Experimental Thermal and Fluid Science 55 (2014) 181–186

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

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

Gas–liquid two-phase flow equal distribution using a wheel distributor

Fachun Liang [a,b,*], Dong Wang [c], Jing Chen [a], Guiyun Yang [a]

[a] *College of Pipeline and Civil Engineering, China University of Petroleum, Qingdao 266580, China*
[b] *State Key Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190,China*
[c] *State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, China*

ARTICLE INFO

Article history:
Received 5 September 2013
Received in revised form 11 February 2014
Accepted 15 March 2014
Available online 29 March 2014

Keywords:
Gas–liquid two-phase flow
Distributor
Phase splitting
Flow pattern

ABSTRACT

A specially designed wheel distributor is proposed to extract equal small fraction (7%) of gas and liquid from the total gas–liquid mixture. The distributor mainly consists in a wheel, splitting channels and two fluid receiving rooms. With the rotation of the wheel, the total flow is conducted alternately into main flow loop and sample loop through their corresponding splitting channels. The fraction of gas and liquid taken off is determined by the structure of the wheel distributor and independent of gas and liquid flow rate, flow patterns and the wheel rotation velocity. Experiments were carried out in an air–water two-phase flow loop to verify the feasibility of the device. The inner diameter of the test loop was 50 mm. the superficial gas velocity varied from 4.0 m/s to 22 m/s, and the superficial liquid velocity was within the range of 0.018–0.2 m/s. The flow pattern occurred during the experiments involved wave flow, slug flow and annular flow. Experimental results were in good agreement with the theoretical value. The advantages of the proposed distributor are that the fluid in the branch is extracted from the whole cross section instead of a local place and the phase splitting phenomenon is substantially eliminated.

1. Introduction

Gas–liquid two-phase flow commonly exists in the power and process industries, such as steam power plants, evaporators and condensers, boiling-water and pressurized-water nuclear reactors. When two phases encounter a dividing device such as the junction, inevitable mal-distribution occurs, i.e., the liquid and gas phase do not split in equal proportion. This phenomenon is called phase splitting. When phase splitting takes place, the quality of gas and liquid at the outlet are different, and they are both different from those at the inlet.

Phase separation has been studied and discussed by Azzopardi [1], Shoham et al. [2], Hwang et al. [3] and Roberts et al. [4]. Although some models are available in literature, it is still poorly understood. A number of factors can affect the flow split, including the inlet flow pattern, the inertia of gas and liquid, the distributor geometry, mass split ratios, and even the fluid properties[5].

Uneven distribution of two-phase flow deteriorates the thermal and hydraulic performance of the downstream equipments. For instance, in the evaporator of the heat exchanger, dry-out phenomenon may happen unexpectedly in the parallel channels due to the phase uneven split at the *T*-junction [6]. Therefore, in the last two decades, various types of distributors have been proposed to distribute gas–liquid two-phase flow more evenly.

The feature of a *T*-junction is that it has two downstream legs in opposite directions, which are both perpendicular to the inlet. Considering the symmetrical structure, it can largely improve the phase distribution compared with branching *T*-junction. Several studies including Hong and Griston [7], Chien [8], Fujii et al. [9], El-shaboury et al. [10], Mohamed et al. [11] and Elazhary and Soliman [12] were published on multiphase flow spitting in impacting Junctions. Unfortunately, experiments performed by Azzopardi demonstrated that good phase distribution only achieved at 50% mass flow split [13]. The change of mass splitting ratio can lead to single-phase gas or liquid flow at one of the outlets [11]. Wren and Azzopardi [14] reported an improved junction, in which baffles were used to control the phase split at a large diameter *T*-junction. Their experimental results showed that uniform phase distributions between the two downstream arms were not achieved, although the phase separation could be minimized under certain condition.

According to Azzopardi's finding, the fluid emerging through the branch outlet is mainly taken from the segment of the main pipe nearest the side arm [15]. In order to reduce the phase splitting, efforts have been focused on how to adjust the upstream flow pattern to ensure all the downstream legs have the same chance to

---

* Corresponding author at: College of Pipeline and Civil Engineering, China University of Petroleum, Qingdao 266580, China. Tel.: +86 15239981150.
E-mail address: alpha.upc@gmail.com (F. Liang).

http://dx.doi.org/10.1016/j.expthermflusci.2014.03.009
0894-1777/© 2014 Elsevier Inc. All rights reserved.

contact both gas and liquid. Stoisits and Pinto [16] applied a static mixer to mix the phases before the junction. The major disadvantage of the device is that it often results in undesirable pressure loss. Schneider and Byrd [17] constructed a static, centrifugal two-phase flow distributor to distribute two-phase refrigerant equally. However, it is difficult to achieve the annular flow with uniform film thickness at a low mixture velocity in the large diameter pipes.

Compared with the two-phase flow, the single-phase flow is much easier to be distributed evenly. Based on this fact, distribution after separation was proposed by Zhang et al. [18] to avoid the splitting in multiphase environment. First, the gas–liquid mixture was separated into single phase fluids. Then the single gas and liquid flows were recombined at a desired gas liquid ratio. The method converts two-phase flow distribution process into single phase process and avoids the phase separation. Texaco Inc. also reported a patented gas–liquid two-phase distributor, which is similar to Zhang's method [19]. The major problem of the method is that a gas–liquid separation system must be employed, which increases the distributor size and cost. Besides, the device can only work well within a specific pressure and gas quality range.

