Features of reducing the turbulent friction of a liquid on the channel wall by gas-saturation

Aleksei Evseev*, *Leonid* Maltsev

Kutateladze Institute of Thermophysics, Novosibirsk, 630090, Russia

Abstract. The report presents the results of an experimental study of the efficiency of reducing the local friction at gas saturation of the turbulent boundary layer (TBL) in the input section of the channel at different gravitational orientation of the wall, and its dependence on the structure of gas-liquid flow. Profiles of gas concentration have a peak near the wall, which increases with the gas flow increase. The growth of concentration in the near-wall zone leads to rapid coalescence of bubbles, as a result of which the flow in TBL transits to the film-bubble regime with increasing the buoyancy effect of the gas phase, especially at low flow rates. It is shown that the key parameter of friction reduction by gas saturation is the gas phase concentration in the inner region of the boundary layer, whose magnitude is determined by the gas flow rate, the flow velocity, the distance downstream behind the gas generator, and the gravitational orientation of the wall.

1 Introduction

The technology for reducing turbulent friction using microbubbles has received increasing attention due to such advantages as high efficiency (80%), environmental friendliness, simplicity of design and low costs.
The state-of-the-art in research and the latest achievements in the reduction of friction using gas saturation of the turbulent flow are given in the reviews [1, 2].
The aim of the research is to measure shear stresses on the top and bottom channel walls at introducing gas into the flow through a porous wall, and to determine the dependence of friction reduction on the profile of gas concentration in the range of numbers $Re_x = (0.23\text{-}1.5)\times10^7$ and specific gas flow rates up to $q = 0.05\ m^2/s$

2 Experimental setup and experimental technique

Studies on the effect of gas saturation on TBL and friction at the wall were carried out in the input section of the channel with section of 100 mm (height)×300 mm (width) and a length of 2200 mm. Water from the receiving tank was directed into the channel by a centrifugal pump through a honeycomb and a confuser (1:10). The gas bubbles were removed from the flow to an open receiving tank. The gas was injected into the flow

* Corresponding author: evseev@itp.nsc.ru

through a porous (20 μm) inset (140×172 mm), which was mounted flush with the channel wall at a distance 429/615 mm from the confusor in an open or closed working part. The gas flow was varied in the experiments up to 7 l/s and was measured with a standard orifice plate with an accuracy of ±3%. The local friction on the channel wall with accuracy of 10% was measured by sensors of the type "floating wall" (diameter 23 mm). Sensors (P1-P4)/(P5-P9) were mounted flush on the top/bottom channel wall at distances X*=93, 168, 243 and 488 mm downstream over the porous inset. Measurements of the local gas concentration (φ) were carried out using a fiber optic sensor. The diameter of the sensor was 0.15 mm. The measurement error was ±10%. First, we measured the local friction on the bottom wall of the channel behind the gas generator (X*=93, 168, 243 and 488 mm) with gas saturation of TBL at three flow velocities U=3.6, 6.3-6.5 and 10.2 m/s. Then, instead of the block of local friction the unit with a fiber sensor was mounted, and the gas concentration profile was measured in the sections of the boundary layer at X*=50, 200 and 445 mm. Similarly, measurements were carried out in a hydrodynamic tunnel on the upper wall of the working part. Experimental methodology is presented in [3].

3 Experimental results

Fig. 1 a, b show the dependence of the drag reduction (DR=1-C_f/C_{f0}) on the specific gas flow rate (q=Q/b) on the top (Fig. 1a) and bottom channel walls (Fig. 1b), where b = 140 mm is the width of the gas generator. For comparison, the graph shows data [4]. By reducing friction in TBL using gas saturation it is proposed to consider three modes depending on the specific gas flow rate (q): bubble regime (DR up to ~20%); transitional film-bubble mode (DR~ (20 -80)%); film mode (ALDR), which is characterized by a thin air layer (film) between the surface and the liquid flow with friction reduction of 90 % ± 9 %. The reduction in local friction increases with increasing q, but the steepness of the data varies at different X* and flow velocities on the upper and lower walls. At a flow rate U=10.2 m/s the dependence of the effect on q for the upper and lower walls is almost identical. At q = const the reduction of the flow rate leads to a larger reduction of friction. Near the generator q has its optimum (bottom wall), when the DR effect is maximum.

