IAC-08-A2.2.8

ON GROUND STUDY OF BUBBLE JETS COLLISION

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ABSTRACT

Collisions of bubble jets have been experimentally studied in normal gravity conditions. The experimental setup, designed for a future use in a low gravity environment, allows the control of the impact angle between jets, bubble size and velocity. Individual bubble properties and the whole jet structure are analyzed from the images recorded. We present results on the role played by the impact angle and the distance between injectors on the structure of the final jet. A systematic study for different gas and liquid flow rates has been carried out in order to compare the results obtained in normal gravity with those to be obtained in a future campaign at the INTA drop tower.

INTRODUCTION

Two-phase gas-liquid flows are present in a wide variety of situations in chemical processing, power generation, and energy production facilities. In addition to normal gravity applications, two-phase flows also occurs in many space systems, such as thermal control systems, propulsion devices and long duration life support systems. In the last decades, development of two-phase flow research under reduced gravity conditions has acquired great importance due to the numerous advantages that presents over the single phase flows [1,2]. Such advantages involve reduction of weight, improvement of thermal management and the capability of achieving high specific power levels.

The use of bubble jets with very small bubble sizes is required in a large number of applications. Therefore, the control of jet dynamics turns out to be a very important issue for the designs related to such applications. Single phase opposed-jet configuration had been widely investigated in combustion science and turbulence modeling [3,4], but new studies are required for a better knowledge of the behavior of a two-phase flow system. The way how the collision of jets takes place as well as the coalescence of bubbles in the resulting flow are important issues for the prediction of the dynamics at the pipe junctions of space devices.

In this work we present the design of an experimental setup for the study of two colliding bubble jets in low gravity conditions. Structure of these jets in quiescent water under different parameter regimes has been studied in normal gravity conditions. The influence on the final jet structure produced by the impact angle, separation between injectors and bubble mean velocities have been taken into consideration.

EXPERIMENTAL SETUP

The experimental setup (see Figure 1) is designed to the study of the behavior of two colliding bubble jets in microgravity conditions. The test cell consists in two bubble injectors directed inside a 200x150x250 mm^3 cavity full of distilled water. Jet dynamics inside the cavity is recorded by a high speed video camera (RedLake MotionXtra HG-SE), necessary to account for the high bubble generation frequencies. Illumination is provided by a source of 280 ultra-bright LEDs and homogenized by a diffuser sheet. Movies were recorded at 1000 fps

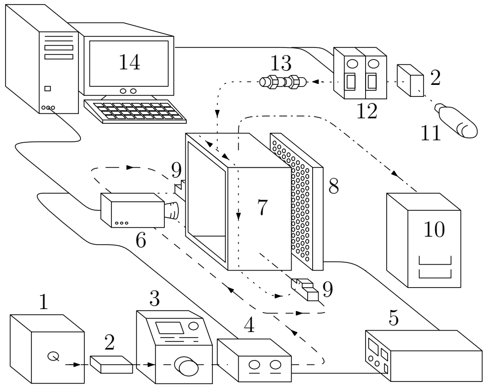

Figure 1: Experimental setup.
— Electric connections, ··· Gas tubes, - - - Liquid tubes, -·-·- Gas+Liquid tubes. 1: Liquid tank, 2: Filter, 3: Pump, 4: Flow meter, 5: Power supply, 6: HS Camera, 7: Cavity, 8: Illumination source, 9: Injectors, 10: Residual tank, 11: Gas bottle, 12: Pressure controller and flow meter, 13: Choked orifice, 14: PC.

with a resolution of 640x512 pixels, and post-processed by an image processing software.

The method used to generate bubbles is a BUBGEN injector [5,6]. This method is based on the use of a cross-flow configuration in a capillary ($d_C = 0.7$ mm) tube T-junction, creating a slug flow with a nearly fixed bubble size and generation frequency. This method is insensitive to gravity force since Bond number is very low ($Bo = \Delta\rho g d_c^2/\gamma \ll 1$), and is mainly dominated by capillary forces. This device allows a large range of bubble generation frequencies. Bubble velocity at the outlet of the injector is controlled by gas and liquid flow rates.

