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An Experimental Study on Holdup Measurement in Fluidized Bed by Light Transmission

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***Abstract*—**Nowadays, fluidized bed plays an important part in industry. The design of this kind of reactor requires knowing the interfacial area between two phases and this interfacial area leads to calculate the solid holdup in the bed. Consequently achieving interfacial area between gas and solid in the bed experimentally is so significant. On interfacial area measurement in fluidized bed with gas has been worked, but light transmission technique has been used less. Therefore, in the current research the possibility of using of this technique and its accuracy are investigated. Measuring, a fluidized bed was designed and the problems were averted as far as possible. By using fine solid with equal shape and diameter and installing an optical system, the absorption of light during the time of fluidization has been measured. Results indicate that this method that its validity has been proved in the gas-liquid system, by different reasons have less application in gas-solid system. One important reason could be non-uniformity in such systems.

***Keywords*—**Fluidization, Holdup, Light Transmission, Two-phase system.

I. INTRODUCTION

IN the last decade or so, application of fluidized bed has been important to various chemical industrial processes such as in pharmaceutical, metallurgical and mineral processing, in heat transfers, catalytic cracking, pyrolysis, combustion, etc [1].

Therefore, an optimum design of these reactors and related processes needs to know the interfacial area between two gas solid phases. According to the interfacial area, solid holdup can be calculated. Accordingly, many researches on solid holdup obtaining in a fluidized bed with gas have been done such as: measurement with a dual-electroresistivity probe [2], measurement with a optical fiber probe [3], measurement by using ultrasonic technique [4], [5], measurement by using momentum probe [6], measurement by using γ-ray [7], [8].

Nevertheless, light transmission technique has been used less. Therefore, in the current research the possibility of using of this technique to achieve solid holdup in a fluidized bed and its accuracy are investigated. Of course, fluidizing solid in gas phase is so difficult and it encounters problems such as gas improper distribution, channeling, bubbling and other non-uniformities so as a first step of such study, it will adequate to examine the problem without the complication of chemical kinetics. The paper also presents results of an experimental investigation on the transmission of light through a fluidized bed.

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II. LIGHT TRANSMISSION METHOD

Light transmission is a well-developed technique for determining particle size in dispersions [9], [10], [11], and it has often been adopted for measurement of interfacial area in liquid-liquid and gas-liquid dispersions [12], [13], [14], [15]. The theory for the attenuation of the light beam has been given by a number of workers [9], [12]. Mclaughlin & Rushton (1973)[16] have published a numerical confirmation of the theory for polydisperse systems. And the same result has been obtained more simply by Curl (1974) [17].

When a flat bed is irradiated, the light can be divided into many portions. Part of the light will be reflected by the front wall and lost. The rest of the light energy enters the bed and can either be absorbed or reflected by the particle or transmitted through the back wall. A minute portion of the photons reflected by the particles may be lost through the front or back walls [18].

The portion of the parallel beam that passes through the transparent suspension is scattered by the particles of the dispersed phase by reflection, refraction, and diffraction.

The angular distribution and intensity of the scattered and transmitted light for dilute suspension (no multiple scattering) has been calculated by Mie [19] and is thoroughly discussed by Sinclair [20]. For more concentrated suspensions (particles closer than about 10 diameters to each other), the above laws no longer hold because of multiple scattering and Chu [21] has shown the difficulties arising in trying to solve for this case.

Clarke [22], Vermeulen [23], and Trice [14] have measured the amount of both transmitted and forward scattered light passing through concentrated dispersions and have empirically correlated their results with the interfacial area using photographic methods. These correlations depend on the particular geometry of the optical system used and the refractive indices of the two phases.

A more satisfactory technique with a firm theoretical background has been indicated by Rose [9]. In this, the optical system is so arranged that light scattered by reflection or refraction is not received by the photocell. This is achieved by arranging the photocell at such a large distance from the region of scattering that the solid angle subtended between them is small. Scattered light passes outside the photocell and is lost and only that part of the incident parallel beam which passes through the dispersion without meeting any obstacle is recorded. In this manner, the dispersed phase, as viewed by the photocell, appears as an assembly of black discs and the amount of light received does not depend on the refractive indices of the two phases, or indeed on whether the dispersed phase is opaque or not. The amount of light transmitted to the photocell in this manner depends only on the projected area of the dispersed phase.

