A Review on non-boiling two phase flow regime transition and development of flow pattern map in mini channel

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***Abstract*—Two phase flow is complex because of the presence of two phases with different estimations of fluid properties basically density and viscosity. It is therefore needed to determination complex physical mechanisms associated with each flow regime in two phase flow. In two phase flow, instability emerges, where little perturbations draw kinetic energy from the mean flow scale. Intermittent flow is thus described by non-continuous motion in the axial direction, and exhibits local unsteady behaviour. Here, Brief literature review is carried out for the present topic.**

***IndexTerms*—non boiling, flow map**

I. INTRODUCTION

Multi-phase flow is commonly found in natural environment such as rainy or snowy winds, tornadoes, typhoons, air and water pollution, volcanic activities etc. It has got a great importance in a variety of conventional and nuclear power plants. Recently the emergence of the micro chemical technology demands high efficient reactors with more compact structure, which have to consider gas/non-Newtonian fluid two-phase flow in micro- or mini-channels. Since the morphology of two phase flow always plays a critical role in determining the heat and mass transfer during the reaction process, it is essential to have a clear understanding of the physical mechanism of two phase flow in micro or mini-channels.

The most important characteristic of two-phase flow is the existence of interfaces, which separate the phases and the associated discontinuities in the properties across the phase interfaces. Because of the deformable nature of gas-liquid and liquid-liquid interfaces, a considerable number of interface configurations are possible. Gas–liquid flow is complex because of the existence of deformable interfaces and the fact that one of the phases is compressible. Consequently, the various heat and mass transfers that occur between a two-phase mixture and a surrounding surface, as well as between the two phases, depend strongly on the two-phase flow regimes.

II. LITERATURE REVIEW

Triplett et al. [7] conducted experiment on investigation of air/water two-phase flow in circular mini-channel having inner diameters of 1.1 and 1.45 mm, and in semi-triangular micro-channel having hydraulic diameter of 1.09 and 1.49 mm, where the gas and liquid superficial velocity ranges from 0.02 to 80 and from 0.02 to 8 m/s, respectively. The discernible flow patterns were recognized as bubbly, churn, slug, slug-annular, annular, which occurred in all test sections. It showed that the flow pattern maps using gas and liquid superficial velocities as coordinates are similar. The results agree well with other experimental data and the inconsistencies can be attributed to the confusion in the identification of flow patterns. Comparison with available relevant regime transition models implies that there are generally poor agreements between the models and the experimental data.

Xu et al. [8] carried out adiabatic air/water two-phase flow in vertical rectangular channels with narrow gaps of 0.3, 0.6 and1.0 mm, respectively. It is observed that the flow regimes in channels with gaps of 1.0 and 0.6 mm are similar to those found in conventional larger channels. However, the flow regimes in the channel with the gap of 0.3 mm are dramatically different from previous studies; and the bubbly flow is not observed even at low gas flow rates. A new criterion has been developed to predict the transition of the annular flow.

Zhao et al.[9] performed an experimental study of co-current upward air/water two-phase flow in three vertical small triangular channels with hydraulic diameters of 2.886, 1.443 and0.866 mm. The images of the two-phase flow patterns were taken by a high-speed motion analyzer and the flow regime maps for the three channels were developed. The results suggested that the typical flow patterns encountered in conventional, large-sized vertical circular tubes, such as dispersed bubbly flow, slug flow, churn flow and annular flow, can also be found in the two larger triangular channels while the dispersed bubbly flow is not found in the smallest triangular channel. A new type of flow patterns, referred as the capillary bubbly flow was identified, which is characterized by a single train of bubbles with ellipsoidal shape flowing upwards along the channel axis. It is also found that in the slug flow regime, slug-bubbles are substantially elongated and the transition boundary from slug to churn and from churn to annular shift to the right as the hydraulic diameter of the triangular channels decrease according to the flow regime maps they obtained.

Hibiki and Mishima et al.[2]developed the flow-regime transition criteria for the vertical upward flow in narrow rectangular channels based on Mishima and Ishii model for round tubes. They compared the criteria with the existing experimental data for air–water flows in narrow rectangular channel with the gaps ranging from 0.3 to 17 mm and satisfactory agreements have been found.

They concluded that a model for the gaps narrower than 1 mm should be modified in accordance with new flow regimes to be observed in a rectangular channel with a micro gap.

Serizawa et al. [4]carried out visualized investigations on air–water two-phase flow in circular tubes with 20, 25 and100 μm inner diameter and steam–water flow in a 50 μm inner diameter circular tube, with the superficial velocities covering a range UL = 0.003–17.52 m/s and UG = 0.0012–295.3 m/s. Some distinctive flow patterns and a special type of flow pattern were identified both in air–water and steam–water systems with their special features described. It concluded that two-phase flow patterns are sensitive to the surface conditions of the inner wall of the test tube. The comparison of the two-phase flow pattern map with the Mandhane's correlation (Mandhane et al., 1974) shows that general trends in the micro channels follow the Mandhane's prediction. And the cross-sectional average void fraction agrees well with the Armand correlation (Armand and Treschev, 1946) for larger tubes.

