

ANALYSIS OF TEMPERATURE CHANGES IN MEMBRANE GAS SEPARATION - A THEORETICAL INVESTIGATION

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ABSTRACT

The usual assumption that a membrane gas separation process is isothermal may not be valid in certain situation. This paper shows that temperature changes does occur in a bio-gas separation. The temperature decrease happened in high feed pressure is severe and cannot be ignored in designing such a process. This analysis shows that the drop of temperature increase with feed pressure.

INTRODUCTION

Over the past decade, membranes have entered territories that were previously dominated by more traditional separations such as cryogenic distillation, absorption and adsorption. Even in many cases where membranes have not obsoleted these technologies, hybrid systems based on membranes combined with one of these more traditional techniques are being accepted as attractive options (Koros, 1993).

Membrane technology has been applied successfully in various gas separation processes such as natural gas sweetening, recovery of CO₂ in enhanced oil recovery, recovery of H₂ from purge gas in NH₃ production, oxygen enrichment and recovery of methane from biogas.

Apart from the membrane itself, process conditions such as stage cut, feed pressure, temperature and feed composition influence the performance of membrane gas separation. The process conditions are always assumed to be isothermal. However this assumption is not always valid. In this paper, an example is used to demonstrate that temperature changes in a membrane gas permeator can not be neglected. The thermodynamic analysis and calculation method used are based on the proposal by Gorissen (1987) with some modifications.

In designing a membrane separation process it is very important to predict possible temperature effects, because both the permeabilities and the separation factor are temperature dependent. The permeabilities tend to increase with temperature, whereas in general the separation factors tend to decrease.

THEORY

Figure 1 shows a schematic representation of a membrane gas permeator. The pressure of the retentate is almost equal to the feed pressure. The permeate has a much lower pressure and is relatively rich in the fastest permeating components.

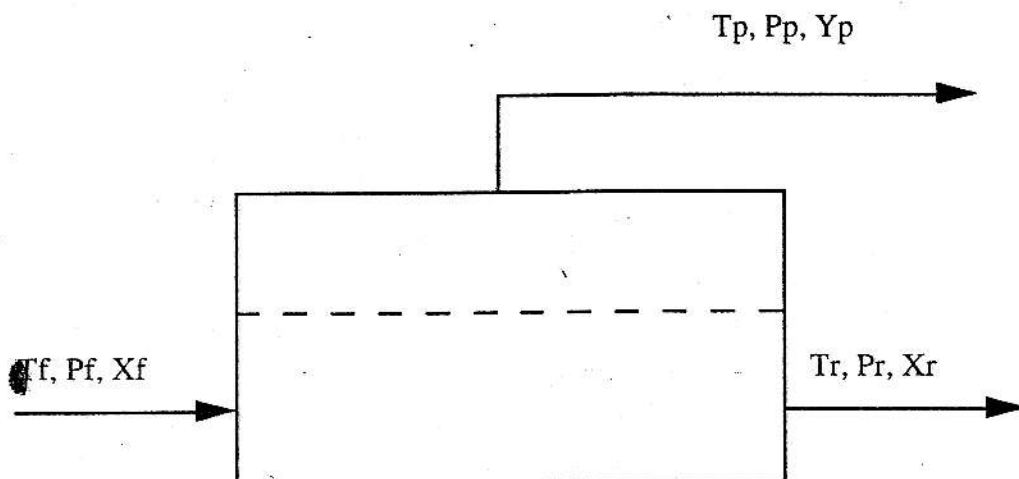


Figure 1. Schematic diagram of membrane gas separation process

Membrane gas separations can be assumed as an isenthalpic processes. The overall heat balance can be written as:

$$h_f = (1 - q)h_r + qh_p \quad \text{----- (1)}$$

In ideal condition where all the streams contain perfect gases, the enthalpies of these streams will not alter as a result of pressure changes or heat of mixing because there are no interactions between the gas particles.

In this case the enthalpies of the gases are dependent on the temperature only. The temperatures will remain constant since the enthalpies do not change.

