1.5	1.5	1.5	1.5	1.5
0.50	0.55	0.55	0.55	0.55
15.4	18.7	20.35	21.45	26.95
608	609	610	620	624
352100	362100	373100	38100	39400
352708	362709	373710	38720	40024
$500kPa$	$700kPa$	$800kPa$	$900kPa$	$1000kpa$
3.25×10^5	5.56×10^5	1.01×10^6	5.023×10^5	1.012×10^6
5386	9216	16710	8328	16780
60.361	60.329	60.44	60.314	60.309
537.8	367.115	376.29	387.688	376.272
167600	129200	131300	133800	131300
6.459×10^4	3.029×10^4	1.888×10^4	2.294×10^4	1.886×10^4
$500kPa$	$700kPa$	$800kPa$	$900kPa$	$1000kpa$
4.68×10^5	4.479×10^5	3.106×10^5	4.077×10^5	5.654×10^5
7755	7426	5150	6759	9374
60.31	60.31	60.31	60.319	60.31
649.1714	649.1714	649.1714	649.1714	649.1714
84000	84000	84000	84000	84000
382.4	346.112	474.445	340.656	252.083
132600	124600	153300	123400	104100

3.4 Simulation of Distillation column with Top vapour recompression Heat Pump

As the name mention top vapour recompression using heat pump, here top column outlet stream is compressed using compressor. First we define three streams one feed stream and the other two are respectively reflux and reboiled stream and solve them by inserting the appropriate composition and condition data. Next we take a absorption column and by double clicking in the column we opened the design page. In the design page we give the column name, connect the solved streams, name of overhead vapour outlet stream and bottom liquid outlet stream name. Then we add the required specifications to solve the column. Next from the object palette we take the compressor.By double clicking in the compressor we opened the design page. There in the place of inlet stream we connected top vapour outlet stream from the absorber and the place of energy we wrote name like Qcomp as a compressor energy and in the place of outlet we gave outlet stream name. We increased the pressure and temperature of the outlet stream. Next we took an Heat Exchanger from the object palette we designed the heat exchanger in such a way that top vapour outlet stream vapour fraction was zero, bottom outlet stream boiled up to the desired vapour fraction. Thereafter we used a separator to setarate the liquid product and recycle the vapour stream to the column. Next we took a cooler and designed the cooler in such a way that the top column outlet stream was cooled in cooler upto the reflux stream temperature. Thereafter using a valve we decreased the pressure upto the designed pressure of the top column inlet stream pressure.Next we added the required specifications and the whole system was converged successfully. We performed this simulation at different pressure conditions like column top pressure 500 kPa, 700kPa, 800 kPa, 900 kPa and 1000kPa.The flow diagram of the top vapour recompression heat pump cases are given in the fig from Fig 3.9-Fig 12. In time of recycling the stream we we have to remember that Temperature, Pressure, Composition and vapour fraction should match with the stream with which we are connecting the stream. Suppose we are recycling top stream. then top stream composition and properties should match with the reflux stream. Similarly when we are recycling bottom stream it's composition and properties should match with the Boilup stream. Otherwise stream was not solving.

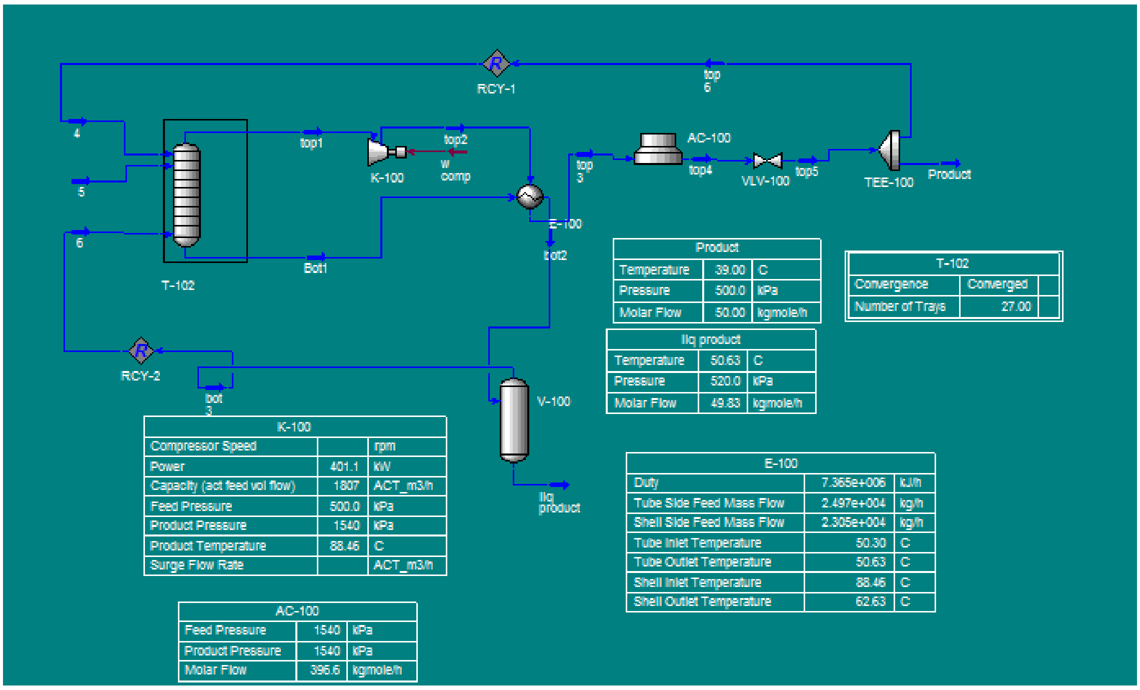


Figure 3.9: Flow Diagram of the MVRHP of multi component mixture at 500 kPa of multi component mixture

