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GAS-LIQUID FLOW-PATTERN TRANSITION IN HORIZONTAL PIPES – ANALYSIS OF REPORTED MODELS

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Abstract. *In the last decades, several studies have been devoted to the modeling of gas-liquid flow through the two-fluid model and have established phenomenological criteria for the flow pattern transition, in addition, several works have studied experimentally the flow-pattern transition at different conditions in recent years. Based on experimental databank available in the open literature the accuracy of a flow pattern transition model is tested, results show a good accuracy for air and water two-phase flow at ambient temperature and pressure.*

Keywords: *Two-phase flow, Gas-liquid flow, flow Patterns, horizontal pipe, transition models*

1. INTRODUCTION

The simultaneous flow of gas and liquid is of common occurrence in the chemical, petroleum and nuclear industry. The determination of the flow patterns is a vital problem in two-phase flow analysis since it strongly affects important design parameters such as pressure drop and phase separation. In the last decades, several studies have been devoted to the modeling of gas-liquid flow through the two-fluid model and have established phenomenological criteria for the flow pattern transition. In gas-liquid flow in horizontal and slightly inclines pipes, Taitel and Dukler (1976) proposed four transition criteria for the following flow patterns: stratified smooth, stratified wavy, intermittent, dispersed bubble and annular. The transition from stratified flow equilibrium is due to Kelvin-Helmholtz (KH) instability, i.e., the stratified interface is perturbed by a finite wave over which the gas flows; as the gas velocity increases, due to inviscid effects, a pressure gradient is present between the phases and the wave tends to grow in time. Two types of KH instability have been considered: in the viscous one (VKH) shear stresses are included, while the inviscid case KH (IKH) the shear stresses are neglected. For medium/high gas velocities, the stratified wavy flow occurs; the gas velocity is sufficiently high to overcome the liquid viscous forces and transition from stratified smooth takes place.

For medium/low gas velocities and high liquid velocities, intermittent flow occurs and for even higher liquid velocities dispersed bubble flow takes place when the liquid turbulent fluctuations overcome the bubble-coalescence and buoyancy force. Those authors argued that the stable slug (intermittent flow) or annular flow formation depends uniquely upon the liquid level in the stratified equilibrium, i.e., when it is higher than the center line, an intermittent flow is formed, otherwise an annular flow occurs.

Lin and Hanratty (1986), Barnea (1991) and Barnea and Taitel (1993) reexamined the Kelvin-Helmholtz instability analysis and showed that for high-viscosity liquids, the IKV and VKH present a similar result, given that the effect of the liquid inertia becomes negligible; however, for low viscosity fluids, the results diverge. Brito *et al.* (2015) used a correlation for the interfacial friction factor based on experimental data to improve the results of Taitel and Dukler (1976) model for high viscous liquids. A concave downward curved gas-liquid interface is reported on the duct cross section for small diameters and low viscosity liquids. Chen *et al.* (1997) developed a mechanistic model for stratified-wavy flow which describes the interface based on a double circle model, the wetted perimeter of the phases with the wall and interfacial is directly affected by its geometry and consequently affects the wall and interfacial shear stresses. Tzotzi *et al.* (2011) and Shmueli *et al.* (2015) have observed experimentally the curved interface in gas-liquid flows of low viscosity liquid and low liquid holdup.

In recent years, several works have studied experimentally the flow-pattern transition under different conditions. Kristiansen (2004), Khaledi *et al.* (2014) and Shmueli *et al.* (2015) performed experiments with low density ratio between the gas and liquid phases. Brito *et al.* (2014) evaluated the effect of liquid viscosity on the flow-pattern transitions and identified that IKH tends to overpredict the transition for low liquid viscosity and VHK presents good results and Tzotzi *et al.* (2011) performed experiments with different surface tensions and evaluated the shift to lower gas velocities for the all the transitions except for slug.

This paper presents a review of Taitel and Dukler (1976) model to predict the gas-liquid flow pattern transition in horizontal pipes, testing the accuracy of this model with an experimental databank available in the open literature, incorporating more than 1000 experimental points.

2. METHODOLOGY

The theoretical model proposed by Taitel and Dukler (1976) was implemented on MATLAB numerical computing environment and the roots for the non-linear system of Taitel and Dukler's equations was obtained with the secant method. Those results were assessed with the dataset summarized in Table 1, the experimental points were chosen to cover a wide range of fluid properties and pipe diameters.