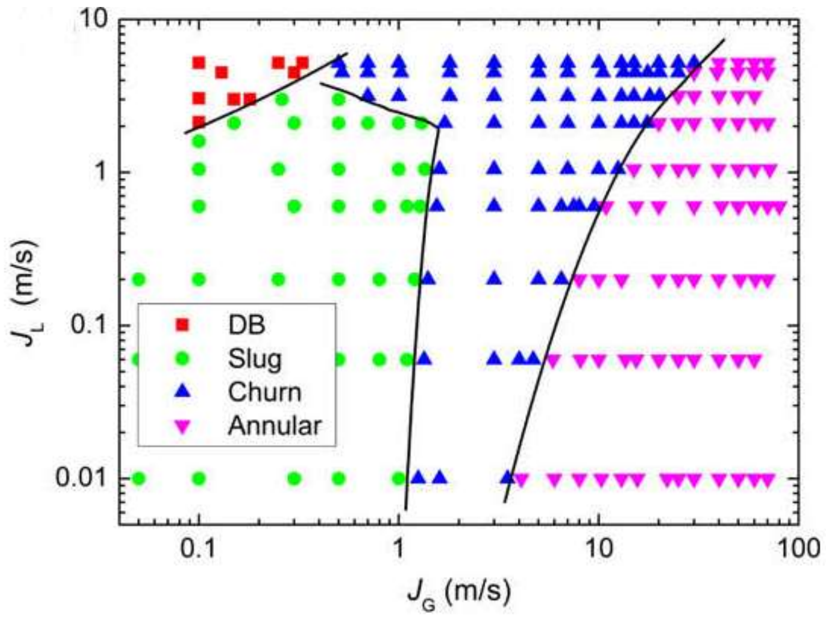

Figure 1 N2-CMC flow regime map for triangular channel of 2.886 mm hydraulic diameter

Kawahara et al. [3] conducted experimental investigation of de-ionized water and nitrogen two-phase flow in a circular tube having diameter 100 μm, with superficial velocities of UG = 0.1–60 m/s and UL = 0.02–4 m/s. Two-phase flow patterns were recorded and a flow pattern map was developed based on the probability of appearance of each type of flow, and compared with the existing flow pattern maps obtained for 1 mm diameter channels. Dziubinski et al. [3] developed a map of the rising flow of multi-phase mixtures of solid particles suspended in the non-Newtonian liquid and gas in vertical pipes with the inner diameters of25.3, 40.6 and 50.5 mm, respectively. 5% water solutions of CMC and suspensions of 2–17.8 wt% spherical glass particles in CMC solutions were used as a continuous phase, which were treated as a homogeneous system. The same flow structures were observed during the flow of multi-phase mixtures with non-Newtonian liquids as those in the case of two-phase Newtonian liquid-gas flow. The results also suggest that the particles had no significant effect on the type of flow. They concluded that non-Newtonian features of liquids have negligible effect on the type of the two-phase flow structure and the most important appeared to be the apparent velocities of liquid and gas flow.

Cubaud et al. [1] conducted experimental studies on two phase flows in micro channels with surface modifications, i.e., hydrophilic and hydrophobic micro channels. The shapes of static and moving bubbles in micro channels with square cross-sections for different angles were investigated. The two-phase flows were made of pure water and air, and made of water with surfactant and air. The transient rheological behaviour of polymer solutions was checked as the length of the polymers is comparable with the height of the channel. It is found that the measured viscosity of the solution is several times larger than the expected value and does not show typical shear-thinning behaviour with polyacrylamide (PAM) solution being the working fluid.

Shuangfeng Wang et al. [5] Conducted experiment to understand the phase split of nitrogen gas/non-Newtonian liquid two-phase flow passing through a 0.5 mm T-junction. Nitrogen and CMC,(Pseudo plastic non Newtonian fluid) whose viscosity decreased with increased shear rate, used as working fluids. They identified three types of flow regimes slug flow, annular flow and slug annular flow. They studied that splitting curves of nitrogen/non-Newtonian liquid systems gradually shifted from gas rich zone to liquid rich zone as the inlet flow patterns change from slug flow to slug–annular flow then to annular flow, which was similar to those observed in nitrogen/Newtonian liquid flow under the same conditions. They showed that the properties of non-Newtonian fluid have little effect on phase split for slug flow while for annular flow influence was significant.

Z. C. Yang et al. [8] Conducted experiment on Nitrogen- Non Newtonian fluid flow through vertical noncircular square and triangular minichannel of hydraulic diameter 2.5, 2.88 and 0.885 mm. They used CMC (Carboxymethyle cellulose), Polyacrylamideand Xanthan gum as non-Newtonian fluids. They identified three flow pattern in that experiment; slug flow, churn flow and annular flow in N2/CMC fluid system where as another flow pattern dispersed bubble flow was also observed in another two fluid flow system. They also developed the flow pattern map for different Nitrogen- non Newtonian fluid for different hydraulic diameter channel. They also studied the influence of hydraulic diameter and channel cross section on the flow pattern transition.

T Zhang et al. [6] studied the influence of liquid physical properties and channel diameter on gas–liquid flow patterns in horizontal circular micro-channels with inner diameters of 0.302, 0.496 and 0.916 mm experimentally. They used water, ethanol, three sodium carboxy methyle cellulose (CMC) solutions (0.0464%, 0.1262%, 0.2446% CMC) and two sodium dodecyl sulfate (SDS) solutions (0.0608%, 0.2610% SDS) are chosen as working fluid and nitrogen as working gas. They study the effect of viscosity, surface tension and channel diameter on transition line and developed the flow pattern map.

III. CONCLUSION

Literature from various authors has been studied for non-boiling two phase flow regime transition and development of flow pattern map in minichannel.

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