

EVALUATION OF LOCAL VOIDAGE IN TWO PHASE SYSTEM BY OPTICAL METHOD

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ABSTRACT: - One of the important characteristics in predicting the flow of two phases (gas and liquid) in the industrial equipment is the gas percentage in the liquid, which is called voidage. This characteristic can be measured by different methods; the optical method is one of them. In the present work, a He-Ne laser light is employed to measure the voidage. The measurement depends on the principle of laser light attenuation during its passage through a mixture of fluids, which is governed by Beer-Lambert law. The attenuated light is measured using silicon type detector and an oscilloscope with a plotter. The gas phase was air while the liquid phase was contaminated water situated in a vertical column. The experiments were done with different air flow rates in water (1, 2, 3, 4,5and 6 liters per minute) with two spot sizes of laser (5mm dia & 10 mm dia). The results illustrated the possibility of measuring the voidage using laser beam and are compared with another one based on the liquid level variation (level ratio) in the column. Furthermore, the results provide that the 10mm dia spot size of laser beam gives better results.

Keywords: voidage, two phase system, He-Ne laser, light extinction.

INTRODUCTION

Many chemical engineering processes are concerned with multiphase flow. The two phase flow is the simplest case of multiphase ⁽¹⁾. Such industrial process like power generation refrigeration, drying units, sprayers, and distillation columns are all implicit two phase flow system, in which; processes such as evaporation and condensation take place.

To improve the knowledge of the structure of a two phase system flow pattern (e.g. air flow in water or steam flow in water), it is necessary and essential to have local values of fundamental parameters. The voidage (or void fraction) is one of those parameters. It is

important quantity in measuring and predicting the pressure drop, the average density, and flow pattern of two phase flow namely gas-liquid systems ⁽¹⁾. The voidage measurement which is gas percentage in the gas-liquid mixture is important in many chemical processes, ⁽²⁾ so that different techniques were employed by many researchers to measure it ^(2,3).

Zhou et al. ⁽⁴⁾ developed a reconstruction technique that recovers instantaneous phase information of two phase flow based on electrical impedance signal from a 16 channel electrode array and correlating this signal with simultaneously captured image data. Kendoush and Sakis in 1995 ⁽⁵⁾ employed capacitance method by placing parallel plates on strip-type capacitance around a tube which contains the mixture, an electrical field is created inside the tube which carries liquid flow. Huang et al. in 2001 ⁽⁶⁾ used a method based on electrical capacitance tomography technique. Their experimental results showed that the accuracy of void fraction measurement is satisfactory. An auto-transformer method was developed by Kendoush and Sakis in 1996 ⁽⁷⁾. It is based on winding low resistance wires around the tube which carries the two phase mixture in a method analogous to the auto-transformer winding. Most of the former methods are based on the electrical properties which may be useless for non-conducting fluids. However, optical methods, which are suitable for non-conducting fluids, were also used.

Schleicher et al. ⁽⁸⁾ has introduced the design of an optical tomography using 256 light emitters and 32 light receivers arranged about the object's cross-section. Besides, the measurement of bubble diameter, velocity and number density in gas-liquid two-phase flows is done by Miller and Mitchie in 1970⁽⁹⁾ using Laser-based Optical Fiber Probing which is intrusive measurement but a very useful technique. In the present work, a He-Ne laser is used to measure the voidage in air-water system, based on the extinction of laser light during its transmission through gas-liquid mixture.

THEORY

When a laser beam passes through a medium, its intensity may attenuate and extinct. The extinction may be resulted by reflection, refraction, absorption and scattering ⁽¹⁰⁾. These phenomenas may caused by existence of different phases and impurities. However, the laser intensity ⁽¹⁾ on its passage through a medium of length (L) is given by Beer-Lambert law ^(10, 11):

$$I = I_o e^{-K_T L} \dots\dots\dots 1$$

Where: (I) is the laser intensity at length (L)

(I_o) is the incident laser intensity

(L) is path length

(K_T) is the total extinction coefficient.

The total extinction coefficient (K_T) of a two phase system (air-water) medium is given by ⁽¹¹⁾:

$$K_T = \alpha(K_a) + (1 - \alpha) K_w \dots\dots\dots 2$$

Where: K_a : is laser extinction coefficient in air.

K_w : is laser extinction coefficient in water.

α : is the voidage (void fraction).

