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EFFECT OF FLOW OBSTRUCTIONS ON VOID FRACTION PROFILE IN VERTICAL AIR/WATER FLOW

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ABSTRACT

Difficulties associated with the flow measurement of multiphase mixtures of oil, water and gas in production pipelines could be considerably reduced if the flow was homogenised. This paper presents initial flow homogenisation results obtained with air/water mixtures in the course of development of a multiphase flow meter.

A series of short pipe inserts with a length to bore ratio of 2.0 and varying flow area, were used to homogenise the upflow of air/water mixtures of varying component fractions in a vertical pipe 27.4 mm internal diameter. A miniature fiber optic sensor with associated electronics was used to obtain local time averaged void signal at given intervals over the pipe radius

$$\alpha = \frac{1}{T}(\Sigma_0^T t_g)$$

This measurement was repeated for several stations close to and downstream from the flow obstruction. The effectiveness of flow mixing was assessed for a range of air fractions on the basis of flatness of the measured radial void profile at a given downstream plane.

INTRODUCTION

Most industrial piping systems incorporate flow obstructions such as valves, junctions and orifice plates, all of which affect the flow behaviour in their proximity. In the case of multiphase pipeline flow, increased flow shear and turbulence, among other things, produced by such obstructions are likely to promote mixing of the phases (e.g. crude oil and gas) flowing through them.

The problem of accurately metering multiphase flow on-line and in real time is particularly difficult because of, among other things, the infinite variety of ways which a flow distribution of phases can assume. Some experimental parameters affecting phase topology include the flow elevation, direction and physical properties (ρ, σ, μ, c and k) as well as system parameters (ϵ, D, p and T). Attempts to predict multiphase flow patterns have been only moderately successful as transitions between them have been difficult to determine precisely experimentally.

The difficult task of metering such complex flows can be made somewhat easier if a particular flow pattern can be constructed and maintained in a given portion of a conduit, irrespective of the flow range and history (Hayward, 1985, Graves, 1987). The homogeneous flow pattern is particularly attractive not only because the number of parameters necessary to describe it is least, but because, it can be readily modelled analytically also.

The aim of this paper is to present results of an exploratory experimental study to determine the effectiveness of axysymmetric flow obstructions as flow homogenisers of air/water mixtures. The extent of homogenisation was judged optimum on the basis of flatness of measured time averaged radial void fraction profiles.

BACKGROUND

Early theoretical descriptions of void fraction distributions (Bankoff 1960, Levy 1963) used single phase turbulence concepts (power law distribution and mixing length theory respectively) with moderate success. In the meantime, improved experimental techniques enhanced better modelling. Herringe & Davis (1976) drew attention to the importance of adequate flow settling on void profile development, which generally peaked at the pipe centre, unlike data of Subotin et al. (1971), which showed void fraction peaks near the pipe wall. Beyerlein et al. (1985) showed that eddy diffusivity in the liquid together with a lateral force could account for the wall phenomenon.

A recent and more comprehensive experimental and theoretical study (Wang et al. 1987) than reported previously, took into account local turbulence structure of the continuous phase and lateral lift force acting on bubbles to explain more generally the measured phase distribution. They also showed that the local static pressure is reduced in regions where turbulent fluctuations are large.

While the available literature on the subject mainly reports on unobstructed flow in increasing detail, there appeared to be no detailed study on the effect of presence of flow obstructions on radial distribution of void fraction in vertical upflow of two-phase mixtures directly applicable to the current multiphase flow meter development in the Division. Particular features of interest were the extent and persistence of flow homogenisation following a flow obstruction and the geometry of the associated obstruction.

EXPERIMENTS

The experimental flow loop, the test section and flow chokes are shown in Figure 1. One 1kW centrifugal pump was used to circulate demineralised water, the excess flow being by-passed back to the liquid reservoir. The mass flow rate of water was measured with a Coriolis flow meter and was mixed with the flow of air 100 diameters before the test section vertically above.

The air flow rate was metered with a variable area flow meter and was kept constant at 0.023 g/s for five flow rates of water (0.083, 0.167, 0.250, 0.333 and 0.666 kg/s). A heat exchanger was used in the main flow circuit to keep the liquid temperature constant and close to ambient temperature.

The test section was made of a 84 mm square section of acrylic (Perspex) with a set of five horizontal ports for the introduction of the fiber optic probe and was designed to accommodate a thick wall orifice in its upstream end. Four thick wall acrylic orifice plates were used to reduce the flow area by a factor of 3/4, 2/3, 1/2 and 1/3.

