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INVESTIGATION ON CFC DIFFUSIVITY WITH AN IMPROVED DOUBLE VOLUME METHOD

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ABSTRACT

Some heat transfer experiments have shown that the CFC mixtures have smaller heat transfer coefficients than the ones of pure components due to the diffusion resistance in evaporating and condensing processes.

In this paper an improved double volume method has been developed to investigate diffusion coefficients for binary mixtures. Chromatograph analysis shows that the diffusion coefficients Dab obtained in our investigation are about 30% less than the ones calculated from the formulas published before, in some cases, even less than 100%. The CFCs investigated are R_{22}, R_{142b}, R_{152a}, R_{12}, R_{114}, R_{115} etc.

NOMENCLATURE

- C -- mole concentration
- D -- Diameter
- D_{AB} -- binary mixture diffusion coefficient
- H -- hight
- J* -- mole flux reletive to mean mole velocity
- L -- length
- R -- radius
- S -- cross area
- T -- temperature
- t -- time
- V -- volume

Subscript .

- A,B -- component A,B
- 0 -- center, oriegin
- R,Z -- direction
- 1,2, -- persition in the diffusion path

INTRODUCTION

The potential benefit of using CFC mixtures in the refrigerating and air conditioning equipements has resulted in much interest among researchers in the past few years. However, heat transfer experiments have shown that the CFC mixtures have smaller heat transfer coefficients than the ones of pure components, which is caused by diffusion resistance[1]. To the end, diffusion resistance depends on the diffusivity of CFC.

In the past half century, great progress has been made in the field of diffusivity investigation. There are about ten or more experimental methods to determine diffusion coefficients. It is judged that the evaporation-pipe method is most accurate and widely used[2], but it's too difficult to use. Besides, drop evaporating and double volume method are also often used[3] and there are a number of equations from which diffusion coefficients can be calculated[4]. Usually, an average deviatior about 10% exists between calculated data and experimental ones. So, for special problem, experimental determination of the diffusion coefficients is forturnately needed if possible.

Up till now, there is few experimental information on diffusion coefficient of CFC. The authors of the paper choice the double volume method to investigate CFCs diffusion coefficients. This work belongs to a series investigation projects on CFC mixture.Based on theoritical deducing and calculations, an improved static double volume method has been developed and also, with this method, some data of diffusion coefficients on CFC are firstly reported in this paper.

THE PRINCIPLE OF DOUBLE VOLUME METHOD

The experimental apparatus of double volume method is shown in Fig.1. Volume V_1 and V_2 is connected by a thin straight tube. The length of the tube is L, cross area is S. A valve is arranged in the middle of tube. The volume of the tube is too small comparing with two volumes, V_1 and V_2. In V_1 and V_2 turners are placed respectively to keep a good mixing effect. Before experiment, pure gas A is pumped into V_1 and pure gas B into V_2 and a same pressure is mantained in both volumes.

After open the value, diffusion process between gas A and B through the thin tube starts. After a period of time, close the value, take readings of time and temperature.

As mentioned above, the volume of the tube is quite small, so, it is negligible. Assuming that the diffusion process through the thin tube is static, we have,

$$J_A^* = - D_{ab} \frac{dc}{dz} = - D_{ab} \frac{C_{A2} - C_{A1}}{L} \quad (1)$$

From mass conservation:

$$SJ_A^* = -S \frac{D_{AB}(C_{A2}-C_{A1})}{L} = V_2 \frac{dC_2}{dt} \quad (2)$$

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Finally, we can get

$$\frac{\overline{C}_A - C_{A2}}{\overline{C}_A - C_{A2}^{o}} = e^{-\beta t} \quad (3)$$

$$\beta = \frac{D_{ab}(V_1+V_2)}{(L/S)V_1 \cdot V_2} \quad (4)$$

where

$\overline{C}_A$ -- average concentration of gas A in equilibrium condition
C_{A2}^{o}-- initial concentration of gas A in position 2.
t -- diffusion time

Thus, if C_{A2} measured, D_{ab} can be easily calculated from Eq.(3) and (4).

