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Flow patterns and heat transfer of oil-water two-phase upward flow in vertical pipe

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ABSTRACT

In this paper, local heat transfer coefficients (HTC) and different flow patterns of oil-water two-phase flow in a vertical pipe were investigated. The test section was an 11 mm inner diameter (ID) copper pipe with a length to diameter ratio of 145. Water and kerosene (1.49 mPa s viscosity and 780 kg/m^3 density) were selected as immiscible liquids and high speed photography technique was used for the flow pattern identification. The superficial Reynolds numbers ranged from 750 to 6000 for oil and 1000 to 11500 for water. The heat transfer experimental data showed a very strong dependency on the flow pattern. In addition, a heat transfer correlation was proposed for churn flow pattern. The experimental data were successfully correlated by the proposed heat transfer correlation with an average deviation of 10.6%, a standard deviation of 5.6%, and a deviation range of −20% to 3%.

1. Introduction

A flow consisting of two immiscible liquids through a vertical pipe forms a non-stationary system as it exists only under certain flow conditions. Such a system is characterized by instability both in terms of the shape and quantities of the specific flow patterns. The knowledge of characteristics of two-phase liquid flow is important for many industrial applications, such as petrochemical processes, extraction processes, tubular reactors, heat exchangers and crude oil production and transportation through horizontal, inclined and vertical pipes [1–4]. Various parameters can affect the liquid two-phase flow behaviour in pipes such as flow rates, pipe diameter, flow patterns, pipe orientation, pressure, temperature, pre-wetting, etc.

Heat transfer between the pipe wall and the liquid–liquid system which flows inside the pipe makes a typical example of the convective heat transfer phenomenon. However, it occurs under two-phase unstable liquid dispersions flow conditions. In this situation the shapes and sizes of dispersed elements are not stable and change over time. Generally those parameters are dependent on the fluid nature and flow conditions and they defined as flow patterns in a pipe. As noted earlier, although the heat transfer in two-phase flows is one of the interesting topics of the authors, but the influence of the flow patterns on the HTCs of oil-water flow in vertical pipes has not been reported in the literature.

Several studies attempted to recognize of flow patterns in vertical oil-water two-phase flow. For example, Jana et al. [5], Farrar and Bruun [6], Flores et al. [7], Du et al. [8] and Gabryk et al. [9] and Aziz et al. [10] carried out experimental studies on the flow pattern of adiabatic oil-water flow in vertical pipes. The identification of the flow patterns in those studies were performed according to different physical and electrical properties of the mixture flow media.

Limited studies on heat transfer to flowing immiscible mixtures in horizontal and vertical pipes have been reported compared with the gas-liquid heat transfer [1]. Wright [11] experimentally measured pressure drop and heat transfer coefficient (HTC) of oil-water two-phase flow in a horizontal pipe. He studied only the dispersed flow patterns in his experiments. Legan and Knudsen [12] conducted an experimental investigation of heat transfer to liquid-liquid dispersions in a horizontal pipe. They suggested an empirical correlation (a j-factor type equation) to predict the HTC of liquid dispersions. They reported that the correlation is applicable for mixture Reynolds numbers greater than 60000. Somer et al. [13] experimentally studied heat transfer to the oil-water dispersions in a horizontal pipe and concluded that the rate of heat transfer is dependent on volumetric fraction of liquids. They also proposed a correlation to predict the HTC of oil in water dispersions. Lang and Auracher [14] experimentally investigated heat transfer to n-heptane-water flow in a vertical pipe and measured phase distribution and the HTC of the flow. They concluded that the heat transfer to liquid-liquid mixtures is controlled by the properties of the continuous phase. Leib et al. [15], Shang and Sarica [16] and Stockman

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and Epstein [17] developed different mathematical models to determine the HTC and fluid temperature of oil-water flow in horizontal and vertical pipes. Karimi and Boostani [18] used flow of diesel-water in a horizontal pipe (ID = 11 mm) to experimentally investigate the influence of flow pattern on the oil-water HTCs. Their experimental results revealed that the HTC of oil-water two-phase flow was significantly dependent on the flow patterns. Their results also showed that the influence of the water Reynolds number on the two-phase HTCs was stronger than that of the oil Reynolds number. In addition, in this study a new correlation was developed to predict the HTCs for STMI and Dw/o & o/w flow patterns. Boostani et al. [1] experimentally measured the HTCs of oil-water two-phase flow for different flow patterns in a horizontal and slightly upward inclined (+4° and +7°) pipe. They reported that the effect of the flow pattern on the oil-water HTCs can be higher than that the pipe inclination, especially for dispersed oil in water and stratified flow patterns. In addition, they developed an artificial neural network (ANN) model to predict the HTC of oil-water flow for different inclination angles of the pipe (0°, +4° and +7°). The obtained optimal ANN model had good prediction in the studied positions and all flow patterns.

