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Experimental Investigation of the Bubbly Drag Reduction in the Presence of Axial Flow in a the Couette-Taylor System

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ABSTRACT

Modification of frictional drag reduction due to the presence of small bubbles and axial flow is investigated experimentally using a Couette-Taylor system. Flow condition between concentric cylinders is fully turbulent and Taylor vortices are appeared into flow when rotational Reynolds number is changed from 5000 to 70000. Torque acting on rotating inner cylinder and bubble behavior are measured while air bubbles and axial flow are injected constantly from the bottom of the system into annulus gap. Pure water is used to avoid the uncertain interfacial property of bubbles and to produce nearly mono-sized bubble distributions. Bubble diameter is measured by image processing method. The result showed that in the absence of small bubbles, axial flow reduces the friction drag. Moreover, it is observed that axial flow improves positive effect of bubbles on drag reduction. In this case, a drag reduction of 28% is obtained which is decreased by increasing the rotational Reynolds number.

KEYWORDS

Micro-bubbles, Taylor-Couette, Skin Friction, Turbulent Flow, Axial Flow.

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1- INTRODUCTION

When fluid moves on a solid body or a solid object moves through fluid, a resistance force called drag force is produced in the opposite direction of the movement. This force is the resultant of two forces. One is due to skin friction drag and the other is the result of pressure drag.

Everyday energy is used for keeping the motions mentioned above and the great amount of it is used to overcome the resistant force. Since energy is expensive and energy degradation has a worldwide effect on the environment, drag reduction has been important recently. Various methods of drag reduction have been reported in recent decades. These methods are categorized into laminar flow control and skin friction reduction methods in the boundary layer. They are also subdivided into active control and passive control methods.

One of the active control methods is the injection of air bubbles into flow that is the cheapest compared to the other methods and it has the lowest environmental pollution. In recent decades, utilization of air bubbles has been increased especially in small size (micro bubbles) to decrease skin friction. The so called "micro bubbles drag reduction" method was first reported by McCormick and Bhattacharyya [1]. Micro bubble drag reduction occurs in complex situations, which makes the study of its mechanism extremely difficult. In recent years, Couette-Taylor (CT) systems have been used to solve this problem. The first study on micro bubble drag reduction in CT flow systems was done by Murai et al. [2]. The results indicated that appearance of micro bubbles elongated Taylor vortices along cylinders axis, which reduced the number of Taylor vortices in annulus gap between two co-axial cylinders and decreased the angular momentum transfer. The effect of micro bubbles on drag reduction in turbulence flow was investigated by van den Berg et al. [3]. In their study, and low rotary Reynolds number, drag reduction was insignificant, and in $\mathrm{Re}_{\omega} = 10^6$ it reached 20%. Sugiyama et al. [4] investigated micro bubble drag reduction in a CT flow system using DNS. They observed that micro bubbles reduced the torque acting on inner cylinder, which consequently led to the drag reduction

According to recent researches, the injection of micro bubbles into CT flow leads to drag reduction by decreasing the density of flow and the momentum transfer. Also, the experimental and numerical results indicate that the injection of axial flow by delaying the occurrence of Taylor vortices in CT flow causes drag reduction. In these researches, the effect of these parameters (bubble injection and axial flow) on drag reduction has not been investigated simultaneously. In this experimental study, the effect of an imposed axial flow on drag reduction and bubbly drag reduction has been investigated experimentally in a vertical CT system. The air bubbles and axial flow have been injected at the bottom of the concentric cylinders and more air bubbles with size smaller than 1.5*mm* were generated. To investigate the drag reduction changes in the presence of bubbles and axial flow, torque acting on inner cylinder was measured. This was done in various void fractions and at relatively high rotary Reynolds numbers. Torque is considered the most effective parameter related directly to the skin friction and to the flow field.

2- METHODOLOGY

In this study, a vertical CT setup with a special closed circulating water system was designed. The main parts of the apparatus include a test section, water supply system, air supply system, electric motor, ball bearings and mechanical seals.

The experimental tests were conducted in a stable condition as follows. At first, the air and the water flow were injected into the system to predetermined rates. Then the inner cylinder was rotated at a predetermined rotational speed. After determining input parameters, the system worked between 15 *s* to 60 *s* and then the acted torque on the rotational inner cylinder was measured in its stable condition. The rotational speed of the inner cylinder specifies the duration time of working system before torque measurement. The time is longer for tests in which rotational speed is less than the others. The tests were repeated by changing input parameters and gap time between each of the two consequent tests was about 60 *s*. In these tests, the main control parameters were rotary and axial Reynolds numbers, the Taylor number and void fraction.

