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Horizontal two-phase flow pattern recognition

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ABSTRACT

In the present work a Wire Mesh Sensor (WMS) has been adopted to characterize the air–water two-phase flow in a test section consisting of a horizontal Plexiglas pipe of internal diameter 19.5 mm and total length of about 6 m. The flow quality ranges from 0 to 0.73 and the superficial velocity ranges from 0.145 to 31.94 m/s for air and from 0.019 to 2.62 m/s for water. The observed flow patterns are stratified–bubble–slug/plug–annular. The WMS consists of two planes of parallel wire grids (16 × 16) that are placed across the channel at 1.5 mm and span over the measuring cross section. The wires of both planes cross under an angle of 90°, with a diameter D_{wire} of 70 μm and a pitch equal to 1.3 mm. The void fraction profiles are derived from the sensor data and their evolution in time and space is analyzed and discussed. The dependence of the signals on the measured fluid dynamic quantities is discussed too. The main task is to identify the flow pattern under any set of operating conditions as well as to establish the value of the characteristic flow parameters.

1. Introduction

The complexity of two-phase flows is due to the existence of multiple, deformable and moving interfaces, and to significant discontinuities of the fluid properties across the interface, that lead to different spatial and temporal scales of the flow structure and state. The flow regimes are defined as the macrofeatures concerning the multiphase interface structure and its distribution. In horizontal flow the effect of the gravity force contributes to the asymmetric distribution of the flow in the vertical direction.

The flow pattern is the result of the mechanical and thermal dynamic equilibrium between the phases, that depends on a large number of important parameters: the phases superficial velocity, the flow conditions (pressure and temperature), the fluid properties (density, viscosity, surface tension), the channel geometry and the flow direction (upward, downward, co-current, counter-current). A comprehensive classification of flow regimes in different pipe configuration and operating conditions is given by Rouhani and Sohal [1], Dobson [2] and Thome [3].

Generally, the flow recognition is performed by visual observation or by using flow pattern maps (Baker [5], Mandhane et al. [6] and Duckler et al. [7] for example); when the direct visualization is unavailable other techniques have to be used: optical techniques, nuclear radiation attenuation, impedance electrical techniques. A straight approach used to characterize the flow, is based on the measurement of the local void fraction and on the average cross-section or volumetric void fraction value. The void fraction can be measured by means of techniques like radiation attenuation (X or γ-ray or neutron beams) for line or area averaged values (Jones and Zuber [4]), optical (Bertola [8]) or electrical contact probes for local values, impedance techniques by using capacitance or conductance sensors (Prasser et al. [9]) and quick-closing valves based on the phases volume measurement.

The Wire Mesh Sensors (WMS), based on the measurement of the local instantaneous conductivity of the two-phase mixture, allows the evaluation of local void fraction, bubble size and phases velocity distribution. The WMS has been used, in different geometries and for different configurations, to study the mean cross-section void fraction and gas profile evolution (Prasser et al. [10]). Comparative measurements between WMS and an X-ray tomography techniques have shown that the accuracy of the cross-section average void fraction depends on the two-phase flow pattern. Differences in the absolute void fraction were determined by Prasser et al. [11] for bubbly flow in the range of ±1%, and for slug flow with an underestimation of approximately −4%. Da Silva et al. [12] have developed a WMS system based on permittivity (capacitance) measurements, which has been applied to investigate non-conducting fluids multiphase flows.

In the present work a WMS has been adopted to characterize the air–water two-phase flow in a horizontal Plexiglas tube ($D = 19.5$ mm): local, chordal, cross-section void fraction values are derived from the sensor data and the flow evolution in time and space is analyzed and discussed. The dependence of the signals

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Nomenclature

A	area (m^2)
D	pipe diameter (m)
D_{wire}	WMS wires diameter (m)
d_b	bubble diameter (m)
f	frequency (Hz)
G	mass flux (kg/m^2s)
h^*	interface position
J	superficial velocity (m/s)
L	length (m)
p	pressure (bar)
p	WMS wires pitch (m)
t	time (s)
T_T	total observation time (s)
v	velocity (m/s)
$V(i, j, k)$	WMS output matrix
V^*	WMS normalized signal
W	mass flow rate (kg/s)
x	flow quality
z	vertical coordinate (m)