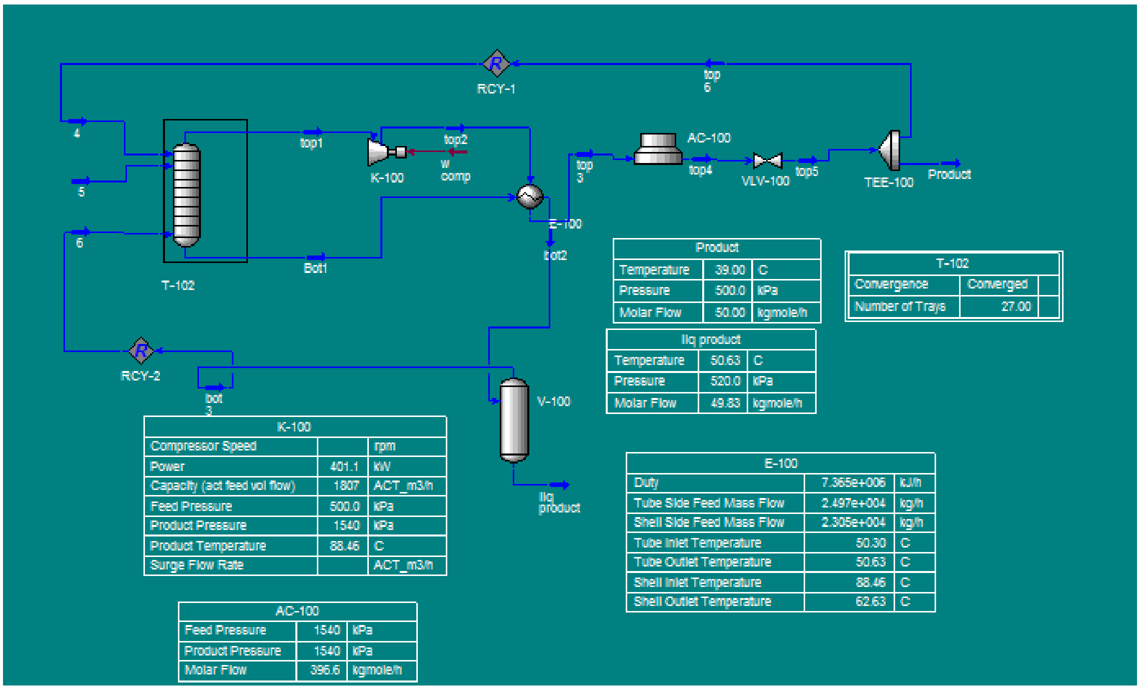


Figure 3.10: Flow Diagram of the MVRHP of multi component mixture at 700 kPa

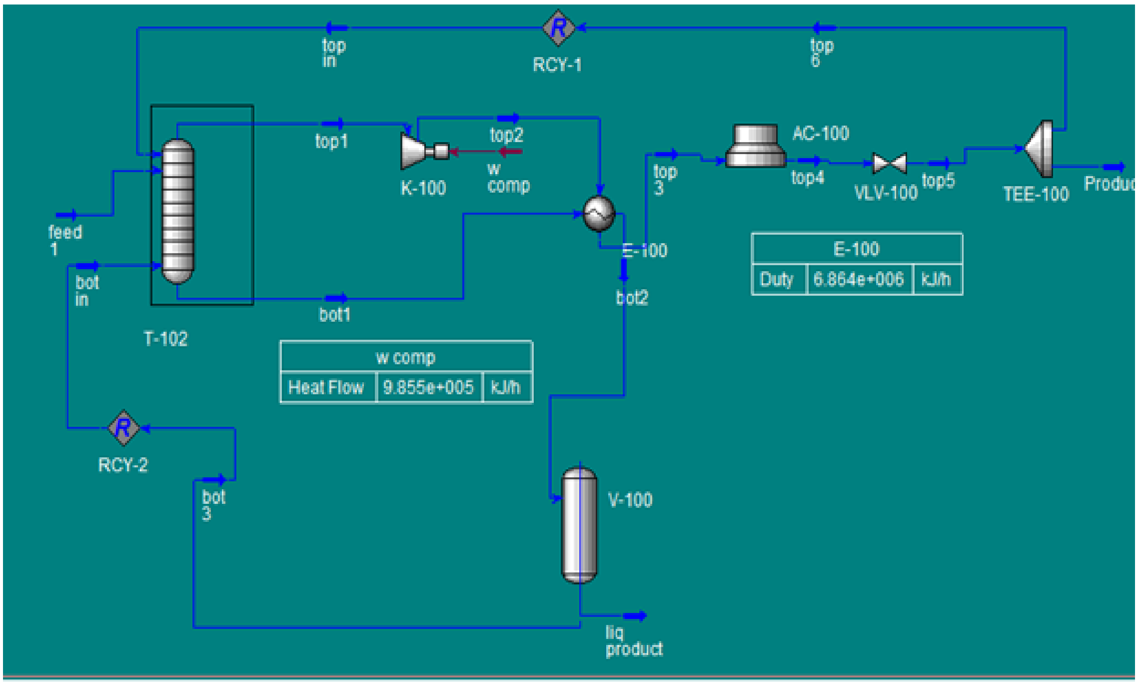


Figure 3.11: Flow Diagram of the MVRHP of multi component mixture at 800 kPa

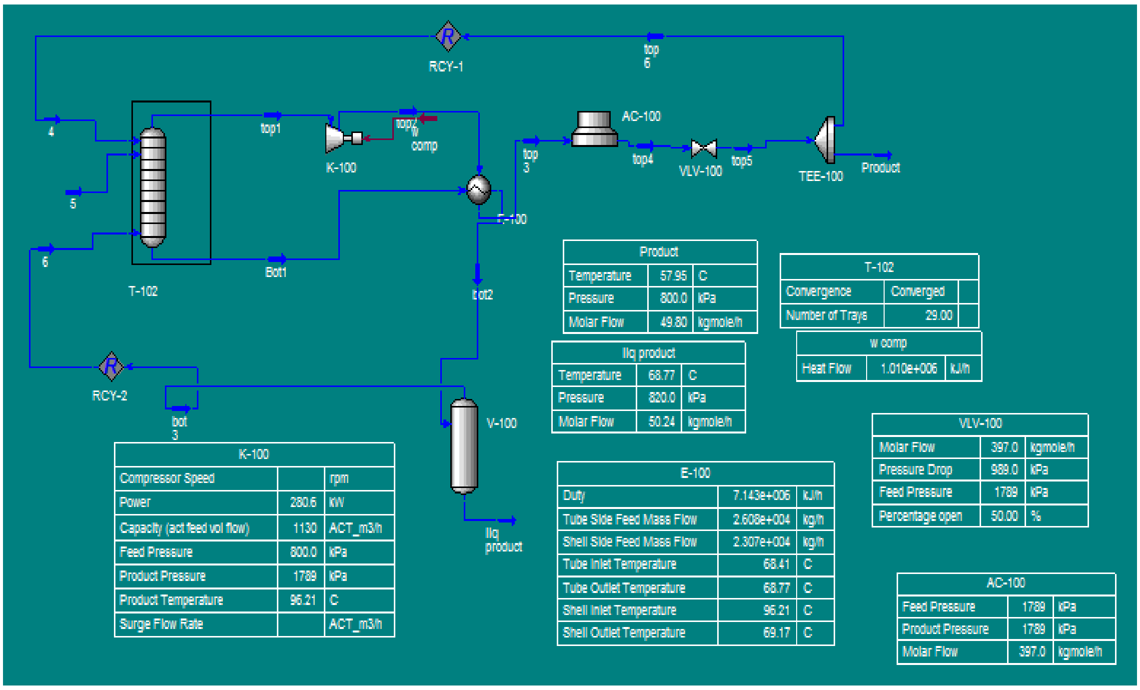


Figure 3.12: Flow Diagram of the MVRHP of multi component mixture at 1000 kPa

3.5 Simulation of Distillation column with bottom flashing Heat Pump

In the Bottom Flashing Heat Pump case like top vapour recompression case we solve the absorber . Here the bottom column outlet stream is expanded in a valve to the desired pressure. Using a Heat Exchanger column top outlet stream is condensed fully that is we made the vapour fraction zero and bottom column outlet stream is fully vaporized that is we made the vapour fraction 1. Thereafter we used a Tee to get the desired product and recycled the rest liquid stream to the column. Next tube side outlet of the Heat Exchanger was sent to a compressed upto the column bottom Pressure. Then we sent it the cooler to cool it to the boilup stream and to the desired vapour fraction. Thereafter using a separator we collect the liquid bottom product and recycle the vapour stream to the column bottom.

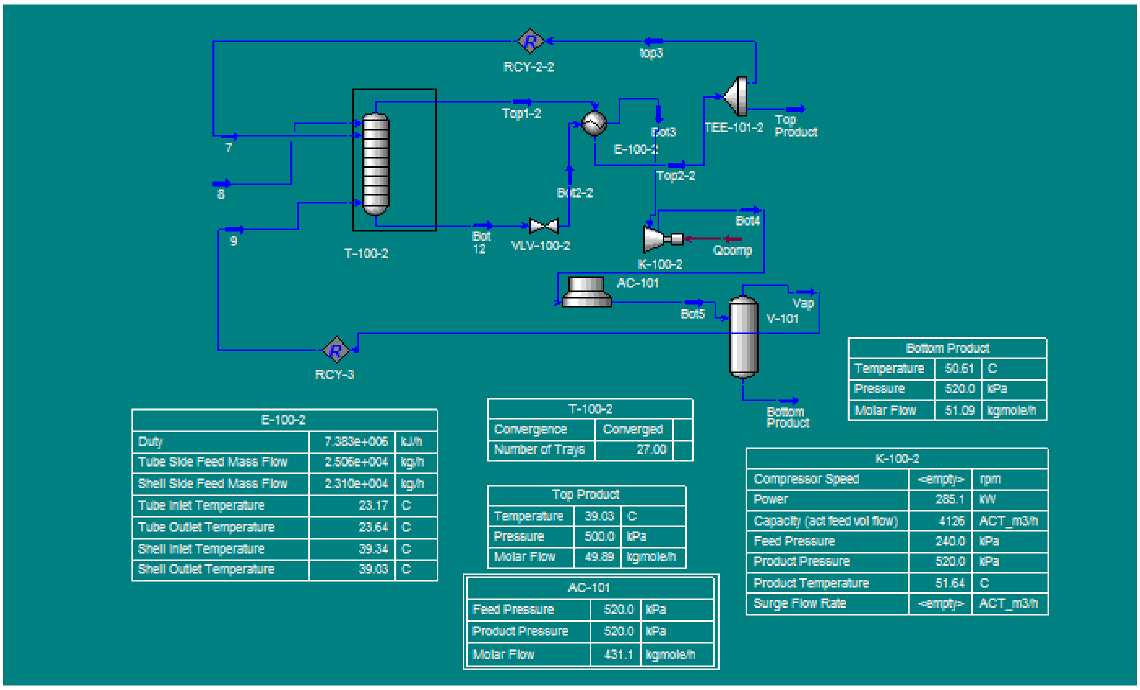


Figure 3.13: Flow Diagram of the Bottom Flashing Heat Pump of multicomponent mixture simulated at 500 kPa

