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Effects of pipe size and system pressure on the phase redistribution in horizontal impacting tee junctions

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ABSTRACT

An experimental investigation was conducted on the phase redistribution during air–water flow in horizontal impacting tee junctions. The main objective of the investigation was to examine the individual effects of pipe diameter and system pressure on the phase redistribution. The data correspond to a wide range of inlet conditions encompassing inlet flow regimes of stratified, wavy, and annular; the whole range of mass split ratios at the junction; pipe diameters of 13.5 and 37.8 mm; and two system pressures of 150 and 200 kPa (abs). The experiments have shown that the pipe diameter has a small effect on phase redistribution for the whole tested range. On the other hand, system pressure was found to have a significant effect on phase redistribution at small inlet velocities and this effect was found to decrease as the inlet velocities increased. The experimental data were compared with predictions from three analytical models. None of the three models succeeded in predicting these trends with consistency.

1. Introduction

Two-phase flow is encountered in many industrial systems such as the condensers and evaporators of refrigeration systems, conventional steam power plants, pressurized-water and boiling-water nuclear power plants, and in a wide variety of petroleum and chemical processing systems. In most, if not all, of these systems, the two-phase flow encounters dividing tee junctions (branching and impacting) as it passes through the system. Considerable research efforts in the recent past have shown that (a) in general the phases do not split evenly at the junction, (b) the manner in which the phases are redistributed is a complicated function of the inlet flow rates, inlet flow regime, junction geometry and orientation, mass split ratio at the junction, and fluid properties, and (c) the existing models for predicting the phase redistribution at dividing junctions are not yet adequate to handle all situations. The manner in which the phases are redistributed at the junction is important because it has a strong impact on the performance of components downstream from the junction. A number of excellent reviews on phase redistribution were reported (e.g., [1] for branching junctions and [2] for impacting junctions).

The present investigation is concerned with the geometry of impacting tees. Earlier experimental studies on this junction geometry have produced data on the phase redistribution for a number of different operating conditions. Most of these studies considered tees with horizontal inlets and outlets (e.g., [3–7]), while the case of vertical inlet and horizontal outlets was considered in [8–10]. Only one study [11] involved a junction with a horizontal inlet and inclined outlets. In each one of these studies, the effects of the inlet flow rates of gas and liquid, inlet flow regime, and total mass split on the phase redistribution at the junction were examined. However, the data in [3–10] do not include information that isolates the effects of pipe size or system pressure while holding all other parameters constant. Therefore, the purpose of the present investigation is to assess these effects on the phase redistribution at horizontal impacting tee junctions. This was done by conducting experiments on an impacting tee using air–water mixtures at two different pressures while maintaining the same inlet superficial velocities of gas and liquid, and also by comparing the data from the present experiment with previous data [6] corresponding to a larger diameter while holding the pressure and superficial velocities constant. The observed trends from the experiments are compared with the predictions from predictive models. These results can further our understanding of the problem and guide future modeling efforts.

2. Experimental

The experiments were conducted in an equal-sided, horizontal impacting tee junction using air–water mixtures. Two sets of tests were conducted: one at a junction pressure $P_s = 150$ kPa and the other at $P_s = 200$ kPa, both at or near the ambient temperature. A steady value of P_s was established in each experiment at the

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Nomenclature

D	inside diameter of the tube, (m)
F_{G3}	gas mass fraction extracted into outlet 3
F_{L3}	liquid mass fraction extracted into outlet 3
J	superficial velocity (m/s)
P	pressure (kPa)
W	mass flow rate (kg/s)

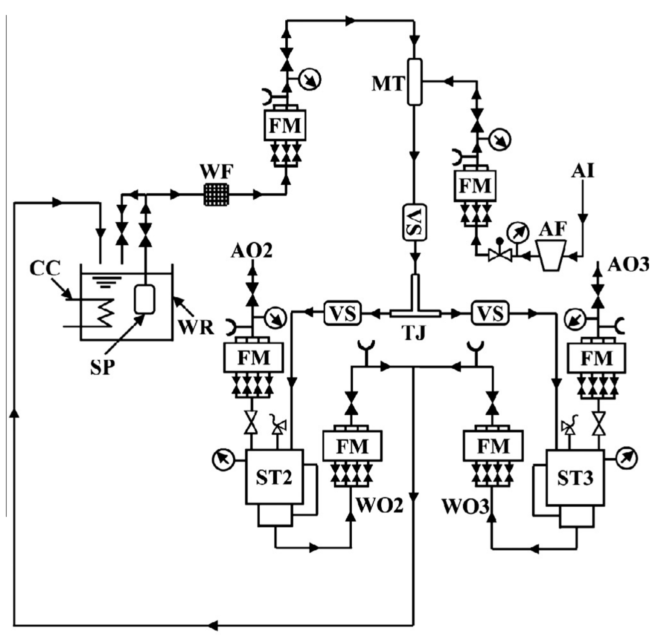
Greek symbols

ρ	density (kg/m^3)