Special characters

α	void fraction
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
σ	surface tension (N/m), standard deviation
τ	moving average time, characteristic time (s)

Subscripts

acq	acquisition
b	bubble
g	gas
i	*i*-th vertical wire index
j	*j*-th horizontal wire index
k	WMS time index
l	liquid
s	slug
tot	total
TP	two-phase

Abbreviation

WMS	Wire Mesh Sensor
f.s.v.	full scale value
r.v.	read value

on the measured fluid dynamic parameters is discussed too. The main task is to estimate the flow pattern under any set of operating conditions, as well as to predict the characteristic fluid and flow parameters (like characteristic times, liquid levels, droplets distribution) from the analysis of the void fraction chordal profiles that can be derived from the time history of the WMS signal.

2. Wire Mesh Sensor

2.1. Geometry and electronic circuit

The sensor used in the present work has been manufactured by Teletronic Rossendorf GmbH [13]. The sensor working principle is the measurement of the conductivity of the fluid. Because air and water have different electrical properties (water is highly conductive while air has a very low conductivity) the measurement of the conductance can be analyzed to detect the presence of each phase in the channel. The WMS (Fig. 1) consists of two planes of parallel wire grids (16 × 16) that are placed across the channel at a short distance from each other (1.5 mm); the wires of both planes cross under an angle of 90°. The sensor has been designed to cover the cross section of a channel having a 19.5 mm inner diameter; the wires have a diameter D_{wire} of 70 μm and a pitch p equal to 1.3 mm, so that only the 5.4% of the pipe section is occupied by the sensor. The measuring grid allows a spatial resolution of the order of the pitch length (1.3 mm) and it is possible to analyze the evolution of the investigated flow pattern, as the time resolution is rather high (up to 10.000 frames/s).

2.2. Signal processing

The WMS signals are acquired by means of WMS200 electronics and processed in Matlab® environment. The output is a 3-D matrix $V(i, j, k)$, where the indexes i and j are related to the space position of the mesh points and k is the time index, having a value between 1 and $T_T f_{acq}$, where T_T is the total observation time and f_{acq} is the acquisition frequency.

The value of $V(i, j, k)$ is a 12 bit digital signal proportional to the local fluid conductivity; the maximum value of the signal is 4079. The indexes i and j refer to transmitting wires and to receiving wires respectively. In order to analyze the signals, the location of the wires within the channel is defined: the points of the grid, that are located near the wall, are analyzed taking into account the wall influence, while the points, that are located outside the cross section of the pipe are excluded from the analysis. The developed signal processing scheme is structured to obtain the desired two-phase flow parameters.

First of all the signal is normalized taking into account the single-phase reference matrix:

$$V^*(i,j,k) = \frac{V(i,j,k) - V_l(i,j)}{V_g(i,j) - V_l(i,j)} \tag{1}$$

where V_l and V_g are the time averaged values of the signals at the beginning of the test when the pipe is filled with water or air. The signal normalization can be considered as an approximation of the local void fraction value, if a linear relationship between conductivity and void fraction and a reference area equal to the square of the wire pitch p are assumed.

According to [12] slight overshoots and noise in the signal are corrected by:

$$V^*(i,j,k) = \begin{cases} 0 & V^*(i,j,k) \leqslant 0 \\ V^*(i,j,k) & 0 < V^*(i,j,k) < 1 \\ 1 & V^*(i,j,k) \geqslant 1 \end{cases} \tag{2}$$

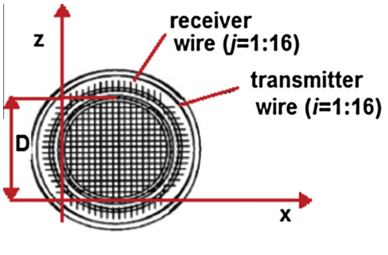

Fig. 1. Scheme of the WMS.

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