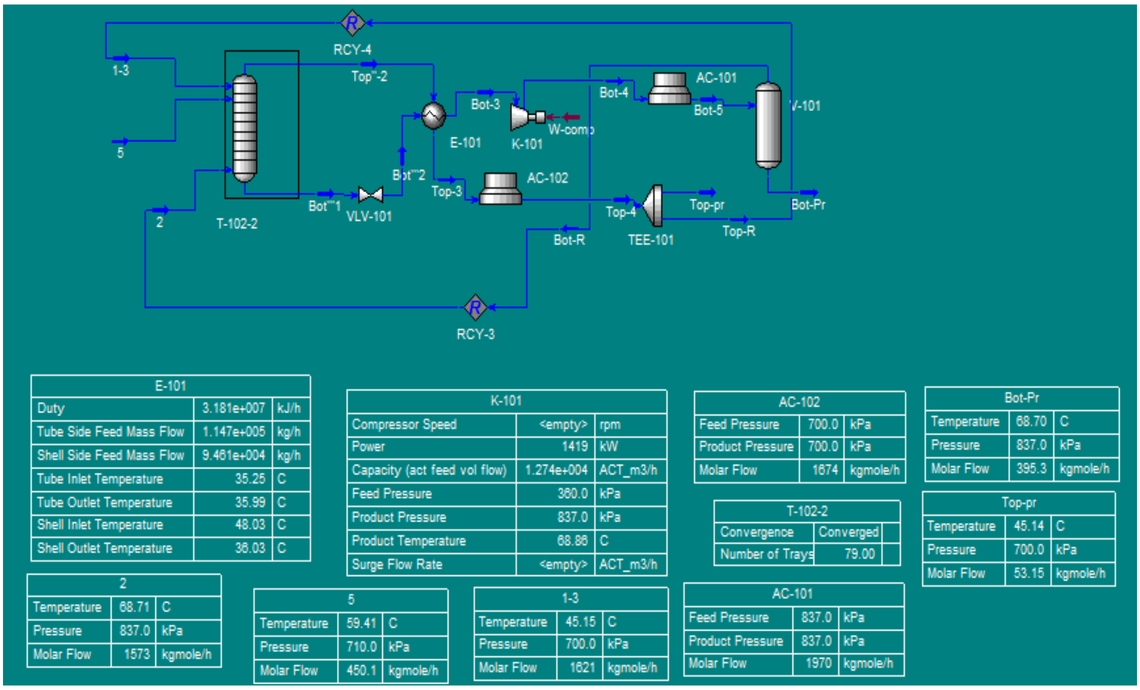


Figure 3.14: Flow Diagram of the Bottom Flashing Heat Pump simulated at 700 kPa

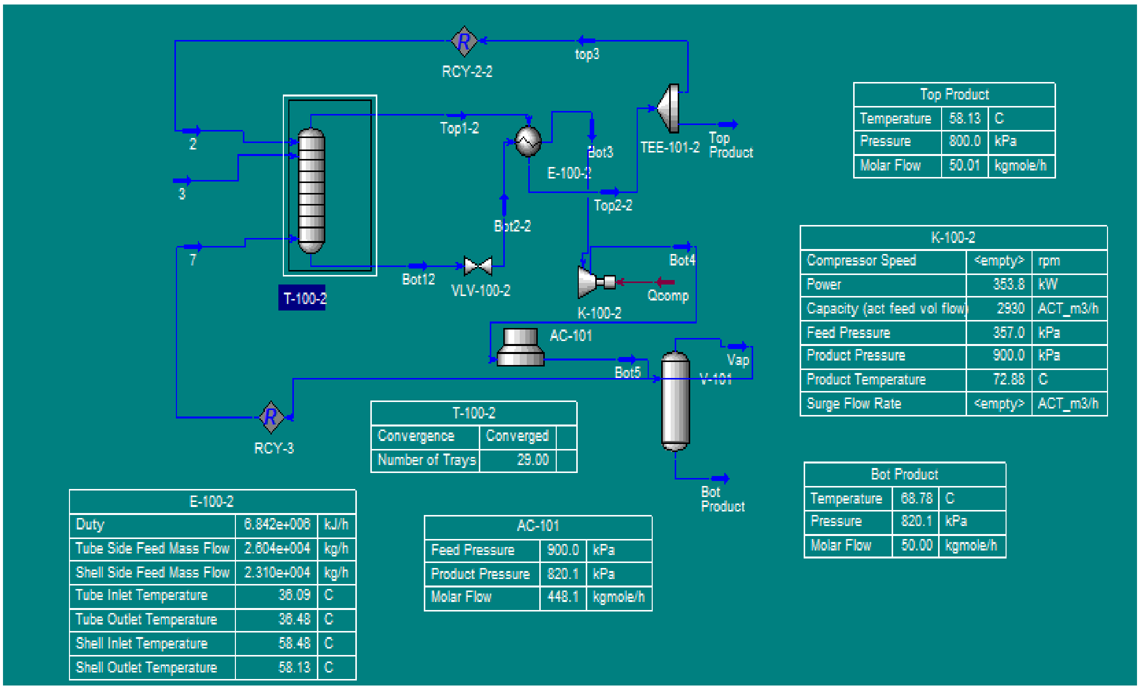


Figure 3.15: Flow Diagram of the Bottom Flashing Heat Pump simulated at 800 kPa

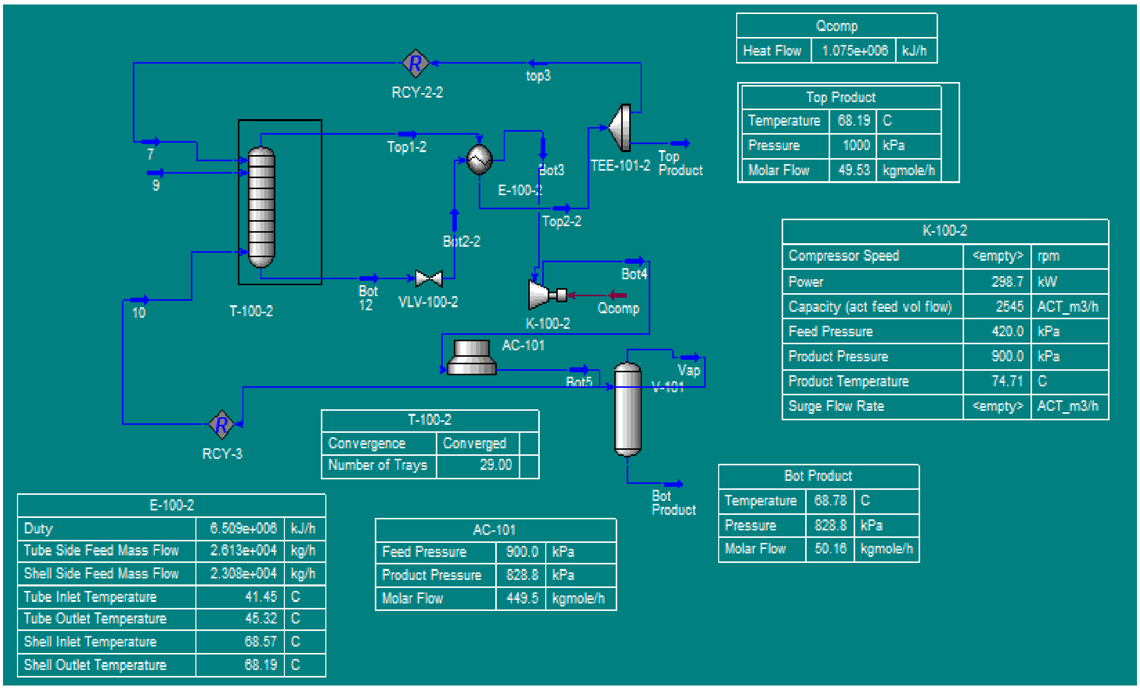


Figure 3.16: Flow Diagram of the Bottom Flashing Heat Pump simulated at 1000 kPa

Table 3.2: Energy saving calculation for the separation of binary mixture for three different schemes

Parameter	500 kPa	700 kPa	800 kPa	1000 kPa
Conventional case				
Condenser Duty kJ/h	0.7385×10^7	0.7006×10^7	0.6829×10^7	0.6484×10^7
Reboiler Duty kJ/h	0.7389×10^7	0.7020×10^7	0.6923×10^7	0.6945×10^7
Total Energy Required	1.4774×10^7	1.4026×10^7	1.3752×10^7	1.3429×10^7
MVRHP Case				
Compressor Duty (kJ/h)	0.144×10^7	0.0985×10^7	0.101016×10^7	0.101017×10^7
Heat Exchanger duty (kJ/h)	0.7365×10^7	0.6864×10^7	0.7143×10^7	0.7144×10^7
Cooler Duty(kJ/h)	0.1437×10^7	0.1015×10^7	0.0071×10^7	0.00709×10^7
Total Energy Required (kJ/h)	1.0242×10^7	0.8864×10^7	0.8224×10^7	0.82249×10^7
Energy Saved for MVRHP Case	30.67%	36.80%	40.19%	38.75%
BFHP Case				
Heat Exchanger Duty(kJ/h)	0.7383×10^7	0.6652×10^7	0.6842×10^7	0.6509×10^7
Compressor Duty (kJ/h)	0.1026×10^7	0.09289×10^7	0.12737×10^7	0.1075×10^7
Cooler Duty (1) (kJ/h)	0.1039×10^7	0.0001802×10^7	0.0071×10^7	0.06783×10^7
Total Energy Required(kJ/h)	0.9448×10^7	0.75827×10^7	0.81867×10^7	0.17533×10^7
Energy Saving for BFHP Case	36.049%	45.93%	40.46%	56.94%

3.6 Cost Estimation details

Cost of Column

Capital Cost The following approximates installed cost and purchased cost for the Shell and Trays. This cost relates the diameter, height and design variables of the column. The design variable is a correction used to allow specificity of the column pressure and material.

$CC = ((MS))/280) * 120 * D_T * H^{0.8} * (218 + Fc) = ((M\&S))/280) * 120 * 2.9 * 51.8^0.8 * (218 + Fc)$

Where CC =Cost of Shell and Trays Fc= Design consideration for the column

Step 2.

Capital cost

The installed cost of the reboiler heat Exchanger is:

Cr=$((M\&S)/280)*328*(\Delta Hv/11250)^0.65*V^0.65$. =$((M\&S)/280)*328*((1.859*10^4)/11250)^0.65*1274^0.65$

Where Cr is cost of Reboiler.

ΔH_v=Heat of vaporization of bottoms

V=Rate of boilup

Operating Cost:

If we use steam to supply heat for the reboiler The steam required is :

$Ws=(\Delta H_V/\Delta Hs)*V=((1.859*10^4)/2240)*(25.57)$ Where

Ws= Amount of steam needed

ΔH$_V$= Heat of vaporization

ΔHs=Heat of Saturation V= Mass flow rate

$Cs=8.74*10^{-3}*(Steamcost)*\Delta Hv*V=8.74*10^{-3}(steamCost)(1.859*10^4)*(25.57)$

Cost of Condenser

Capital Cost

If we assume that the cooling water is available at $90°F$,

The Heat transfer area of the condenser is

$Ac=(\Delta Hv/3000).ln((Tb-90)/(Tb-120))*V=((1.791*10^4)/3000).ln((47.02-90))/((47.02-120)))*28.42$

Ac= Area of condenser Heat Exchanger

$\triangle H_V$= Heat of vaporization Tb=Bubble point of Distillate

V= Mass flow rate Installed Cost of the Condenser

$Cc=(^{M\&S}/_{280}*101.3*(2.29+Fc)*A*C^{0.65}$

Where Cc= cost of condenser

Fc=Design consideration for correction factor.

Operating Cost: Amount of Cooling water needed for the condenser is

$W_c={}^{\triangle H_V}/_{30}*V$

=(1.791/30)*28.42 Cc

=((1.791)/30)* 28.42 Cc

=$3.26*10^{-4}$*(Cooling water cost)*($\triangle H_V$)* V

W_C=Amount of cold water to condenser Cc =Cost of condenser

$\triangle H_V$= Heat of vaporization V=Mass flow rate.

3.7 Summary of Economic potential of three different Schemes

Table 3.3: Summary of simulated results of three Different Schemes for binary mixtures

Parameters		Conventional	MVRHP	BFHP
CAPITAL COST	Cost of Column ($)	565000	565000	565000
	Cost of Condenser($)	53600		
	Cost of Reboiler($)	69700		
	Cost of Compressor($)		116700	111610
	Cost of Heat Exchanger($)		106010	98211
	Cost of Cooler($)		19911	2710
OPERATIONAL COST	Steam ($)	183211		
	Electricity ($)	74411	189600	176300
ECONOMIC POTENTIAL	($)	498700	497100	448500

Chapter 4

Case Study on Energy saving for Multicomponent Mixture

4.1 Problem Statement

For the case study on multicomponent mixture we have used the mixture of Propane Isobutane, N-butane, C4 olefins, Neo-pentane, Isopentane & N-Pentane. Measured feed and product flows and compositions were as in the Table 4.1.

