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Review Paper on Gas NonNewtonian Two Phase Flow in Mini/Micro Channel

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Abstract— **The present paper discuss overall study of the gas Non Newtonian two phase flow in micro and mini channel. This study carried out based on brief literature review to understand flow behavior of gas Non Newtonian two phase flow in horizontal as well as vertical mini and micro channel. Over the past few decades a prodigious interest in two-phase flow in micro channels has developed because of their application in a wide range of new technologies, ranging from lab, chip devices used in medical and pharmaceutical applications to Micro-structured process equipment used in many modern chemical plants. Two phase flow in which gas and liquid NonNewtonian. Wherebubbles are surrounded by a liquid film and separated by liquid slugs, is the most common flow regime encountered in such applications. This review introduces the important attributes of two phase flow in micro and mini channels and then focuses on the flow regime and flow pattern.**

Keywords: **Two-phase flow, Mini channel, Non-Newtonian liquid, Flow regimes, Flow Pattern.**

I. INTRODUCTION

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 behavior. Intermittent flow regimes are usually seen in horizontal two-phase flow. A phase is simply one of the states of matter and it can be a gas, a liquid, or a solid. Multi-phase flow is the simultaneous flow of more than two phases or immiscible liquids within a common boundary. Two-phase flow is the simplest case of multiphase flow. It may be classified according to the phases involved as (1) gas-solid mixture, (2) gas-liquid mixture, (3) liquid-solid mixture, and (4) two-immiscible-liquids mixture.
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.
Two-phase flow has a wide range of engineering applications such as in the power generation, chemical & petroleum industries, refrigerators, heat exchangers, condensers, gas & oil transport pipelines, process pipelines, metallurgy etc. Due to the complexity of multiphase flow behavior, it presents a great challenge to the study of the flow mechanisms and the measurement of multiphase flow. The accurate measurement of two-phase flow parameters has always been a key issue and tough work for decades. From a practical engineering point of view, one of the major design difficulties in dealing with multiphase flow is that the mass, momentum, and energy transfer rates and processes can be quite sensitive to the geometric distribution or flow patterns that are observed in common multiphase flow.

1.1 FLOW REGIMES

A specific kind of geometric distribution of the components is known as a flow pattern or flow regime. Typically the flow patterns examples are perceived by visual inspection, however different means for example, analysis of the spectral content of the unsteady pressure or the change in the volume fraction has been conceived for those circumstances in which visual data is hard to acquire. For some of basic flows, for example, those in vertical or horizontal pipes, a generous number of examinations have been led to focus the reliance of the flow pattern on component volume fluxes, on volume fraction and on the liquid properties such as density, viscosity and surface tension. The results are regularly shown as flow regime map that identifies the flow patterns distinguishes the flow examples happening in different parts of a parameter space characterized by the component flow rates. The flow rates utilized may be the volume fluxes, mass fluxes, momentum fluxes, or other comparative qualities.

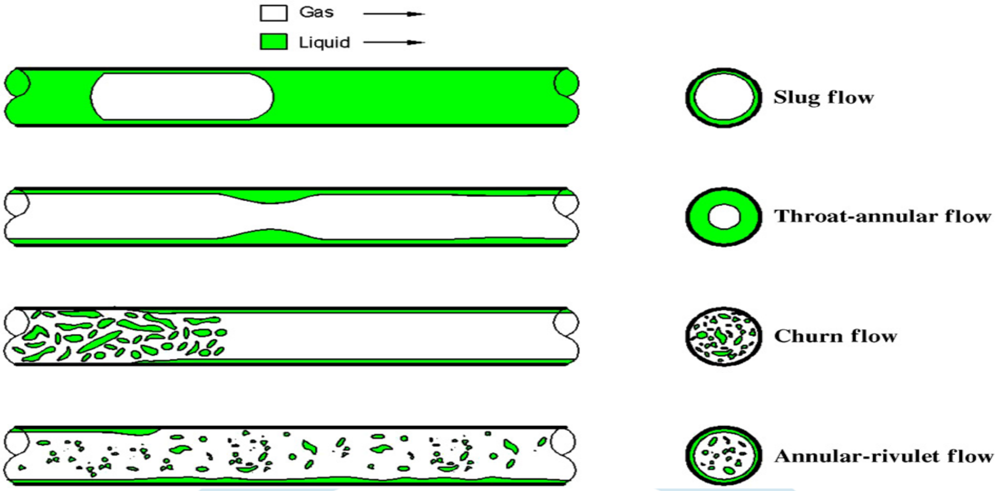

Figure 1 Major flow regimes in horizontal channel. [8]

