Study of Interdiffusion of Calcium Chloride-Water system Using Laser Beam Deflection Sensor

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Abstract. Deflection of a laser beam on passing through an interdiffusing transparent medium of calcium chloride-water system is monitored and explained. A fanned out laser beam using a cylindrical lens is found to follow a Gaussian profile corresponding to the refractive index gradient in the inter diffusing medium. The emerged deflected beam profile at different time depends on the diffusion coefficient. Square of the full width at half maximum of this Gaussian concentration gradient profile is directly proportional to the diffusion coefficient. Exponential decrease of diffusion rate with time is also reported. The diffusion coefficient of calcium chloride in water at room temperature is calculated with better accuracy, and this study can be extended to study diffusion of many transparent, completely miscible samples in micro and nano scales.

Keywords. Laser beam deflection sensor, diffusion.

1. INTRODUCTION

Diffusion, which is the movement of solute particles from higher concentration to lower concentration plays a vital role in many fields like physics, biochemistry, pharmacology, low gravity experiments, food synthesis, etc. The slow rate of diffusion is responsible for its importance because in many cases it limits the overall rate of the transport process. For example, the electrical properties of semiconductor devices are controlled by diffusion of charge carriers, rate of chemical reaction in chemical processes depends on the diffusion of anions and cations, in biological systems the food intake, action of drugs and medicines etc. depends on diffusion phenomena. Diffusion often limits the efficiency of commercial distillations and the rate of industrial reactions using porous catalysts. It limits the speed with which acid and base react and the speed at which the human intestine absorbs nutrients. It controls the growth of micro organisms, the rate of corrosion of steel, and the release of flavour from food. Ficks law of diffusion uses a diffusion coefficient for the description of diffusion phenomena [1].

When two transparent miscible liquids with different solute concentrations are allowed to mix slowly, a refractive index gradient (RIG) is formed at the interface due to the concentration gradient from which an incident laser beam can be deflected (LBD) and studied [2-6]. The deflection suffered by the beam is a direct measure of the diffusion parameters inside the liquid. Being an optical sensor, LBD provides an accurate result. In this study diffusion of calcium chloride solution at known concentration in water is discussed.

