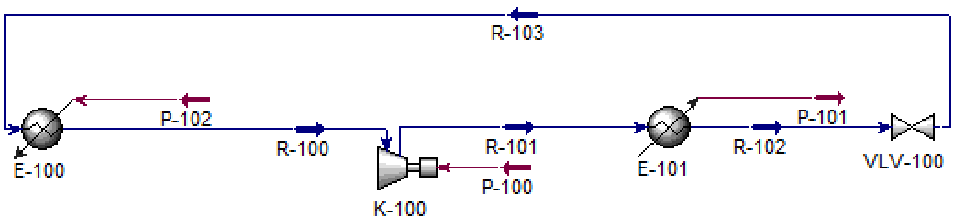
Question 1

Refrigerant 134a enters the compressor of a refrigerator as a superheated vapour at 0.14 MPa and -10 °C at a rate of 0.05 kg/s and leaves at 0.8 MPa and 50 °C. The refrigerant is cooled in the condenser to 26 °C and 0.72 MPa and is throttled to 0.15 MPa. Disregarding any heat transfer or pressure drop in the connecting lines, determine: (a) rate of heat removal from the refrigerated space (b) power input to the compressor (c) isotropic efficiency of the compressor and (d) COP of the refrigerator. Use NRTL with Peng Robinson for vapour phase equation of state for prediction of thermodynamic properties.

Answer

Fluid Package: NRTL



E-100		
Duty	28375.0	kJ/h
Feed Temperature	-17.13	C
Product Temperature	-10.00	C

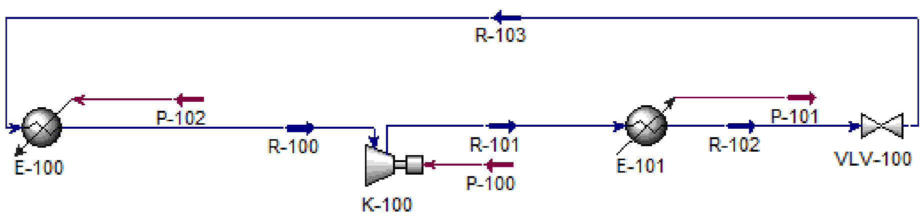
E-101		
DUTY	37357.5	kJ/h
Feed Temperature	50.00	C
Product Temperature	26.00	C

K-100		
Energy	8983	kJ/h
Feed Temperature	-10.00	C
Product Temperature	50.00	C
Feed Pressure	140.0	kPa
Product Pressure	800.0	kPa
Adiabatic Efficiency	82	

VLV-100		
Feed Pressure	720.0	kPa
Product Pressure	150.0	kPa
Feed Temperature	26.00	C
Product Temperature	-17.13	C

a) Rate of heat removal from the refrigerated space, $Q_{in} = 28380\ kJ/h$
b) Power input of the compressor, $W_{in} = 8983\ kJ/h$
c) Isotropic Efficiency 82
d) COP of the refrigerator, $\frac{Q_{in}}{W_{in}} = \frac{28380}{8983} = 3.16$

Fluid Package: Peng-Robinson



E-100		
Duty	28722.6	kJ/h
Feed Temperature	-17.08	C
Product Temperature	-10.00	C

E-101		
DUTY	36245.2	kJ/h
Feed Temperature	50.00	C
Product Temperature	26.00	C

K-100		
Energy	7523	kJ/h
Feed Temperature	-10.00	C
Product Temperature	50.00	C
Feed Pressure	140.0	kPa
Product Pressure	800.0	kPa
Adiabatic Efficiency	91	

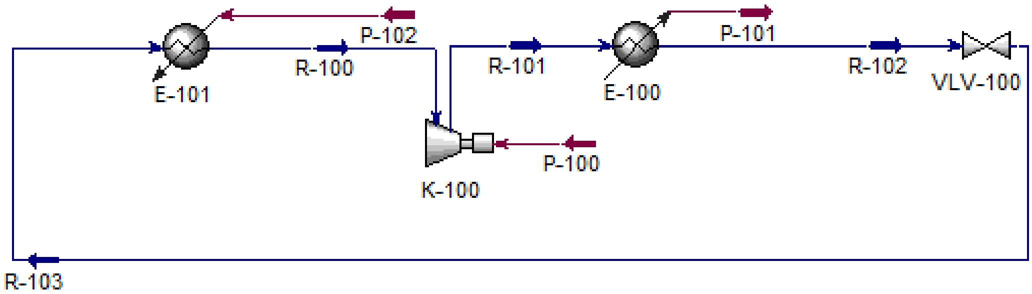
VLV-100		
Feed Pressure	720.0	kPa
Product Pressure	150.0	kPa
Feed Temperature	26.00	C
Product Temperature	-17.08	C

a) Rate of heat removal from the refrigerated space, $Q_{in} = 28722.6\ kJ/h$
b) Power input of the compressor, $W_{in} = 7523\ kJ/h$
c) Isotropic Efficiency 91
d) COP of the refrigerator, $\frac{Q_{in}}{W_{in}} = \frac{28722.6}{7523} = 3.81$

