XXI ICTAM, 15-21 August 2004, Warsaw, Poland

SIGNS OF FLOODING INSTABILITY IN INCLINED LIQUID FILMS AT HIGH PRESSURE AND MASS TRANSFER IN HIGH DENSITY GAS SLUGS

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Summary The influence of gas density on flooding instability phenomena is investigated experimentally both in long gas slugs of CO_2 rising in vertical tubes filled with water at pressures up to 5.2 MPa, and inside a rectangular column with flat walls positioned in the vertical and at 15º, 45º and 60º from the horizontal, at absolute pressures up to 0.6 MPa with air and up to 1.5 MPa with argon, at Reynolds numbers for the water between 2667 and 26667.

INTRODUCTION

Our team have shown (see Ref. 1 to 7) that when long high density gas slugs rise in vertical tubes filled with liquid, signs of flooding instability of the wetted-wall flow become apparent, if the gas density is raised sufficiently (above about 2-3 MPa with argon, for slugs in 32.8 mm i.d. and in 21 mm i.d. tubes, respectively). The detection of flooding instability was carried out by means of measuring pressure drop (and its rapid fluctuation) along the gas slugs[8].
Despite the considerable evidence provided, for tubes with 21 mm and 32.8 mm i.d., there is some scepticism about the possibility of flooding instability occurring with the low gas velocities reported. However, it should be remembered that the drag force exerted by the gas on the descending waves, that leads to flooding instability is directly proportional to the density of the gas.

Experiments in inclined liquid films at high pressures
In order to investigate further the influence of gas density and the inclination of the column on flooding phenomena, a new study was performed based both in visualization and on the measurement of pressure gradients inside a rectangular column, 3.0 m long, with cross section 25 × 30 mm, positioned in the vertical and at 15º, 45º and 60º from the horizontal, at absolute pressures up to 0.6 MPa with air and up to 1.5 MPa with argon, at Reynolds numbers for the water between 2667 and 26667. The technique adopted follows closely that originally presented by the authors (see Ref. 1 to 7).

Experiments in high density gas slugs
In an independent study, on long gas slugs at high pressure, Nakazatomi *et al.*[9] measured the velocity of the waves moving along the falling film as well as the average thickness of the film and, it may be concluded, that flooding instability was obtained with slugs of nitrogen in water, in a 19.2 mm i.d. column, for gas pressures above 5 MPa.
In the present work we provide additional evidence of flooding instability by means of the measurement of mass transfer rates for long slugs of CO_2, at pressures up to 5.2 MPa, rising in water. The mass transfer coefficients were measured by the constant volume method[10,11], in which the pressure variation is followed inside a tightly closed tube along which a single long slug of CO_2 is allowed to rise. Under these circumstances, mass transfer is totally determined by conditions on the liquid side and therefore, the value of the mass transfer coefficient gives a significant indication of the flow pattern on the liquid film. For laminar film flow the original theory of Higbie[12] is valid, but where transition to turbulent film flow occurs, there is a steep increase in the mass transfer coefficient.
The experiments performed in this work show that for pressures above a certain threshold (corresponding to flooding instability), there is a further substantial increase in the mass transfer coefficient, which results from the gas-liquid interface being severely disrupted. This is strong additional evidence in favor of our claim that flooding instability is observed with high gas densities. We conducted our experiments at up to 5.2 MPa, in tubes with internal diameters of 21, 32.8 and 40.5 mm.

CONCLUSIONS

The experiments in high density gas slugs rising in vertical tubes filled with water at pressures up to 5.2 MPa and inside a rectangular column with flat walls positioned in the vertical and at 15º, 45º and 60º from the horizontal operanting at high pressures (up to 0.6 MPa with air and up to 1.5 MPa with argon), have shown that there is a critical value of $\rho_g\,(u + u_i)^2$ above which flooding instability sets in, for a given liquid at a given flow rate in a given column (where ρ_g is the density of gas, u the average velocity of gas and u_i is the liquid velocity on gas-liquid interface).

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