

BRIEF COMMUNICATION

COMMENTS ON "VERIFICATION OF MULTICOMPONENT MASS TRANSFER MODELS FOR CONDENSATION INSIDE A VERTICAL TUBE"

R. KRISHNA

Eikenweg 38, 1092 CA Amsterdam, The Netherlands

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In a recent paper Webb & Sardesai (1981) have tested the applicability of multicomponent film models of Krishna & Standart (1976), Toor (1964) and Stewart & Prober (1964). The mass transfer coefficients in the gas phase are evaluated with the aid of the Chilton-Colburn analogy. I believe that there are fundamental objections against the use of the generalization of the Chilton-Colburn analogy to multicomponent systems; my objections are as explained below.

The first step in the calculation of the mass transfer rates is the estimation of the binary pair mass transfer coefficients, k_{ij} . Following the procedure of Krishna & Standart (1976) and Toor (1964) these coefficients are evaluated from the relationship:

$$\frac{k_{ij}\bar{M}_G}{\rho_G U_{av}} = j_H Sc_{ij}^{-2/3} \quad [1]$$

where ρ_G is the mass density of the gas mixture and U_{av} is the mean gas velocity of the gas mixture inside the tube; other symbols are as defined in Webb & Sardesai (1981).

Once all the binary pair mass transfer coefficients in the multicomponent mixture have been evaluated using [1], the matrix of zero flux multicomponent mass transfer coefficients $[K]$ is evaluated using the relationship:

$$[K] = [M]^{-1} \quad [2]$$

where the elements of the $(n-1) \times (n-1)$ dimensional square matrix $[M]$ are given by:

$$M_{ii} = \frac{m_i}{k_{in}} + \sum_{j=1}^n \frac{m_j}{k_{ij}}, \quad i = 1, 2, \dots, n-1 \quad [3]$$

$$M_{ij} = -m_i \left(\frac{1}{k_{ij}} - \frac{1}{k_{in}} \right), \quad i, j = 1, 2, \dots, n-1. \quad [4]$$

In the Krishna & Standart (1976) model the m_i in [3] and [4] are equal to the bulk gas phase mole fractions y_{iG} ; in the approach of Toor (1964) and Stewart & Prober (1964), m_i is to be taken as the average composition between the bulk gas and the interface (Webb & Sardesai 1981): $m_i = 0.5 (y_{iG} + y_{iI})$.

Now, since only j_H in the [1]-[4] is a function of the Reynolds number, Re , it is easy to see

that the ratio of the cross-coefficient to the main one in $[K]$, i.e.

$$\frac{K_{ij}}{K_{ii}} (i \neq j)$$

is independent of Re . Now, we might expect that increasing the Reynolds number for flow of the gas mixture inside the tube will have the effect of increasing the turbulent eddy transport mechanism in relation to the molecular diffusion contribution. Turbulent eddy transport is not species specific (Krishna 1981a) and therefore we might expect that the effect of increasing Re would be to decrease the influence of the molecular diffusion coupling. However, the multi-component generalization of the Chilton–Colburn analogy, embodied in [1]–[4], shows that the relative influence of molecular diffusion coupling remains *unchanged* with increasing turbulence intensity (increasing Re). It must be concluded that the predictions of the multicomponent generalization of the Chilton–Colburn analogy are physically unrealistic. The proper procedure is to model, separately, the molecular diffusion and turbulent eddy contributions (Krishna 1981b); such an approach is only possible for simple flow situations: flow over flat plates and inside tubes (Krishna 1981a), where complete information on the eddy diffusivity as a function of distance from the interface is available. The multicomponent condensation phenomena inside a vertical tube lends itself to such an approach.

For condensation inside a vertical tube of a mixture of acetone (1)–benzene (2) in the presence of inert gas helium (3), calculations were performed for the ratio K_{12}/K_{11} using the Chilton–Colburn approach, [1]–[4], and a turbulent film model using the von Kármán universal velocity distribution (for details of this model see Krishna (1981a)); the results of the two model predictions are shown in figure 1, as function of the gas phase Reynolds number. The turbulent film model predicts a relative decrease in molecular diffusional coupling as the turbulence level is increased (by increase of Re), in accord with our physical intuition. The multicomponent Chilton–Colburn model predicts that K_{12}/K_{11} is independent of Re , an unlikely circumstance.

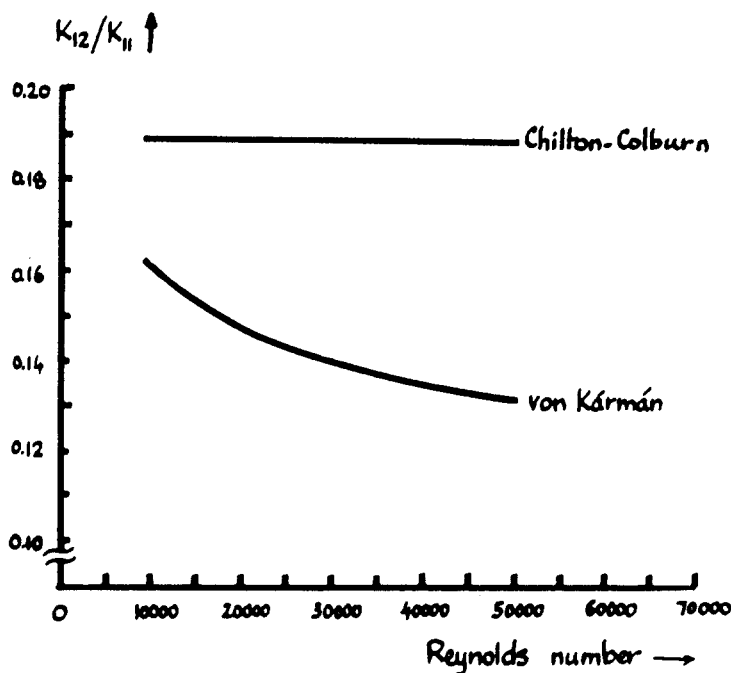


Figure 1. K_{12}/K_{11} as function of the gas phase Reynolds number inside a vertical tube. The system considered is a vapour mixture of acetone (1)–benzene (2)–helium (3). The bulk vapour composition (in mole fractions) is $y_{1G} = 0.05235$, $y_{2G} = 0.04$. The composition of the vapour at the interface between the vapour and the condensed liquid film is $y_{1I} = 0.0357$, $y_{2I} = 0.1277$.

We conclude from the arguments above that for forced convective multicomponent mass transfer a proper modelling of the constituent mechanism of transfer (molecular diffusion, turbulent diffusion) is necessary. The multicomponent Chilton–Colburn approach does not meet with this requirement and must not be used in the calculation of multicomponent mass transfer rates.

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