Hence for a medium consists of a mixture (air-water) we will have:

$$I_{mix} = I_o e^{-(\alpha K_a + (1-\alpha) K_w) L} \dots\dots\dots 3$$

and for a medium with only water (i.e. $\alpha = 0$):

$$I_w = I_o e^{-(K_w) L} \dots\dots\dots 4$$

and for a medium with only air (i.e. $\alpha = 1$):

$$I_a = I_o e^{-(K_a) L} \dots\dots\dots 5$$

By taking the logarithms for equations 3, 4, and 5:

$$\ln(I_{mix}/I_o) = -(\alpha K_a + (1 - \alpha) K_w) L \dots\dots\dots 6$$

$$\ln(I_w/I_o) = -(K_w) L \dots\dots\dots 7$$

$$\ln(I_a/I_o) = -(K_a) L \dots\dots\dots 8$$

Substitute equations 7 and 8 in 6 and re-arranging yield:

$$\ln(I_{mix}/I_o) = \alpha \{\ln(I_a/I_o)\} + (1 - \alpha) \{\ln(I_w/I_o)\} \dots\dots\dots 9$$

$$\alpha = \frac{\ln(I_{mix}/I_w)}{\ln(I_a/I_w)} \dots\dots\dots 10$$

EXPERIMENTAL WORK

To measure the voidage of air-water mixture, an experimental set up as shown in figure (1) was adopted. The rig is consists of a He-Ne laser with a 0.6328 μm wavelength, 1 mW output power and 5mm and 10mm diameter spot size. A container made of Perspex (which is good window for the mentioned laser light) have a dimensions of 5 \times 5 \times 50 cm, composes a vertical column. The two-phase (air-water) fluid is presented in the column. A porous stone with a perforated plate is fixed at the bottom of the column that tends to creation of two phase, i.e. air bubbles in continuous water.

A rotameter (maximum flow rate: 600 liters/hour) with valve is used to control the air flow to different flow rates. The air is injected to the system using a suitable size air compressor. At the opposite side of the laser, the transmitted laser light through the column and mixture will incidence on a silicon type detector of 10 mm diameter active area. A

pinhole is situated front of the detector, so that to exclude any scattered light from incidence on the detector that may cause errors in readings. By this method the errors are minimized. A beam expander is used to modify the laser beam diameter to 5mm and 10mm spot size. It consists of a collection of lenses and pinholes fixed in a straight line. Changing the position of the lenses with respect to each other will change the diameter of the beam. This tool is always is used in many optical and laser systems ⁽¹⁰⁾.

The beam modifier is useful to exclude any stray light from incidence on the detector as well. The signals from the detector are received by an oscilloscope and a plotter that shows the signals and changes happens to the laser intensity.

PROCEDURE

According to equation 10 different intensities of laser light; in which its radial intensity distribution is given in the figure (2), should be measured so that to measure the voidage of the mixture. The intensity of laser light (I_0) with the absence of the column and mixture is measured first of all. Besides, (I_a) which is the intensity of laser incidence on the detector when the container is empty (i.e. filled with air) is measured. Then the container (column) is filled with the contaminated water to a specific height (h) and the intensity of laser is measured, that is (I_w), see situation A in figure (3).

The voidage (α) is measured for different air flow rates. Air which is compressed by a suitable size compressor to the container is controlled using valves to 1, 2, 3, 4,5and 6 liters per minute. The level of water will change to higher level as shown in situation B in figure (3), due to presence of air bubbles in the column. For each flow rate the intensity of laser light incident on the detector (I_{mix}) after its pass through the mixture (two-phase) is measured, and the height of the mixture (air-water) in the column (H) is measured as well. This procedure is done for both cases of laser beam diameter 5mm and 10mm diameter. All laser intensity readings are taken from oscilloscope and a plotter. The voidage (α) is measured by laser according to equation 10. Besides, it is measured according to the following equation based on the water level change in the column named as level ratio:

$$\alpha = \frac{H-h}{H} \quad \dots\dots\dots 11$$

RESULTS AND DISCUSSION

According to the experimental work, the voidage is given by two ways, the laser system and the change in the level of the liquid in the column (or liquid level ratio). For the

first method the equation 10 is employed, which gives the voidage or void fraction (α) as a function of intensity of laser light measured by the detection system. For each experimental run; i.e. various air flow rates from 1 to 6 liters per minute with step change one, the unattenuated laser intensity I_{mix} is measured and the voidage (α) is obtained using equation 10 after measuring and recording all required values of laser intensity. The results are plotted and shown in figure (4) for the both cases of laser beam diameter 5mm and 10mm. It is very clear from the figure that the voidage obtained by laser system is directly proportion to the air flow rate⁽¹²⁾.