The literature survey indicates that, although distributors with different structures have been developed, a generally applicable method or device to realize the uniform distribution of the gas and liquid two-phase flow is still not obtained yet. The objective of this paper is to present a specially designed wheel distributor to distribute gas–liquid two-phase flow evenly. According to the design principle, the splitting is not be affected by the flow pattern, gas and liquid flow rate, and the wheel rotational velocity. Experiments have been carried out at an air–water two-phase flow loop to verify the feasibility of the proposed method and device.

2. The wheel distributor

2.1. Structure of the wheel distributor

The wheel distributor proposed in this study is schematically presented in Fig. 1. The distributor consists in three parts: a wheel, the fluid splitting channels and two fluid receiving rooms. The wheel is located at the center of the distributor, and the splitting channels are equally positioned around the wheel.

The splitting channels are divided into two groups. One group is connected to the main fluid receiving room and named as main fluid channel (MFC). The other group is connected to the branch fluid receiving room and called branch fluid channel (BFC). The branch fluid channel and the main fluid channel are separated by the baffles. The fluid that enters the main fluid channel builds up in the main flow room and flows into the main pipe. Similarly, the fluid enters the branch fluid channel accumulates in the branch flow room and flows into the branch pipe finally. There are three BFCs (see Fig. 1a) and they are distributed 120° from one another around the wheel. Fig. 1a shows the width of the branch fluid channel is 11 mm and the corresponding angle α is 8.4°.

As shown in Fig. 1b, the wheel is vertically installed in the bracket with a shaft and two bearings. The wheel can rotate around its center axis under the force acted by the fluid from the flow path. The cover of the distributor is made from Plexiglas plate to monitor the splitting process. The inlet of the distributor is located at the center of the cover. The inlet tube and the wheel are 50 mm and 150 mm in diameter, respectively.

Three flow paths equally surround the flow entrance extending to the edge of the wheel (see Fig. 1a). As the two-phase mixture flows downwards into the center of wheel (see Fig. 1b), the fluid will pass through the three flow paths (see Fig. 1a) and form three jets at the exit of the path. A reaction force will act on the wheel when the jets leave, which pushes the wheel to rotate around the shaft at a high speed. With the rotation of the wheel, the total two-phase flow is conducted alternately into the main flow loop and branch flow loop through their corresponding fluid channels.

2.2. The splitting principle of wheel distributor

Assume the rotation speed of the wheel is ω, the rotating period of the wheel is

$$T = \frac{2\pi}{\omega} \tag{1}$$

According to Fig. 1a, during one period, the time of the fluid flowing into the branch fluid channel, Δt, can be given as below:

$$\Delta t = \frac{W \cdot N_s}{R\omega} \tag{2}$$

where W and N_s represent the width and the number of the branch fluid channel, respectively; R is the radius of the wheel; ω is the rotation speed of the wheel.The mass flow rate of gas or liquid phase entering a flow path is

$$q_j = \frac{M_{1j}}{N_{jet}} \tag{3}$$

where M_{1j} is the mass flow rate upstream of the distributor; N_{jet} is the number of flow path in the wheel; j represents gas phase or liquid phase.

The mass flow rate of one phase extracted to the branch in one splitting period can be written as:

$$\Delta m_{3j} = \Delta t \cdot N_{jet} \cdot q_j \tag{4}$$

where Δm_{3j} is the mass flow rate extracted to the branch in one rotating period; Δt represents the time duration of fluid flowing into the branch fluid channel in one splitting period; q_j represents the mass flow rate of one phase enter the flow path.

We can combine Eqs. (2)–(4) to derive the new expression of Δm_{3j}

$$\Delta m_{3j} = \frac{W \cdot N_s}{R\omega} M_{1j} \tag{5}$$

In one period, the total mass flow of fluid entering the distributor can be calculated as:

$$\Delta m_{1j} = M_{1j} \cdot T \tag{6}$$

Define K_j as the mass flow rate ratio of the branch flow over the total flow. K_j is often called fraction of taken off and the value can be given as:

$$K_j = \frac{\Delta m_{3j}}{\Delta m_{1j}} \tag{7}$$

Plug Eq. (5), Eq. (6) and Eq. (1) into Eq. (7), we have

$$K_j = \frac{W.N_s}{2\pi R} \tag{8}$$

According to the geometrical relationship among α, W and R (see Fig. 1a), Eq. (8) can be rewritten as:

$$K_j = \frac{\alpha}{2\pi} \cdot N_s \tag{9}$$

where α denotes the angle corresponding to the branch fluid channel.

Eq. (8) indicates that the extraction ratio K_j depends only on the ratio of the total branch fluid channel length to the wheel circumference. K_j is independent of the rotation speed. The rotation period varies with the change of gas and liquid flow rate, while the extraction ratio will still remains constant. We can change the fraction of