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BUBBLE FORMATION IN A ROTATING FLOW

T.L. HARIKRISHNAN, J.A. RAPER & G.J. JAMESON

DEPARTMENT OF CHEMICAL ENGINEERING

UNIVERSITY OF NEWCASTLE, NSW. 2308 AUSTRALIA

SUMMARY Centrifugal force has been used to simulate an increase in gravitational force and its effect on bubble formation has been studied in a nitrogen-water system. As predicted by current theories, the size of the bubbles were observed to decrease with increasing gravitational force.

1. INTRODUCTION

Operations involving contact of two immiscible fluids for the purpose of heat and mass transfer are very common in industry. One of the simple and widely used methods to facilitate such transfer is by dispersing one of the fluids (the dispersed phase) through nozzles or orifices submerged in the other (the continuous phase).

A large interfacial area per unit volume is necessary if the mass and/or heat transfer is to be obtained rapidly in equipment of finite size. The larger the interfacial area provided per unit volume, the more efficient is the operation. To achieve this it is necessary that smaller bubbles/drops of the dispersed fluid be produced.(1)

Hence, the phenomenon of bubble and drop formation has been the subject of extensive research. However, the effect of gravity on the size of bubbles or drops formed has attracted little attention, as it is normally simpler to change other parameters (such as the nozzle diameter) to suit a particular application. Most of the current theories describing bubble formation incorporate 'g', but sufficient effort has not been made to test the validity of these models by observing the influence that varying 'g' has on the size of the bubbles. (2-7)

One method of indirectly varying the buoyancy force is to replace one of the fluids by another with a different density. This method, apart from being inconclusive, cannot always be employed in actual practice as the choice of the fluids easily examined may be limited. Under such circumstances, it may be simpler and more practical to achieve better bubble sizes by using acceleration as a design parameter in addition to those parameters traditionally employed.

An experimental investigation is reported in this paper, of nitrogen bubbles grown by means of a small nozzle submerged in water; both the nozzle and water traverse a circular path so that the centrifugal acceleration tends to aid bubble detachment by enhancing the buoyancy force.

2. APPARATUS

The apparatus consists of two parallel transparent discs, 10mm apart and sealed around the circumference (see Fig.1). A nozzle is placed between the two discs on the circumference through which industrial dry nitrogen is passed. As the discs are made to spin about their common axis of symmetry, the nozzle and the water held between the discs also rotate along with them. While the discs are in motion, the water takes the shape of an annulus with its free surface being cylindrical and coaxial to the axis rotation. The rotational velocity, obviously, has to be above a certain minimum, otherwise the water will not be thrown outward and travel in a circular path along with the discs.

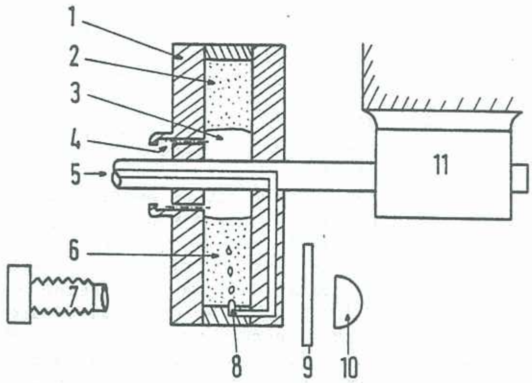

Fig.1 Schematic diagram of apparatus. (Not to scale).
1. Transparent disc, 2. Water, 3. Gas, 4. Vent for gas, 5. Gas inlet, 6. Gas bubble, 7. Camera, 8. Nozzle, 9. Light diffuser plate (stationary), 10. Stroboflash, 11. Motor

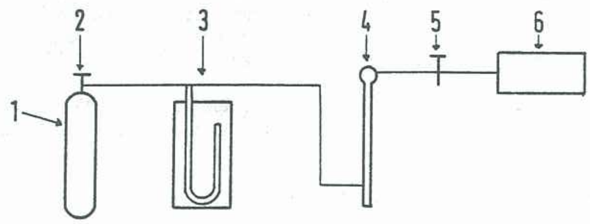

Fig.2 Diagram of gas supply.
1. Gas tank, 2. Diaphragm valve, 3. U-tube manometer, 4. Soap film flow meter, 5. Needle valve, 6. Apparatus

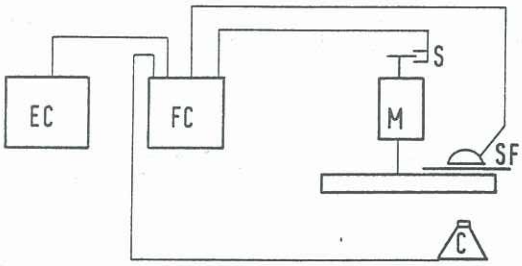

Fig.3 Diagram of electrical arrangement.
M - Motor, SF - Stroboflash, C - Camera, S - Sensor,
FC - Flash controller, EC - Electronic counter

The gas supply to the apparatus was connected to the rotating discs by means of a dynamic rotary-shaft lip seal. The air was sent to the nozzle through the hollow shaft. A nitrogen gas cylinder was used as the gas supply (Fig.2). The flow meter used to measure the gas flow rate was an ordinary soap film bubble-meter suitably modified so that the exit gas from it was connected to the apparatus. The exit of the meter had a chamber so that the soap film which reached it broke up and flowed down the walls of the meter back to the reservoir. The volumetric flow rate of the gas emerging from the nozzle into the water need not be the same as that indicated by the flow meter as the conditions at the flow meter could differ from that at the nozzle. Hence, a U-tube manometer gave the pressure at which measurements were taken, from which flowrate at nozzle conditions could be calculated.

