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The use of an ultrasonic technique and neural networks for identification of the flow pattern and measurement of the gas volume fraction in multiphase flows

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ABSTRACT

In the oil industry, the well stream often consists of a full range of hydrocarbons and a variety of non-wanted components such as water, carbon dioxide, salts, sulfur, and sand. The need for multiphase flow metering (MFM) arises when it is necessary or desirable to meter the flow upstream of the separators. The ultrasonic technique fulfils many of the requirements for MFM in the oil industry (mainly, non-invasive, non-radiative, robust, and relatively non-expensive) and has the capability to provide the information required. The drawback of current ultrasonic techniques, as is the case with other MFM methods, is the need for prior signal calibration. A broader solution to this issue could be the use of artificial neural networks (ANNs). ANNs provide a non-linear mapping between input and output variables and the cross-correlation among these variables and could be an alternative tool for automatic identification of flow patterns. In this context, the objectives of the current investigation are two-fold: (i) to present and analyze acoustic attenuation data for vertical, upward oil-continuous multiphase flows in 1-in. and 2-in. acrylic pipes and flow patterns ranging from bubbly flows to annular flows; (ii) to develop neural networks for flow pattern recognition and gas volume fraction (GVF) measurement using the ultrasonic attenuation data as input. The results shown testify to the ability of the neural networks and the ultrasonic technique to perform these tasks.

1. Introduction

A simplified view of an oil and gas production plant is shown in Fig. 1. The wellheads on the left feed into production and test manifolds; the remainder of the figure is the actual gas and oil separation plant (GOSP). Often the well stream will consist of a full range of hydrocarbons and a variety of non-wanted components such as water, carbon dioxide, salts, sulfur, and sand [3]. Separation of these components is accomplished mainly by gravity production separators. The need for multiphase flow metering (MFM) arises when it is necessary or desirable to meter the flow upstream of the separators. MFM enables measurement of unprocessed multiphase streams very close to the well, thereby providing continuous monitoring of well performance and better reservoir exploitation and drainage.

A detailed discussion of different instruments and techniques that have been considered for MFM applications can be found in [3–5]. Table 1 below groups these instruments and techniques according to the flow parameter involved in their principle of operation. The *Remarks* column summarizes information in the literature [3,6] involving the application of these techniques to MFM. It can be seen that most techniques either call for additional research and development before they can be reliably applied to multiphase flows or still need further development despite already being used in MFM applications. Gamma densitometry, despite requiring carefully implemented procedures to handle radioactive sources, is used in many commercial multiphase flow meters (MPFMs) [3]. However, it is subject to errors due to phase distribution in time and space and thus needs to be used in combination with other devices that properly account for the flow upstream conditions. Scheers [6] points out an almost 20% difference between actual and measured gas volume fraction (GVF) in the annular flow pattern using gamma ray densitometry.

Many other techniques in Table 1 can be seen to use radioactive sensors. In this connection, Arora [8] discusses the advantages of

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Nomenclature

Latin symbols

a	bubble or particle radius (m)
A	projected cross sectional area (m^2)
A	parameter defined in Atkinson and Kytömaa [1] (Pa s/m^2)
A	parameter defined by Isakovich [2]
B	parameter defined in Atkinson and Kytömaa [1] (kg/m^3)
c	speed of sound (m/s)
c_p	specific heat at constant pressure (J/kg K)
E	acoustic pulse energy (V^2 s $\propto$ J)
I	acoustic intensity (W/m^2)
j_l	spherical Bessel function of the first kind
k	thermal conductivity (W/m K)
k	wave number (m^{-1})
K	wave vector (m^{-1})
j	imaginary unity, $\sqrt{-1}$
n	thermal wave vector (m^{-1})
n_l	spherical Bessel function of the second kind
N	border between transducer near and far fields (m)
P	pressure or pressure amplitude (Pa)
r	specific acoustic resistance (rayl)
R_I	intensity reflection coefficient (–)
Re	Reynolds number (–)
x	spatial coordinate (m)
S	total extinction area (m^2)
T	normalized amplitude of transmitted signal (–)
T_I	intensity transmission coefficient (–)
T	temperature (K)
U	amplitude of particle velocity (m/s)
V	voltage (V)