As shown by the Mie [19] theory, for particles large compared with the wave length of the incident light, the scattering cross-section of a particle of the dispersed phase is twice its projected area. This result may also be deduced on the Babinette principle [24] which states that a disc scatters by diffraction an amount of light equal to that incident upon it. However, for large scattering particle such as were encountered in this work (particle diameter>0.1 mm), diffracted light is scattered at such a small forward angle that it is practically impossible to avoid its reception by a photocell placed even at vast distances from the dispersion, a fact which has been discussed by Walton [25].

Thus for scattering particles very large in comparison with the wave length of light, the scattering cross-section of the dispersed phase should be found in practice to be equal to its projected area. The shadow cast by each particle is infinitely long, and that particles in this shadow do not contribute to the scattering [12]. So

$$I_0 / I = A_0 / A \tag{1}$$

In this theory, the intensity of transmitted light is compared with the intensity of incident light (when the bed consists of only the gas phase) therefore; the effect of reflected light by the glassy wall disappears.

The bubbles are essentially transparent and form the most significant contribution to light transmitted through the bed. The bubble sizes are dependent on gas flow rate and particle characteristics, which are therefore important variables that will affect the performance of a fluidized bed.

So in this method it is better to let the bed be in bubbling fluidization state than in smooth state, because in smooth fluidization state the bed expands uniformly and the average density of the bed is high, so, the intensity of transmitted light is very little [18].

III. Experimental Setup

Fig. 1 shows a schematic representation of a gas-solid fluidized bed where the light transmission investigation was carried out. The column walls were made of 5mm thick glass. The height of the glass bed is 1m and the cross section area is square (8cm×8cm). This fluidized bed consists of two sections: 1) The compressed gas enters the bed and traverses 20cm of the bed length so it becomes approximately uniform and passes all over the cross section. 2) In this section, gas passes through a perforated plate distributor of aluminum type (81 pores with 2mm in diameter) to fluidize the solid particles.

A compressor compressed the air that used as a fluidizing medium. Air from the top of the bed exited into atmosphere.

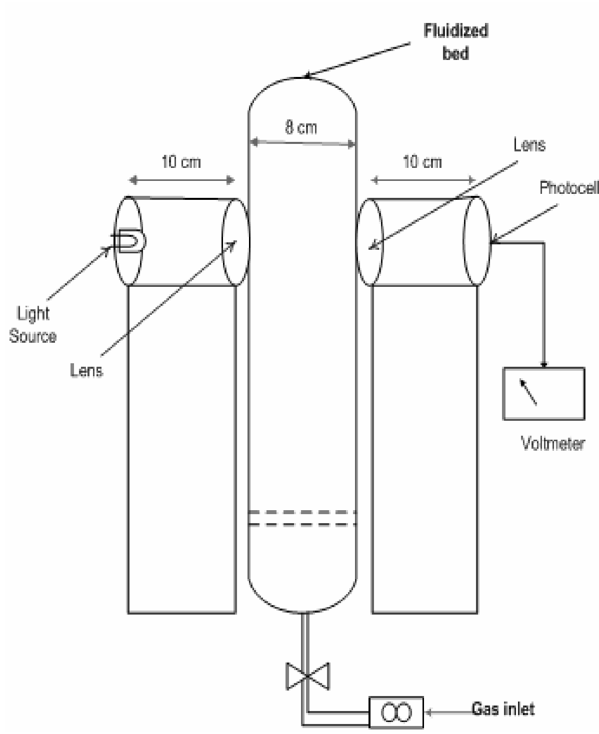

Fig. 1 Schematic representation of setup

The solid particles used were Purslane seeds. The physical properties of particles are presented in Table I. According to the particle diameter and density, solid particles fall into Group B of Geldart's classification [1].

TABLE I
PROPERTIES OF PARTICLES

Solid name	Latin name	Mesh No.	Mean diameter *[mm]*	Density *[kg/m^3]*	Solid mass *[kg]*
Purslane seeds	*Portulaca oleracea L*	30	0.6-1	1200	0.1-0.2

Two convex lenses of focal length equal to 10cm and a photocell and a light source were placed as shown in Fig. 1. The properties of the photocell used are presented in Table II.

The used light source was a hyperlight lamp with 4mm o.d. in a chamber provided with an opening that suitable as a point light source. The voltage input to the light bulb was kept constant (3volt, direct current) by a voltage regulator. This light source was placed in the focus of a first lens to produce a parallel incident beam. Light which passed through the bed without being absorbed was directed on to a photocell by placing photocell in the focus of another set of collimator lens. To minimize interfering, reflecting light and loss of light irradiation, two dark cylinders surrounded the light source and first lens, also photocell and second lens.

