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Experimental investigation of phase split of gas-liquid swirling flow through a multi-slot sampler

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ABSTRACT

A special sampler is proposed to extract a fraction of fluid from the main stream of gas-liquid two-phase flow. Four rectangular slots (2mm × 110 mm) were arranged along the circumference of the pipe wall, and a moving plate is used to adjust the fraction of taken off. Experiments were conducted in an air-water two-phase flow loop and the flow patterns tested were: wavy, slug and annular flow. Experimental results show that, on contrary to the phase split behavior of conventional horizontal T-Junction, the liquid preferentially enters the sample slots. Phase split is affected by the gas and liquid superficial velocities, slot length ratio (L_s/L_m) and pressure difference ratio between the sample slot and main slot ($\Delta P_3/\Delta P_2$). In case of L_s/L_e equaling to 0.046, the fraction of liquid taken off can even exceed 0.4 due to much higher pressure difference of the sample slots compared with that of the main slots.

1. Introduction

In gas-liquid two-phase flow system, sampler is often used to withdraw a portion of fluid from the main stream [1]. As shown in Fig. 1, the inlet gas-liquid mixture is divided into two-parts: sample fluid and main fluid. It is commonly assumed that sample fluid and main stream should present the same gas quality. However, it is found that in many cases the gas-liquid mixture flowing through the sampler is usually split into two parts with different gas to liquid ratios. Such phenomenon is referred as phase separation or maldistribution [2,3].

A number of factors can influence the phase split performance, such as gas and liquid superficial velocity, incoming flow pattern, thermodynamic properties of gas and liquid, and sampler own structure [4]. According to the difference of phase separation behavior, the samplers can be basically classified into three types: uniform sampler, gas dominant sampler and liquid dominant sampler.

In the case of uniform sampler, component of sample fluid is identical to that present in the main fluid. The uniform fluid sampler may be applied in many engineering applications, ranging from thermal to chemical processes. For example, it can be used for gas-liquid flow metering [5,6]. A small fraction of total mass flow is diverted into a division loop using a specially designed sampler. Then, the diverted mixture is separated into gas and liquid streams by means of a small separator and, after that, they are metered by single-phase flow meters respectively. The single phase readings are then converted to total flowrates according to the individual extraction ratios. In order to obtain a representative fluid sample, Wang et al. [5] invented a rotational drum type sampler, from which about 20% of the two-phase mixture withdrawn from the main stream. Later, Wang et al. [7] further proposed a rotational wheel type sampler to periodically switch the total flow to the sample loop. Liang et al. [8] invented a multi-nozzle sampler for gas-liquid two-phase flow metering. The extraction ratio was determined by the number of sample nozzle. Their experimental results indicate that the measurements errors were less than ± 5%.

T-junction might be the simplest and most widely used gas dominant sampler. For a T-Junction with horizontal or upward side branch, the lighter phase tends to be diverted into the side arm whereas the heavier one tends to flow directly into the run branch, due to the noticeable momentum difference between gas and liquid. Sometimes, the maldistribution behavior is desired. For example, a T-junction with vertical side branch can be used as separator for gas-liquid flow [9,10]. Yang et al. [11] investigated the phase separation of stratified and plug flows in multi-tube T-junction. The T-junction type separator could have advantages of cost, size and weight over conventional separators. In the last several decades, extensive studies have been carried out on phase separation at T-junctions, and the experimental scale ranged from macro to micro [12–19].

The research of liquid dominate sampler is rather rare. Some

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Nomenclature

A	pipe cross sectional area
C	discharge coefficient
Err	measurement error
K	fraction of taken off
M	mass flow rate, kg/s
N	number of slots
W	width of the slot, mm
L_s	length of the sample slot, mm
L_m	length of the main slot, mm
L_e	effective length of the slot, mm
ΔP	pressure difference, Pa
U_{SL}	superficial liquid velocity, m/s
U_{SG}	superficial gas velocity, m/s
X	gas quality