While figure (5) shows the relation between the air flow rate and the received laser light intensity (the unabsorbed light) by the optical detector for the both cases of laser beam diameter 5mm and 10mm. It's very clear that the relation is inversely proportion for the both cases. This is because of that by increasing the air flow the number of bubbles will increase which tends to attenuate the laser light more and more⁽¹³⁾. In other words, the transmitted light will decrease, because each bubble plays as attenuator that comes from reflection, refraction, scattering and other optical phenomena.

Figure (6) illustrates the relation between the air flow rate and the voidage (α) obtained using equation 11, which depends on the level of the liquid in the column for each experimental run. The relation here is directly proportion as well, and that is predictable result.

The results obtained by equation 10 (the laser method) and equation 11 (level ratio method) are compared and illustrated in the figure (7). The figure shows a close results obtained by both methods. This result gives an indication about the capability of using laser to measure the local voidage of two-phase systems which include liquids and gases. It's clear from figure (7) that there is a difference between the voidage obtained by the methods at a certain flow rate. The figure shows that the values obtained by level ratio (equation 11) are most often greater than that obtained by laser for both laser diameters 5mm and 10mm. This is because of that the level ratio method provides the whole or the total voidage. While the laser method reads only the local voidage, in which it may be different slightly from a moment to another. Furthermore, the results obtained by 10mm dia. laser beam are more close to the total voidage obtained by level ratio, than that obtained by 5mm dia. laser beam. This is due to that 10mm beam diameter covers more area and more attenuators than 5mm beam diameter, in which it means more approach to the total voidage. For the same reason, it can be observed that the result of 10mm beam diameter is smoother than that of 5mm beam diameter.

CONCLUSIONS

It is deducible from the present work the feasibility of measuring the voidage in two phase systems using laser to a certain extent. That is because of the optical effects of the fluids to the laser light should be taken in consideration, so that the laser beam be able to penetrate (transmit) the fluids and hits the detector. Besides, it is observed that the wider laser beam shows better results due to covering more area.

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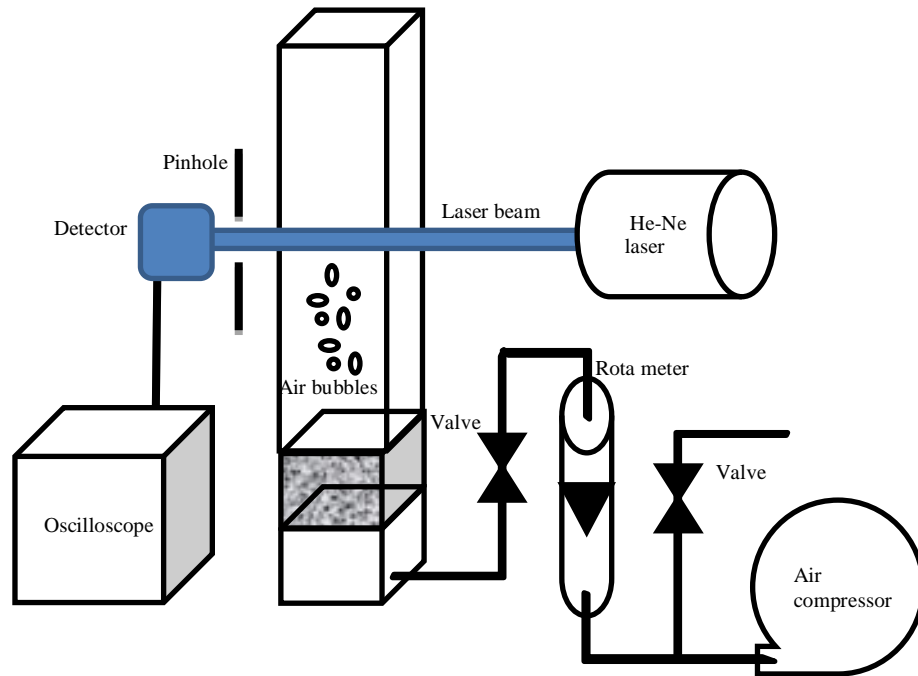


Figure (1): the experimental rig.

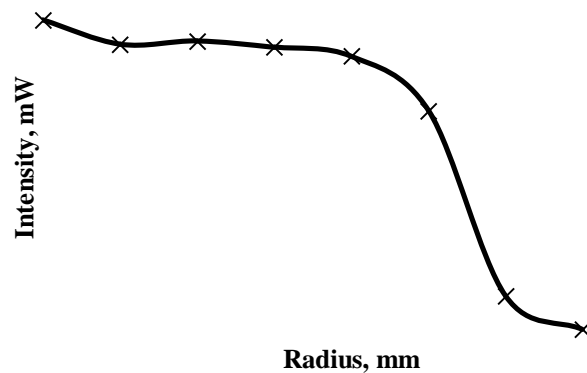


Figure (2): the radial intensity distribution of laser beam.