2. EXPERIMENTAL SETUP AND MEASUREMENTS

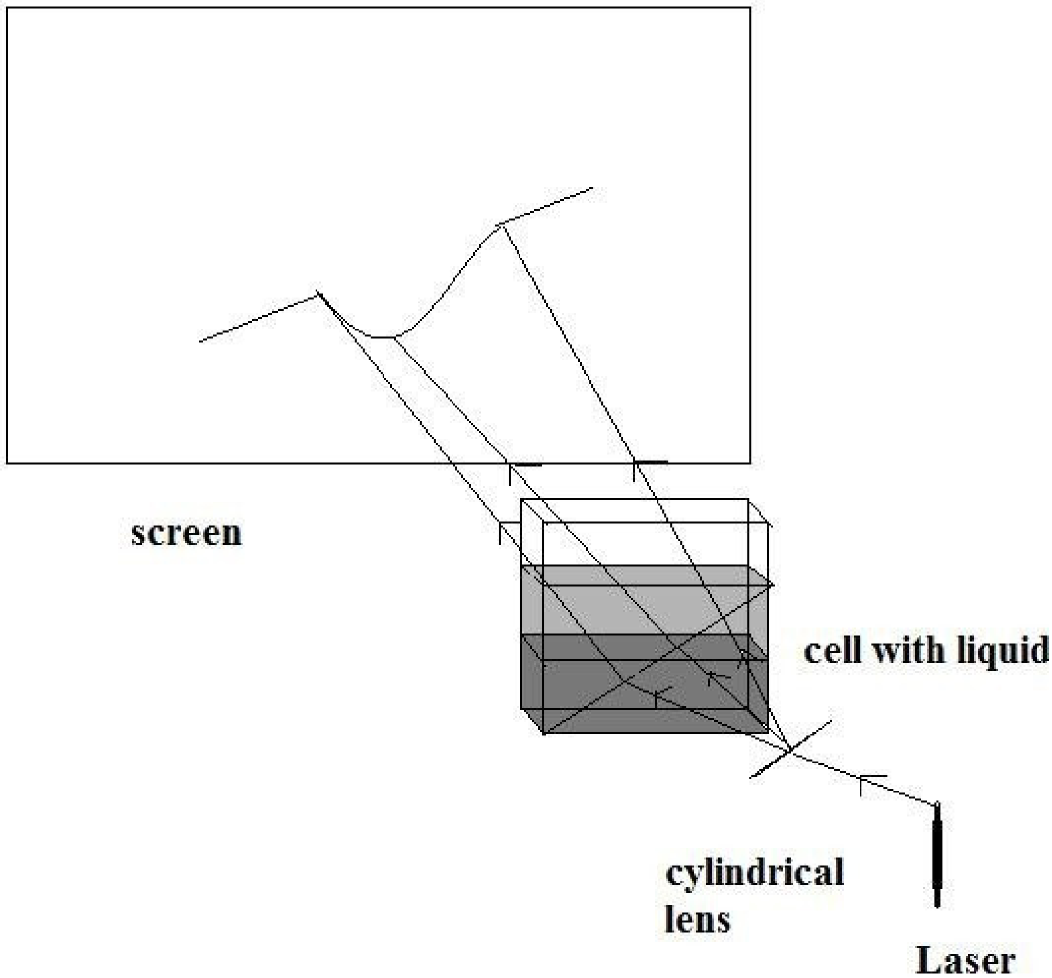

Figure 1. The experimental set up for Laser beam deflection measurement.

The dimension of the experimental cell is $6 \times 4.5 \times 2cm^3$ with $1.2mm$ thick glass plates on both sides of a stainless steel body. The screen is arranged at $1.5m$ from the cell. A fanned out laser beam is created by passing it through a cylindrical lens mounted at 45^o with the vertical. The emergent beam is allowed to fall diagonally on a cuvette containing the liquid where there is a concentration gradient of calcium chloride (Fig.1). Calcium chloride solution with specific molarity is prepared by taking 20 ml of water in the cell and the prepared solution is pipetted to the bottom of the cell avoiding random mixing so that a sharp boundary between the liquids is formed with low concentration solution above and high concentration solution below the boundary. After some initial turbulence the deflection of the beam by the RIG is traced out on the screen at different time intervals till the mixing almost completes. The observed LBD pattern is shown in Fig. 2.

Figure 2. The Laser beam deflection pattern seen in the experimental setup of Fig.1.

3. MATHEMATICAL EQUATIONS

Taking a step like variation of concentration in a plane with in the medium, we can write [3,5]

$$\frac{\partial C}{\partial y} = \frac{C}{2\sqrt{\pi X t}} \exp\left(\frac{-y^2}{4Dt}\right) \tag{1}$$

This is a Gaussian function and will be of the same shape traced out by the deflected beam at the boundary.

The shape of beam trajectory inside the liquid is given by a Gaussian function.

$$Z(y) = k \exp\left(\frac{-y^2}{4Dt}\right) \tag{2}$$

Here $Z(y)$ is the deflection of the laser beam on the screen, y is the depth of deflecting region within the cell below the interface, k is a proportionality constant. As time evolves the boundary smears out until the concentration gradient disappears. This results in the broadening of the Gaussian function. We can evaluate the diffusion constant D from the half width ($y_{1/2}$) of the Gaussian function as

$$D = \frac{y_{1/2}^2}{4tln2} \tag{3}$$

4. RESULTS AND DISCUSSIONS

The image of the deflected beam is traced out on the graph paper for analysis. The observations are made for various time intervals for the same concentration and each time D is calculated. A graph is plotted between dC/dy and y (Fig. 3). The FWHM ($y_{1/2}$) of the graph is measured for a particular time interval. This is repeated for different time intervals. A graph is plotted between $(y_{1/2})^2$ and time interval and its slope is used to evaluate D (Fig. 4). The measured value of diffusion

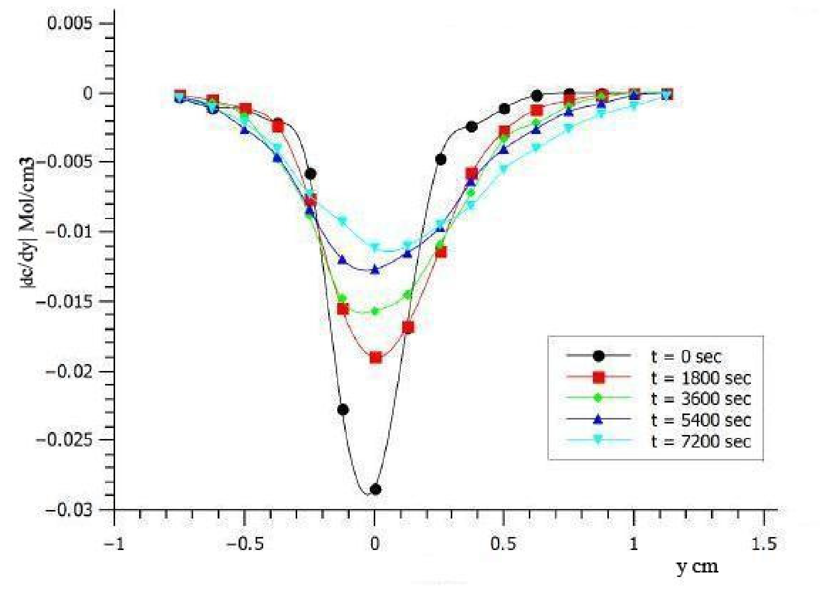

Figure 3. Plot of concentration gradient against deflection at different times.