However, it is not always correct to assume that all gases are perfect, especially in the case of high feed pressure. For imperfect gases the enthalpies are dependent on pressure, composition and temperature. Thus equation (1) can only remain valid if the temperatures of the streams change.

CALCULATION METHOD

The temperature profile in a membrane permeator can be calculated by splitting up the permeator into differential volume elements as shown in Figure 2.

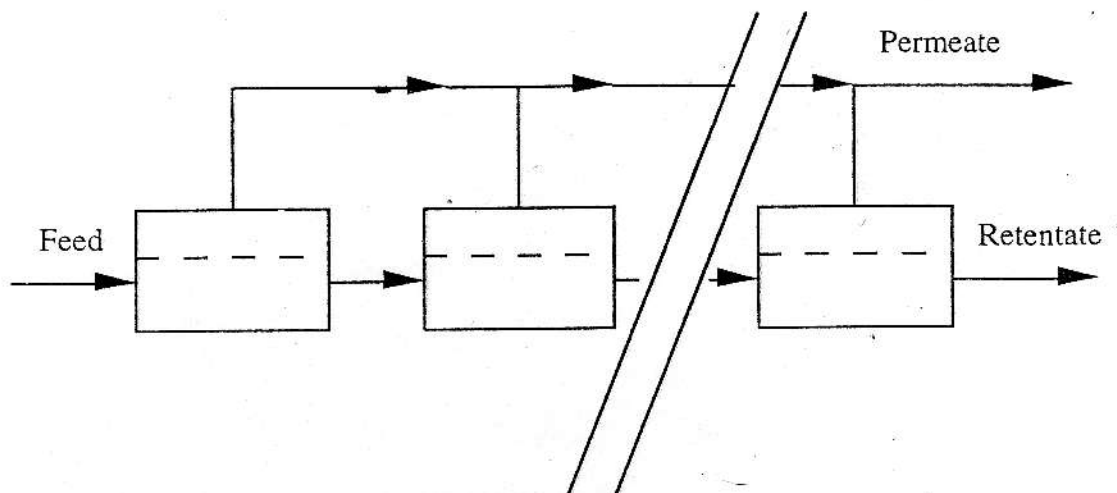


Figure 2. Membrane permeator split into elements

The temperature for each element can be calculated from the enthalpy balance equation below:

$$f h_f = (f - Dq) h_r + Dq h_p \quad \text{----- (2)}$$

With the help of a computer, the temperature profile of the membrane gas separation can be calculated fairly easy. No detailed knowledge of the membrane transport mechanisms is needed to calculate the temperature changes. The temperature changes are determined by the thermodynamic properties of the involved gas streams only.

EXAMPLES

Recovery of methane from biogas

A gas stream consists of 40 mol% carbon dioxide and 60 mol% methane. Three different feed pressure, i.e. 50, 40 and 30 bar are used. Carbon dioxide is the fast gas. The separation factor is 30 and the permeate pressure is 2 bar. The stage cut used is 0.5.

Gas enthalpy values are calculated with the aid of Soave-Redlich-Kwong equation of state (Edmister, 1984). The permeate and retentate compositions are calculated using a computer program SHETAL (Sutransno, 1994). The separation factor is assumed to be independent of the temperature. It is assumed that there is no pressure drop in the feed side ($P_F = P_R$).

RESULTS AND DISCUSSIONS

The temperature profiles for three different feed pressure are shown in Fig. 3. The temperatures of retentate are 9, 15, 21 °C respectively for feed pressures 50, 40, 30 bar. Thus the separation involves a major temperature decrease. As can be seen in Fig. 3, the temperature changes is most severe when feed pressure is 50 bar. The higher the feed pressure, the greater is the temperature changes.

The process may be strongly influenced as a result of these changes, for example a higher membrane surface area might be required because of decreasing permeabilities. In a more serious condition, condensation may also occur. More examples will be investigated to study the temperatures changes in membrane gas separation process in the coming articles.

CONCLUSION

The assumption that the process condition is isothermal when designing a membrane gas separation process may not always be valid. The biogas example shows that major temperature changes may occur. This is especially obvious in high pressure operation. In designing such a process this temperature changes should be taken into consideration.

