THE FLOW FIELD OF A VERTICAL AIR BUBBLE PLUME: COMPARISON BETWEEN NEWTONIAN AND NON - NEWTONIAN FLUID AS STAGNANT LIQUID

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Abstract: In this work, characteristics of the flow field of air bubble plume when the stagnant liquid is non Newtonian is investigated. Comparisons are made with the equivalent situation where the liquid is Newtonian. It is an experimental study and the particle image velocimetry (PIV) technique for flow characterization is used.

Key words: non-Newtonian fluid, viscoplastic material, axisymmetric bubble plume, PIV, two-phase flow.

1. INTRODUCTION

The use of bubble column is often found in several industrial processes. Food, chemical, biochemical and waste treatment industries are examples in which airlift columns are widely applied. As advantages of using gas bubble column instead of handling with traditional mechanical mixers for processes homogenization are the reduction of equipment size and the non necessity of moving parts be introduced in the flow.

In many of those industrial processes non-Newtonian fluid are present The flow of a non-Newtonian fluid shows complexity which depends on the geometry where the flow occurs, the stresses and the fluid behavior. The success of the control and improvement of such processes are strongly linked to the knowledge of the fluid flow dynamics. In the literature, most of bubble flow investigations are related to Newtonian liquid (examples are Kulkarni et al. [1], Harteveld et al. [2], Kandakury [3], among other. Although the demand for understanding the dynamics of such flow signalizes a source for research on fluid flow, particularly in case of mixing process dealing with bubbles in non-Newtonian fluid, few experimental investigations have been found in the literature. Fransolet et al. [4] used aqueous solutions of xanthan (a non-Newtonian shear thinning fluid) for analyzing the influence of the liquid rheology on the gas flow pattern in a bubble column reactor. The authors showed differences between the stablished flow pattern of Newtonian and non-newtonian liquid in the column. They used parietal pressure probes and electrical resistance tomography(ERT) as experimental techniques. Shamlou et al. [5] presented an experimental study on gas holdup, liquid velocity and shear rate as a function of the flow behavior index, in an airlift device containing pseudoplastic liquids (solutions of sodium carboxymethyl cellulose-CMC). The authors mentioned about the difficult to see the independence levels of the shear rate in the column to the flow behavior index.

Kobus [6] showed through experiments with water, that in a flow field induced by upward bubble plume the Gaussian profile of the vertical velocity distribution spreads under linear mode in the vertical direction. Recently, Farias et al. [7] studied experimentally the influence of a cylinder and a flat plate placed near the air injection point of a vertical bubble plume inside a tank filled with water, to the vertical velocity distribution in this flow. The particle image velocimetry (PIV) was used for flow visualization and flow field analyses. The Coanda effect was observed as influential in the resultant flow field.

In the present work, the flow field for axisymmetric bubble plume in non-Newtonian liquid is analyzed and compared to the respective case of Newtonian liquid. The PIV technique is applied for visualizing the velocity field of the shear thinning liquid.

2. GENERAL PROCEDURE

In this investigation, the bubble plume is generated by controlled air flow which is injected through the bottom of a tank filled with stagnant liquid. Filtered water, glycerin and Carbopol 940 are the liquids under test. Carbopol is an aqueous solution which is representative of the shear thinning behavior of a non-Newtonian liquid. Five different concentrations (in mass) of such aqueous solution are the samples of non-Newtonian liquid on different behavior index *n* during the tests.

Glycerin and filtered water are the representatives of Newtonian liquids, and since a diluted glycerin provides certain levels of viscosities, the flow using this last fluid can be compared to that of a shear-thinning liquid with similar level of apparent viscosity.

A Rheometer (TA-Instruments) is used for non-Newtonian fluid characterization. This work considers the shear thinning liquid behavior as described by the Herchel -Bulkley mathematical model, as follows:

$$\eta = \begin{cases} \dfrac{\tau_0}{\dot{\gamma}} + K\dot{\gamma}^{\,n-1}, & if \quad \tau \geq \tau_0 \\ \infty, & if \quad \tau < \tau_0 \end{cases} \qquad (1)$$

where

n = behavior index
K=compliance index [Pa.s^n]

τ =yield stress [Pa]
τ_0 = minimum yield stress [Pa]
η = viscosity function [Pa.s]
$\dot{\gamma}$ =strain rate [1/s]

In equation (1), if τ_0=0, $K=\mu$ and n=1, the mathematical model represents the Newtonian fluid behavior.

Stereo PIV System (La Vision) with two CCD cameras is the tool for flow visualization and description. Particles of Rhodamin B ranging from 20 to 50 micron in diameter are the reflecting element inserted in the liquid for the PIV application. A set of images is taken and analyzed through interrogation window size of 32 X 32 pixels. The vertical velocity profile distribution is the main item for comparison and discussion on this bubble plume behavior study.