The average wall shear stress acting on the rotating inner cylinder surface (τ_w), was calculated by measuring the pure torque acting on this cylinder in all tests. To measure this torque, resistance torques of ball bearings and mechanical seals were eliminated. These resistance torques were measured separately as a function of the rotational speed, after removing the water from the annulus gap. The wall shear stress is defined by

$$\tau_w = \frac{T}{2\pi r_1^2 L_1} \tag{1}$$

In the Eq. (1):

T is the torque acting on inner cylinder.

r_1 is the radius of inner cylinder.

L_1 is the length of inner cylinder

After τ_w is obtained from the Eq. (1), the friction coefficient of the inner cylindrical surface was calculated by

$$C_f = \frac{2\tau_w}{\rho_w (r_1 \omega)^2} \tag{2}$$

In the Eq. (2):

ρ_w is the density of water.

ω is the angular velocity of inner cylinder.

To study the effect of axial flow on drag reduction and air bubble drag reduction, the drag reduction ratio was defined by

$$\eta = \frac{C_{f0} - C_f}{C_{f0}} \tag{3}$$

In the Eq. (3):

C_f is the drag coefficient in two phase flow and in the presence of axial flow.

C_{f0} is the drag coefficient in two phase flow and the absence of axial flow.

The void fraction is a dimensionless parameter for the bubbles. This parameter determines the magnitude of the interaction between bubbles and vortices made in the air gap. The changes of void fraction depend on the two-phase flow pattern appearing in the steady stead [2]. For a given volume flow rate of continuous bubble injection and a volume flow rate of water injection in the annulus gap, the average void fraction in the test section is estimated by

$$\alpha = \frac{Q_a}{Q_a + Q_w} \quad (4)$$

In the Eq. (4):

Q_a is the air flow rate

Q_w is the water flow rate

Fig. 1 shows the changes of the drag reduction ratio based on the void fraction.

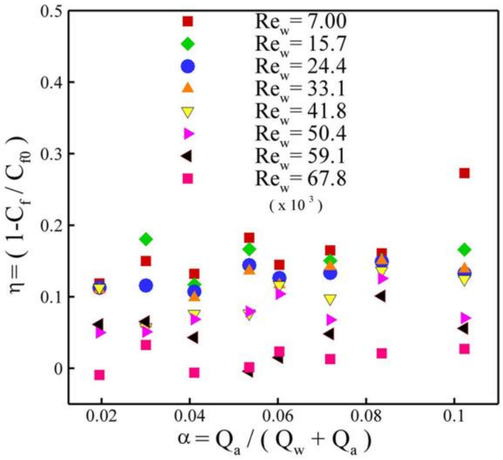

Fig. 1 Drag reduction ratio changes by increasing void fraction α in various Re_ω

In fact, in this figure, the simultaneous effect of Q_a and Q_w on drag reduction has been investigated.The results show an increased trend of the drag reduction ratio, when the void fraction increased in all Re_ωs. Likewise, by increasing Re_ω in all void fractions, the drag reduction ratio decreased. Therefore, the maximum drag reduction has occurred in the maximum void fraction (10.33%) and lowest Re_ω when the bubbles and axial flow were simultaneously applied into the CT system.

3- CONCLUSION

This experimental study on a vertical CT flow system was conducted to investigate the effect of axial flow on the drag reduction and bubbly drag reduction. The changes of skin friction were obtained through measuring the torque acting on the rotating inner cylinder as the main factor. The results show that in a two-phase CT flow without axial flow, air bubbles reduce the drag resistance by reducing fluid density. Moreover, the axial flow in the absence of air bubbles causes drag reduction and by increasing its volume rate, drag reduction has been increased. It has occurred due to damping Taylor vortices which have a major role in reducing momentum transfer and increasing flow stability. Similarly, it has been observed that axial flow improved the effect of bubbles on the drag reduction when they were simultaneously applied into the CT flow. Comparing cases of drag reduction mentioned above has showed that the amount of achieved drag reduction in the simultaneous presence of axial flow and bubbles in CT system was more than other cases. The created drag reduction referred to the axial flow effect on the Taylor vortices and the upward velocity of air bubbles.

4- REFERENCE

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