Table 4.1: Measured Feed and Product Flows and Compositions

Species	Feed	Top	Bottom
Propane	1.50	5.3	0.0
Isobutane	29.4	93.5	0.30
N-Butane	67.7	0.20	98.1
C4 Olefins	0.50	1.00	0.20
Neopentane	0.1	0.00	0.20
Isopentane	0.8	0.00	1.10
N-Pentane	0.10	0.00	0.10
Total Flow (Kg/h)	26234	8011	17887

Table 4.2: Details of isobutane/n-butane fractionator

Parameter	Value
Reflux flow rates (kg/h)	92838
Reflux Temp $^{\circ}C$	18.5
Column Top Pressure (kPa)	658.6
Pressure drop per tray (kPa)	0.47
Feed Pressure (kPa)	892.67
Boiler Duty (MW)	10.24

4.2 Property Package for hysys

For hysys simulation we have selected Peng Robinson Property package. It was suitable for n-butane and iso-butane hydrocarbon mixture.

4.3 Simulation of Conventional Column

First we have solve short-cut column to know the actual number of trays required and calculated the needed reflux ratio for the conventional column. Here we have taken an eqimolar binary mixture of i-butane and n-butane. Feed flowrate was 100 kmol/hr. Feed was introduced into the column at a pressure of 710 kPa. Mole fraction of i-butane in the feed was 0.9 and mole fraction of n-butane in the bottom product was 0.9.

For solving the conventional column, first we defined the feed stream. Then we placed a distillation column. By double clicking in the column we opened the design page.There we connected the feed stream and inserted column name, condenser energy stream, reboiler energy stream, actual number of trays, reboiler pressure and condenser pressure. We added specifications like reflux ratio or top product rate or sometimes both to converge the column successfully. Next we double clicked in the converged column and entered into the column environment to get the flow diagram with reflux and boilup stream . We performed this simulation at different pressure conditions like 500 kPa, 600kPa, 700kPa, 800 kPa, 900kPa and 1000kPa.

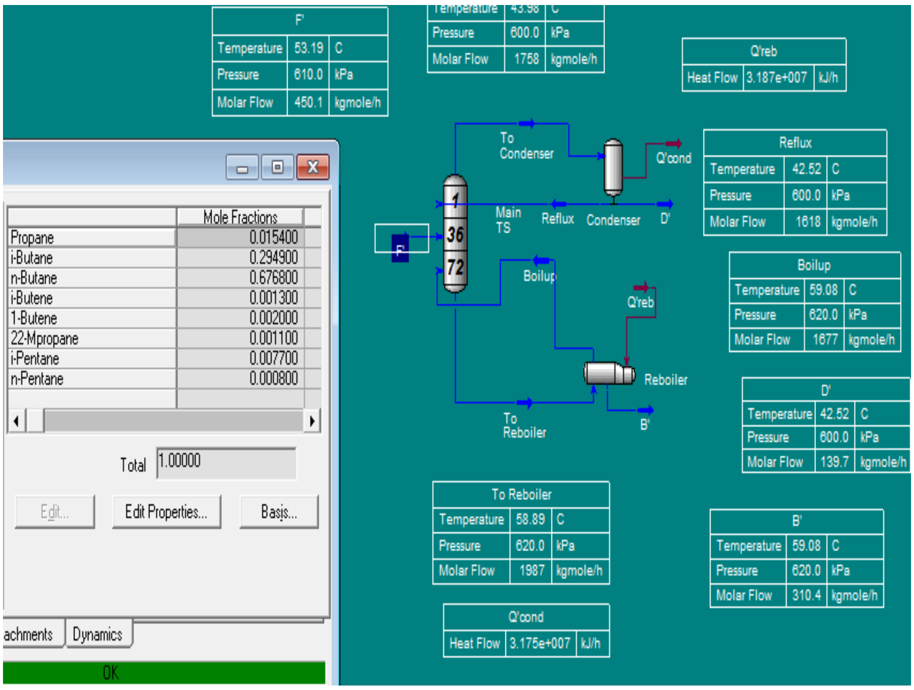


Figure 4.1: Flow Diagram of the Conventional Column at 600 kPa simulated by hysys

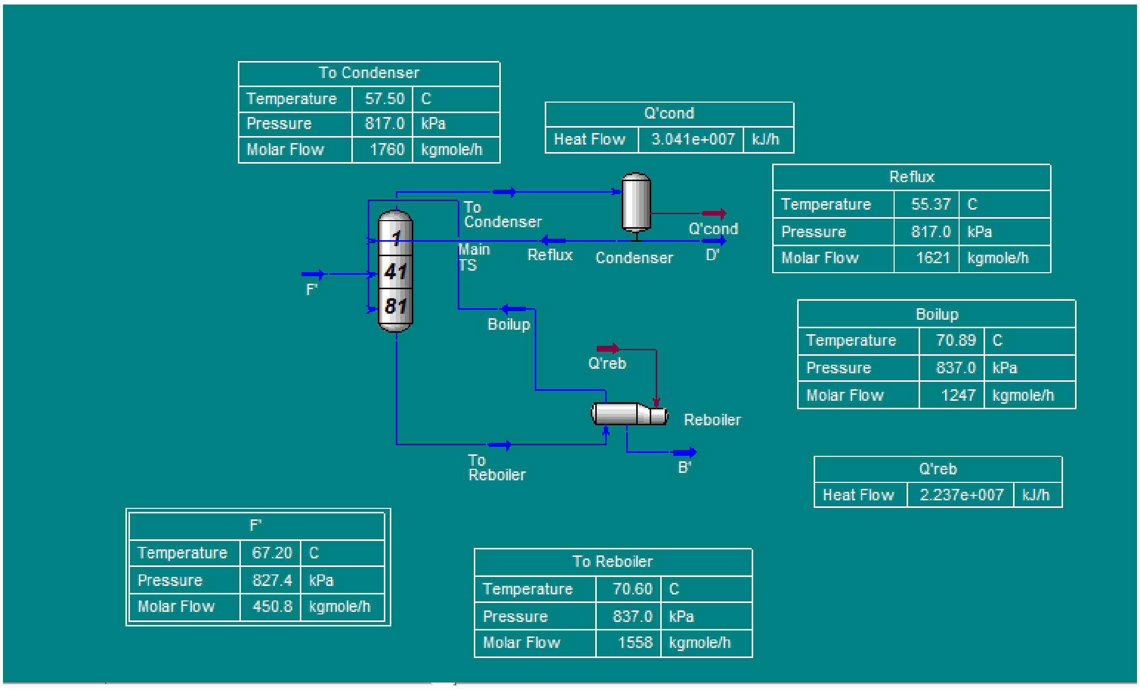


Figure 4.2: Flow Diagram of the Conventional Column at 817 kPa simulated by hysys

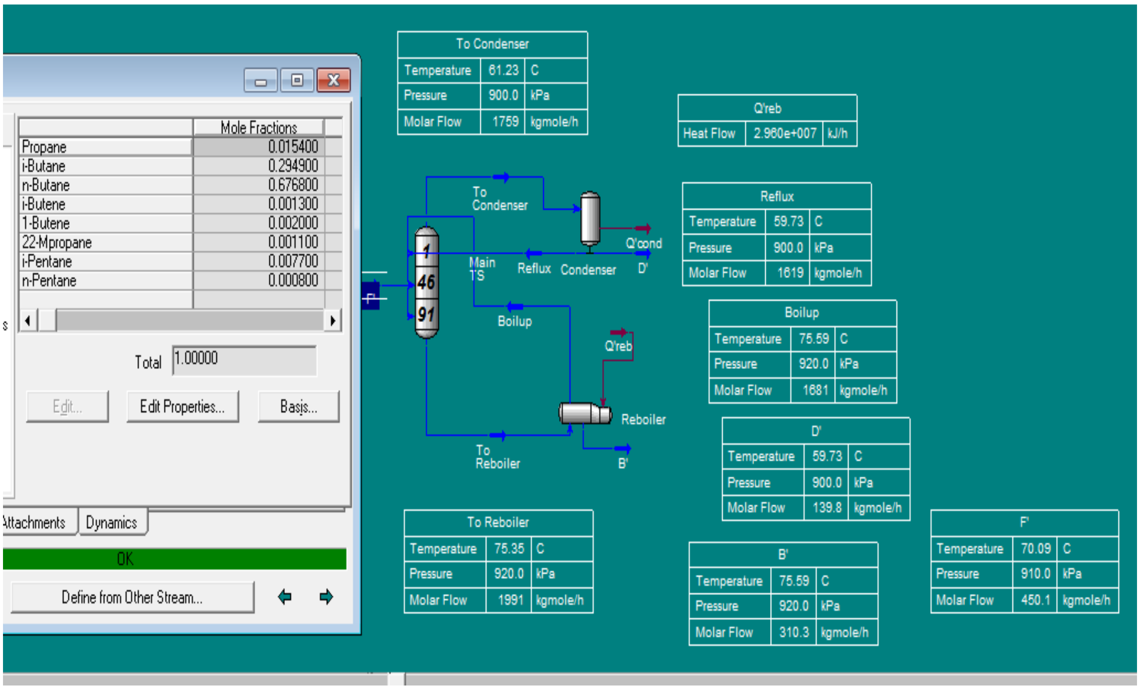
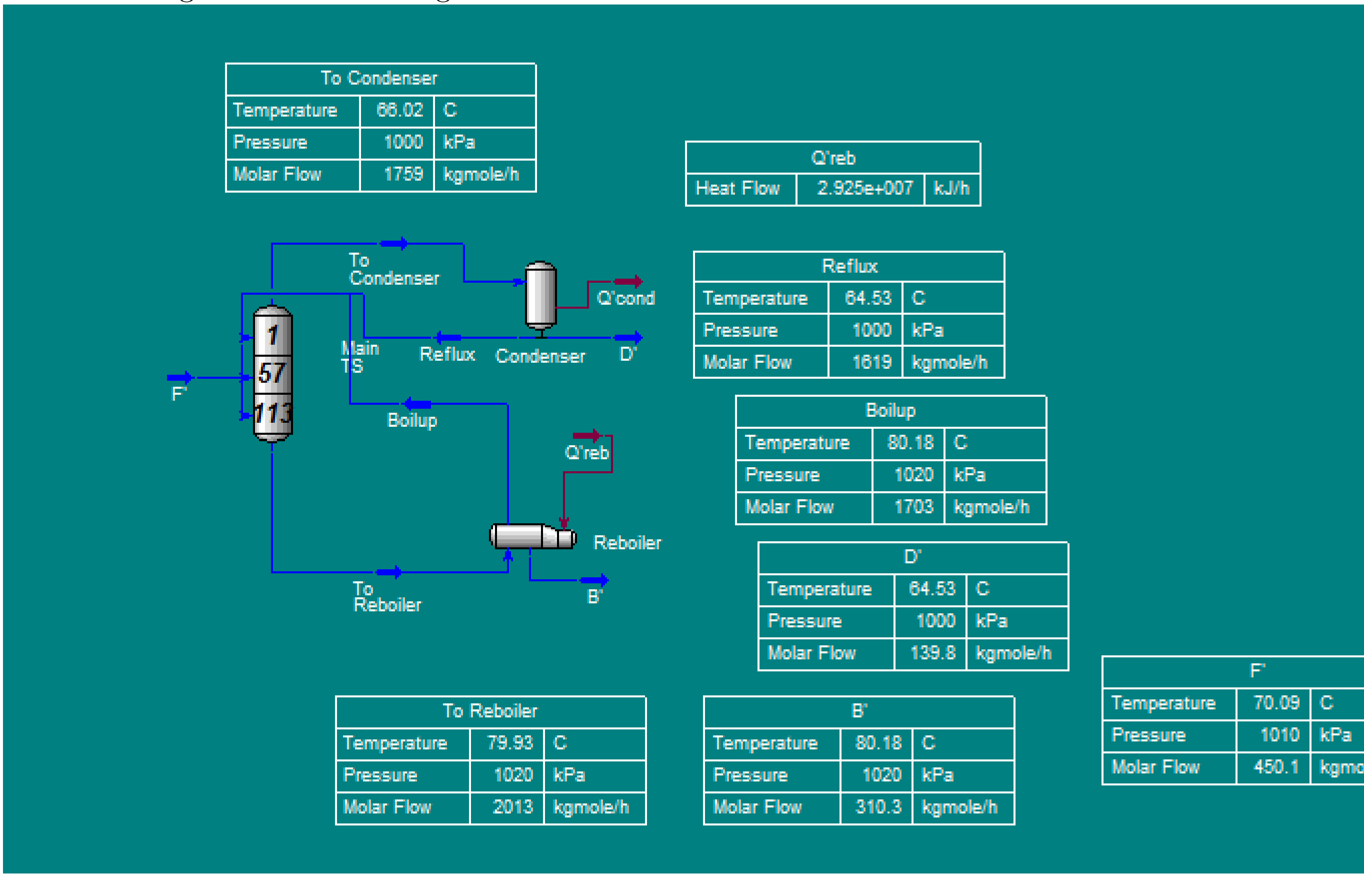