TABLE II
PHOTOCELL IDENTIFICATION

Opening slit	Dimensions	Stand rod length
0-8 mm adjustable	53 mm × 70 mm	13 Cm ×8 mm

The photocell output was measured by a voltmeter. Because of the fluctuation of voltage obtained from voltmeter, an electrical circuit included a 1MΩ resistance and a 10μF capacitor, as a smoother was used.

Changes in temperature and humidity influence on photocell so the voltage from voltmeter varies and in the different temperature shows different digits, accordingly the temperature and humidity of surrounding had to be constant.

In this research, first to calibrate the photocell output, the parallel beam was allowed to pass through an empty fluidized bed. The irradiation received by the photocell gave a measure of the light that passed through the empty bed without being absorbed (I_0). The lenses and the photocell were fixed in a known height toward the column then in different gas flows the voltage of passed light through fluidized bed with 100gr solid in it has been measured. Then this work has been repeated in various heights of the lenses. This procedure has been done for 3 quantities, 100gr, 150gr, 200gr, of solids. The behavior of the fluidized bed was observed visually.

IV. RESULTS AND DISCUSSION

In all the experiments performed the particles were observed to fluidize nonuniformly throughout the bed. The distribution of bubble size was characteristic of a freely bubbling bed. As the bubble moved up the bed and coalesced, voidage in the bed increased.

respectively, the fraction of light transmitted through the bed, I, was found to increase with bed height, h. Figs. 2, 3, 4, 5 presented I/I_0 as a function of height at three flow rate 5.67, 6.15, 6.4, 6.8 lit/s using 100, 150, 200gr Purslane seeds particles. In this case because very little light passed through above the distributor, thus their values have not been included for analysis.

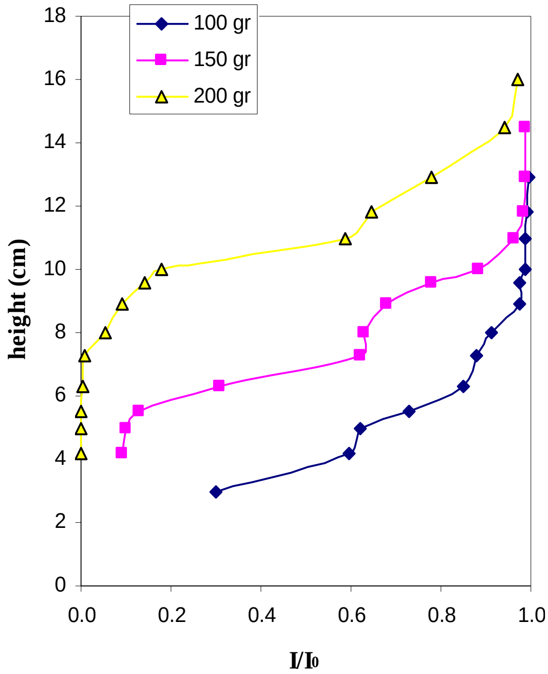

Fig. 2 Variation of I/I_0 with bed height for various solid masses at flow rate=5.67 lit/s, Purslane seeds

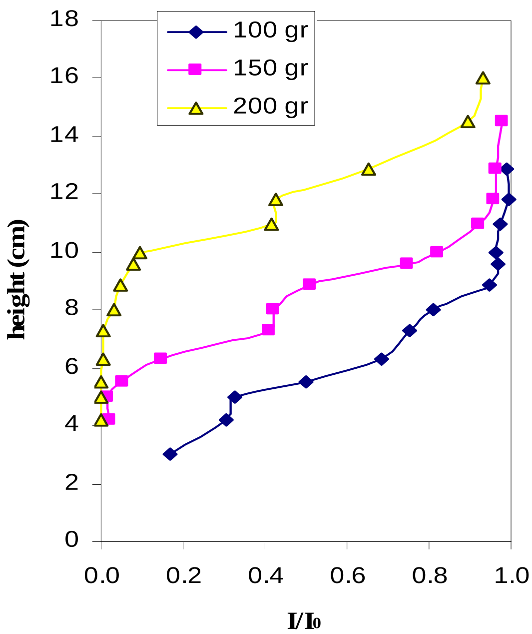

Fig. 3 Variation of I/I_0 with bed height for various solid masses at flow rate=6.15 lit/s, Purslane seeds