Bubbly flow:
The pipe is almost completely filled with liquid and free gas phase is present in small bubbles. The bubbles move with different velocities and except for their density, have little effect on the pressure gradient. The wall of the pipe is always contacted by the liquid phase. The bubbles may vary in size and shape but they are typically nearly spherical and much smaller than the diameter of the tube itself.
Slug flow:
The gas phase is more pronounced. Although the liquid phase is still continuous, the gas bubble coalesces and form plug or slug which almost fill the pipe cross section. These bubbles have a characteristics shape similar to a bullet with a hemispherical nose with a blunt tail end. These commonly referred to as Taylor bubble**.** The gas bubble velocity is greater than that of the liquid .The liquid in film around the bubble may move downward due to the force of gravity at low velocity. Both the gas and liquid have significant effect on the pressure gradient.
Churn flow:
Increasing the velocity of the flow, the structure of the flow becomes unstable with the fluid traveling up and down in an oscillation fashion but with net upward flow. The instability is the result of the gravity and shear forces acting in opposite direction on the thin film of liquid of Taylor bubble. This flow pattern is in fact an intermediate regime between the slug flow and annular flow. Churn flow is typically a flow regime to be avoided in two-phase transfer lines, such as those from a re-boiler back to a distillation column or in refrigerant piping networks because the mass of the slug may have a distractive consequence on the piping system.
Throat-Annular flow:
Once the interfacial shear of the high velocity gas on the liquid film becomes dominant over gravity, the liquid is expelled from the center of the tube and flow as a thin film on the wall tube. The interference is disturbed by high frequency wave. In addition liquid may be entrained in the gas core as small droplets, so much so that the fraction of liquid entrained may become similar to that in the film. This flow regime is particularly stable and is the desire flow pattern for two phase flows.
Dispersed flow:
At very high gas flow rates, the annular film is thinned by shear of the gas core on the interface until it becomes unstable and is destroyed, such that all the liquid is entrained as droplets in the gas phase. The pipe wall is coated with a liquid film, but the gas phase predominantly controls the pressure gradient. The droplets in mist flow are often too small to be seen without special lightning or magnification.

1.2 Classification of fluids:

Newtonian Fluids: At constant temperature and pressure, the shear stress σ is proportional to the rate of shear γ and the constant of proportionality is defined as dynamic viscosity, these types of fluid are known as Newtonian fluids i.e. air, water, glycerol, Ethylene glycol, mercury etc. For most of liquids, the viscosity decreases with temperature and increases with pressure. For gases, it increases with both temperature and pressure.
Non Newtonian Fluids: In some fluids at constant temperature and pressure, the shear stress is not proportional to rate of shear or in other word dynamic viscosity not remains constant. These types of fluids are known as Non Newtonian fluids. i.e. paint, lubricating oil, cosmetic products like cream, nail polish, shampoos, Pharmaceutical products like creams, foams etc.

II. Literature Review

Dongying Qian et al. [7] studied a T-junction empty micro channel with varying cross-sectional width (0.25, 0.5, 0.75, 1, 2 and 3 mm). A finite volume based commercial computational fluid dynamics (CFD) package, FLUENT, was adopted for the numerical simulation. The gas and liquid slug length studied at different inlet conditions, gas and liquid superficial velocity, surface tension, liquid viscosity and contact angle. They developed the proposed correlations for slug length in the T-junction micro channel. The micro channel reactor comprises a vertical inlet mixing zone and a horizontal reaction zone. A stream of water and a stream of air are fed separately into the two inlets of the mixing zone, and then enter the reaction zone. The cross-sectionaldimensions of the channel are the same, which are represented by d. The mixing zone has a length of 6d while the reactor zone has a length of 60d. “Cold” flow without any chemical reaction is considered. The whole system is maintained at room temperature, and the pressure is atmospheric at the exit. The superficial gas velocity as well as superficial liquid velocity varies from 0.01 to 0.25 m/s. According to the flow regime maps by Chung and Kawaji (2004), Triplett et al. (1999), Yangand Shieh (2001), Fukano and Kariyasaki (1993), Coleman andGarimella (1999) and Akbar et al. (2003), at these operatingconditions, the flow falls within the Taylor slug regime in micro channels.

Cubaud et al. [2] 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.

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 of 25.3, 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.

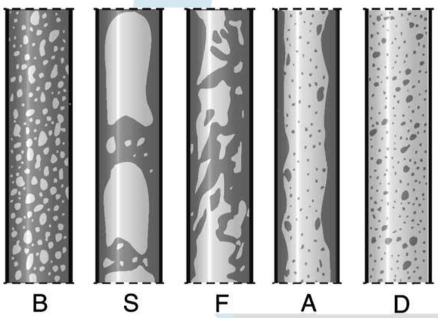

Fig. 2 Basic flow structures in vertical upward flow: [3]

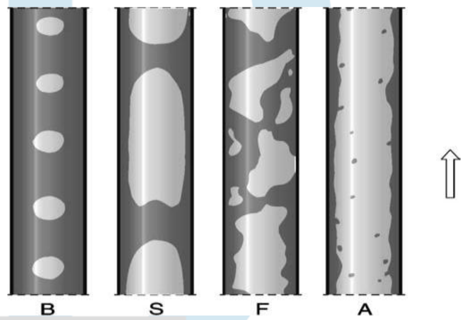

Fig. 3 Flow structures in highly viscous liquids:[3]

B–bubble flow, S–slug flow, F–froth flow, A–annular flow.B–bubble flow, D–dispersed flow.