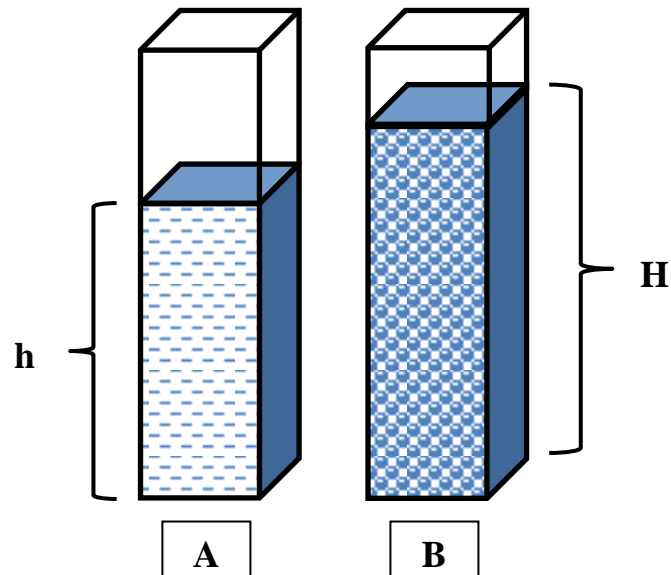


Figure (3): the situations of the gas-liquid mixture in the column.

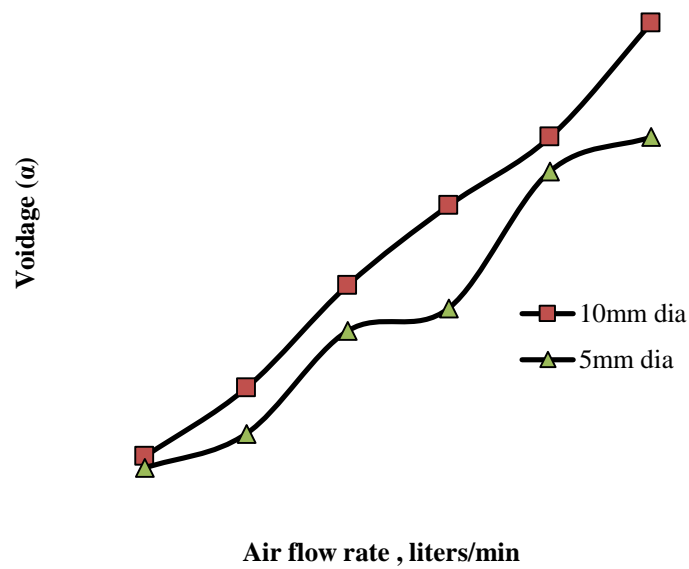


Figure (4): Voidage (α) Vs Air flow rate based on He-Ne laser system method for both beam diameters, 5mm and 10mm.

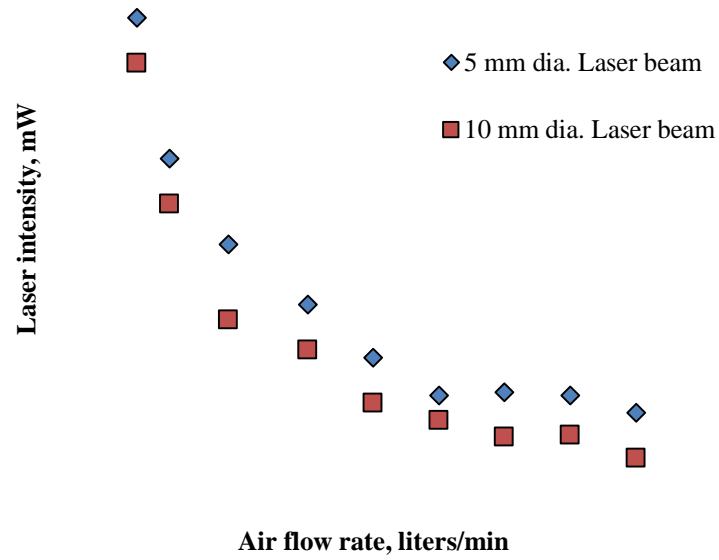


Figure (5): Laser intensity as a function of air flow rate.