Figure 4.3: Column Environment of the Conventional Column at 900 kPa simulated by hysys

Figure 4.4: Flow Diagram of the Conventional column at 1000 kPa



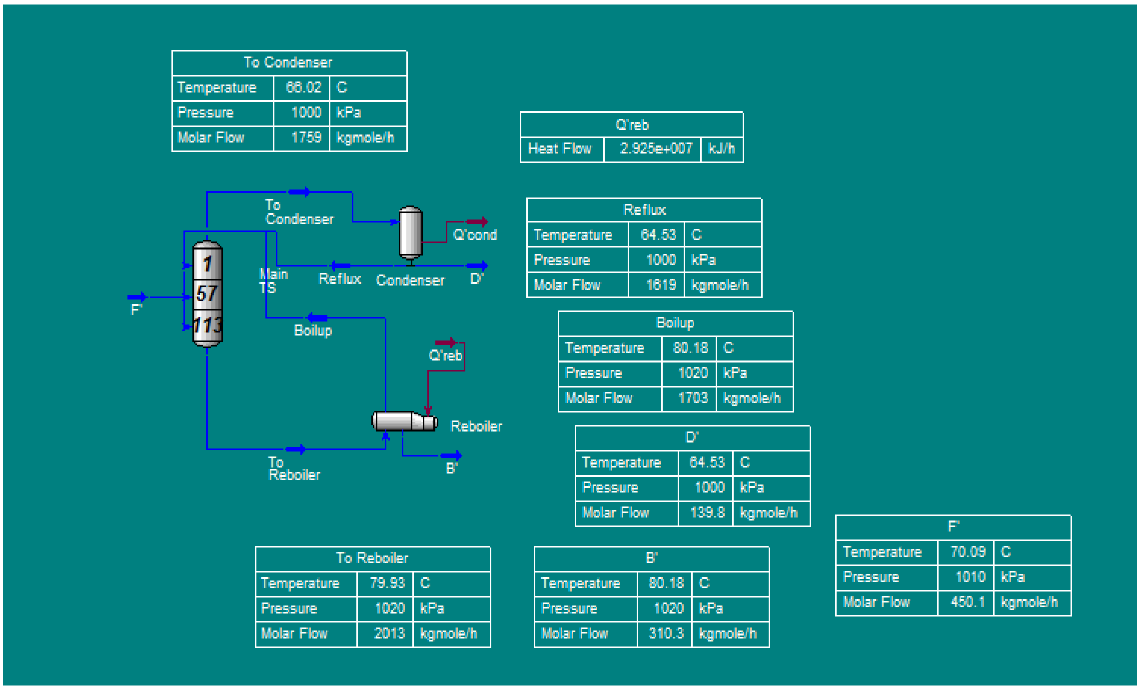


Figure 4.5: Column Environment of the Conventional Column at 1000 kPa simulated by hysys

Table 4.3: Simulated Results for Conventional Case at various pressure

Parameters	600	817	900	1000
Number of stages	72	81	91	113
Feed Stage	36	41	46	57
Reflux ratio	1.3	1.3	1.3	1.3
Diameter (m)	1.5	1.5	1.5	1.5
Tray space (m)	0.5	0.5	0.5	0.5
Height (m)	43.8	49.2	55.2	68.4
Reboiler Duty$^{KJ}/_{Kg}$	$3.187 * 10^7$	$3.041 * 10^7$	$2.999 * 10^7$	$2.925 * 10^7$
Condenser Duty $^{KJ}/_{Kg}$	$3.175 * 10^7$	$2.237 * 10^7$	$2.960 * 10^7$	$2.926 * 10^7$
Total Energy Required $^{KJ}/_{Kg}$	$6.362 * 10^7$	$5.278 * 10^7$	$6.362 * 10^7$	$5.851 * 10^7$

4.4 Simulation of Distillation column with Mechanical Vapour Recompression Heat Pump

As the name mentions top vapour recompression using heat pump, here top column outlet stream is compressed using compressor. First we define three streams one feed stream and the other two are respectively reflux and reboiled stream and solve them by inserting the appropriate composition and condition data. Next we take a absorption column and by double clicking in the column we opened the design page. In the design page we give the column name, connect the solved streams, name of overhead vapour outlet stream and bottom liquid outlet stream name. Then we add the required specifications to solve the column. Next from the object palette we take the compressor.By double clicking in the compressor we opened the design page. There in the place of inlet stream we connected top vapour outlet stream from the absorber and the place of energy we wrote name like Qcomp as a compressor energy and in the place of outlet we gave outlet stream name. We increased the pressure and temperature of the outlet stream. Next we took an Heat Exchanger from the object palette we designed the heat exchanger in such a way that top vapour outlet stream vapour fraction was zero, bottom outlet stream boiled up to the desired vapour fraction. Thereafter we used a separator to setarate the liquid product and recycle the vapour stream to the column. Next we took a cooler and designed the cooler in such a way that the top column outlet stream was cooled in cooler upto the reflux stram temperature. Thereafter using a valve we decreased the pressure upto the designed pressure of the top column inlet stream pressure.Next we added the required specifications and the whole system was converged successfully. We performed this simulation at different pressure conditions like column top pressure 500 kPa, 700kPa, 800 kPa, 900 kPa and 1000kPa.The flow diagram of the top vapour recompression heat pump cases are given in the figure below.

