



University of
Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: PET550 Natural Gas Processing and
Transportation

DATE: August 24th 2017

(Continuation exam)

TIME: 09 AM – 01 PM

AID: Category C:
No printed or written means are allowed;
Definite, basic calculator allowed.

THE EXAM CONSISTS OF 7 PAGES

REMARKS:

This set exists only in English

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Exercise 1

A thermodynamic property z of a simple, compressible substance can be expressed as a function of two other, arbitrarily chosen properties, x and y , which gives the total differential:

$$dz = \left(\frac{\partial z}{\partial x} \right)_y dx + \left(\frac{\partial z}{\partial y} \right)_x dy \quad (1)$$

The thermodynamic property enthalpy $h(s, p)$, expressed as a function of entropy s and pressure p , represents a special case where the partial derivatives themselves are thermodynamic properties, i.e. temperature T and volume v :

$$dh = T ds + v dp \quad (2)$$

a) Now, consider the enthalpy $h(T, p)$ as a function of temperature and pressure. Show how the partial derivative of enthalpy with respect to p (at constant T) can be derived from equation 2, to become:

$$\left(\frac{\partial h}{\partial p} \right)_T = T \left(\frac{\partial s}{\partial p} \right)_T + v$$

(Hint: In this context partial ("∂")- and ordinary ("d") derivatives are equivalent)

b) Write the total differential of the enthalpy expressed as a function of temperature and pressure, $h(T, p)$ (cf. equation 1), and then find an expression for the Joule-Thomson coefficient, μ_{JT} , which is defined as:

$$\mu_{JT} \equiv \left(\frac{\partial T}{\partial p} \right)_h$$

(Remember that $\left(\frac{\partial h}{\partial T} \right)_p = c_p$)

c) Show that $\mu_{JT} = 0$ for an ideal gas.

Exercise 2

Figure 1 shows the binary phase diagram ($T-x-y$) for ethane and isobutane at two different pressures, 10 and 20 bar.

a) Answer the following from the diagram in Figure 1:

- I: What are the boiling point temperatures of pure ethane and i-butane at 20 bar ?
- II: What are the dew point temperatures for a mixture of 30 % ethane (and 70 % i-butane) at 10 and 20 bars, respectively ?
- III: What will be the liquid- and vapour mole fractions of ethane for a system in vapour-liquid equilibrium at 10 bar and +20 °C ?

b) Consider the following hypothetical experiment: A liquid mixture originally at $x = 0.45$ (45 % ethane) is heated at a constant pressure of 10 bar, up to a temperature where it becomes 2-phase. Then the vapour phase is extracted, and pressurized to 20 bar at this same,

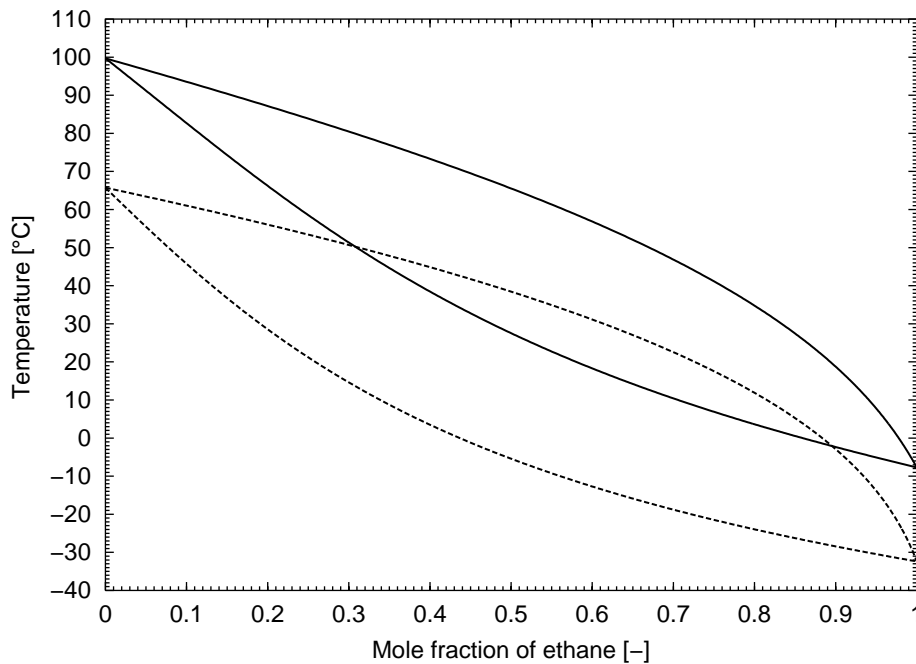


Figure 1: Binary phase diagram ($T - x - y$) for ethane and i-butane at 10 and 20 bar.