STATIC DOUBLE VOLUME METHOD

As the turners work in volume A and B during diffusion process, the concentration in V_1 or V_2 keeps the same value everywhere. There is no diffusion resistance in both volumes and thus simplify the mathematical model.

In fact, introduce the turners into the apparatus will cause following troubles:

First, the working frequency of any turner is not infinite. Its work can cause pressure pulsation in V_1 and V_2, thus increase the diffusion process.

Secondly. As the diffusion process is usually lasted about ten hours or more, any change in heat accumulation which could be caused by turners friction during operation can result in soret effect to increase the diffusion process. More seriously, temperature difference between both volumes V_1 and V_2 would cause pressure gradient which could cause bulk motion between V_1 and V_2 to say nothing of it make things much more difficult.

Is it necessary to introduce turners into both volume ? this question can be answered from the model below. As shown in Fig.2, two ball is connected by a thin tube and a valve in the middle section of the tube. The radius of both balls is R_1. Tube's radius is r, length is L. The tube is inserted in centers of the balls. As there is no turner, concentration gradient exists in both balls. In ball centers, concertrations are C_{A10} and C_{A20} respectively and in ball interfaces concentration are C_{A1R1} and C_{A2R1}.

Also, the diffusion process is token as a static process and from equation(1):

$$J_A^* = -D_{AB}\frac{dc}{dz} = -D_{AB}\frac{C_{A20}-C_{A10}}{L} \tag{5}$$

The flux in the thin tube is

$$SJ_A^* = -\pi r^2\frac{C_{A20}-C_{A10}}{L} \tag{6}$$

After neglect the concentration increasement, the flux at R is

$$-4\pi R^2 D_{ab}\frac{dC_{A2R}}{dR} \tag{7}$$

where
C_{A2R} -- concentration of gas A in V_2 at R.

From continuity:

$$-\pi r^2 D_{AB}\frac{C_{A20}-C_{A10}}{L} = -4\pi R^2 D_{AB}\frac{dC_{A2R}}{dR} \tag{8}$$

so,

$$\frac{dC_{A2R}}{dR} = \frac{C_{A20}-C_{A10}}{4L}\cdot\frac{r^2}{R^2} \tag{9}$$

Integral,

$$\int_{C_{A2Ro}}^{C_{A2R1}} dC_{A2R} = \int_{R=r}^{R=R_1}\frac{C_{A20}-C_{A10}}{4L}\cdot\frac{r^2}{R^2}\,dR \tag{10}$$

$$C_{A2Ro}-C_{A2R1} = \frac{C_{A10}-C_{A20}}{4L}\,r^2\left(\frac{1}{r}-\frac{1}{R_1}\right) \tag{11}$$

Let

$r = 2mm$
$R_1 = 22\ mm$
$L = 4R_1$

we get:

$$C_{A2Ro}-C_{A2R1} \doteq 0.005(C_{A10}-C_{A20})$$

thus

$$(C_{A1R1}-C_{A1Ro}) + (C_{A2Ro}-C_{A2R1}) \doteq 0.01(C_{A10}-C_{A20}) \tag{12}$$

It means that the concentration gradient in two balls is only 1% of the one in the thin tube. In other words, the diffusion coefficient obtained with static double volume method is about 1% less than the one obtained from double volume method. This deviation can be found by calculation and can be reduced by increasing tube's length or decreasing tubes radius. It is certainly negligible.

EXPERIMENTAL APPARATUS AND MEASURING PROCESS

Before measuring CFCs diffusivity, O_2 , N_2 and air is used to verify the accuracy of the system made by the authors. The specifications of the experimental apparatus are listed in table 1. The measured diffusion coefficient N_2 , O_2 and air are shown in table 2 . The mean deviation between measured data and the one from literatures is 1-2%, maximum deviation is less than 4%.