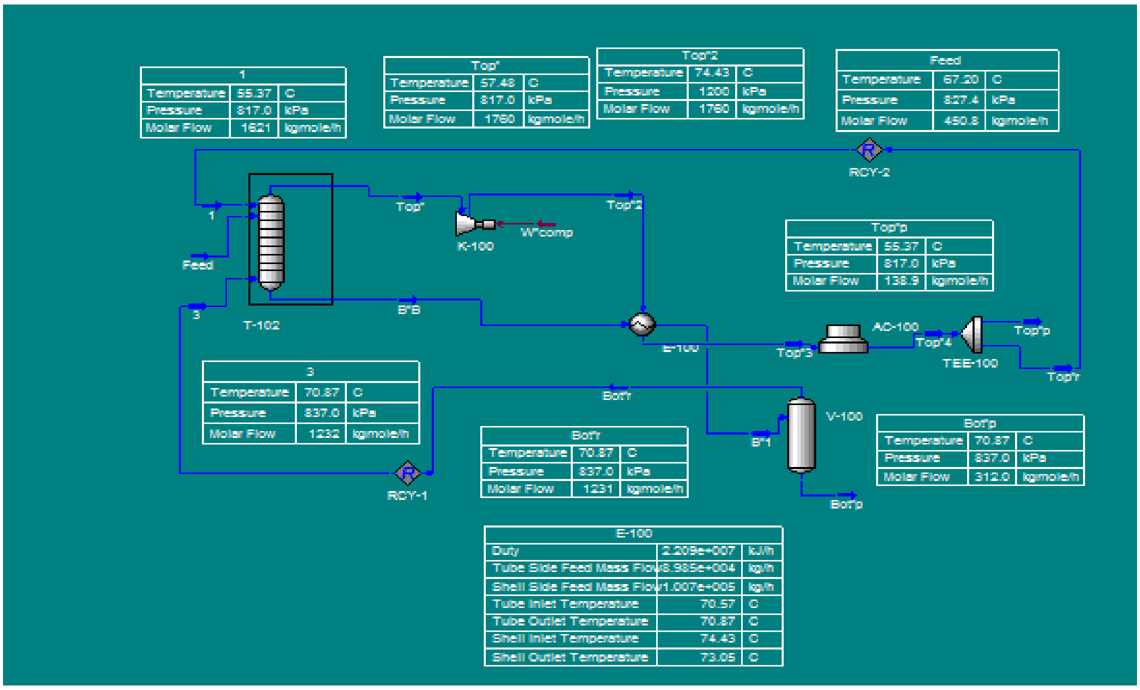


Figure 4.6: Flow Diagram of the MVRHP at 817 kPa

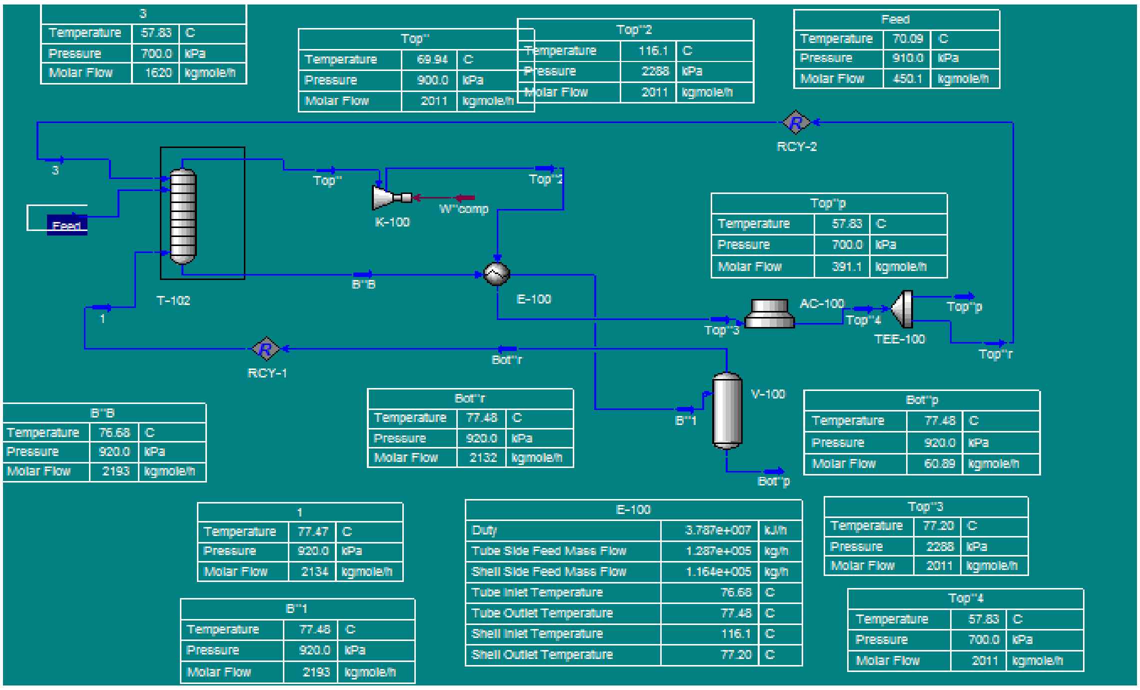


Figure 4.7: Flow Diagram of the Top Vapour recompression at 900 kPa

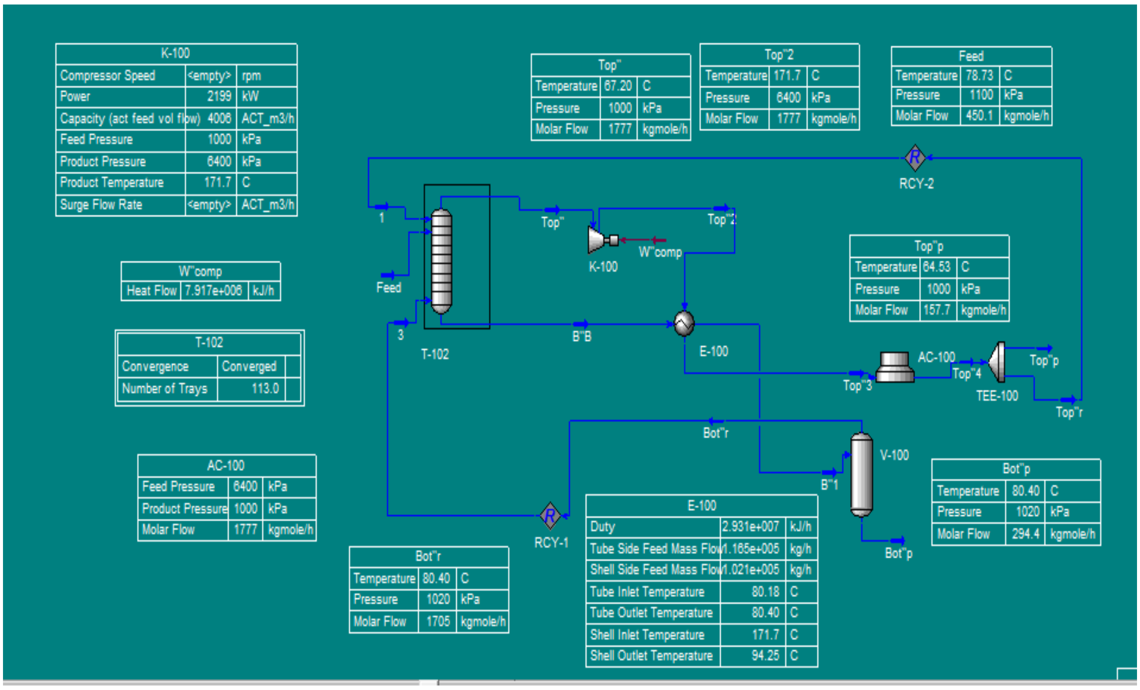


Figure 4.8: Flow Diagram of the Mechanical Vapour recompression at 1000 kPa

4.5 Simulation of Distillation Column with Bottom Flashing Heat Pump

In the Bottom Flashing Heat Pump case like top vapour recompression case we solve the absorber . Here the bottom column outlet stream is expanded in a valve to the desired pressure. Using a Heat Eexchanger column top outlet stream is condensed fully that is we made the vapour fraction zero and bottom column outlet stream is fully vaporized that is we made the vapour fraction 1. Thereafter we used a Tee to get the desired product and recycled the rest liquid stream to the column. Next tube side outlet of the Heat Exchanger was sent to a compressed upto the column bottom Pressure. Then we sent it the cooler to cool it to the boilup stream and to the desired vapour fraction. Thereafter using a separator we collect the liquid bottom product and recycle the vapour stream to the column bottom.