3. PRELIMINARY RESULTS AND DISCUSSION

As initial measurements, the velocity profiles distribution of an axisymmetric bubble plume in water were acquired, in different vertical height of a tank, by using PIV technique. The tank is made of glass, and its mean dimensions are 1 x1 x 1m^3. The mean water shallow was 950mm. The results were as follows:

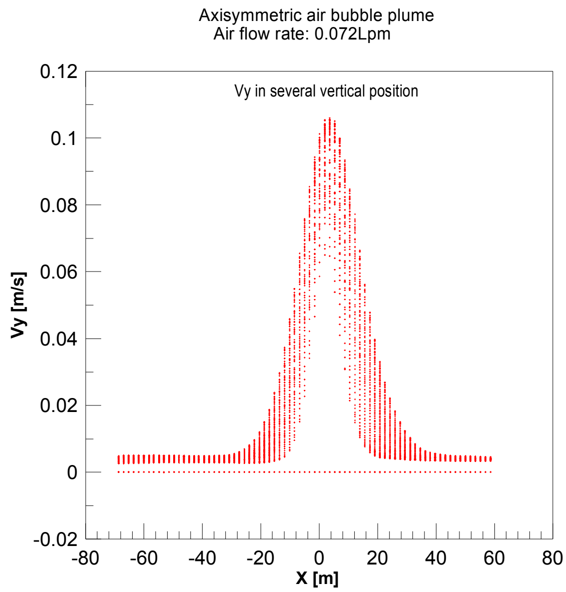

Fig. 1. Vertical velocity distribution in an axisymmetric bubble plume. Liquid: water; air flow rate: 0.072Lpm.

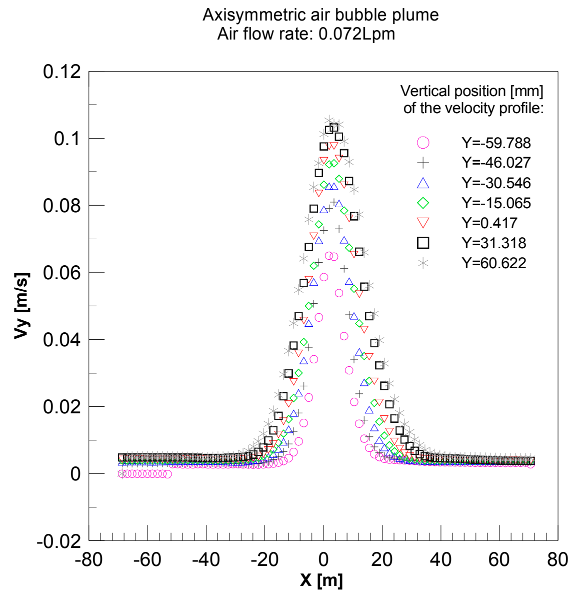

Fig. 1. Vertical velocity distribution for seven axial positions. Liquid: water; air flow rate: 0.072Lpm.

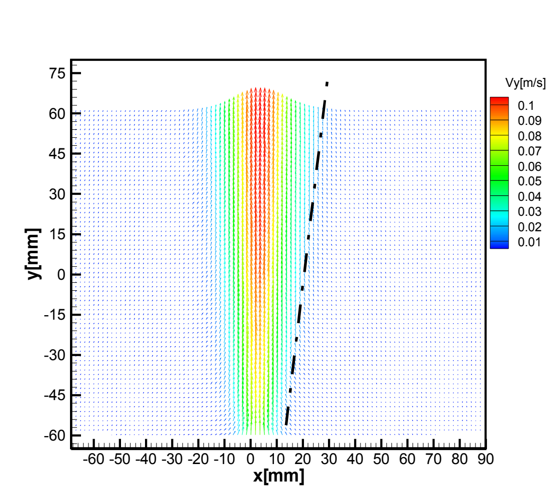

Fig. 1. Field of velocity of the axisymmetric bubble plume. Liquid: water; air flow rate: 0.072Lpm. Dashed line shows the linear spreading of the velocity profile as the axial position increases.

As can be seen, the figures 1 to 3 show the Gaussian profile of the vertical velocities, as expected for axisymmetric plume. Figure 1 shows the Gaussian profile for a wide range of axial positions in the plume and, in order to clarify the data, figure 2 shows only Vy profiles for seven vertical positions along the plume axis. Such vertical distances are related to the scale as presented on the y axis of the figure 3.

The figure 3 shows the mean field of velocity of a vertical plane that crossed the air injection point inside the tank. Through this velocity mapping it is clear a linear trend of spreading of the vertical velocity profile of the plume (dark dashed line). There is an overture of the Gaussian profile which is provoked by the liquid entrainment effect. In the present work, the deviation of this linear trends will be discussed for non Newtonian liquid, considering several behavior index *n,* as well as the characteristic apparent viscosities. Since in the literature there is a lack of experimental data on the flow field generated by a bubble plume in non Newtonian liquid, the results obtained with this work play an important role as support for improving and promoting best comprehension and control on mixing process (as column reactor) where this kind of fluid is present.

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