Gas (CO_2) is injected from a pressure bottle through a pressure controller (Bronkhorst P-702CV) and a choked orifice, setting the gas flow rate Q_G from 15 ml/min to 20 ml/min which is measured by a gas flow meter (Bronkhorst F-201CV). Distilled and filtered water is injected from a tank by means of a high accuracy pump (Ismatec MCP-Z Standard) with liquid flow rate Q_L ranging from 15 ml/min to 30 ml/min, which is measured using a liquid flow meter (Bronkhorst L30).

In order to study different configurations of colliding jets, the impact angle φ (angle between the jet centerline and the horizontal) and the distance between injectors s can be modified. A schematic definition of φ and s, with the used coordinate system (x, y) is shown in Figure 2, in which two colliding bubble jets generated at $\varphi = 30°$ are shown. The different bubble sizes that can be observed are mainly due to some coalescence events, although the performance of the injectors has also some influence on bubble diameters since they generate bubbles of a certain size with slight deviations.

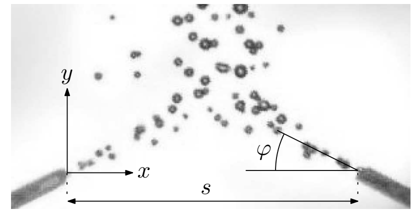

Figure 2: Snapshot of two colliding bubble jets with the definitions of the impact angle φ and the separation between injectors s.

RESULTS AND DISCUSSION

With the aim of carrying out a fundamental analysis of the behavior of bubbles and jets after injection, the described experimental setup has been used with different gas and liquid flow rates and at different distances between injectors. The variation of the impact angle φ has also been considered.

According to Schlichting [7] and Davidson [8], the momentum flux J can be regarded as the main parameter that characterizes the jet structure, and is given by

$$J = 2\pi\rho \int_0^\infty v_x^2 r dr, \tag{1}$$

where ρ is the density, v_x is the velocity and cylindrical coordinates (r, θ, x) are used. Taking into account both liquid and gas phases, J can be computed by

$$J = J_G + J_L = \frac{4}{\pi d_C^2}(\rho_G Q_G^2 + \rho_L Q_L^2) \tag{2}$$

where ρ_L and ρ_G are the liquid and gas densities respectively, and d_C is the capillary diameter.

Many studies have been done [7-9] concerning the velocity field of a single-phase jet. In the case of two-phase flows we have to take into account the role played by gravity, specially when the difference between the densities of each phase is high. As a first approximation, we can consider that in the region where gravity is negligible in front of dominant inertial forces, the bubbles are moving passively through the jet without perturbing significantly the flow field. In order to reinforce the basis of this approximation, the velocities of bubbles at the jet centerline have been measured with $J = 54$ g cm/s^2 at two different distances between injectors s. Averaging the velocities of 5 sample bubbles in each case, the variation of the velocity with the distance to the injector outlet has been obtained (see Figure 3). The average bubble velocity at the outlet of the injector is $v_{out} = 159 \pm 16$ cm/s. Good agreement between the ex-

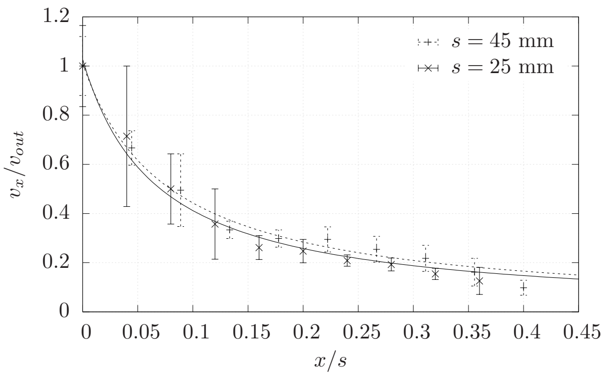

Figure 3: Average bubble velocity at jet centerline, for $J = 54\ \mathrm{g\,cm/s^2}$. Lines correspond to data fitting to $v_x \sim a/(b + x/s)$.