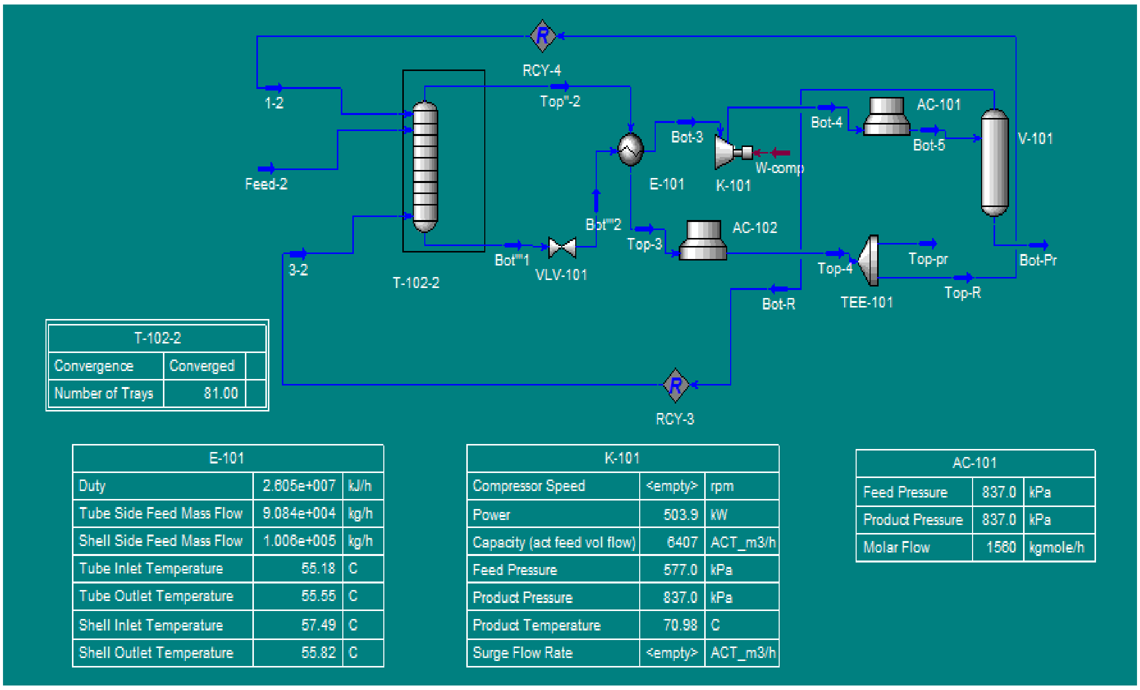


Figure 4.9: Flow Diagram of the bottom flashing Heat Pump at 700 kPa

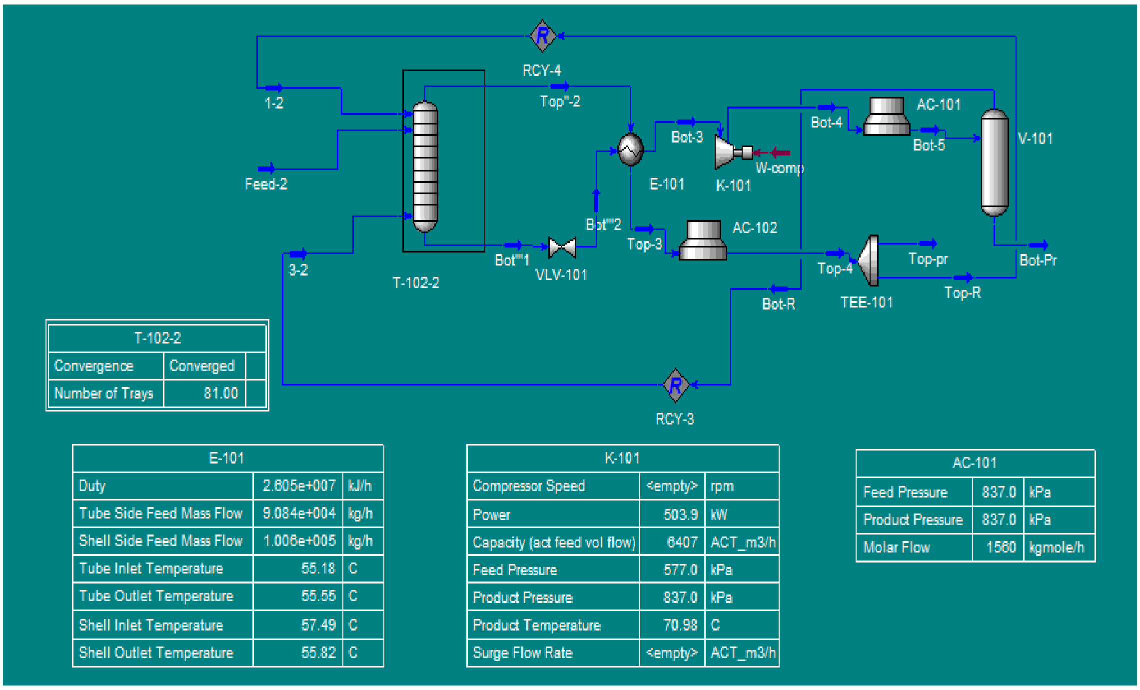


Figure 4.10: Flow Diagram of the bottom flashing Heat Pump at 817 kPa

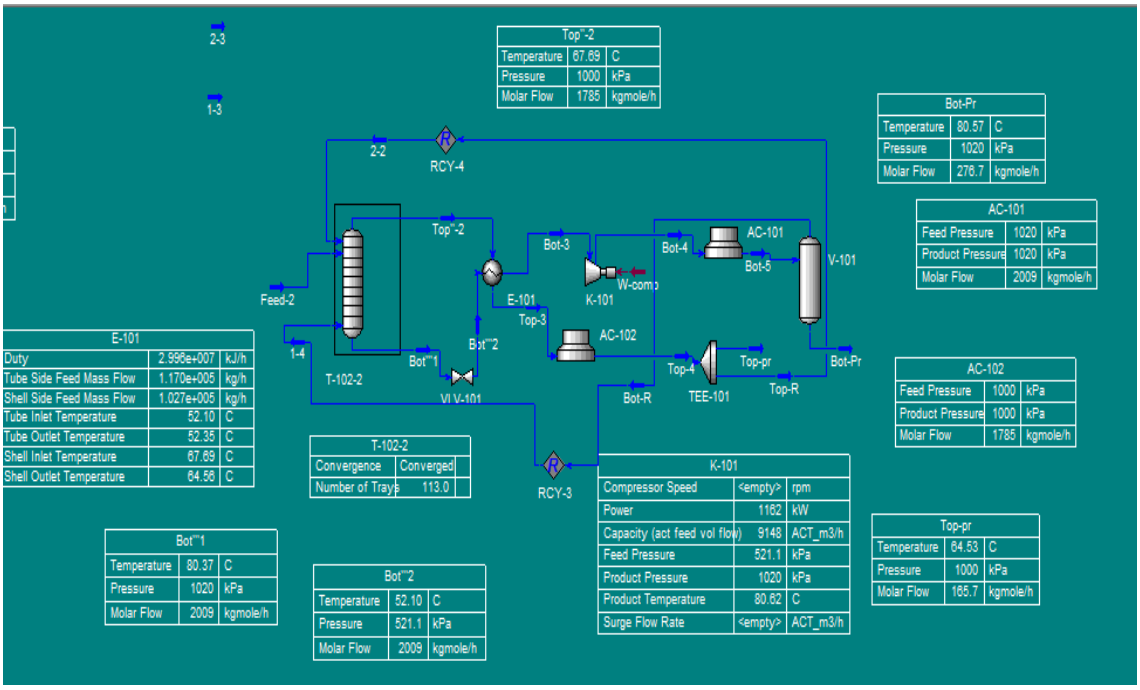


Figure 4.11: Flow Diagram of the bottom flashing Heat Pump at1000 kPa

Figure 4.12: Energy Saving Calculation of Case II data for 817 kPa

Parameter	Value
Conventional case	$4.707 * 10^7$
Condenser Duty (kJ/h)	$3.836 * 10^7$
Reboiler Duty (kJ/h)	$0.66 * 10^7$
Total Energy Required	$8.543 * 10^7$
MVRHP Case	
Compressor Duty (kJ/h)	$0.66 * 10^7$
Heat Exchanger duty (kJ/h)	$3.836 * 10^7$
Cooler Duty (kJ/h)	$1.52 * 10^7$
Total Energy Required (kJ/h)	$4.696 * 10^7$
Energy Saved for MVRHP Case	45.031
BFHP Case	
Heat Exchanger (kJ/h)	$3.896 * 10^7$
Compressor (kJ/h)	$0.606 * 10^7$
Cooler (1) (kJ/h)	$8.132 * 10^6$
Cooler (2) (kJ/h)	$4.78 * 10^7$
Energy Saving for BFHP Case (kJ/h)	44.048

Chapter 5

Double Effect Distillation

5.1 Feed Split Distillation

Fig.5.1 shows the configuration of double-effect feed split distillation. The feed stream was splitted and sent to the High Pressure (HP) column and Low pressure (LP)column separately.The stream of HP column was used to heat the reboiler of LP column. Here pressures are adjusted in such a way that condenser from High Pressure can provide heat to the reboiler of LP column. The pure product streams could be got from the both of the top and bottom of HP column and LP column. Here energy exchange between the two columns and the fluxes of each column could change in a range which can influence the energy saving rate. We have used the same multi-component mixture for this case study also.

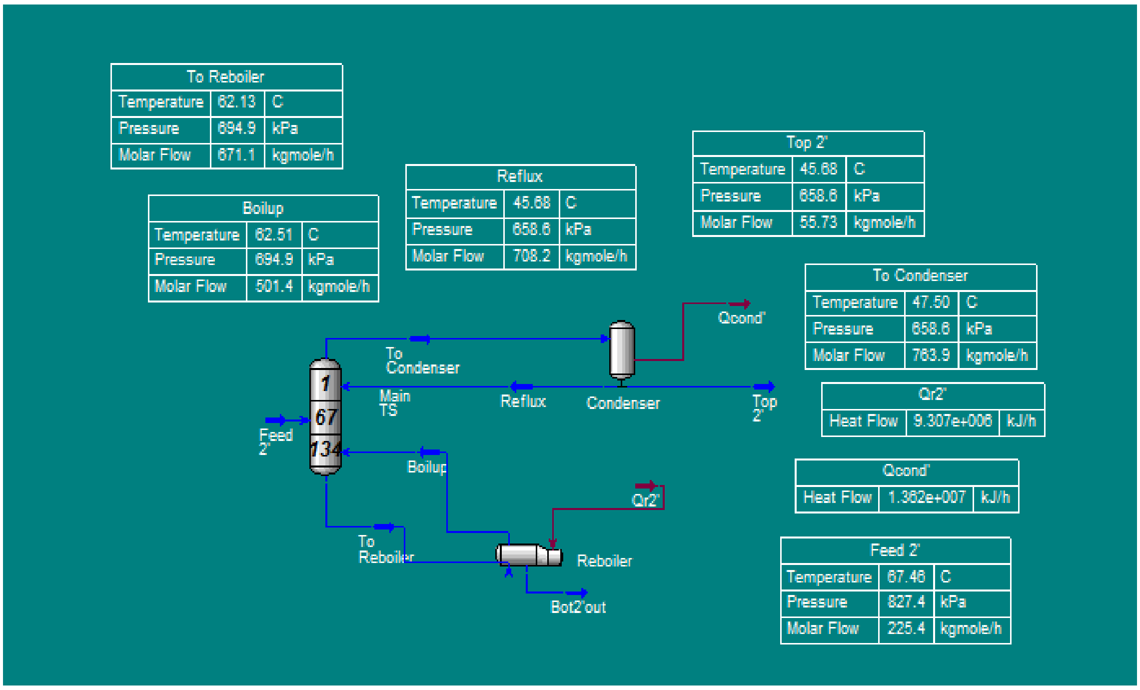


Figure 5.1: Column Environment of the feed split Distillation Column

Table 5.1: Energy requirement of the Conventional Column

Parameter	value
Condenser Energy$^{kJ}/_{h}$	1.362×10^7
Reboiler Energy$^{kJ}/_{h}$	9.307×10^7
Total $^{kJ}/_{h}$	10.669×10^7

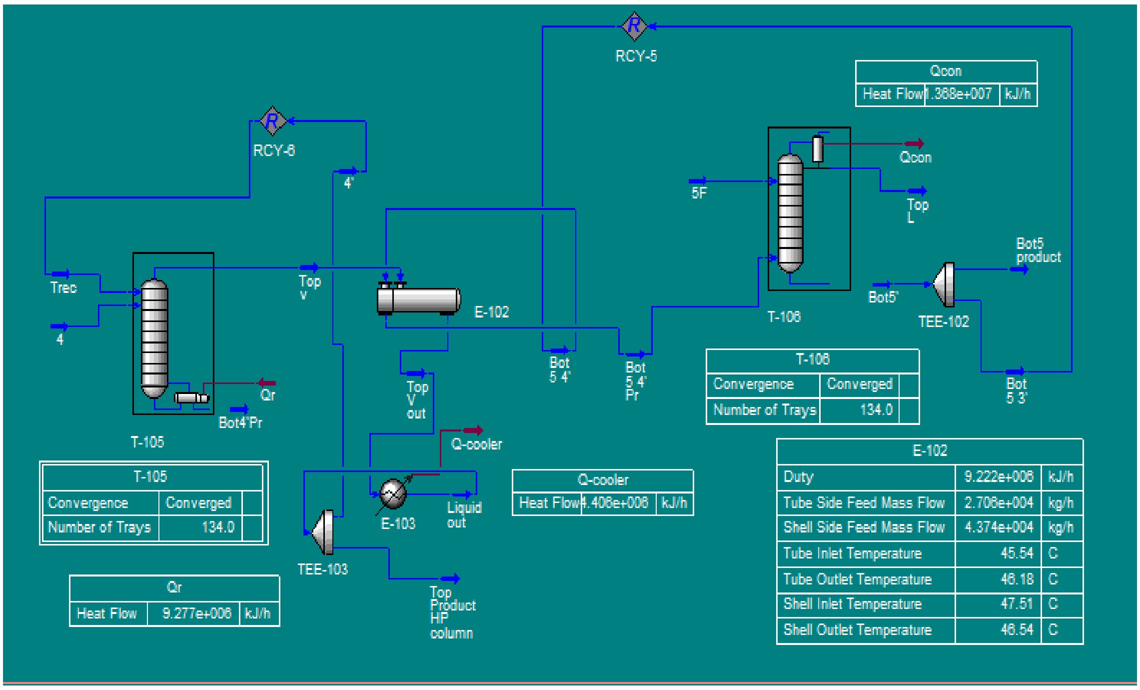


Figure 5.2: Flow Diagram of Double Effect Feed Split Column

Table 5.2: Energy Calculation of Feed Split Column

Parameter	Value
Reboiler$^{kJ}/_{h}$	9.277×10^7
Condenser$^{kJ}/_{h}$	1.368×10^7
Cooler$^{kJ}/_{h}$	4.406×10^7
Total$^{kJ}/_{h}$	15.051×10^7

