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Integration a Design of Experiment in the Mass Transfer Laboratory to Investigate the Effect of Temperature Change on Diffusion Coefficient of Acetone in Air

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Abstract: *An experiment was developed in the mas transfer laboratory to test the diffusion of Acetone in the air. In this approach, Students designed an experiment to investigate and test the change of diffusion rate of Acetone in air by measuring the change of the level surface. Applying Fick's Law in which diffusion of a fluid into stagnant Air is applied. Acetone was selected since it has a relatively high vapor pressure, which increase the evaporation rate, thus the diffusion will be increased and can be observed in a brief time. The diffusion coefficient* $\boldsymbol{D_{AB}}$ *was calculated at different temperatures and it was found that deviation of the results from the actual one was acceptable. For example; at 298.15 K the diffusion coefficient was found to be* $\mathbf{0.1063}$ cm^3/s *compared with 0.109* cm^3/s *in literature. This type of experiments improve the understanding of students to transfer of masses through air and give them the opportunity to observe several fundamental concepts in mass transfer.*

Keywords— Acetone, Diffusion, Coefficient, Temperature.

1. INTRODUCTION

When a system contains two or more components whose concentrations vary from point to point, there is a natural tendency for mass to be transferred, minimizing the concentration differences within a system. The transport of one constituent from a region of higher concentration to that of a lower concentration is called mass transfer. The transfer of mass within a fluid mixture or across a phase boundary is a process that plays a key role in many industrial processes. Fick's laws of diffusion describe diffusion and can be used to solve for the diffusion coefficient, D. Fick's first law relates the diffusive flux to the concentration field, by postulating that the flux goes from regions of high concentration to regions of low concentration, with a magnitude that is proportional to the concentration gradient. The diffusivity or diffusion coefficient for a gas, liquid or solid can be measured, experimentally and empirically. Molecular diffusion is the transfer or movement of individual molecules through a fluid by random molecular movements In the diffusion process, the molecules of interest flow from regions of high concentration to low concentration. Molecular diffusion can occur in both directions with the system. In the case of the diffusion tube experiment, however, acetone diffuses through non-diffusing air, which is passed over the top of the test tube containing the acetone. The air is allowed into the test tube, but does not diffuse into the acetone.

2. REVIEW OF LITERATURE

Molecular diffusion of gases has been studied for many years. Molecular diffusion is a mass transport process Motivation for its study comes from the fact that chemical separation processes such as distillation, drying, ion exchange systems as well as many other processes depend on molecular diffusion. There were many scientists who studied the effects of the temperature and pressure and came up with correlations that can be applied on too many of fluids. For example Stocks-Einstein equation:

$$D_{AB} = \frac{9.96 * 10^{-16} T}{\mu V_A^{\frac{1}{3}}}$$

Also, Fuller et al. (1966) equation:

$$D_{AB} = \frac{10^{-3} T^{1.75} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{\frac{1}{2}}}{P\left[\left(\sum V_A\right)^{\frac{1}{3}} + \left(\sum V_B\right)^{\frac{1}{3}}\right]^2}$$

It is one of the most important correlations for the diffusion coefficients in different temperature in which give a rate of 30% of error.

3. METHODOLOGY

For steady state diffusion through air Fick's law can be applied assuming ideal gas behavior for air which leading to the following equation:

$$\mathbf{D_{AB}} = \frac{\rho_{Acetone}\left(Z_f^{\,2} - Z_o^{\,2}\right)RTP_{BM}}{2(M.W_{Acetone})t_f P(P_{A1} - P_{A2})}$$

Assuming that the temperature is constant non-diffusing air, total pressure P constant, ideal gas behavior, One-dimensions diffusing and no chemical reaction, the experiment carried out in water bath to control the temperature of the fluid in the tube this tube is filled with acetone measured level from the top of the tube to the level surface of the fluid then immersing the tube in the water bath until the temperature is in equilibrium between the water inside the bath and the acetone inside the tube starting the timing and taking reading of the temperature in interval of time.