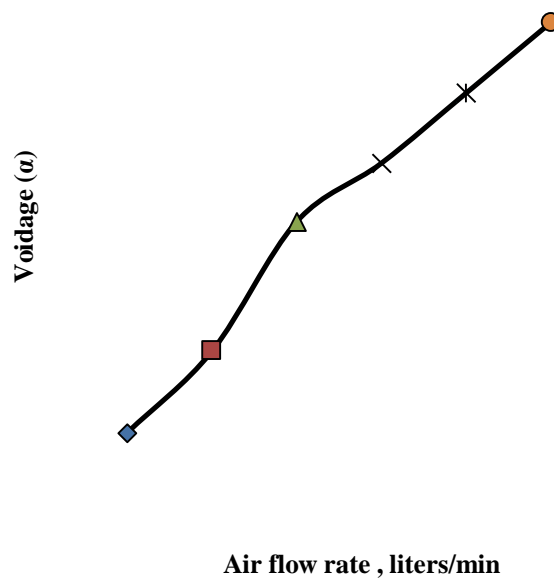


Figure (6): Voidage (α) Vs Air flow rate based on level ratio method.

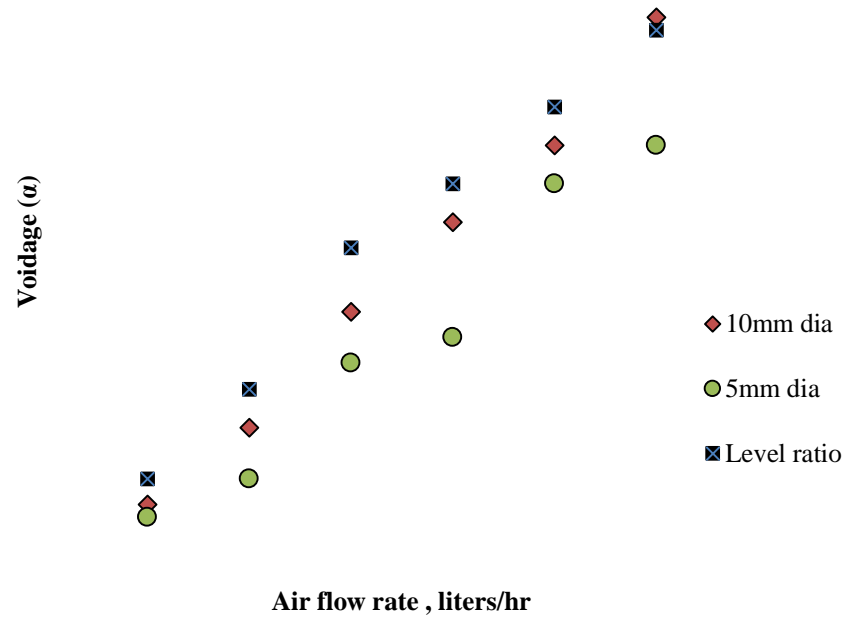


Figure (7): Comparison of voidage (α) measurement between 5mm dia and 10mm dia laser beam and the Level ratio methods.

حساب نسبة الفراغ الموقعية في نظام ثنائي الطور بطريقة بصرية

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الخلاصة

إن من احد الخصائص المهمة عند تنبؤ ودراسة الجريان ذو الطورين (الغاز والسائل) في المعدات الصناعية هي نسبة الغاز إلى السائل والمسمى بنسبة الفراغ. ويمكن قياس هذا الخاصية بعدة طرق والطريقة البصرية هي إحدى هذه الطرق. في هذا البحث تم استخدام ليزر هيليوم - نيون لقياس نسبة الفراغ. حيث أن مبدأ القياس يعتمد على التوهين الحاصل في ضوء الليزر المار خلال خليط الموائع، والذي يعتمد على قانون بيير-لامبرت. ويتم قياس شدة الضوء الموهن باستخدام كاشف ضوئي سيليكوني ورسم الذبذبة (اوسيلوسكوب) ورسم مخططات. تم استخدام الهواء كطور غازي بينما الطور السائل كان ماء ملوث موضوع داخل حاوية عمودية الموضع. تم إجراء التجارب بمختلف معدلات جريان الهواء داخل السائل وكان 1 و2 و3 و4 و5 و6 لتر في الدقيقة مع بقعتي ليزر مختلفة الأقطار 5 و10 ملم. أظهرت النتائج إمكانية قياس نسبة الفراغ باستخدام حزمة الليزر وقورنت مع طريقة قياس أخرى تعتمد على تغير ارتفاع السائل داخل العمود الحاوي على الغاز والسائل وسميت بنسبة المستوى. هذا إلى جانب ملاحظة كون الليزر ذو القطر 10ملم أبدت نتائج أفضل من الـ 5ملم.