Question 2

In an industrial refrigeration unit, 300 $kgmole/h$ of $R\ 134a$ is used as a refrigerant. A compressor with 70% adiabatic efficiency is used to compress the refrigerant vapour coming out of the evaporator (cooling unit) at 1 bar and 25 °C to a pressure of 10 bar. The superheated refrigerant vapour coming out of the compressor is air cooled in an outdoor heat exchanger to 30 °C. The liquid refrigerant is then throttled through an adiabatic expansion valve to 1 bar exit pressure whereby the refrigerant flashes and its temperature drops. The low temperature refrigerant is now allowed to pass through the evaporator (use a heater for simulation), where a fan forces fresh air to blow over tubes containing the liquid refrigerant while the refrigerant evaporates to vapour. Calculate the (a) cooling capacity, which is the heat load of the evaporator and (b) Compressor power requirement.

Answer



E-101		
Duty	1530	kW
Feed Temperature	-26.37	C
Product Temperature	25.00	C

E-100		
DUTY	2288	kW
Feed Temperature	121.3	C
Product Temperature	30.00	C

K-100		
Feed Pressure	100.0	kPa
Product Pressure	1000	kPa
Feed Temperature	25.00	C
Product Temperature	121.3	C
Energy	757.2	kW

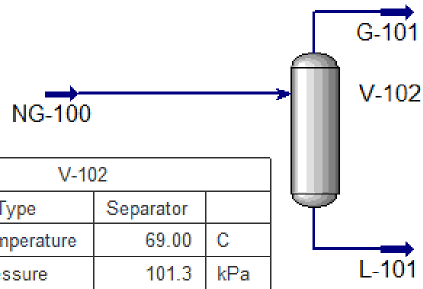
VLV-100		
Feed Pressure	1000	kPa
Product Pressure	100.0	kPa
Feed Temperature	30.00	C
Product Temperature	-26.37	C

a) Rate of heat removal from the refrigerated space, $Q_{in} = 1530\ kW$
b) Power input of the compressor, $W_{in} = 757.2\ kW$
c) Heat release, $Q_{out} = 2288\ kW$
d) COP of the refrigerator, $\frac{Q_{in}}{W_{in}} = \frac{1530}{757.2} = 2.02$

Question 3

A liquid mixture of 25 mol % n-pentane, 45 mol % n-hexane and 30 mol % n-heptane, initially at 69 C and high pressure, is partially vapourised by isothermally lowering the pressure to 1 atm. Find the relative amounts of vapour and liquid and their compositions.

Answer



V-102		
Separator Type	Separator	
Vessel Temperature	69.00	C
Vessel Pressure	101.3	kPa
Liquid Mass Flow	60.38	kg/h
Vapour Mass Flow	39.62	kg/h

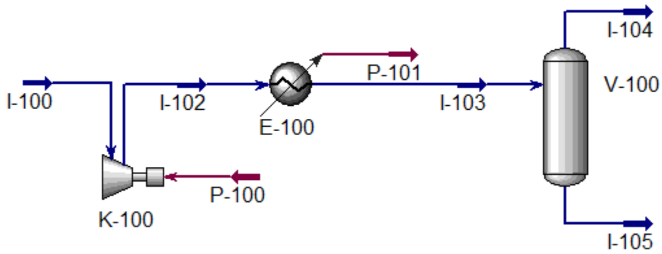
G-101		
Mass Flow	39.62	kg/h
Phase Comp Mole Frac (Vapour Phase-n-Heptane)	0.1605	
Phase Comp Mole Frac (Vapour Phase-n-Hexane)	0.4500	
Phase Comp Mole Frac (Vapour Phase-n-Pentane)	0.3895	

L-101		
Mass Flow	60.38	kg/h
Phase Comp Mole Frac (Liquid Phase-n-Heptane)	0.3989	
Phase Comp Mole Frac (Liquid Phase-n-Hexane)	0.4500	
Phase Comp Mole Frac (Liquid Phase-n-Pentane)	0.1511	

Question 4

We have a 100 $lb\ mol/h$ of a stream containing 15% ethane, 20% propane, 60% i-butane and 5% n-butane at 50 °F and atmospheric pressure. This stream is to be compressed in a compressor with 75% efficiency to 50 $psia$, and then cooled to 32 °F. The resulting vapour and liquid are to be separated as the two product streams. What are the flowrates and compositions of these two streams? Use Peng Robinson equation of state.