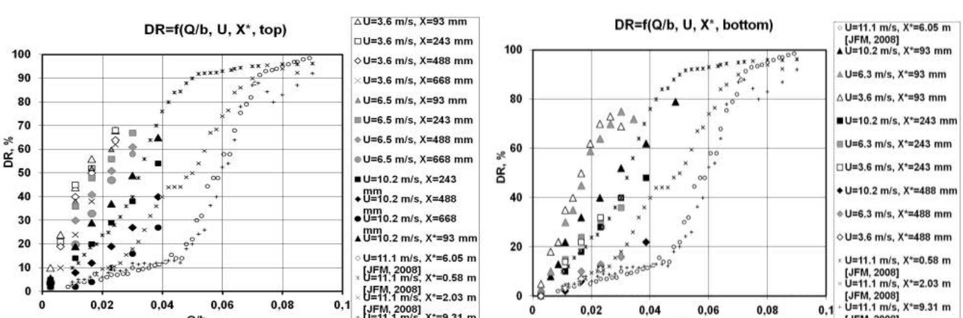

Fig. 1 a, b. Dependence of drag reduction at top (a) and bottom (б) channel walls on q=Q/b.

Fig. 2 a, b show the dimensionless concentration profiles of the gas phase in the bottom (a) and top (b) walls of the channel at X* = 445 mm for three flow velocities and three gas flow rates. Here δ is the thickness of the boundary layer without gas injection. For maximum flow rate (U = 10.2 m/s) and Q = 2.3, l/s the concentration peak was reduced to φ_m =22% / φ_m =16%, and moved away from the wall at a distance of 3 and 4 mm (top/bottom). But for U = 3.6 m/s and Q = 2.3, l/s the peak (φ_m =65%) at the upper wall remained at a distance Y≈1 mm, which is close to the concentration at X*= 50 mm (70%). When increasing the gas flow rate there is a transition from bubble to film-bubble regime of

DOI: 10.1051/matecconf/201711505014

the mixture flow, resulting in deformation of the concentration profile (Fig. 2b) due to the effect of buoyancy.

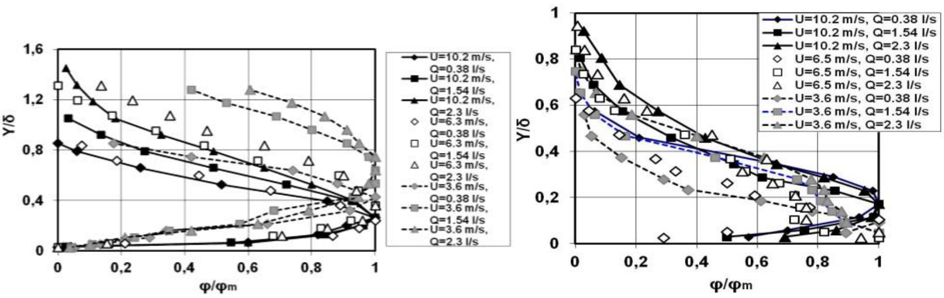

Fig. 2. a, b. The dimensionless concentration profiles of gas phase at the lower (a) and top (b) walls of the channel at X* = 445 mm for three flow velocities and three gas flow rates.

Mechanisms of friction reduction at gas saturation of TBL were considered in many theoretical works, an overview of which can be found in [5]. Fig. 6 shows the results of measurements in which the relative reduction in friction is a function of φ*, that is, the average gas concentration in the near-wall zone of the boundary layer ($Y^+<250$). Here, the straight line 1 corresponds to a change in the mixture density in the near-wall zone of the boundary layer, and the curve 2 corresponds to a theoretical dependence, taking into account changes in the mixture density, increase in its effective viscosity and modification of turbulence [5]. All known data on friction reduction at gas saturation are generalized by the dependence on gas concentration φ* in the near-wall zone of TBL, which is a key parameter. This confirms the hypothesis that the principal features of the mechanism of friction reduction at gas saturation by bubbles ($18<d^+<200$-250) is the decrease in mixture density near the wall, increase in its effective viscosity, as well as modification of turbulence at the interaction of bubbles with vortex sheath in the inner region of the boundary layer.

