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Research Paper

Experimental investigation of the phase fraction of wet gas based on convective heat transfer

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HIGHLIGHTS

- A correlation of liquid fraction in wet gas annular flow is acquired.
- Electrical heat belt and Pt100 resistances are used to form a thermal sensor.
- Dimensional analysis is adopted to find out the important parameters.
- Relative deviations are less than ±15% while GVF is from 23.8% to 100%.

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ABSTRACT

In the present stage, wet gas measurement is playing an increasingly significant role in the oil and gas industry. Phase fraction is an important parameter for the determination of pressure drop and heat transfer coefficient in wet gas flow. In this paper, experimental investigations of the wet gas phase fraction based on convective heat transfer (CHT) is conducted. In order to describe the "over reading" of CHT coefficient due to the existence of the liquid phase, it is innovative to define ω as the ratio of the CHT coefficients of wet gas and gas alone. An easy-to-use correlation is proposed by using the gas flow rate and the temperature measured before and after the electrical heating belt. The experiment was carried out in the wet gas flow loop in Tianjin University. System pressure ranges from 0.6 MPa to 1.2 MPa, and gas mass fraction (GMF) is from 23.8% to 100%. Final results show that the relative deviation of all data points are less than ±15%. There is no doubt that this correlation provides new data on the phase fraction in wet gas annular flow and benefits other researchers in wet gas measurement.

1. Introduction

Wet gas is a subset of gas-liquid two phase flow, which exists in various areas such as in refrigeration and air condition systems, pipeline network systems, nuclear power systems, chemical process systems and aircraft and spacecraft environmental control and life-support systems [1]. In ISO/TR 11583 [2], wet gas is defined as a two-phase flow of gas and liquid in which the flowing fluid mixture consists of gas in the region of 95% volume fraction or more.

Among the measurement of wet gas, the parameters about phase fraction, such as void fraction, are important in many two-phase flow pressure drop and heat transfer correlations [3]. Furthermore it is closely related to the two-phase flow behavior, which in turn has a strong effect on the total heat transfer rate and pressure drop [4]. Therefore it is meaningful to investigate the phase fraction of wet gas. However, comparing with the single phase flow, measuring direct and indirect parameters accurately in gas liquid two phase flow is still a vital problem [5]. A number of techniques are used in the measurement of phase fraction, such as wire mesh tomography [6], hot wire anemometry [7] and optical techniques [8]. Except these techniques, a large variety of research on the fluid mechanics of annular flow have been presented, including liquid film [9,10], void fraction [11] and entrained liquid fraction [12,13], etc. By combining technique and theoretical research, the improved and easy-to-use measurement methods of phase fraction in wet gas annular flow are still ongoing.

In nearly a half century, a series of experimental facilities were established to investigate the mechanism of fluid flow and heat transfer. In 1972, Whitaker [14] collected the previously obtained experimental heat transfer data and presented the forced

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convection heat transfer correlations for flow in pipes, which was widely applied and easily used. In the investigation of Traviss [15], the momentum and heat transfer analogy was applied to an annular flow model using the von Karman universal velocity distribution to describe the liquid film, and the results were used to substantiate a general design equation for forced-convection condensation. In 1979, Shah [16] presented a simple dimensionless correlation for predicting heat transfer coefficients during film condensation inside pipes, and the correlation had been verified by comparison with a wide variety of experimental data. In 1982, Dobran [17] presented a new method for the analysis of hydrodynamics and heat transfer of two-phase annular flows with turbulent liquid films. In this method, the liquid film in two-phase annular flow is divided into a continuous layer adjacent to the channel surface and a wavy layer close to the liquid-gas interface. In 1999, Hurlburt [18] used annular flow modeling relations to develop ratio metric equations for liquid fraction, pressure drop, and heat transfer that allow general trends to be predicted when the operating parameters of a refrigeration system were changed. In 2001, Kwon et al. [19] developed an analytical model for condensation heat transfer coefficients for a turbulent annular film flow in tubes, and this model incorporated not only a new turbulent eddy viscosity profile modified from the Blangetti and Schlunder model [20] but also liquid entrainment effect. In 2009, Cioncolini [21] considered algebraic turbulence modeling in adiabatic and evaporating annular two-phase flow, focusing in particular on momentum and heat transfer through the annular liquid film. In 2013, Jeon [22] assessed total 19 annular flow condensation models which were collected from the published literature and incorporated in reactor safety code. It was found that these models of Cavallini and Zecchin [23], Dobson and Chato [24], Kosky and Staub [25], Traviss et al. [15], Moser et al. [26], etc., had good predictive capabilities on the condensation heat transfer for the steam-water annular flow.