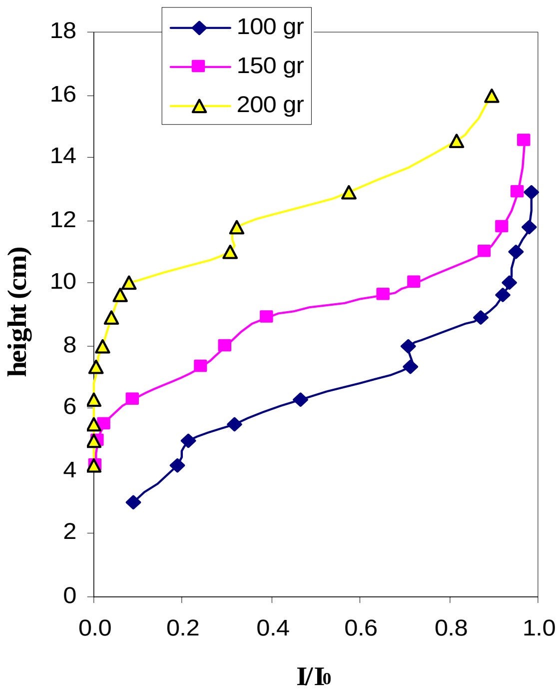

Fig. 4 Variation of I/I_0 with bed height for various solid masses at flow rate=6.4 lit/s, Purslane seeds

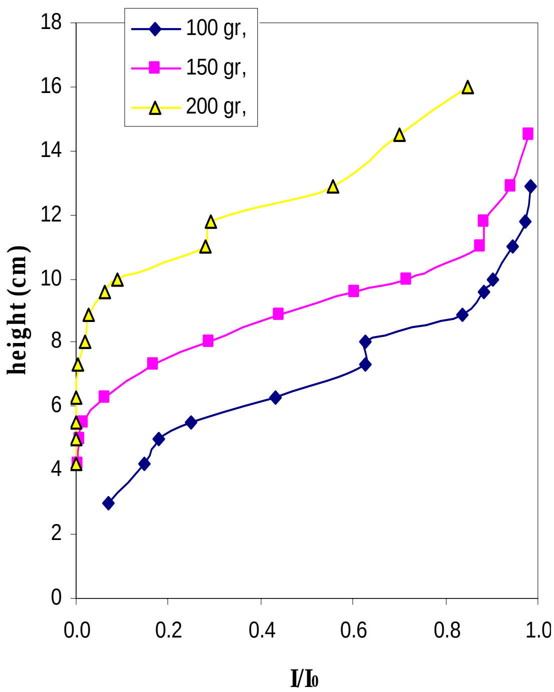

Fig. 5 Variation of I/I_0 with bed height for various solid masses at flow rate=6.8 lit/s, Purslane seeds

These results show that very little light passed through the bottom of the bed above the distributor just as visually was observed that bulk density in different gas velocities at the bottom of the bed was high. The value of I reported here represent average of fluctuating measurements. The maximum errors in the measurement of I were estimated to be ±10%.

In all charts, the variation of I/I_0 with height was therefore highly non-linear and it can be seen that I/I_0 increased with increase in height of the fluidized bed and is deduced that flow regime was nonuniform. In beds of Geldart B solids, bubbles form as soon as the gas velocity exceeds u_{mf} (u_{mf}= minimum fluidization velocity and u_{mb}= minimum bubbling velocity) thus $u_{mf} \approx u_{mb}$.

In most charts, some regions are observed that have almost the same I/I_0 and is concluded that in these regions smooth fluidization have nearly taken place.

Considering that flow regime in flow rate 5-7 lit/s is approximately between bubbling and turbulent regime, obtained points trend accord nearly with existing samples in papers and literature [1], [6]. (I/I_0 is proportional to gas holdup and $1-I/I_0$ is proportional to solid holdup in the fluidized bed.)

V. Conclusion

It is observed that the light transmission through fluidized beds is small. In a freely bubbling bed light is transmitted through the bed mainly through the bubbles. This transmitted light varies with bed height. Thus Optical techniques such as Light Transmission cannot be used for investigation of solids flow and total holdup in such opaque systems. At best this technique should be used as local measurement in the fluidized bed from middle on top of bed not at the bottom of the column because the degree of densification at the bottom of the bed was high.

