International Journal of Multiphase Flow 85 (2016) 86–95

Contents lists available at ScienceDirect

International Journal of Multiphase Flow

journal homepage: www.elsevier.com/locate/ijmultiphaseflow

Developments for the application of the Wire-Mesh Sensor in industries

Ragna Kipping[a,*], Rosmer Brito[c], Eckhard Scheicher[b], Uwe Hampel[a,b]

[a] AREVA Endowed Chair of Imaging Techniques in Energy and Process Engineering, Technische Universität Dresden, 01062 Dresden, Germany
[b] Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany
[c] McDougall School of Petroleum Engineering, The University of Tulsa, Tulsa, OK, USA

ARTICLE INFO

Article history:
Received 14 December 2015
Revised 8 May 2016
Accepted 31 May 2016
Available online 6 June 2016

Keywords:
Wire-Mesh Sensor
Two-phase flow
Flow pattern identification
Fuzzy clustering
Vertical pipe flow
Void fraction
Regime transition

ABSTRACT

Wire-Mesh Sensors (WMS) are applied in many research applications to determine the distribution of the phase fraction and to visualize the flow behavior within a pipe. However, their application in industries is restricted due to the procedure of data acquisition and offline post processing. Here a new design of Wire-Mesh Sensor for monitoring void fraction and flow pattern behavior is presented. As result of online data evaluation cross-sectional void fraction information is provided in almost real-time. Additionally, the present flow pattern is determined by statistical analysis of recorded data of a time period of 10 s. This is the first time a Wire-Mesh Sensor was used for this purpose. With the help of fuzzy methodology a distinction of the four main flow patterns of vertical upward gas-liquid flow is possible. Furthermore, transition regions can be identified. The algorithm is based on the evaluation of statistical void fraction distribution as result of Wire-Mesh Sensor data. Validation experiments of the new adopted algorithms are carried out in a 50 mm-ID two-phase air-water flow-loop at Tulsa University Horizontal Well and Artificial Lift Projects (TUHWALP).

1. Introduction

Processes in chemical, as well as mineral oil and nuclear industry always appear with the occurrence of multiphase flows. In comparison to single-phase flow, the description of multiphase flows is very complex and since its behavior and distribution has a main influence on the performance and efficiency of processes its understanding is of main interest. Flow structures, which can occur in pipes, are mainly dependent on the flow rate of the fluids. Some of them are undesired in industrial applications, e.g. slug flow for transportation processes. Here, at moderate gas flow rates the gas occupies the whole cross-section of the pipe, which is associated with a pressure gradient within the pipe. Different material properties, especially a high viscosity of the medium can enhance this effect and plug the pipe. If this goes undetected the pressure within the pipe increases and can result in a major safety hazard. For this reason, the knowledge of flow behavior within the pipe is essential.

Due to the diversity of multiphase flows (e.g. gas–liquid, liquid–solid and gas–liquid–solid flow) a general description of flow behavior is rarely possible. Several research groups investigated the behavior of multiphase flows within pipes and proposed models for different material systems, e.g. (Taitel and Dukler, 1976), (Barnea, 1987). In this way they are able to predict the distribution of the phases as a function of the flow rates, physical properties and others. These models give good agreement under ideal conditions. However, besides these well-known parameters, the flow within pipes can also be influenced by impurities of the fluids and environmental factors such as temperature change, which changes the physical properties of the fluids (e.g. viscosity). Here theoretical models reach their limits. Therefore, process monitoring plays a crucial role in industrial applications, such as increasing the performance of chemical reactors and for reason of safety assurance issues.

Currently, many classes of local probes are used for process monitoring in industrial applications such as temperature probes, conductivity probes and probes for concentration measurement of different species, e.g. oxygen or nitrogen. These probes are invasive in nature and provide local information, which are not representative for the whole cross-section, especially for pipes with large diameters. Cross-sectional information about the flow can be obtained from non-invasive measurement techniques like Electrical Resistance Tomography (ERT) or Electrical Capacitance Tomography (ECT). However, reconstruction algorithms are necessary for

* Corresponding author.
E-mail address: ragna.kipping@tu-dresden.de (R. Kipping).

http://dx.doi.org/10.1016/j.ijmultiphaseflow.2016.05.017
0301-9322/

Nomenclature

A	Area
a	Weight coefficient
COG	Center of gravity
v	m/s, superficial velocity
E	%, Error
ε	%, void fraction
μ	-, membership-function
z	Measuring point
ED	Euclidian distance
N	Total number of frames
n	Single frame of data set
PDF	Probability Density Function
c	Class center to flow patterns respectively
C	Total number of flow patterns considered for COG calculation
y	Centroid of line
Δx, Δy	Dimension of imaginary control volume around cross-point of WMS
U_{meas}	Array containing measurement data in each time step
U_{high}	Array containing the calibration values of high conducting liquid

Indices

LS	Liquid superficial
GS	Gas superficial
R	Range of void fraction
s	Standard deviation of void fraction

data processing, which limits its application for real time data provision. Furthermore, the spatial resolution is rather low in comparison to other measurement techniques, e.g. Wire-Mesh Sensor. I n contrast, Wire-Mesh Sensors are an invasive measurement technique. However comparative studies with non-invasive measurement techniques showed good agreement of experimental data (Azzopardi et al., 2010), (Prasser et al., 2005).