Reference

1. Koros, W.J., and Fleming, G.K. (1993). "Membrane Based Gas Separation." Journal of Membrane Science, 83: 1 - 80.
2. Gorissen, H. (1987). "Temperature Changes Involved in Membrane Gas Separation." Chemical Engineering Progress, 22: 63 - 67.

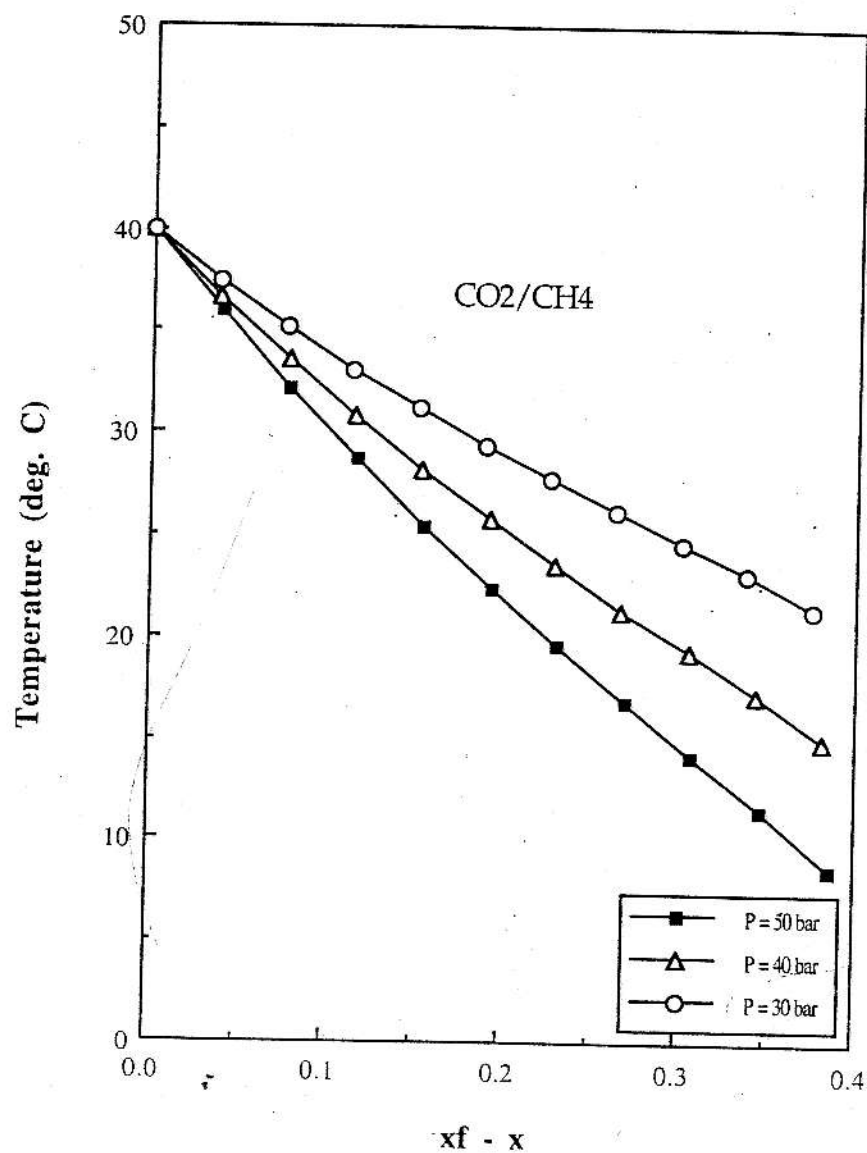


Figure 3. Temperature profile of a biogas permeator

3. Edmister, W.C., and B.I. Lee. (1984). Applied Hydrocarbon Thermodynamics, Vol. I. Houston, Texas : Gulf Publishing Company.
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Nomenclature

h	molar enthalpy
P	pressure
T	temperature
x	feed side mole fraction
y	permeate side mole fraction
q	stage cut (permeate/feed)
f	feed side fraction (retentate/feed)