Greek symbols

α	spatial absorption coefficient (Np/m or dB/m)
α_c	classical absorption coefficient (Np/m or dB/m)
α_k	thermal absorption coefficient (Np/m or dB/m)
α_s	viscous (Stokes) absorption coefficient (Np/m or dB/m)
β	thermal expansion coefficient (K^{-1})
γ	ratio of specific heats (–)
Γ	interfacial area per unit volume (m^2/m^3)
δ	boundary layer thickness (m)
η	coefficient of shear viscosity (Pa s)
$\bar{\kappa}$	suspension effective bulk modulus of elasticity (Pa]
ν	particles fraction (–)
ρ	density (kg/m^3)
$\bar{\rho}$	suspension density (kg/m^3)
ρ^*	parameter defined in Atkinson and Kytömaa [1] (kg/m^3)
ω	angular frequency (rad/s)

non-radioactive MPFMs over MFM techniques involving radioactive sensors. Non-radioactive MPFMs are much cheaper in terms of construction because they do not use radioactive elements. In addition, the operational expenditure is much less than that of radioactive instruments because of the enormous costs associated with the various health, safety, and environmental requirements for the latter. Furthermore, the costs related to export/import of non-radioactive equipment are much lower because they do not require specialized packing and clearance procedures. Finally, mobile non-radioactive MPFMs can be used with ease for well tests

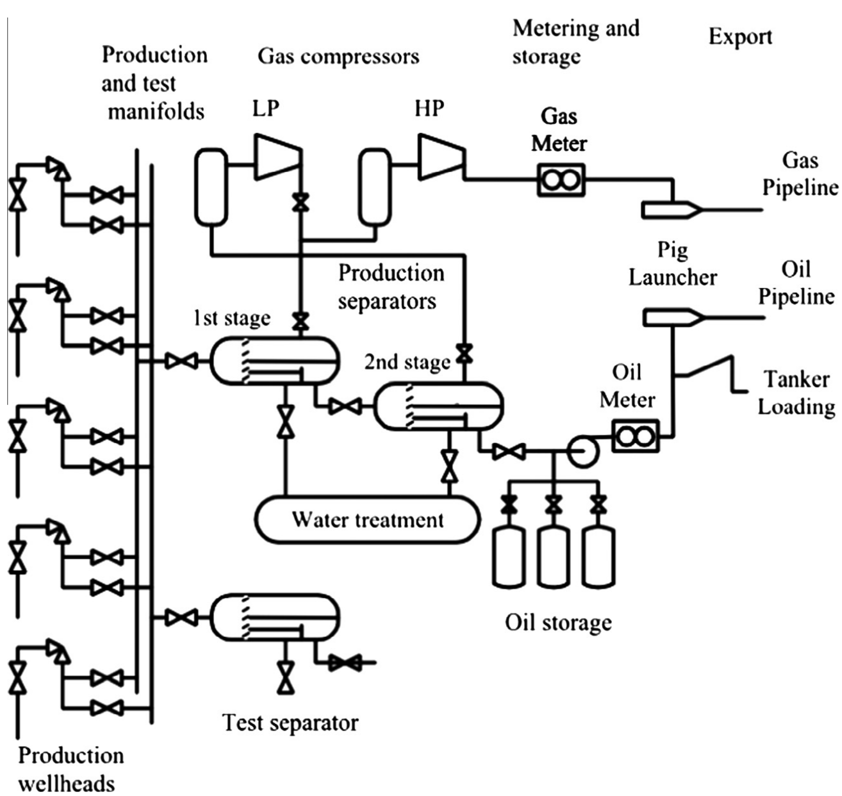

Fig. 1. Oil and gas production overview – adapted from [7].