In the past, Wire-Mesh Sensors are adopted as measuring technique for many research applications (Vieira, 2014), (Ofuchi et al., 2010), (Shaban and Tavoularis, 2015). Currently, its application to industry is restricted due to the offline data processing procedure. This paper presents a first approach for the industrial type of Wire-Mesh Sensor including fast calculation of cross-sectional void fraction. This is possible due to changes in the process of data acquisition and analysis. Up to now, data from Wire-Mesh Sensors were recorded and analyzed offline after the measurement. This is done by generating a calibration file, which is then used for the normalization of the measured data, resulting in three-dimensional data files, containing the instantaneous local gas–liquid distribution information. Based on this data, several algorithms can be applied to capture bubbles (Prasser and Beyer, 2007), calculate bubble-sizes (Prasser et al., 2001) and determine gas-phase velocities and distributions. The new field of application requires an alignment of these algorithms. The offline evaluation of the data is not suitable, because information is needed instantly after the measurement. But regarding the before mentioned parameters, which can be extracted in post-processing of Wire-Mesh Sensor data, only a few subsets of information about the flow are of interest for industrial customers. It is assumed that, with respect to hydrodynamic parameters the knowledge about the composition of the phases within the pipe play a major role in industrial processes. Therefore, the focus in this study lies on the calculation of phase fraction in short time intervals. Additionally, the distribution of the phases or rather the flow pattern might be of special interest. The development of industrial Wire-Mesh Sensor has the ability to become a new tool for process monitoring. Due to its advantages of a cross-sectional analysis in comparison to probes, the monitoring of process conditions could be improved and processes can be controlled more reliable.

In the literature several attempts have been made within flow pattern identification methods. An important finding in this field is that Probability Density Functions (PDF) of the void fraction shows characteristic courses for the different flow patterns of vertical upward gas–liquid flow (Jones and Zuber, 1975), (Matsui, 1984). To the best of our knowledge one of the first activities in the field of flow pattern identification algorithms was done by Mi et al. (1996), who applied a non-intrusive impedance measurement technique to determine the flow patterns of vertical upward two-phase flow (Mi et al., 1996). The basis of the identification algorithm is the Probability Density Function of different flow patterns. The algorithm itself is a mixture of fuzzy methodology and neural networks. Later Mi et al. (2001) also applied impedance probes and determined flow patterns in horizontal flow. Corre and Aldorwish (1999) used a Fuzzy algorithm to determine flow patterns, based on measurements with conductivity probes. In detail, they calculated mean void fraction and volume equivalent surface, which they used as input parameter for flow pattern identification. Ghanbarzadeh et al. (2010) used neural network technique to determine flow pattern in vertical pipe flow based on pressure signals. Pressure signals were analyzed to calculate PDF and identify characteristic frequencies based on Fast Fourier Transformation. Another approach is the elastic map algorithm, which was applied by Shaban and Tavoularis to identify flow pattern of vertical two-phase flow based on the PDF's calculated from differential pressure data (Shaban and Tavoularis, 2014). With this method the characteristic shape of the PDF's is transferred to a two-dimensional map, where clusters can be identified to the flow regimes respectively. They also applied this algorithm on void fraction calculated from Wire-Mesh Sensor data (Shaban and Tavoularis, 2015).

The motivation of this work is the development of fundamental algorithms to make the Wire-Mesh Sensor applicable for industrial use. In this paper, it is strongly focused on fast data processing and provision of information about the main aspects of the flow within vertical pipes, namely void fraction and flow pattern. A main effort is taken to flow pattern identification. Previous works already showed that statistical parameters are suitable for determination of flow patterns. This approach was adopted also in this work using Wire-Mesh Sensor data and is extended by the introduction of a linear scale to capture the transient behavior of flow patterns.

2. Wire-Mesh Sensor

2.1. General measurement principle and data analysis

The Wire-Mesh Sensor is adopted as measurement technique to investigate the phase fraction of multiphase flow with high spatial and temporal resolution (up to 10 kHz) (Prasser et al., 1998). Thereby the spatial resolution is defined by the number of wires which are mounted in the cross-section related to the diameter of the pipe. Wire-Mesh Sensors are characterized by a matrix-like arrangement of crossing points within a cross-section. This arrangement results from the installation of two perpendicular planes with a small distance to each other. These planes consist of parallel sets of wire electrodes.

Previously two types of Wire-Mesh Sensor, based on the change of different physical properties have been developed: a capacitive Wire-Mesh Sensor to study the flow behavior based on the relative permittivity of fluids, enabling the application even for non-conducting liquids (Silva, 2008) and the conductivity Wire-Mesh Sensor (Prasser et al., 1998), which is used in the present study.