The CFCs investigated are R_{22}, R_{142b}, R_{152a}, R_{12}, R_{114}, R_{115} etc. The data obtained are listed in Table 3. The calculated data is derived from Gilliland's Equation[5]. Chromatograph is used in sample analysis. Fig.3 is a representative chromatograph drawing for mixture R_{22}/R_{152a} .

CONCLUSION

1. The improved static double volume method is reliable and has a good accuracy.

2. CFCs diffusion coefficients are usually 30% less than calculated ones, in some cases even less than 100%.

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Table 1

Length of the thin tube	L = 123.00	mm
Diameter of the thin tube	d = 4.04	mm
Diameter of both V_1 and V_2	D = 47.65	mm
Height of both V_1 and V_2	H = 98.10	mm

Table 2

No	Components	Diffusion Condition Temp. K	Pressure MPa	Typical Data Dab cm^2/s	Measured Data cm^2/s	$\frac{(Ty-Mea.)}{Ty.} \times 100\%$
1	O_2, Air	273.1	0.098	0.178	0.181	1.68%
2	O_2, Air	273.1	0.098	0.178	0.182	2.22%
3	O_2, Air	273.1	0.098	0.178	0.181	1.68%
4	O_2, Air	273.1	0.098	0.178	0.184	3.37%
1	O_2, N_2	273.1	0.098	0.132	0.137	3.79%
2	O_2, N_2	273.1	0.098	0.132	0.134	1.52%
3	O_2, N_2	273.1	0.098	0.132	0.137	3.79%

Table 3

Components	Diffusion condition Temp. K	Pressure MPa	Calculated data D_{AB} x10 ^{6} m^2/s	Measured data D_{AB} x10 ^{6} m^2/s	$\frac{M-C}{M}$ x100%
R_{22}/R_{142b}	291.9	0.098	4.583	3.417	-34.12%
R_{22}/R_{152a}	283	0.098	5.317	4.677	-13.68%
R_{142b}/R_{152a}	284	0.098	4.656	2.986	-55.92%
R_{12}/R_{22}	290.6	0.098	4.422	4.179	-5.81%
R_{12}/R_{114}	294	0.098	3.086	2.893	-6.67%
R_{12}/R_{115}	281.1	0.098	3.099	1.804	-71.78%
R_{12}/R_{142b}	291	0.098	3.832	1.95	-96.51%
R_{22}/R_{114}	294.6	0.098	3.745	4.67	+19.8%
R_{22}/R_{115}	293	0.098	3.983	3.139	-26.87%
R_{114}/R_{115}	296.2	0.098	2.725	1.832	-48.7%
R_{114}/R_{142b}	294.6	0.098	3.24	2.513	-28.93%
R_{115}/R_{142b}	295	0.098	3.493	2.40	-45.5%

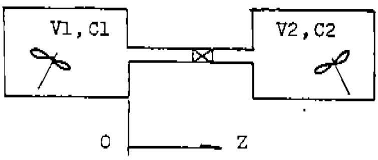

Fig.1 Experimental apparatus of double volume method

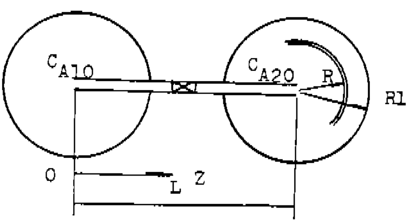

Fig.2 Experimental apparatus of improved double volume method

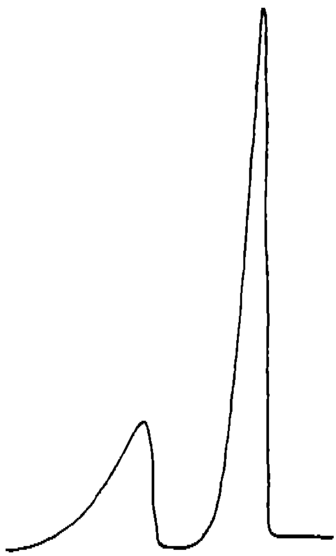

Fig.3 Chromatograph drawing for sample R_{22}/R_{152a}.