coefficient of calcium chloride in water is $6.9505 \times 10^{-5} cm^2/sec$ which is in close agreement with the reported value [7]. As the diffusion progresses, the depth of the beam deflection decreases and

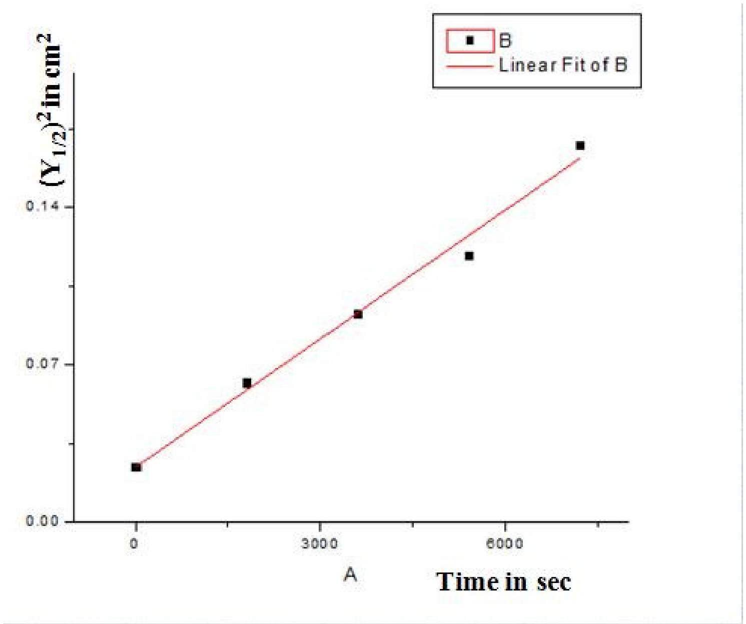

Figure 4. Square of FWHM $(y_{1/2})^2$ vs. time graph.

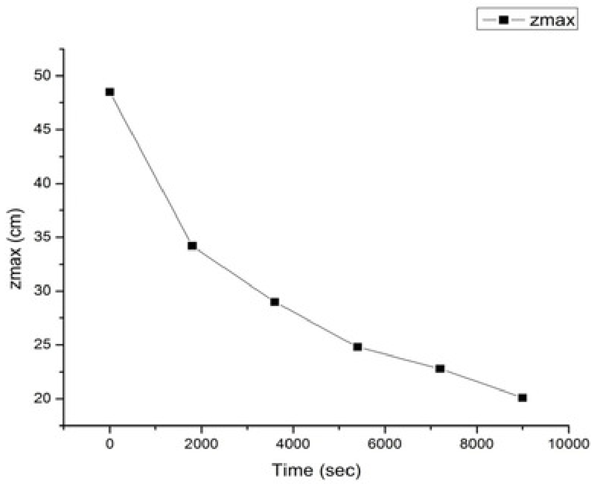

Figure 5. Variation of maximum deflection Z_{max} with time.

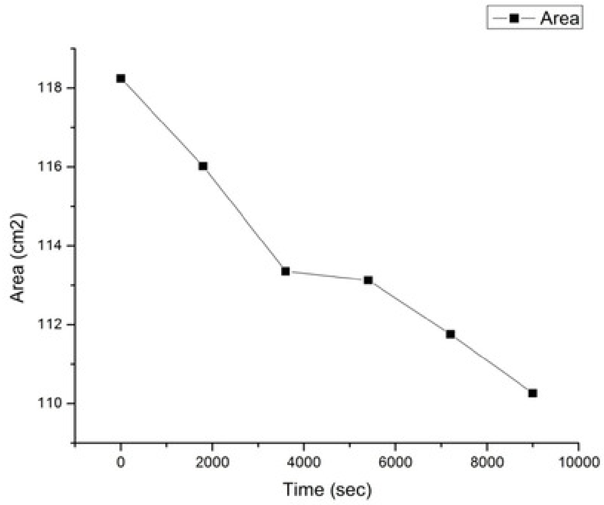

Figure 6. Variation on the area of deflection pattern with time.

the pattern broadens with time (Fig. 3). This is a clear indication of the dependence of refractive index gradient in the liquid medium on time. Plot of maximum deflection, Z_{max} with time (Fig. 5) indicates that diffusion is fast in the beginning and decreases almost exponentially with time. Area of the laser beam deflection pattern also decreases linearly with time.(Fig. 6)

The experiment is repeated several times and the results obtained are in close agreement with the standard values of D obtained by various methods[3-5].

5. CONCLUSION

Diffusion study of calcium chloride in water using LBD sensor is demonstrated. The amplitude of the deflection which is proportional to the concentration gradient is found to decrease exponentially with time.

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