



Techniques of PIV in stratified two-phase headers

W. Saleh, R.C. Bowden, I.G. Hassan*, L. Kadem

Department of Mechanical and Industrial Engineering, Concordia University, Montreal, QC, Canada H3G 2W1

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ABSTRACT

The stratification of two fluid phases, namely gas and liquid, within flow distribution devices, such as headers, that have side or bottom oriented fluid pipe connections, or discharges, has shown relevance to loss-of-coolant accidents in nuclear power plants. Under critical conditions the gas phase could entrain into the predominantly liquid discharge flow causing the fluid quality to be dramatically affected. This condition is referred to as the onset of gas entrainment (OGE) phenomenon and it occurs at a specific critical liquid height which changes with the Froude number. The liquid velocity field at the OGE is of importance, for example, to theorists who may find a semi-empirical approach to model this phenomenon. Stereoscopic particle image velocimetry (PIV) technique is an excellent candidate for non-intrusively investigating the velocity field. The liquid-phase velocity field was investigated for three discharge Froude numbers at the OGE. It was found that the stereoscopic PIV could be used to extract the velocity field experimentally, yet a high degree of error was found in the region closest to the discharge. The relative error was determined through conservation of mass by comparing the flow rate obtained with the PIV data to that obtained using a flow meter. In summary it was found that the number of image planes used, the resolution of the image planes, and consequently the number of vectors used to calculate the flow rate, all contributed a great deal to the relative error.

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1. Introduction

The topic of two-phase flow is one that has far reaching importance to many applications. The two phases could be of the same species, for example water and steam (water's vapour phase), or of different species, such as air and water. Gas–liquid flows are relevant to both the natural sciences (e.g. oceanography) and engineering (e.g. pressurized reservoirs, heat exchangers). The flow of two fluid phases is commonly described by its flow regime. For example, the ocean and atmosphere form two layers, or strata – this is commonly referred to as the stratified flow regime. In engineering practice, this flow regime is also significant to loss-of-coolant accident (LOCA) analysis of nuclear reactors – particularly in fuel channel coolant delivery systems.

As an example, the Canada Deuterium and Uranium (CANDU) fuel channel coolant delivery system incorporates a network of pipes (feeders) connected to four large reservoirs (headers). The headers both deliver (inlet header) and receive (outlet header) coolant from the fuel channels. A postulated LOCA may cause both gas and liquid fluid phases to be present within the header. Under normal operation the coolant supplied to the fuel channels from the headers (through feeders) is liquid but with two-phases in the header gas entrainment may occur, causing two-phase flow

in the feeders and consequently the fuel channels. A coolant comprised of a two-phase gas–liquid mixture has reduced cooling capacity and, in severe cases, may result in a core temperature rise beyond designed safety limits.

Zuber [1] considered the onset of gas entrainment as a quasi-steady problem. The criterion for entrainment was described in terms of the critical liquid height – the distance between the gas–liquid interface to the discharge inlet (or feeder inlet for CANDU example) – and has been characterized as a function of the discharge Froude number. This proposed functional relationship followed from Lubin and Hurwitz [2]'s transient experiments as:

$$\frac{H}{d} = C_1 Fr^{C_2}. \quad (1)$$

The equation states that the critical height (H) is a function of discharge Froude number (Fr), a ratio of inertial to gravitational forces defined as:

$$Fr = \frac{V}{\sqrt{gd}} \left(\frac{\rho_L}{\Delta\rho} \right)^{1/2}. \quad (2)$$

The discharge diameter and gravitational acceleration are defined as d [m] and g [m/s^2], respectively, while the single phase liquid discharge velocity is V [m/s]. The fluid properties included in Eq. (2) are the liquid (subscript L) density (ρ_L) [kg/m^3] and density difference between gas (subscript G) and liquid phases ($\Delta\rho = \rho_L - \rho_G$) [kg/m^3]. The coefficients C_1 and C_2 are determined

* Corresponding author.

E-mail address: IbrahimH@alcor.concordia.ca (I.G. Hassan).