Answer



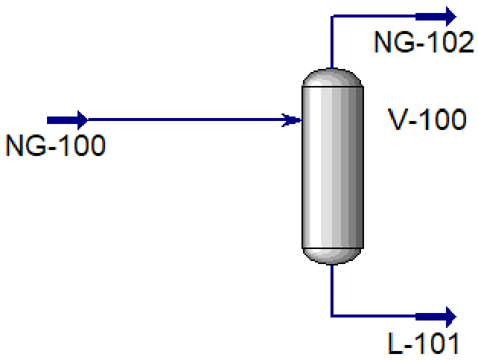
I-104		
Phase Comp Mole Frac (Vapour Phase-Ethane)	0.4026	
Phase Comp Mole Frac (Vapour Phase-i-Butane)	0.3299	
Phase Comp Mole Frac (Vapour Phase-n-Butane)	0.0196	
Phase Comp Mole Frac (Vapour Phase-Propane)	0.2479	
Molar Flow	23.34	lbmole/h

I-105		
Phase Comp Mole Frac (Liquid Phase-Ethane)	0.0731	
Phase Comp Mole Frac (Liquid Phase-i-Butane)	0.6823	
Phase Comp Mole Frac (Liquid Phase-n-Butane)	0.0593	
Phase Comp Mole Frac (Liquid Phase-Propane)	0.1854	
Molar Flow	76.66	lbmole/h

Question 5

Calculate the vapour and liquid compositions in a flash vaporization chamber maintained at 60 C and 1300 kPa for 100 $kmol/h$ of a feed containing ethane, propane, n-butane, and n-pentane, all in equal mol fractions.

Answer



NG-102		
Molar Flow	42.50	kgmole/h
Phase Comp Mole Frac (Vapour Phase-Ethane)	0.4321	
Phase Comp Mole Frac (Vapour Phase-Propane)	0.3050	
Phase Comp Mole Frac (Vapour Phase-n-Butane)	0.1751	
Phase Comp Mole Frac (Vapour Phase-n-Pentane)	0.0878	

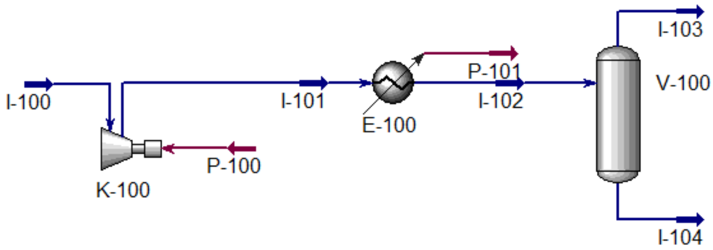
L-101		
Molar Flow	57.50	kgmole/h
Phase Comp Mole Frac (Liquid Phase-Ethane)	0.1154	
Phase Comp Mole Frac (Liquid Phase-Propane)	0.2093	
Phase Comp Mole Frac (Liquid Phase-n-Pentane)	0.3699	
Phase Comp Mole Frac (Liquid Phase-n-Butane)	0.3054	

	Vapour Phase	*Liquid Phase*
Molar Flow Rate (kg mole/h)	42.50	57.50
Ethane (mol %)	0.4321	0.1154
Propane (mol %)	0.3050	0.2093
n-Butane (mol %)	0.1751	0.3699
n-Pentane (mol %)	0.0878	0.3054

Question 6

A 45.36 $kmol/h$ of a stream containing 15% ethane, 20% propane, 60% i-butane and 5% n-butane at 10 °C and atmospheric pressure is compressed in a with 75% efficiency to 350 kpa, and then cooled to 0°C. The resulting stream is then sent to a separation vessel amd the vapour and liquid are withdrawn as two product streams. Determine the flowrates and compositions of these two streams? Use Peng Robinson equation of state.