The fiberoptic probe was of a 'closed loop' type with a glass filament 0.2 mm diameter, and was mounted on a micrometer slide which was manually moved to each required position. Three readings were taken at each radial location over a period of 100 s per reading, and were

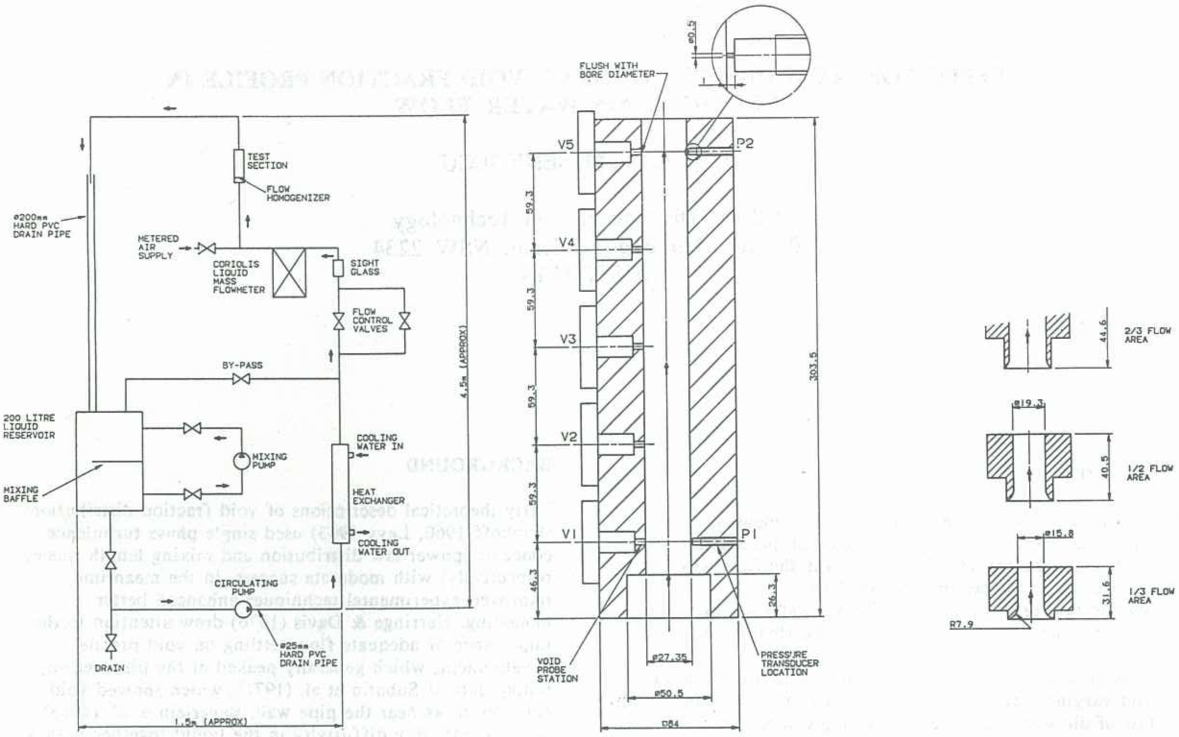

Figure 1 Experimental apparatus

averaged in the course of data processing. This information was then plotted using commercial software. The radial void fraction profile was measured at three planes axially displaced 20, 138.6 and 257.2 mm downstream from the mixing orifice exit.

The ranges of experimental variables in the experiments reported here are summarised in the table below

air fraction (%)	0.003	-	0.028
reduced flow area (A^*)	0.33	-	1.00
axial distance (L/D)	0.73	-	10.22
system pressure (kPa g)	1		
system temperature (°C)	20		

The accuracies associated with the flows were estimated to be 1% for the flow of air and 0.5 % for the flow of water.

RESULTS AND DISCUSSION

The most dramatic manifestation of the homogenisation affect is illustrated in Figure 2. Vastly increased flow shear assisted in fragmentation of air slugs into smaller bubbles when an orifice was placed in the flow. However, small bubbles began coalescing soon after leaving the orifice. The illustration also shows that the flow homogenisation was further enhanced with increased water flow rate. While the mechanism for the bubble fragmentation is probably a combination of rapid acceleration, high shear stresses and turbulent fluctuations, it is the latter factor which presumably predominates in the bubble dispersal or flow homogenisation.