5.2 Feed Forward Distillation

For feed forward distillation all of the feed flows into HP column. The liquid stream of the bottom HP column flows into LP column. The stream from the top of HP column was used to heat the LP column reboiler. The light component could be got from the top of both the columns. The heavy component could be got from the bottom of LP column.

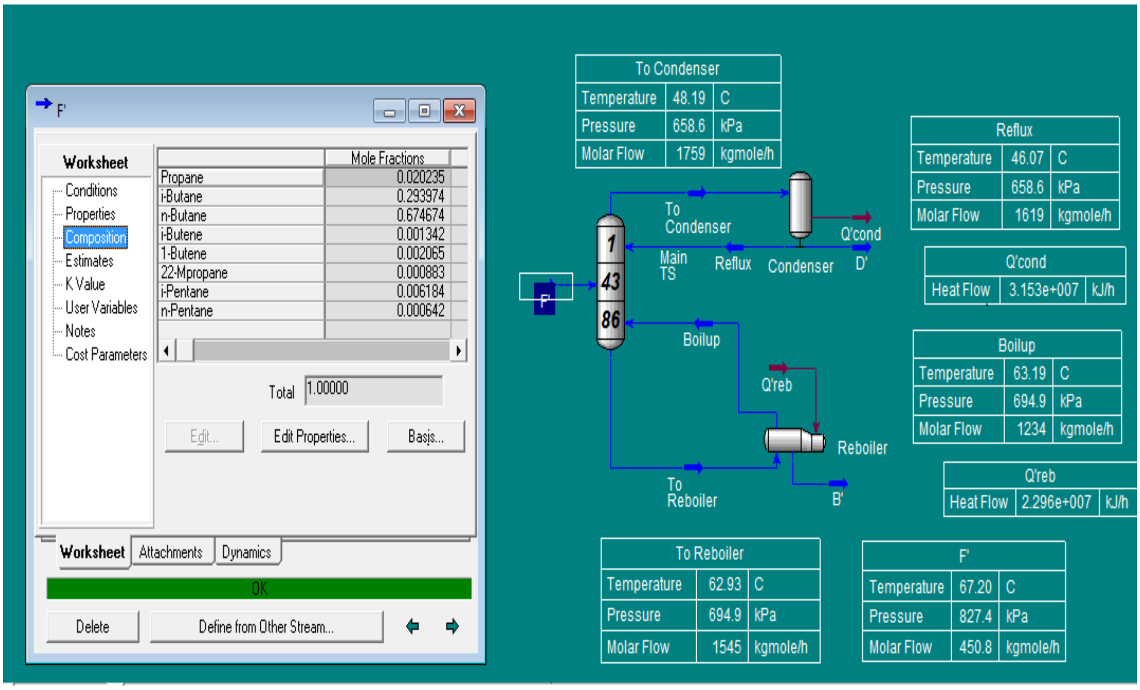


Figure 5.3: Flow Diagram of the Double Effect Feed Forward conventional HPcolumn

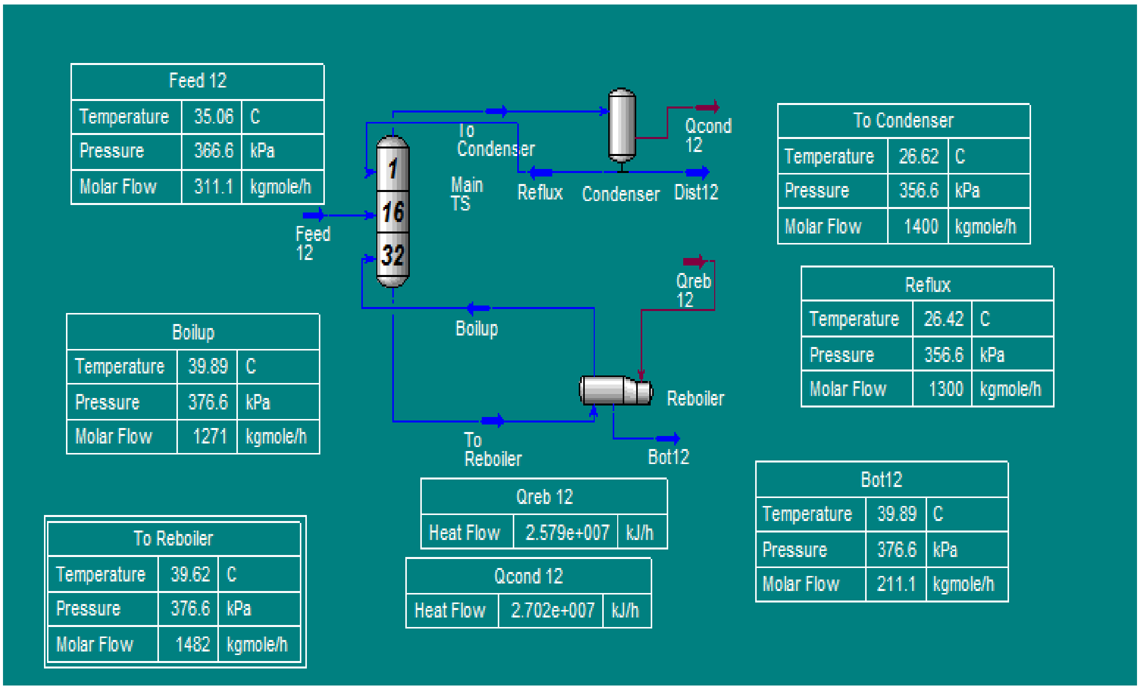


Figure 5.4: Flow Diagram of the Double Effect Feed Forward conventional LPcolumn

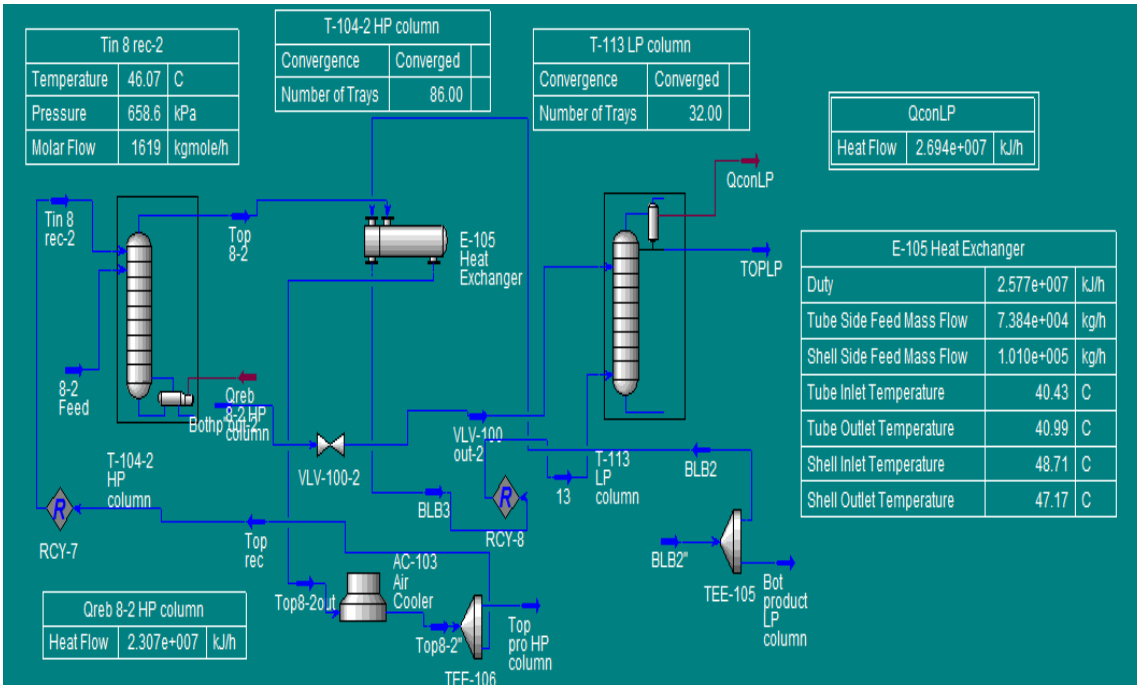


Figure 5.5: Flow diagram of the Feed Forward Distillation simulated by hysys

5.3 Conclusion

We have simulated binary mixture as well as multicomponent mixture of n-butane and iso-butane. Conventional Distillation, Mechanical vapour recompression, Bottom flashing heat pump technology, Double effect Distillation with feed split and Feed forward distillation technology were used . Simulation results have been shown that all technologies can be implemented to save energy than convention distillation. Details of the energy saving have been given in the Table 3.2 and Table 4.12 .For our case studyof binary mixture BFHP showed better energy saving than MVRHP case.For the multicomponent mixture MVRHP showed 44% energy saving and BFHP showed 45%energy saving. For the feed split case there was no energy saving.

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