The present work, primarily focused on the oil-water flow pattern characteristics were experimentally investigated in vertical upward. The influence of oil and water Reynolds numbers in different flow patterns on HTC were discussed in detail. A correlation is also developed to estimate the oil-water HTC of churn flow.

2. Experimental setup

All experiments were carried out using a flow facility designed and constructed in the multiphase flow laboratory of the Yasouj University. Fig. 1 shows schematically the experimental system and the corresponding instruments.

The experiments were conducted using kerosene (with the properties shown in Table 1) and water as test fluids. During the experimentation, water and kerosene were pumped separately from their storage tanks. Before being introduced into the mixing chamber, the flow rate of oil was measured using a rotameter model RGL/240 (0.75–7.57 l/min) with an AMC (Azmoon Motamam Co.) calibrated with accuracy of 1.5% full scale, while water flow rate was measured by two rotameter models RGL/240 (up to 1 l/min) and RGL/240 (up to 10 l/min) respectively and calibrated with accuracy of 1% full scale.

Table 1
Thermo-physical properties of kerosene.

Properties	Value
c_p, specific heat	2090 J/kg-K @ 20 °C
k, thermal conductivity	0.149 W/m-K @ 20 °C
ρ, density	780 kg/m^3 @ 20 °C
μ, viscosity	1.49 mPa s @ 20 °C 1.1 mPa s @ 40 °C

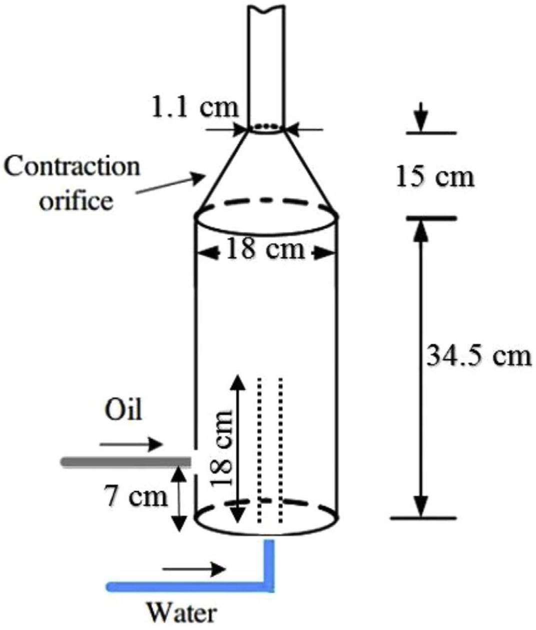

Fig. 2. Oil-water mixing chamber.

The fluids were joined at the beginning of the test section via a mixing chamber as shown in Fig. 2.

After passing the oil-water mixture through the mixing chamber, the oil-water flow enters the calming section (a copper tube with 11 mm ID and length of 1.15 m) to ensure fully developed flow, and then enters the heat transfer test section. After passing the test section, the flow

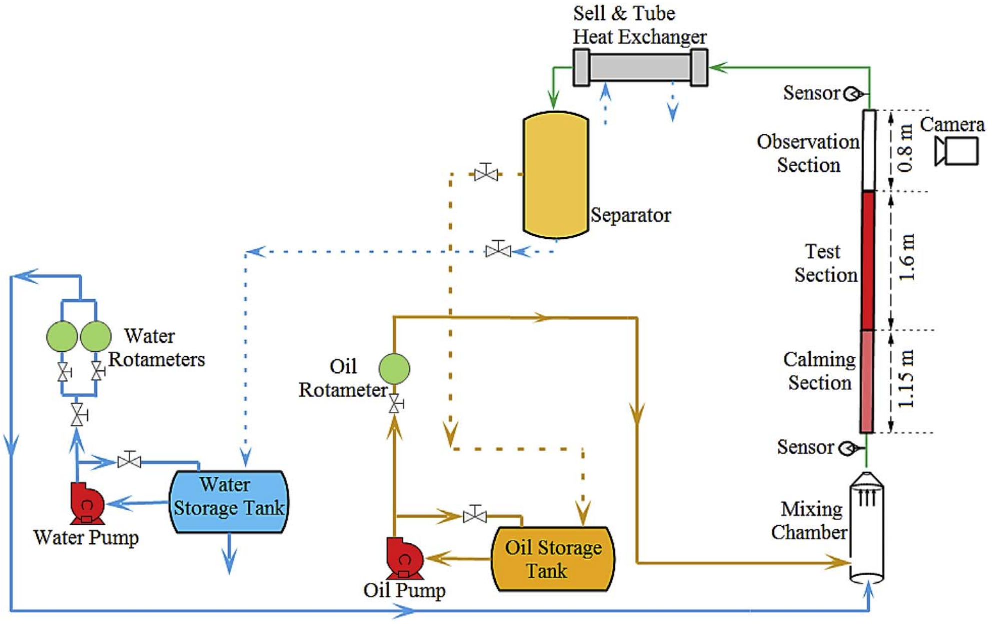

Fig. 1. Schematic view of the test facility.