The ranges of particular flow structures are illustrated in diagrams called the flow maps. So far, dozens of such maps have been proposed in the available literature for the two-phase mixture of a Newtonian liquid and gas flowing in vertical pipes (Golan and Stenning, 1969–1970; Oshinowo and Charles, 1974; Taitel et al., 1980; Spedding and Ngyuen, 1980; Barnea et al., 1982; Crawford and Weisman, 1984; Spisak, 1986; Ulbrich (1989)). For instance, Spisak (1986) gives information on 32 maps for rising flow and 10 maps for down flow of the two-phase mixture.

T Zhang et al. [11] 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 carboxymethyle 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. Also the results have been compared with transition criteria given by Akbar et al. [1] and Waelchli et al. [15].

Xu et al. [14] conducted experimental investigations on concurrent flow characteristics of air/non-Newtonian liquid system in inclined smooth tubes with diameters of 20, 40 and 60 mm. CMC solution was used as the non-Newtonian fluid. Bubbly flow, stratified flow, plug flow, slug flow, churn flow and annular flow were recognized. It is observed that the properties of non-Newtonian fluid have a minimal effect on the flow pattern in horizontal and near horizontal flow. It is also found that the non-Newtonian features of liquids exert a significant effect on void fraction of two-phase mixture flows, and the average void fraction decreases for specific JG and JL as the liquid becomes more shear-thinning.

Z. C. Yang et al. [16] Conducted experiment on Nitrogen- Non Newtonian fluid flow through vertical noncircular square and triangular mini channel of hydraulic diameter 2.5, 2.88 and 0.885 mm. They used CMC (Carboxymethyle cellulose), Polyacrylamide and Xanthan gum as non-Newtonian fluids. They identified three flow pattern in that experiment; slug flow, churn flow and annular flow in N_2/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.

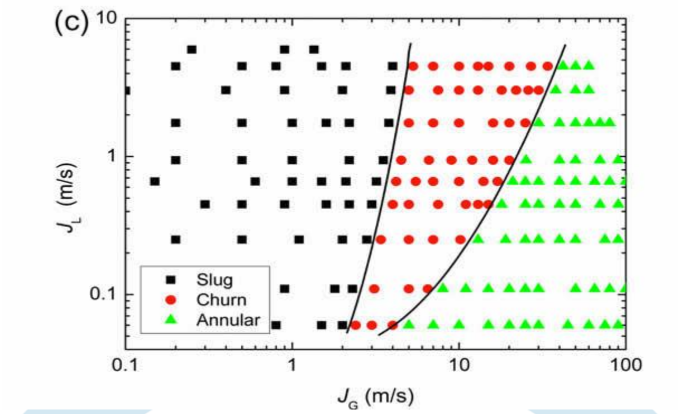

Fig. 4 Flow regime map of nitrogen/CMC solution two-phase upward flow in micro channels: (a) squared channel, Dh = 2.5 mm; (b) triangular channel, Dh = 2.886 mm; (c) Triangular channel, Dh = 0.866 mm.

According to the flow regime maps shown in Fig. 4, three flow patterns, namely, slug flow, churn flow and annular flow, are observed in the nitrogen/CMC solution two-phase flow in the present microchannels. It is noticed that dispersed bubble flow is observed in the larger triangular channel (T2, Dh = 2.886 mm), but not found in the other two channels with smaller hydraulic diameter (S1, Dh = 2.5 mm and S3, Dh = 0.866 mm). This trend is somewhat similar to the results of air–water co-current two-phase flow in microchannels by Zhao and Bi (2001). However, the capillary bubbly flow has not been found for nitrogen/CMC solution two-phase flow in the same triangular microchannel (Dh = 0.866 mm).

III. CONCLUSION

The overall study of the Gas Non Newtonian two phase flow in micro and mini channel. This study carried out based on brief literature review to understand flow behavior of gas Non Newtonian two phase flow in horizontal as well as vertical mini and micro channel. The study understood that the slug length is not uniform throughout the channel. When the gas or liquid flow rate increases, the slug non-uniformity becomes more pronounced. The slug length is also highly dependent on the inlet configuration. From the studies of gas and liquid slugs in a micro and mini channel at various operating conditions. The gas slug length increases with increase in superficial gas velocity, and decrease in superficial liquid velocity. The liquid slug length increases with increase of superficial liquid velocity, and decrease of superficial gas velocity. The effects of fluid density and viscosity are also negligible. The surface tension and wall surface adhesion moderately impact the slug lengths. Based on this numerical study of micro and mini channels, we can begin to understand, behavior of two phase flow pattern and flow regimesin micro channels and mini channels.

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