Streamwise variation of void fraction profiles with axial distance for a given air fraction and flow area of the flow obstructing short pipe is given in each element of Figure 3. Each row corresponds to a different flow area, the smallest being at the top and largest (unobstructed) at the bottom. Furthermore, the air 'quality' increases along each column from left to right. Typically for low air fractions (0.003 and 0.007 %), wall peaking of void fraction was observed for obstructed flows close to the exit of the obstruction (at L/D

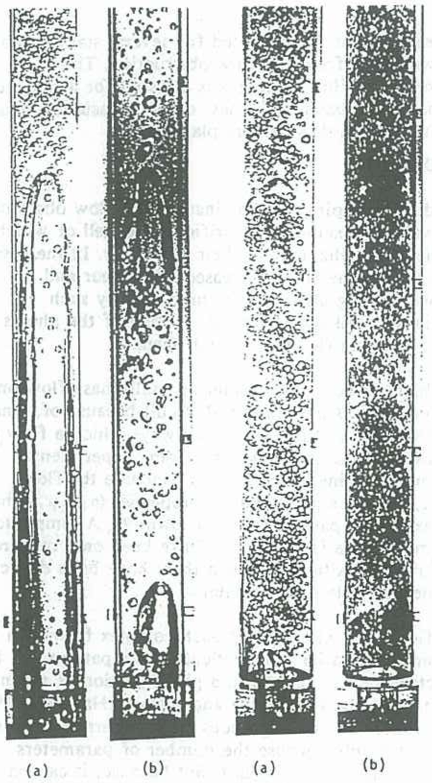

Figure 2 Unobstructed and obstructed ($A_* = 0.33$) flow with 0.023 g/s air and water flowrates of (a) 0.083 kg/s and (b) 0.67 kg/s