constant temperature. After vapour-liquid equilibrium is once more established at this new condition, the composition of the liquid phase is found to be exactly as the original liquid ($x = 0.45$). What temperature are we talking about ?

c) A stream containing 40 % ethane and 60 % i-butane at 20 bar and 60 °C (where it is 2-phase) is expanded down to 10 bar in a Joule-Thomson valve. Numerical values for the Joule-Thomson coefficient can be obtained e.g. from an equation of state, and an average value for the current range of conditions is found to be $\mu_{JT} \approx 2.6$ K/bar.

- I: Use the Joule-Thomson coefficient (defined in Exercise 1) to estimate the temperature after expansion.
- II: Find the vapour- and liquid composition after expansion.
- III: Calculate the vapour phase fraction, α .

Exercise 3

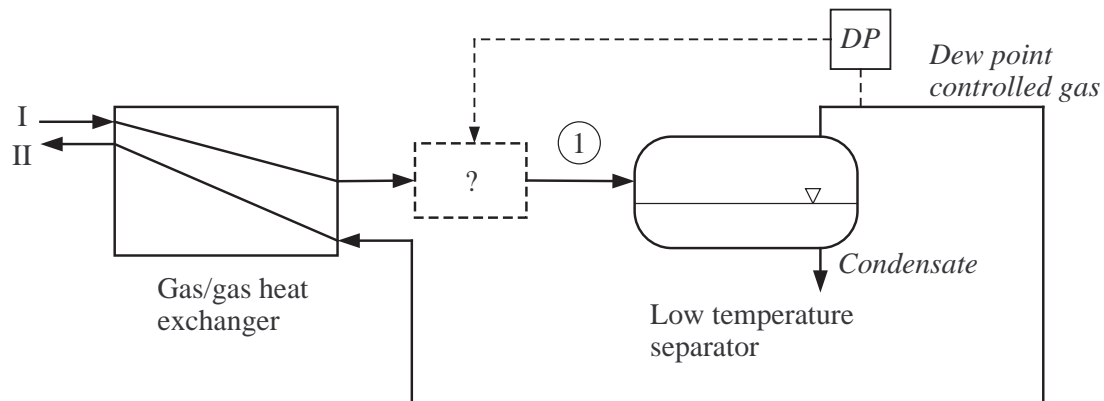


Figure 2: Simple dew point control system, schematically.

Figure 2 shows a sketch of a simple process for controlling the hydrocarbon dew point of a gas by lowering temperature so that the heavier components can be removed as condensate.

a) There are alternative ways to bring down the temperature, as indicated by the box marked by "?". Suggest some pro's and con's by the following devices:

1. Heat exchanger cooled by external refrigeration unit.
2. Joule-Thomson valve.
3. Expansion turbine.

b) The gas/gas heat exchanger utilizes the low temperature in the dew point controlled gas for pre-cooling. What is the main reason why the minimum temperature difference (i.e. approach) will be on the high-temperature side ?