Greek symbols

ρ	density
β	diameter ratio
ψ	thermal correction factor
θ	modification factor

Subscripts

1	total fluid
2	main fluid
3	sample fluid
h	splitting hole
G	gas
L	liquid

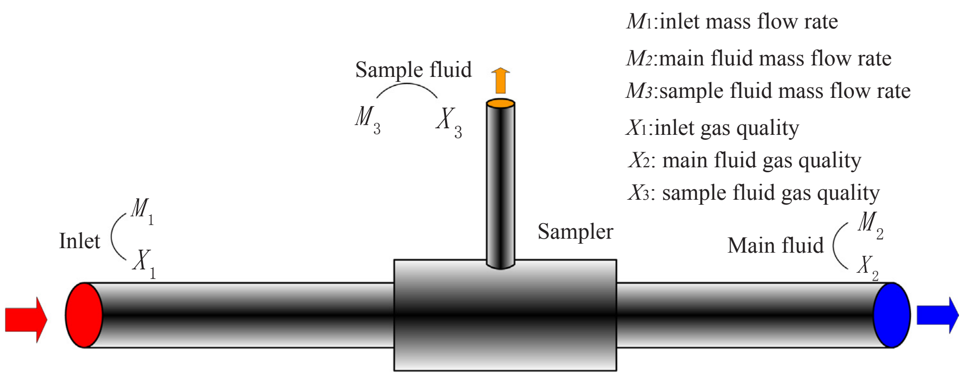

Fig. 1. Division of gas-liquid mixture by a sampler.

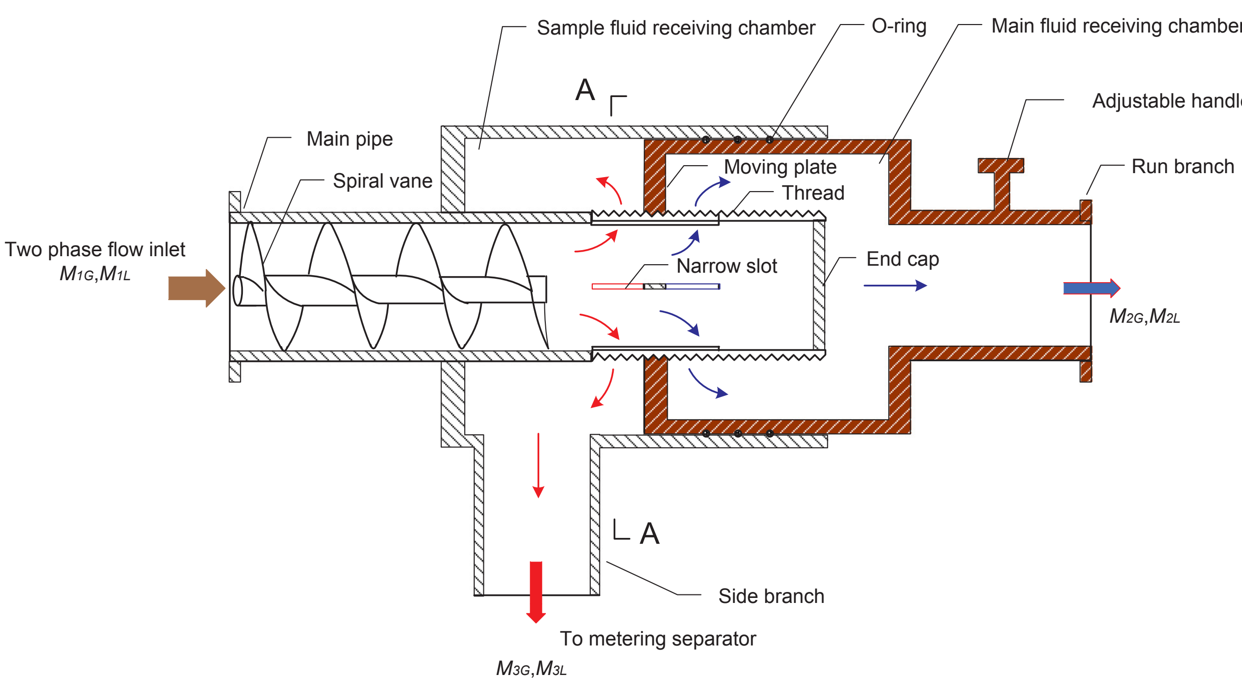

Fig. 2. Configuration of the experimental sampler.

researchers studied the split of gas-liquid two-phase flow through a pipe with a small break (or branch) at the bottom of the pipe [20–25]. It is recognized that severe phase separation may occur, depending on the location of the gas-liquid interface relative to the break and the pressure difference across the break [26]. If gas-liquid interface is above the break, liquid preferentially flows into the break and the fluid is liquid dominant. Unfortunately, in most occasions the location of gas-liquid interface and pressure drop at the break are both unknown, which lead to the prediction of performance of liquid dominant samplers remaining a challenge.