In summary, there are plenty of research about the heat transfer of evaporation and condensation, however, the research on the liquid fraction of wet gas annular flow based on CHT is rarely reported. In 1981, Toral [27] studied the performance of the constant temperature hot-wire anemometer as a local void fraction meter with freely rising bubbles of air and vapor in ethanol. In 2002, Boyer [28] offered an overview of the instrumentation techniques developed for multiphase flow analysis either in gas/liquid or in gas/liquid/solid reactors. Among these method, hot film anemometry, when applied to two-phase flows, leaded to gas fraction and to liquid phase characteristics: mean velocity and RMS fluctuating velocity.

The development of oil and gas industry has put forward a new topic of the wet gas annular flow, which is the phase fraction measurement. It is necessary to emphasis that the existing research on CHT of annular flow all leads to CHT coefficient of two-phase flow. Although the correlations are all depends on the dryness “x”, it is too difficult to obtain the liquid fraction directly in the measurement of wet gas. This research acquired a novel correlation of liquid fraction in wet gas based on CHT and this correlation is easy to use by engineers. In this paper, the phase fraction of wet gas flow is investigated based on the CHT of annular flow. An electrical heating belt was used as the heat source and the temperature was measured by the platinum resistance. The experiment was carried out in the wet gas test loop of Tianjin University. With the data, the relationship between the coefficient of CHT and the phase fraction is analyzed. Finally, a phase fraction correlation of wet gas annular flow was established.

2. Theoretical analysis

If there is fluid motion, energy is transported by potential gradients (as in simple conduction) and by movement of the fluid itself. This complicity of transport processes is usually referred to as convection. The essential feature of CHT is the transport of energy to or form a surface by both molecular conduction processes and gross fluid movement [29]. There are many factors that affect CHT, such as the power of flow, the flow condition and the geometry of the solid surface. Therefore the coefficient of CHT is a complicated function that depends on various factors and large numbers of experimental data are needed in the research on CHT coefficient [30]. In order to improve the efficiency of experimental research and acquire the general rule, dimensional analysis is adopted in the physical process of CHT of the annular flow.

The structure of the thermal sensor is shown in Fig. 1. The inner and outer diameters of the pipe are 50 mm and 60 mm respectively. The heating element is an electrical heating belt which is wounded around the outer side of the pipe. A layer of aerogel

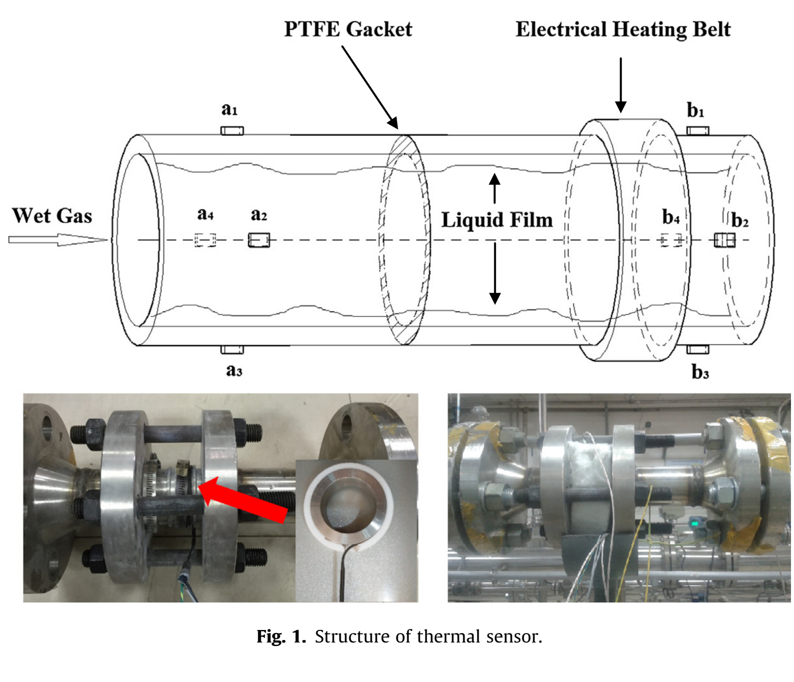

Fig. 1. Structure of thermal sensor.