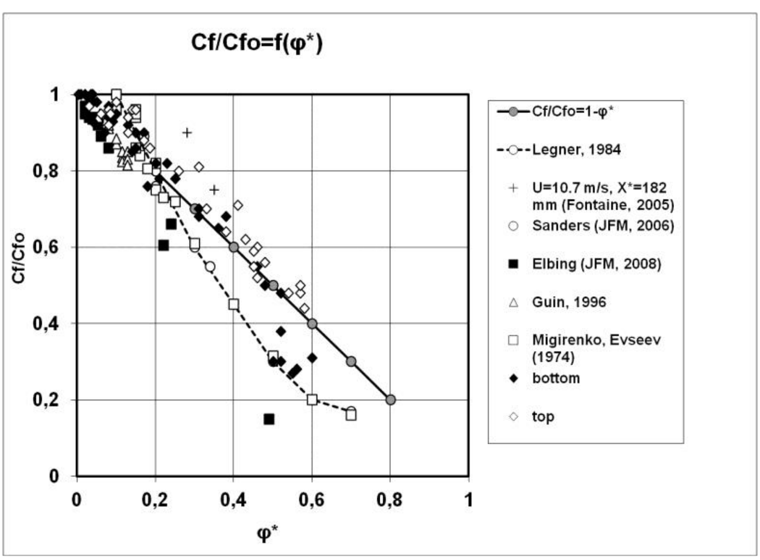

Fig. 3. The dependence of the effect of friction reduction at gas saturation on the average gas concentration **φ*** in the inner region of the turbulent boundary layer $Y^+<250$).

4 Conclusion

The reduction of friction on the upper and lower walls of the channel (inlet section) arising at gas introduction through the porous coating was investigated in the range of Reynolds numbers $Re_x = (0.23\text{-}1.5)10^7$. The friction at the wall was measured by sensors of the "floating" wall, and the gas concentration in TBL was measured by the fiber-optic sensor.

With the growth of Q the maximum effect of reducing friction on the walls amounted to 70-80%. But for the upper wall, the effect remained at a high level downstream, and on the bottom it was lost.

The concentration profiles had a peak near the wall, which increased with increasing gas flow rate up to ~ 60±10%. The growth of concentration in the near-wall area led to intensive coalescence of bubbles, which resulted in the transition of the flow in the boundary layer to the film-bubble regime with increasing buoyancy effect of the gas phase, especially at low flow rates. Downstream, the outflow of air bubbles from the wall area led to a rapid loss of effect on the lower wall, and at the upper wall the effect remained at a high level. Therefore, the key parameter to reduce friction with gas saturation is the concentration of the gas phase in the buffer zone of TBL, the value of which is determined by the gas flow rate, the fluid velocity, the distance downstream behind the gas generator and the gravitational orientation of the wall.

The work was performed with financial support of the Russian Science Foundation (Grant No. 14-19-01685, Leading scientist Markovich D.M.) provided through IT SB RAS.

References

1. L.S. Ceccio, Annu. Rev. Fluid Mech. **42,** 89 (2010)
2. A. Hashim, O.B. Yaakob, K.K. Koh, N. Ismail, Y.M. Ahmed, Jurnal Teknologi (Sciences & Engineering). **74**, 5 39 (2015)
3. A.R. Evseev, L.I. Maltsev, J. Int. Scientific Publications: Materials, Method & Technologies. **6**. Part 3. (2012)
4. B.R. Elbing, E.S. Winkel, K.A. Lay, S.L. Ceccio, D.R. Dowling, M. Perlin, J. Fluid Mech. **612,** 201 (2008)
5. H.H. Legner, Phys. Fluids. **27,** 356 (1984)