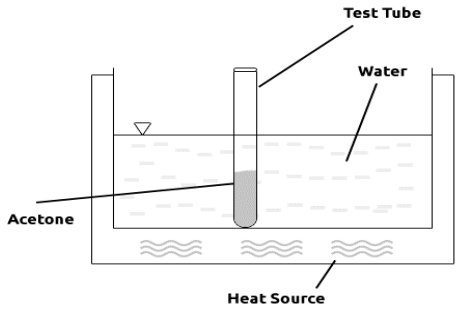

Fig. 1: *experiment setup*

4. DATA

The height of liquid changes with time were recorded and tabulated as follow:

Table 1 Data obtianed at 298K

Time[s]	Distance[cm]
0	6.27
3600	6.32
16200	6.51
28800	6.66
43200	6.86
52200	6.97
86400	7.40

Table 2 data obta*ined at 298 K*

Time[s]	Distance[cm]
0	4.37
5400	4.51
17700	4.83
34800	5.20
41700	5.36
47400	5.51
88800	6.28

Table 3 Data obtained at 303 K

Time[s]	Distance[cm]
0	4.52
4800	4.68
15600	5.05
27300	5.42
39900	5.71
48000	5.96
76800	6.63

Table 4 data obtained 308 K

Time[s]	Distance[cm]
0	4.10
4500	4.33
21600	5.09
31500	5.47
45900	5.99
54000	6.25
90000	7.41

Table 5 Data obtained 313 K

Time[s]	Distance[cm]
0	4.20
4500	4.49
14400	5.11
26100	5.70
38700	6.29
46800	6.60
104100	8.68

Table 6 Data obtained at 318K

Time[s]	Distance[cm]
0	6.27
3000	6.45
14400	7.10
24300	7.62
40200	8.37
43620	8.53
72900	9.80

5. RESULTS

Tables 7 shows the actual values obtained for the diffusivity coefficient at different temperatures. In addition, figure 2 shows the trend of diffusion coefficient with temperature.

Table 7 diffusivity values calculated at different temperatures.

Temperature[K]	Diffusion Coe. [cm2/s]
293	1.058E-01
298	1.063E-01
303	1.115E-01
308	1.19E-01
313	1.20E-01
318	1.24E-01

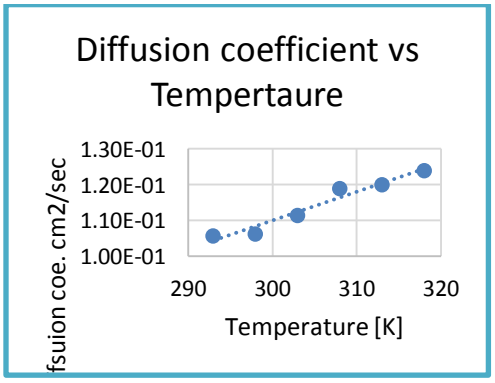

Fig. 2*: This graph shows the relation of diffusion coefficient with temperature and it is obvious that increasing the temperature will result in increasing of diffusion coefficient.*

6. RESULTS AND DISCUSSION

Based on the experimental results in Figure 2, we can observe a deviation in the lower temperature range from the slope, which as stated before due the water bath does not have any cooling system that keep the temperature at low temperature when it increased from the specified value, but as the temperature increases we can observe the temperature has been set constant at the specified temperature. Another source of error could be due the human eye reading in each level even though we were carefully measuring the level but still not so accurate as the advanced tools that might be found in the advanced laboratories. The results mainly were close to those in literature with low range of error. The data were fitted using Polymath Software and gave a good approximation for the diffusivity coefficient at the temperature range studied.

$$D_{AB_{Acetone}} = -0.12 + 0.000736(T) + 1.03E - 07(T)^2$$

Where the temperature in K and D_{AB} $in\frac{cm^3}{s}$.

7. CONCLUSION

From the data obtained and analyzed, it has been observed that the experimental procedure used here can determine the molecular diffusivity coefficient with some level of accuracy. Another increase in accuracy could be achieved by regulating the temperature with more consistency. On the other hand, the equation given can be used with acceptable accuracy within the range provided. More experiments can be done on the same system to expand the range and test the validity of the equation at high temperatures or even at critical conditions

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