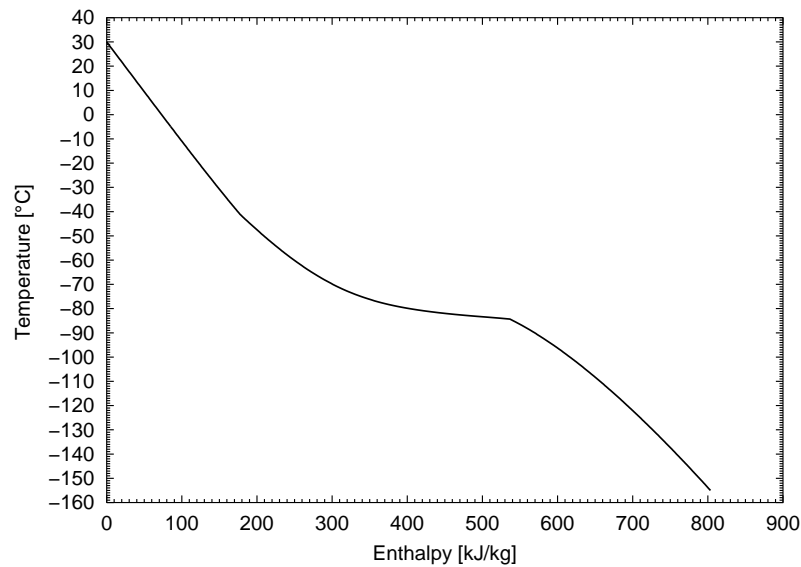
c) Assume that there is a device for continuously monitoring the dew point temperature. If this device suddenly detects a too high value, should the control system bring the temperature at 1 up or down ?

d) If using a JT-valve or a turbine, one might want to recompress the gas. On which side of the gas/gas heat exchanger should the compressor be placed, and why ?

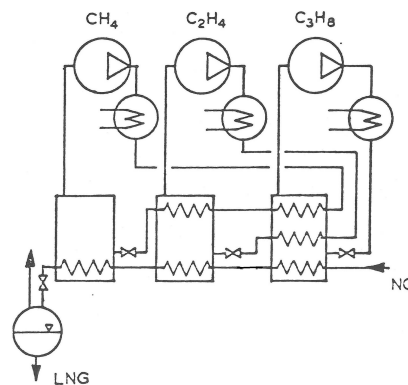
Exercise 4

Figure 3a shows a temperature vs. enthalpy diagram for a natural gas at 40 bar, a so-called cool-down curve. The diagram is arranged so that the horizontal axis shows how much heat per kg gas is removed as it is cooled from +30 °C, down to approximately LNG temperature.

A simplified LNG process is assumed, as in Figure 3b, consisting of a cascade with methane, ethylene and propane coupled in series, but operating with only one temperature level and



(a) Cool-down curve for natural gas



(b) Simplified LNG cascade

Figure 3: Cool-down curve and simplified LNG process

one compression stage per refrigerant.

a) Given that methane, ethylene and propane can operate at evaporation temperatures of $-160\text{ }^{\circ}\text{C}$, $-100\text{ }^{\circ}\text{C}$ and $-40\text{ }^{\circ}\text{C}$, respectively, use the diagram in Figure 3a to estimate how many kJ/kg that each of the refrigerant circuits must remove from the gas. The lowest allowable temperature difference (approach) in any heat exchanger is set to 5 K.

b) The plant is of moderate size, with a production capacity of 1.5 mtpa (million tons per annum) if run continuously. What will be the required cold duty (in e.g. kW) for the methane circuit ?

c) Assuming one-stage compression and an isentropic efficiency $\eta_{\text{is}} = 0.91$, find the methane compressor work requirement.

(Remember that the methane has to be condensed by ethylene)

Attachment 1: Formulae and constants

The Maxwell relations for thermodynamics:

$$\left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial p}{\partial s}\right)_v, \quad \left(\frac{\partial p}{\partial T}\right)_v = \left(\frac{\partial s}{\partial v}\right)_T$$

$$\left(\frac{\partial T}{\partial p}\right)_s = \left(\frac{\partial v}{\partial s}\right)_p, \quad \left(\frac{\partial v}{\partial T}\right)_p = -\left(\frac{\partial s}{\partial p}\right)_T$$

Equation of state for ideal gas:

$$p(v, T) = \frac{R T}{v}$$

Constants:

Universal gas constant:	R	=	8.3144 J/mole K
Absolute zero temperature (0 K):	T_0	=	- 273.15 °C
Atmospheric pressure (1 atm):	p_0	=	1.01325 bar
Standard pressure (1 atm):	p_{sc}	=	1.01325 bar = 101.325 kPa
Standard temperature:	T_{sc}	=	15 °C = 288.15 K

Conversion factors:

1 ton	=	1000 kg		
1 bar	=	100000 N/m ²	=	100 kPa = 0.1 MPa

Attachment 2: $\log(p)$ - h diagram for methane (for Exercise 4)