A CONTRIBUTION TO THE PROBLEM OF PARTIAL CONDENSATION OF A BINARY VAPOUR MIXTURE

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An empirical approach has been proposed to solve the problem of partial condensation of a binary vapour mixture. The approach accounts for the effect of the intensity of cooling on the composition of the streams existing from a partial condenser at constant composition of inlet vapours.

The problem of partial condensation of a binary mixture of vapours has been so far relatively little examined, considering its importance not only from the standpoint of condensation itself, partial or total, but also from the standpoint of nonadiabating rectification.

Theoretical analysis of the problem was provided by Colburn and Drew[1], who considered both local conditions during partial condensation as well as the change of vapour composition during condensation. These authors themselves conceed that a number of questions remains that need further experimental study.

Van Es and Heertjes in their first paper[2] essentially recapitulate results of the previous author[1] and furnish a relationship for the calculation of the temperature difference between the wall of the condensator and the bulk vapour stream. In their next paper[3], the same authors essentially expand and supplement their previous work, but their conclusions all possess only qualitative nature.

Additional papers, concerning partial condensation[4-14], are all experimental and devoted to the determination of the mass or heat transfer coefficient under various conditions.

The principal drawback of the theoretical papers is the fact that the authors start from the assumption of equilibrium conditions on the interface between the condensate and the vapour, or the assumption that the deviations from equilibrium are negligible. Further it is assumed that, due to the heat transfer, the vapour at the interface is colder and richer in the low boiling component compared to the bulk vapour. Thanks to this differences, diffusion takes place transporting the low boiling component away from the interface in the bulk stream, while the thermal process, heat conduction, follows the opposite path.

The mere fact that partial condensation is mostly a process with a finite, sometimes fairly high intensity, rules out the assumption of equilibrium conditions at the interface. It may be assumed that vapour condensation causes local decrease of pressure at the interface, which brings about a sudden influx of ambient vapours. Consequently, the mentioned molecular transports (diffusion of mass and heat conduction) take place at random and depend on the intensity of cooling. The more intensive the cooling, the more intensive influx of the vapour toward the interface and, hence, the greater the deviations from equilibrium. Generally it may thus be expected that the composition of the condensate for a vapour mixture of a given composition is a function of the intensity of cooling and ranges from the composition of vapours, at very rapid condensation, up to the composition of equilibrium condensate, at very slow condensation.

THEORETICAL

From a balance of the low boiling component in the vapour phase there follows

$$\mathrm{d}(Vy) = x\,\mathrm{d}V + k_g(y_i - y)\,\mathrm{d}A\,, \tag{1}$$

where the first term on the right hand side represents the amount of the low boiling component transferred by condensation, while the second term represents the amount transferred by diffusion.

The composition of the condensate, x, may be assumed to be a function of the intensity of cooling, as follows from the foregoing analysis, and this dependence may be taken in the form

$$x = y - a(y - x^*)\,, \tag{2}$$

where a assumes values, depending on the intensity of cooling, from the range

$$0 \leqq a \leqq 1\,.$$

This dependence must be determined experimentally.

Substituting for x from Eq. (2) into Eq. (1) and after some arrangement we obtain

$$\mathrm{d}y/(y - x^*) - k_g(y_i - y)\,\mathrm{d}A/V(y - x^*) = -a\,\mathrm{d}V/V \tag{3}$$

or, after integration and substitution from

$$R = L_1/V_2\,, \tag{4}$$

we obtain

$$a = \left[\int_{y_1}^{y_2} \mathrm{d}y/(y - x^*) - \int_0^A k_g(y_i - y)\,\mathrm{d}A/V(y - x^*)\right](\ln(R + 1))^{-1}\,. \tag{5}$$

The second term in the numerator of Eq. (5) will be mostly negligible and, consequently, as a first estimate we can write

$$a = [\ln(R + 1)]^{-1} \int_{y_1}^{y_2} \mathrm{d}y/(y - x^*)\,. \tag{6}$$

The integral in Eq. (6) may be evaluated using equilibrium data by a numerical or graphical routine. For further use it is convenient to construct the following function

$$\varphi(y) = \int_{y_1}^{y} \mathrm{d}y/(y - x^*)\,. \tag{7}$$

RESULTS AND DISCUSSION

For verification of the proposed approach we used data of Vaněček[14], obtained from experiments with partial condensation of methanol/water and acetone/water systems in vertical glass tubes 8 and 15 mm internal diameter and 468 mm and 1 000 mm long.

First, the dependence (7) was constructed for both mixtures while taking for y_1 the lowest value of inlet vapour composition. From this dependence and experimental values of the outlet concentration, y_2, one could then evaluate for various intensities of cooling the integral in Eq. (6) and the parameter a and hence construct the following dependence

$$a = f(Lr/A)\,. \tag{8}$$

For the methanol/water mixture statistical processing of the data yielded

$$a = 0{\cdot}89 - 0{\cdot}03(Lr/A) \tag{9}$$

while for the acetone/water mixture

$$a = 1{\cdot}028 - 0{\cdot}0308(Lr/A)\,. \tag{10}$$

Using Eqs (9) and (10), values of y_2 were evaluated recurrently for the methanol/water mixture with a mean deviation $\sigma = \pm 4{\cdot}46\,.\,10^{-2}$ and for the acetone/water mixture with a mean deviation $\sigma = \pm 6{\cdot}68\,.\,10^{-2}$.

From the empirical dependences (*9*) and (*10*) it is apparent that their course corresponds to the expectation. For very low intensities of cooling the value of the parameter a approaches unity and it decreases toward zero for rapid cooling. It is noted that the course of a for both mixtures is very similar. The differences in the slope as well as abscissa may be caused by overly simplified form of the dependence (*8*), experimental error, and eventually also by neglect of the diffusional term in Eq. (*5*). In order that the proposed approach may be generalized, additional experimental data, suitable for the evaluation of the parameter a from Eq. (*8*), are needed.

The outlined procedure allows solutions of partial condensation for various input data sets. First of all, Eqs (*9*) and (*10*) provide estimates of the intensities of cooling, leading to total condensation. For the two above mixture this limiting intensity is about 30 kW/m^2. Usually, the input information is the inlet composition of vapours, y_1, and further procedure depends on the requirements put on the condensation. If, for instance, we request a certain composition of the outlet vapours, *i.e.* y_2 is stipulated, a suitable intensity of cooling is selected, the parameter a, Eq. (*8*), is computed and the value of R is computed from Eq. (*6*). With y_1 and R stipulated as input data we again estimate the intensity of cooling, calculate a from Eq. (*8*), the integral from Eq. (*6*) and from Eq. (*7*) its upper limit y_2, *i.e.* concentration of oulet vapour. The estimates of cooling intensities are, if necessary, repeated.

LIST OF SYMBOLS

A	interfacial surface, m^2
a	defined in Eq. (*2*)
k_g	vapour side mass transfer coefficient, kmol m^{-2} s^{-1}
L	molar flow rate of liquid, kmol s^{-1}
R	reflux ratio, defined in Eq. (*4*)
r	heat of evaporation, kJ kmol^{-1}
V	molar flow rate of vapours, kmol s^{-1}
y	mole fraction of low boiling component in vapour
x	mole fraction of low boiling component in liquid
$\varphi(y)$	function defined in Eq. (7)

Subscripts

1	vapour inlet
2	vapour outlet
i	interface
*	equilibrium value

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