A stroboflash was used for back illumination of the nozzle. The stroboflash could be operated in three modes. In the first mode, it could be operated as a normal stroboflash at a constant desired frequency, which was independent of the speed of rotation of the motor. In the other two modes, an electronic controller (FC in Fig.3) was used to trigger the flash so that the lighting was achieved at one particular angular position of the discs. The second mode of operation was when the flash frequency was the same as that of the discs, and the discs were apparently stationary. This permits easy visual inspection and focussing of the camera. The third mode in which the flash could be operated was similar to the second mode just described, except that the flash was triggered only once by means of the flash controller which in turn was triggered by the camera when the shutter was released. The shutter speed of the camera was kept sufficiently low so that for any given rotational speed, the shutter was open long enough for the discs to come to the right orientation when illuminated by the flash.

In addition an electronic counter was employed to display the rotational speed of the discs. The motor employed to rotate the discs was a single phase 230-250V, 50 Hz, 1/6 H.P., 3500 rpm motor. The speed of the motor was controlled using a variac. The outside diameter of the tip of the nozzle used was 0.43mm.

For photographing the bubbles, an Olympus OM-2 camera (35mm) attached to bellows and a macro lens (f=80mm) was used.

3. OBSERVATIONS AND RESULTS

The following photographs show some of the observations made during the experiments. The actual size of the bubbles can be deduced from the photographs since the diameter of the nozzle is known.

Figures 4 and 5 show bubbles generated under normal gravitational conditions, i.e. when the discs are stationary and the nozzle is pointing vertically up. In Fig.4 the gas flow rate was low (less than 0.275 cc/s) and Fig.5 shows bubbles under a higher gas flow rate (less than 0.55 cc/s).

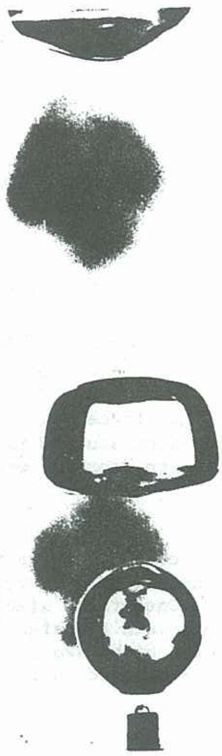

Fig.4 Bubble formation under normal gravitational conditions and low gas flow rate

Fig.5 Bubble formation under normal gravitational conditions and high gas flow rates

At very low rotational speeds and gas flow rates, visual inspection showed that bubbles were released into the water but none could be seen in the actual process of being formed at the nozzle. At first it was thought that the bubbles formed very rapidly and detached with considerable velocity making it difficult for them to be seen. But in spite of several photographs being taken, we were confronted with the same puzzle, as bubbles were visible away from the nozzle but none at or in its immediate vicinity. The puzzle was solved by changing the position of the discs when the flash was triggered, so that the nozzle could be observed at other orientations also while it was rotating. It was then realised that the bubbles were being formed when the nozzle was at the upper portion of its path and none while it was in the lower portion. But the bubbles which were released while at the upper portion had not reached the free surface and were still visible when the nozzle was at its lowest position. It was concluded that 1) low flow rates lowered the gas pressure inside the nozzle, and 2) low rotational speeds had a greater percentage change in the hydrostatic pressure between the lowest point in the water and the highest point, and hence the bubbles were formed intermittently and not continuously.

Fig.6 Bubble formation when g ≃ 20 'G'

Figures 6 and 7 show a stream of bubbles emerging from the nozzle when the acceleration is about twenty times that due to gravity.

The bubbles were noticed to be essentially spherical while they were being formed and also smaller in size. But immediately after detachment they flattened out considerably with the leading edge of the bubble sometimes even being concave outward. This is quite a departure from normal behaviour where we have either spherical or spherical cap bubbles. After travelling a certain distance they swerved sharply to one side before gradually reverting to the original direction of travel and reach the surface.

The effect of increasing the acceleration to about 100'G' can be seen in Fig.8.

At higher rotational speeds, it was found that the bubble formation was difficult to control. The bubbles were formed in a turbulent manner in various shapes and sizes. Even when the flow rate was decreased, it was found that for a small duration bubbles would be formed, followed by an interval wherein no bubbles were formed, after which the gas would again burst into the liquid. However, a measure of control could be obtained by decreasing the amount of water held between the discs so that the submergence of the nozzle was decreased from 30mm (its usual amount in this investigation) to 10mm.

4. DISCUSSION AND CONCLUSIONS

The study of bubble formation under simulated high gravitational accelerations would help us verify the existing theories on bubble formation and also gain a better understanding of the phenomenon. In addition, it could be used as a means to produce smaller bubbles as smaller bubbles are desired in various industrial operations involving heat and/or mass transfer and flotation.

As we would expect, it was observed that the size of bubbles formed decreased when subjected to larger acceleration.

Bubbles were observed to take on a considerably flattened shape once they detached from the nozzle.

The bubbles swerved sharply to one side on their way to the surface.

Fig.7 Bubble formation when g ≃ 20 'G'

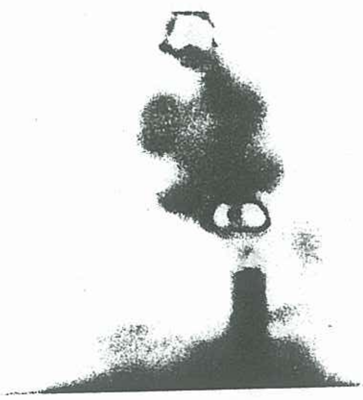

Fig.8 Bubble formation at g ≃ 100 'G'

Fig. 9

Fig. 11

Figures 9 to 11 show bubble formation which are not under stable single bubble regime.

Fig. 10

5. REFERENCES

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