perimental data and the fit $v_x \sim a/(b+x/s)$ is observed, which confirms the validity of our first approximation. Velocities corresponding to $s = 25$ mm are lower than those corresponding to $s = 45$ mm. This fact can be due to the interaction with the opposing jet: when s is small the jets are closer to each other and the flow field generated by the opposing jet can decrease the mean velocity in the jet centerline. This decrease in velocity should be larger at higher values of x. In fact we can observe that when $x > 0.3s$, the velocity values are lower with respect to the fitting curves. We conclude that the presence of the opposed jet decreases the average jet velocity as it reaches the central zone where the two jets are colliding. The interaction between jets is thus not negligible and the velocity field can only be compared with that of a single injector at low values of x.

In order to locate the areas where inertial forces become negligible in front of buoyancy, a parameter δ is defined as the shortest distance from the jet centerline to the point where bubbles start a vertical rise. If a bubble is located above δ, its motion is dominated uniquely by the gravitational force. On the other hand, if a bubble is placed below δ, the flow field is governed mainly by the inertial forces. δ is measured along the injection axis as can be seen in Figure 4.

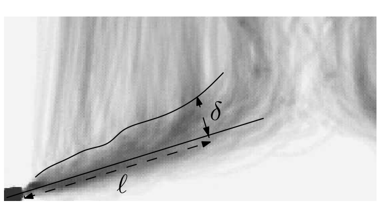

Figure 4: Schematic definition of δ and ℓ.

In Figure 5 the variation of δ along the injection axis is shown, for different values of the distance between injec-

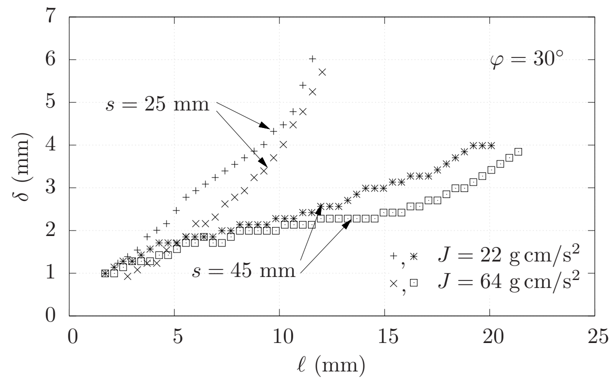

Figure 5: $\delta(\ell)$ at $\varphi = 30°$ for different values of J and s.

tors and the momentum flux J. The behavior is almost linear in all cases. It can be observed for $s = 25$ mm a slight increase of the slope at high values of ℓ due to the interaction with the incoming jet. Data corresponding to $s = 45$ mm can be measured at higher values of ℓ than data corresponding to $s = 25$ mm, because when the injectors are far from each other, the interaction zone between the two colliding jets is located far from the outlet of the injector. It can also be observed that as J increases (with fixed values of φ and s), δ decreases, which is related to a smaller opening angle of the jet.

CONCLUSIONS

We have designed an experimental setup for the study of two colliding bubble jets in microgravity. The impact angle between jets can be modified, and the bubble generation frequency and velocity can be controlled. We have obtained on ground results concerning the jet structure that will be compared with those to be obtained in a forthcoming drop tower campaign. A substantial velocity decrease has been observed at the central zone of the opposed-jet configuration due to the strong interaction between the two jets. The distance from the jet axis where the inertial forces are negligible increases linearly with the distance from the injection point. Further studies are still required both in normal gravity and in microgravity conditions in order to get deeper insight in the role played by the gravity force on the jet structure.

ACKNOWLEDGEMENTS

The authors are very grateful to *Ministerio de Educación y Ciencia* (Spain) for financial support (Project FIS2006-11452-C03-02), and the support by *Comissionat per a Universitats i Recerca del Departament d'Innovació, Universitats i Empresa de la Generalitat* *de Catalunya i del Fons Social Europeu* is also gratefully acknowledged.

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