Notation

A_0	*cross sectional area of light beam (m^2)*
A	*Free area at any cross-section in light beam (m^2)*
I_0	*incident light intensity*
I	*transmitted light intensity*

References

[1] Kunii, D., Levenspiel, O., "Fluidization Engineering", 2rd ed., Butterworth Heinemann, (1991).
[2] Matsuura, A., Fan, L., "Distribution of bubble properties in a Gas-liquid-solid fluidized bed", AICHE journal, vol. 30, No.6, pp. 894-903 (1984).
[3] Kitano, K., Fan, L., "Near-wake structure of a single gas bubble in a two-dimensional liquid-solid fluidized bed: Solids Holdup", Chemical Engineering Science, vol. 43, No. 6, pp. 1355-1361 (1988).
[4] Widyanto, M. R., Utomo, M. B., Kawamoto, K., Kusumoputro, B., Hirota, K., "Local gas holdup measurement of a bubble column using SONIA-ultrasonic non-invasive method", Sensors and Actuators A: Physical, vol. 126, Issue 2, pp. 447-454 (2005).
[5] Zheng, Y., Zhang, Q., "Simultaneous Measurement of Gas and Solid Holdups in Multiphase Systems Using Ultrasonic Technique", Chemical Engineering Sci. 59 3505-3514 (2004).
[6] Won Kim, S., & Kirbas, G., H.Bi, C. jim Lim, J. R. Grace, "Flow behavior and regime transition in a high-density circulating fluidized bed riser", Chemical Engineering Sci. 59. 3955-3963 (2004).
[7] Bhusarapu, S., Al-Dahhan, M. H., Dudukovic, M. P., "Solid flow mapping in a gas-solid riser: Mean holdup and velocity fields". Powder Technology, 163, 98-123 (2006).
[8] Jin, H., Yang, S., He, G., Guo, Z., Tong, Z., "An Experimental study of Holdup in large-scale p-xylene oxidation reactors using the γ-raye

attenuation approach", Chemical Engineering Sci., 60, 5955-5961 (2005).
[9] Rose, H., Lloyd, h.," On the Measurement of the size Characteristics of Powders by Photo-Extinction Methods I. Theoretical Considerations", J. Soc. Chem. Ind., 65, 52 (1946).
[10] Boll, R. H., Sliepcevich, C. M., "Evaluation of Errors of Optical Origin Arising in the Size Analysis of a Dispersion by Light Transmission", J. Opt. Soc. Am., 46, 200 (1956).
[11] Dobbins, R. A. , Jizmagian, G. S., "Optical Scattering Cross Sections for Polydispersions of Dielectric Spheres", J. Opt. Soc. Am.,56, 1345 (1966).
[12] Calderbank, P. H., "Physical rate processes in industrial fermenters. Part I: The interfacial area in gas/liquid contacting with mechanical agitation." Transactions of the Institution of Chemical Engineers, 36, 443–463 (1958).
[13] Lee, J. C., and G. W. K. Ssali, "Bubble transport and Coalescence in a Vertical Pipe, Joint Meeting on Bubbles and Foams", S1-6.1, Verfahrenstechnische Gesellschaft im VDI-Inst. Chem. Engrs., Nurnberg (1971)
[14] Trice, V. G., and W. A. Rodger, "Light Transmission as a measure of Interfacial Area in Liquid-Liquid Dispersions", AIChE J., 2, 205 (1956)
[15] Lockett, M. J. , Safekourdi, A. A., "Light Transmission Through Bubble Swarms", AIChE Journal,vol. 23, No. 3 ,pp. 395-398 (1977).
[16] Mclaughlin, G. F., & Rushton, J. H., "Interfacial Area of liquid-liquid dispersions from Light Transmission Measurements", AIChE J., 19, 817 (1973).
[17] Curl, R. L., "Note on Light Transmission through a Polydisperse dispersion", AIChE J., 20, 184 (1974).
[18] Rizzuti, L., & Yue, P. L., " The measurement of Light Transmission through an irradiated fluidized bed", Chemical Engineering Science, 38, 8, 1241-1983 (1982).
[19] Mie, P. Ann. Phys. Lpz., 33, 1275 (1910).
[20] Sinclair, D., Handbook of Aerosols, Ch. 7 (Washington, D.C.: Atomic Energy Commission) (1950).
[21] Chiao-Min-Chu., J. phys. Chem., 59, 841 (1955).
[22] Clark, N. O. & Blackman, M., Trans. Faraday Soc., 44, 1 (1948).
[23] Vermeulen, T., Williams, G. M. & Langlois, G. E., Chem. Engng Progr., 51, 85 (1955).
[24] Wood, R. W. Optical Physics, (London: The MacMillan Co.), (1911)
[25] Walton, W. H. In Symposium on Particle Size Analysis, (London: The Institution of Chemical Engineers), p. 141 (1947).