Table 1. Experimental data of gas-liquid flow in horizontal pipes

Study	Fluids	Density Ratio	Liquid Viscosity [Pa.s]	Gas-liquid Surface Tension [mN/m]	Pipe Diameter [mm]	Pipe Length/diameter	Superficial velocity range
Barnea and Shoham (1982)	Air and water	815	0.001	72.75	25 51	392 196	U_{sg} = 0.04 to 40 m/s U_{sl} = 0.004 to 4 m/s
Abduvayt *et al.* (2003)	Nitrogen and water	42	0.001	N/A	106	188	U_{sg} = 0.1 to 3 m/s U_{sl} = 0.4 to 6 m/s
Kristiansen (2004)	Air, SF6, water and oil	15 to 815	0.001 to 0.002	21.7 to 72	60 69	266 3145	U_{sg} = 0.5 to 6 m/s U_{sl} = 0.01 to 1 m/s
Tzotzi *et al.* (2011)	Air, CO2, He, water and aqueous solution of n-butanol	5976 547 815	0.001 0.0012	35 70 72	24	531.25	U_{sg} = 2 to 20 m/s U_{sl} = 0.002 to 0.04 m/s
Brito *et al.* (2014)	Air, Kerosene and oil	80 89	0.001 0.418 0.996	N/A	51	1254	U_{sg} = 0.15 to 45 m/s U_{sl} = 0.02 to 4.3 m/s
Khaledi *et al.* (2014)	SF6 and oil	16 33	0.032 0.096	N/A	69	750	U_{sg} = 0.0075 to 3 m/s U_{sl} = 0.04 to 3 m/s
Shmueli *et al.* (2015)	SF6, water and oil	18 22	0.001 0.102	20 62	69	725	U_{sg} = 0.5 to 11 m/s U_{sl} = 0.04 to 0.4 m/s

3. RESULTS

Figure 1 and Figure 2 shows the graphical comparison between experimental data of Barnea and Shoham (1982) with Taitel and Dukler (1976) theoretical model and Table 2 the accuracy based on the experimental point correctly predicted by the model considering only Barnea and Shoham (1982) experimental data and all experimental work detailed in table 1.

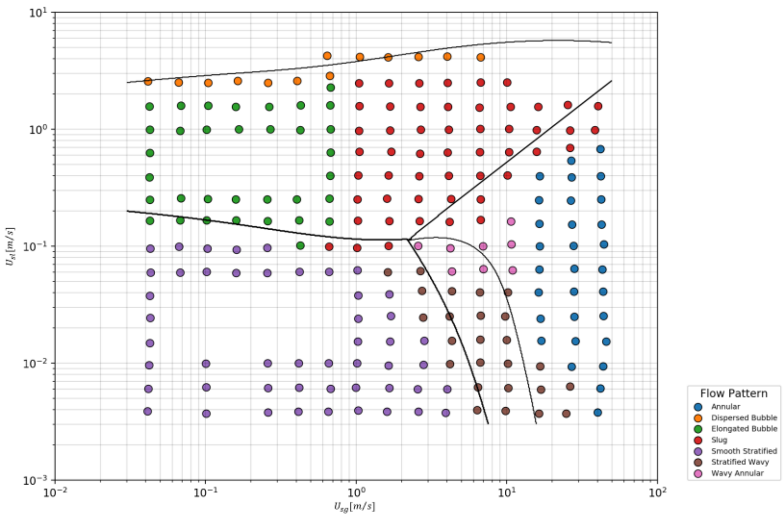

Figure 1. Comparison between Barnea *et al.* (1982) experimental data for 0.025 m pipe diameter with Taitel and Dukler (1976) theoretical model, where U_{sg} and U_{sl} are the gas and liquid superficial velocity respectively

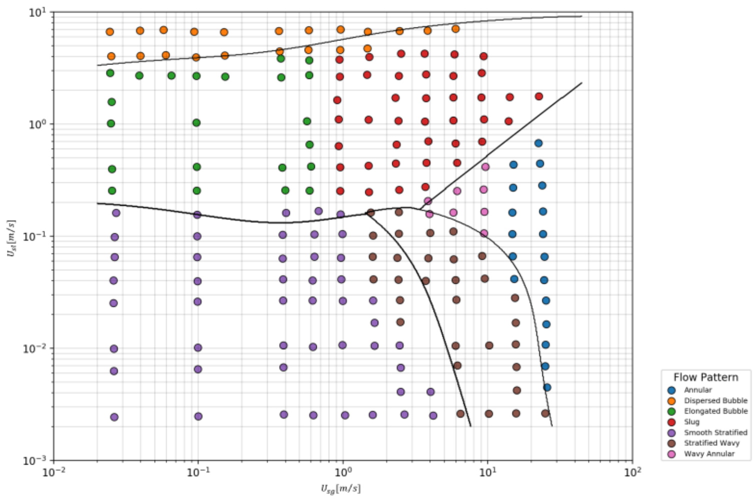

Figure 2. Comparison between Barnea *et al.* (1982) experimental data for 0.051 m pipe with Taitel and Dukler (1976) theoretical model, where U_{sg} and U_{sl} are the gas and liquid superficial velocity respectively

Table 2. Accuracy of Taitel and Dukler (1976) model

Experimental work	Taitel and Dukler (1976) accuracy	Total Points
Barnea and Shoham (1982)	86%	398
Barnea and Shoham (1982), Abduvayt *et al.* (2003), Kristiansen (2004), Tzotzi *et al.* (2011), Brito *et al.* (2014), Khaledi *et al.* (2014), Shmueli *et al.* (2015)	73%	1134

4. CONCLUSION

Taitel and Duckler's model shows good flow pattern prediction accuracy for two-phase air and water flow at ambient pressure and temperature, reaching accuracy over 85%. However, for high density gas and high viscosity liquids, a reduction in the flow pattern prediction accuracy is observed.

5. ACKNOWLEDGEMENTS

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