Answer



I-103		
Molar Flow	10.07	kgmole/h
Phase Comp Mole Frac (Vapour Phase-Ethane)	0.4107	
Phase Comp Mole Frac (Vapour Phase-Propane)	0.2463	
Phase Comp Mole Frac (Vapour Phase-n-Butane)	0.0192	
Phase Comp Mole Frac (Vapour Phase-i-Butane)	0.3238	

I-104		
Molar Flow	35.29	kgmole/h
Phase Comp Mole Frac (Liquid Phase-Ethane)	0.0756	
Phase Comp Mole Frac (Liquid Phase-Propane)	0.1868	
Phase Comp Mole Frac (Liquid Phase-n-Butane)	0.0588	
Phase Comp Mole Frac (Liquid Phase-i-Butane)	0.6788	

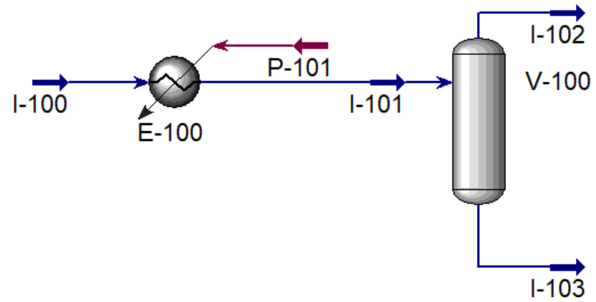
	Vapour Phase	*Liquid Phase*
Molar Flow Rate (kg mole/h)	10.07	35.29
Ethane (mol %)	0.4107	0.0756

Propane (mol %)	0.2463	0.1868
n-Butane (mol %)	0.0192	0.0588
i-Butane (mol %)	0.3238	0.6788

Question 7

100 $kmol/h$ of a hydrocarbon mixture containing 15% i-pentane, 30% n-pentane and rest n-hexane, initially at 30 °C and 1 atm is heated to the extent that 50% of the liquid is vapourised. The resulting liquid-vapour mixture enters an isothermal vessel maintained at atmospheric pressure. Calculate the heat duty of fired heater and the equilibrium compositions of the liquid and vapour coming out of the isothermal flash vessel. Use Peng Robinson equation of state. Assume negligible pressure drop in the fitted heater.

Answer



I-102		
Molar Flow	50.00	kgmole/h
Phase Comp Mole Frac (Vapour Phase-n-Pentane)	0.3773	
Phase Comp Mole Frac (Vapour Phase-i-Pentane)	0.2048	
Phase Comp Mole Frac (Vapour Phase-n-Hexane)	0.4179	

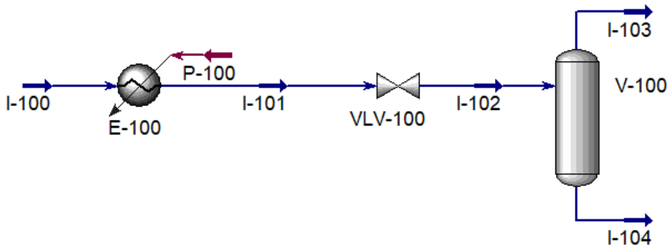
I-103		
Molar Flow	50.00	kgmole/h
Phase Comp Mole Frac (Liquid Phase-n-Pentane)	0.2227	
Phase Comp Mole Frac (Liquid Phase-i-Pentane)	0.0952	
Phase Comp Mole Frac (Liquid Phase-n-Hexane)	0.6821	

	Vapour Phase	*Liquid Phase*
Molar Flow Rate (kg mole/h)	50	50
n-pentane (mol %)	0.3773	0.2227
i-pentane (mol %)	0.2048	0.0952
n-hexane (mol %)	0.4179	0.6821

Question 8

100 $kmol/h$ of a hydrocarbon mixture containing 15% i-pentane, 30% n-pentane and rest n-hexane, at 10 atm and 110 °C (check bubble point of the mixture and ensure that the liquid is below its bubble point) is throttled through isenthalpic valve and then sent to an insulated separator (adiabatic flash) maintained at atmospheric pressure. Calculate the temperature of flash vessel and the equilibrium compositions of the liquid and vapour coming out of the vessel. Use Peng Robinson equation of state. Assume negligible pressure drop in the fitted heater.

Answer



I-103		
Molar Flow	70.45	kgmole/h
Phase Comp Mole Frac (Vapour Phase-n-Pentane)	0.3450	
Phase Comp Mole Frac (Vapour Phase-i-Pentane)	0.1796	
Phase Comp Mole Frac (Vapour Phase-n-Hexane)	0.4754	

I-104		
Molar Flow	29.55	kgmole/h
Phase Comp Mole Frac (Liquid Phase-n-Pentane)	0.1928	
Phase Comp Mole Frac (Liquid Phase-i-Pentane)	0.0793	
Phase Comp Mole Frac (Liquid Phase-n-Hexane)	0.7279	

	Vapour Phase	*Liquid Phase*
Molar Flow Rate (kg mole/h)	50	50
n-pentane (mol %)	0.3450	0.1928
i-pentane (mol %)	0.1796	0.0793
n-hexane (mol %)	0.4754	0.7279