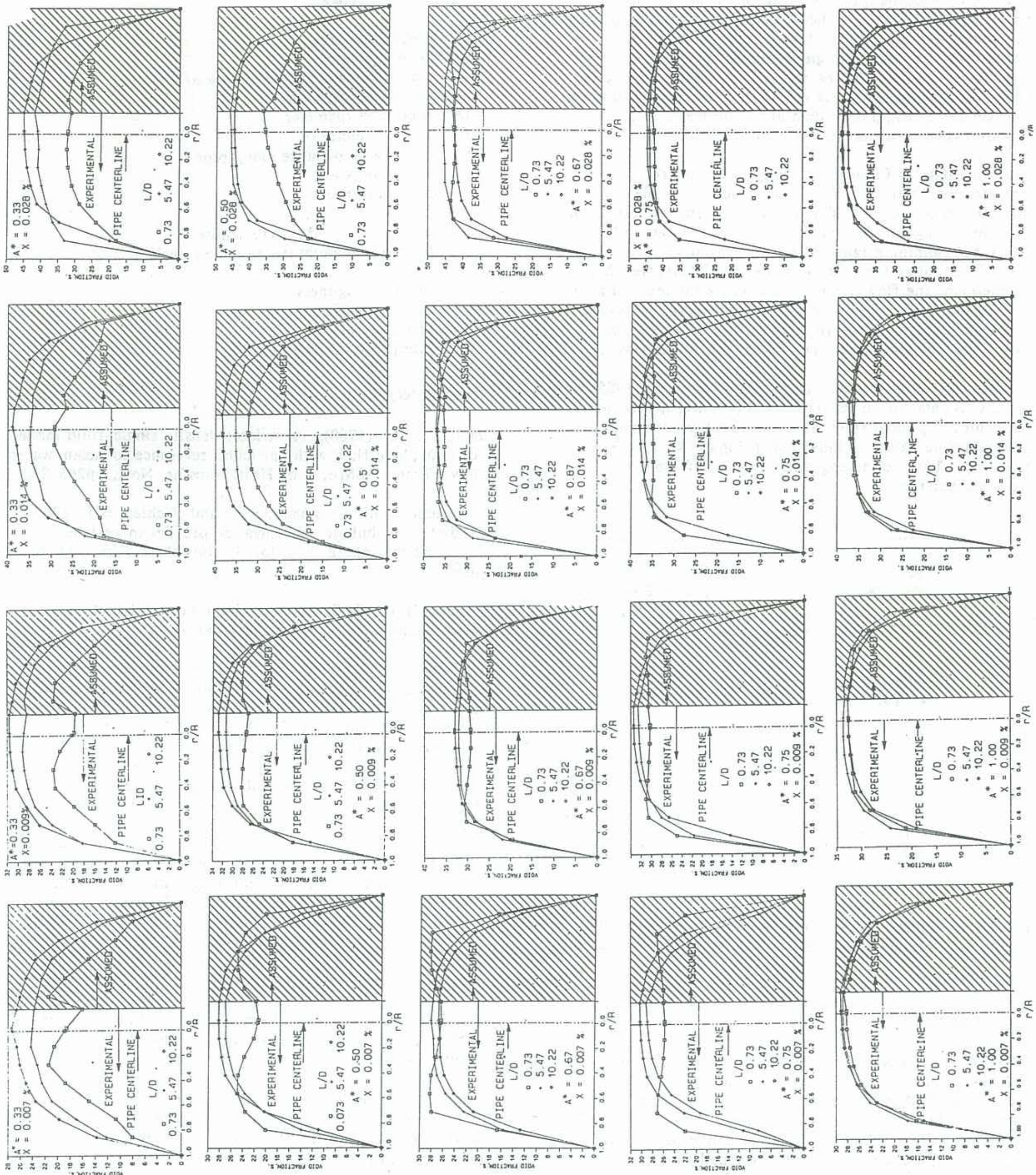

Figure 3 Measured void fraction profiles

= 0.73). Development of the centerline peak was apparent with increasing axial distance downstream from the orifice. In general, the magnitude of void fraction showed streamwise increase, as might be expected with reducing local static pressure. As the centerline peaking appears to persist at least beyond L/D = 5.47, it is the more stable and self-similar configuration than at the upstream location, a feature expected of developed flow.

From the data in Figure 3 it is apparent that, for $A^* = 0.67$, considerable flattening of the void fraction profile occurs at air fraction of 0.009 %. This flattening seems to persist for the whole range of air fraction values to the maximum 0.028 %, spanning a range of area averaged void fractions of 8 to 30 %, unlike for other flow chokes. Therefore, this geometry of the flow obstruction appears the most suitable for the multiphase flow meter development for the given range and type of flows. In addition, the pressure loss over the choke was small (less than 1 kPa) for all the flow rates.

A relatively simple correlation by Van Der Welle (1985) was used with data shown in Figure 3. Typically, it was suitable for centrally peaked flows and considerably overpredicted the centerline value, as indicated in Figure 4. This is probably related to, among other things, different test section diameters.

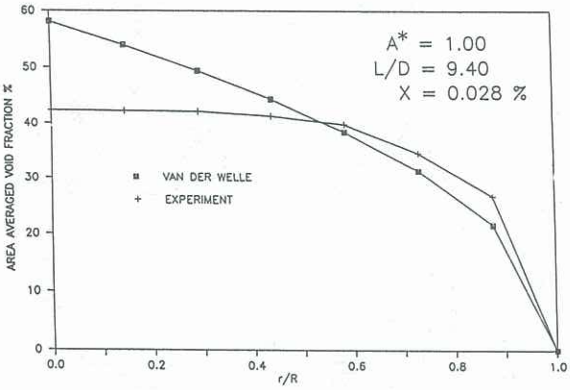

Figure 4 A typical comparison of measured and predicted void fraction profile using Van Der Welle (1985) correlation

CONCLUSIONS

Placing simple chokes in a vertical pipe with upflow of air/water mixtures homogenised the flow considerably. Close to the choke discharge end at L/D = 0.73 and at air fractions up to 0.007 %, void fraction profiles showed wall peaking. At L/D = 5.47 and 10.22, centerline peaking was observed only, a characteristic of developed flow.

The extent of homogenisation was indicated by flatness of the void fraction profile. For the purposes of the multiphase flow meter development, the choke with $A^* = 0.67$ appeared most suitable for air fraction values in excess of 0.009 %. Flow measurements for the purpose of metering could fall in the range $0.73 > L/D < 10.22$ as the extent of flatness of void fraction profiles in this range was nearly the same.

A simple correlation by Van Der Welle (1985) showed excessive peaking and could not be used to describe flat void fraction profiles in tests described here.

Measurement of velocity profiles as well as turbulent structure are required for development of a physical model of void fraction distribution.

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NOMENCLATURE

a	choke flow area
A	pipe flow area
A^*	non-dimensional flow area = a/A
c	phase heat capacity
D	pipe bore diameter
k	heat conductivity
L	streamwise distance along pipe
p	system pressure
r	radial distance
R	pipe internal radius
t_g	bubble transit time over sensor
T	absolute temperature, sampling period
ϵ	surface roughness
μ	phase viscosity
ρ	phase density
σ	interphase surface tension

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