Subscripts

1, 2, 3	sides 1, 2, and 3 of the junction
G	gas
L	liquid
s	condition at the junction

desired value by adjusting the pressure of the incoming air and water streams at a level that depended on the inlet flow rates and the mass split at the junction. All fluid properties (particularly the gas density) were determined at the junction pressure (P_s) where the phase redistribution phenomenon took place. An acrylic piece was machined to produce a square-edged junction with a diameter D = 13.5 mm on all three sides. The flow loop, shown in Fig. 1 was supplied with compressed air from a building supply line, and the air was passed through a filter, pressure controller, and a bank of rotameters before entering the mixing tee. Distilled water was pumped into the flow loop from a water reservoir and passed through a filter and a bank of rotameters before entering the mixing tee. The two-phase mixture leaving the mixing tee was allowed to develop over a length of 62 pipe diameters before passing through a visual section (where the inlet flow regime was observed). The mixture flowed through a further 32 pipe diameters before entering the tee junction. The two outlet streams leaving the junction were directed to individual separation tanks. The air–water mixture entering each separator was divided into two single-phase flows; each measured with a separate bank of rotameters. In order to ensure that the readings of the rotameters were accurate, the liquid level and the pressure in the separators were required to remain steady for at least 20 min before steady-state conditions were assumed. The gas phase exited from the top of each separation tank and was metered by a separate bank of rotameters before exhausting to the room. The liquid phase flowed from the bottom of each separation tank and was metered by a separate bank of rotameters before returning to the water reservoir. Thus, in each test, measurements were recorded for the gas and liquid mass flow rates in the inlet, W_{G1} and W_{L1}, respectively, Outlet 2, W_{G2} and W_{L2}, respectively, and Outlet 3, W_{G3} and W_{L3}, respectively. Deviations between the inlet and outlet mass flow rates were within ±3.1% for both phases in all test runs. For a more detailed description of the loop and the associated instrumentation, please refer to Mohamed et al. [11].



Symbol	Description	Symbol	Description
AF	Air filter	WF	Water filter
AI	Air inlet	WO	Water outlet
AO	Air outlet	WR	Water reservoir
CC	Cooling coil		Valve
FM	Flow meter		Control valve
MT	Mixing tee		Pressure controller
SP	Submersible pump		Pressure gauge
ST	Separation tank		Thermocouple
TJ	Tee junction		Safety valve
VS	Visual section		

Fig. 1. Flow loop.

3. Results and discussion

The experimental investigation included nine data sets (three at P_s = 150 kPa and six at P_s = 200 kPa) with each set characterized by a given combination of J_{G1} and J_{L1}, where $J_{G1} = 4W_{G1}/(\pi D^2 \rho_{G1})$ is the inlet superficial gas velocity, $J_{L1} = 4W_{L1}/(\pi D^2 \rho_{L1})$ is the inlet superficial liquid velocity, ρ_{G1} is the inlet gas density, and ρ_{L1} is the inlet liquid density. The operating conditions for the nine data sets are listed in Table 1. A number of tests were conducted within each set by varying the mass split ratio W_3/W_1, where $W_3 = W_{G3} + W_{L3}$, and $W_1 = W_{G1} + W_{L1}$. The total number of tests in this study was 79, with measurements of the phase redistribution at the junction performed in each test.

Table 1
Data matrix.

Data Set No.	P_s (kPa abs)	J_{G1} (m/s)	J_{L1} (m/s)	Inlet flow regime
1	150	2	0.01	Stratified
2	150	10	0.04	Wavy
3	150	40	0.18	Annular
4	200	2	0.01	Stratified
5	200	10	0.01	Wavy
6	200	10	0.04	Wavy
7	200	40	0.01	Annular
8	200	40	0.04	Annular
9	200	40	0.18	Annular