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# On the comparison of new pressure drop and hold-up data for horizontal air–water flow in a square cross-section channel against existing correlations and models

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## Abstract

New data on pressure drop and liquid hold-up obtained in a horizontal square cross-section channel ($H = 0.02425$ m) were compared against several existing correlations and models for gas–liquid flow. The hold-up data were taken for conditions of wavy-stratified and pseudo-slug flow. Pressure drop results were only obtained for wavy-stratified flow. The correlation developed by Friedel correlates well the pressure drop results, according to the test method used. For the hold-up data, none of the correlations and models tested was able to predict the results. However, a modification in the constants of the model by Turner and Wallis was introduced, and the new expression fits the hold-up data well.


*Keywords:* Two-phase horizontal flow; Square cross-section channel; Pressure drop; Hold-up

## 1. Introduction

Different flow patterns are observed when gas and liquid flow simultaneously through a pipe. These are governed by the physical properties of the fluids, the ratio of gas/liquid flow rates and the system geometry. In horizontal flow, gravity introduces an asymmetry into the system: the density difference between the two-phases causes the liquid to travel preferentially along the bottom of the tube. According to Hewitt et al. (1994), the following regimes can be identified: bubbly flow, plug flow, stratified flow (smooth and wavy), slug flow, pseudo-slug flow and annular flow.

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Stratified flow is characterized by the liquid flowing at the bottom of the tube whilst the gas passes over it. At low gas and liquid flow rates the gas–liquid interface is smooth (smooth stratified flow), but as gas flow rate increases the interface becomes wavy, with the waves traveling in the direction of the flow (wavy-stratified flow). For even higher gas flow rates, drops are torn from the surface of these waves giving drop entrainment in the gas.

The pseudo-slug flow occurs near the annular/slug, stratified/slug and stratified/annular flow transitions. Pseudo-slug flow is characterized by the presence of liquid flow patterns that have the appearance of slugs, but which do not give the identifying pressure pattern a liquid slug does. The liquid can touch the top of the tube momentarily, but do not block the entire pipe section.

Two-phase pressure drop and hold-up are parameters of great importance in the design of adiabatic and non-adiabatic systems. Numerous correlations and models have been developed to predict these two parameters, which are affected by the flow regime. Several authors have studied the performance of published correlations and models used to predict pressure drop and hold-up in horizontal gas–liquid flow against experimental data (e.g. Chen and Spedding, 1983; Sen and Spedding, 1991; Ferguson and Spedding, 1995; Tribbe and Muller-Steinhagen, 2000). These studies report mostly results obtained for two-phase flow in circular cross-section pipes.

In this paper, new data on pressure drop and liquid hold-up obtained in a horizontal square cross-section channel by Ferreira (2004) for wavy-stratified and pseudo-slug flows were compared against several existing correlations and models. For friction pressure drop, the correlation by Lockhart and Martinelli (1949) and the model by Beattie and Whalley (1982), developed for circular section tubes, the correlation by Friedel (1979) based on data for circular, rectangular and annular cross-section channels, and the correlation by Troniewski and Ulbrich (1984) developed for rectangular cross-section channels were tested. The hold-up data were compared against the models by Turner and Wallis (1965), by Abdul-Majeed (1996), and by Spedding and Cooper (2002), all developed for horizontal flow in circular cross-section tubes. Also, both sets of data were tested against the models for stratified flow proposed by Taitel and Dukler (1976), by Andritsos (1986) and by Spedding and Hand (1997) for circular tubes.

## 2. Experimental details

### 2.1. Experimental facility

The experimental apparatus used to obtain hold-up and pressure drop data was a horizontal perspex tube with an ID of 0.032 m, followed by a square cross-section channel where the experiments were carried out. The apparatus is fully described by Ferreira (2004). The air was delivered from a rotative compressor, was controlled by a pressure regulator and a valve, and was measured using a calibrated rotameter. The water was stored in a 100 L tank and was pumped through the system by a centrifugal pump and metered by a calibrated rotameter before flowing into the pipe. The air and the water entered the tube by a tee and were allowed to travel for 5 m to reach developed conditions, before entering the square test section.

The test section was constructed in perspex having a square cross-section ($H = 0.02425$ m), and a length of 2.3 m. Both ends included converging pieces that made a very smooth transition from the circular to the square geometry, and then from the square section back to the circular tube. The length of the square channel was chosen in order to be longer than 50 $D_h$, as specified by Troniewski and Ulbrich (1984), and where $D_h$ is the hydraulic diameter of the channel ($D_h = H$ for the channel in study). The mixture of air/water returned to the stock tank through a section of PVC tube, where the air was vented and the water was re-circulated.

### 2.2. Pressure drop measurements

Pressure drop was measured using Validyne differential pressure transducers (1-N-24-S-4, 1-N-1-26-S-4 and 1-N-1-30-S-4) operating in the range of 225–500 mm $H_2O$. The pressure taps were located 5 mm from the base of the channel and were 0.825 m apart. The acquisition system consisted of a PC-LABCard-818HG data acquisition board connected to a computer. The pressure drop signal was recorded at a frequency of 250 Hz for a period of 5 min, using Labtech data acquisition software.