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ANNULAR TWO-PHASE FLOW SPLIT AT AN IMPACTING T

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Abstract—A phenomenological model has been derived for the split of an annular flow at an impacting T (one where both outlet pipes are at right angles to the inlet direction). This simple model can provide predictions for flows where the inlet pipe is vertical or horizontal or when there is a bend just before the junction. In the latter two cases the circumferential variation of film flow rate must be known. Experimental data has been obtained for the case with a vertical inlet which shows that the model correctly predicts the partition of the phases.

1. INTRODUCTION

Junctions are an often necessary aspect of many pipeline systems. For single-phase flow, the present state of knowledge is sufficiently advanced to enable the majority of cases to be designed in spite of the large number of relevant variabls. In the case of two-phase flow, however, the number of variables is much larger; in particular, there are complicating factors in the partition and mixing of the phases. The problem is particularly acute for dividing junctions, here either phase can pass preferentially into one branch of the junction. In a review of the available information, Azzopardi (1986a) gives a description of the effects of relevant parameters. However, to date, only the work of Azzopardi & Whalley (1982), Saba & Lahey (1984) and Azzopardi (1986b) are physically based models used for the prediction of flow split. The mechanistic model of Saba & Lahey (1984) applies only to high take-off. The phenomenological model of Azzopardi & Whalley (1982), which was relevant to low take-off, has been extended to the complete range of take-off by Azzopardi (1986b). These models are confined to the split of annular flow in a vertical T. The difficulties in predicting the two-phase flow split have led to an attitude amongst designers that the two-phase flow should be separated, processed separately and only combined when totally necessary. Of course such practice is essential in certain circumstances; in natural gas lines which contain condensate, liquid must be separated and pressurized separately before being recombined. However, there are many situations where separate processing is either technically or economically infeasible and, therefore, research into two-phase flow split at junctions is essential to give engineers methods for predicting how the phases are partitioned.

In some designs, equipment to process the entire feed stream would be impractically large and parallel processing streams are necessary. If the feed is a two-phase gas/liquid flow, the dividing junction must be designed to give the same quality in each outlet. Two approaches have been suggested to effect this division. Hong (1978) has presented data for "impacting" junctions where the flows emerge from two pipes each at right angles to the inlet pipe and at 180° to each other. Hong gives data for such a junction (all pipes were lying in a horizontal plane) and his results, shown in figure 1, indicate that the flow emerging from both outlet pipes has the same proportion of gas to liquid except when the fraction of fluids taken off through one exit pipe is $<20\%$ (or $>80\%$) of the flow entering the junction. It is noted that Hong shows a line representing his data but does not give the actual data. In addition, Hong only presents data for one set of inlet flow rates. Fouda & Rhodes (1972) suggest the use of baffles in the pipe upstream of the take-off point to divide the flow. However, they also found that alterations to the take-off rates produced different responses in the amounts of gas and liquid taken off.

As with a junction consisting of a side arm coming off a main tube, flow splits at impacting junctions, such as shown in figure 2, are defined by eight parameters: the flow rates of the phases in the three legs of the junction, $\dot{M}_{1G}$, $\dot{M}_{1L}$, $\dot{M}_{2G}$, $\dot{M}_{2L}$, $\dot{M}_{3G}$, $\dot{M}_{3L}$ and the two pressure drops across

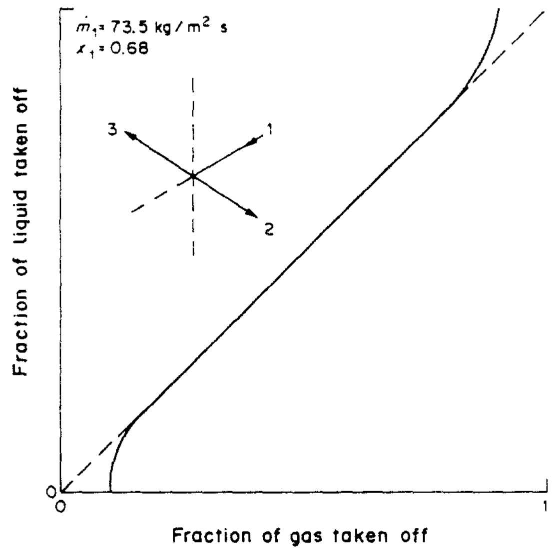

Figure 1. Flow split at an impacting junction (Hong 1978).

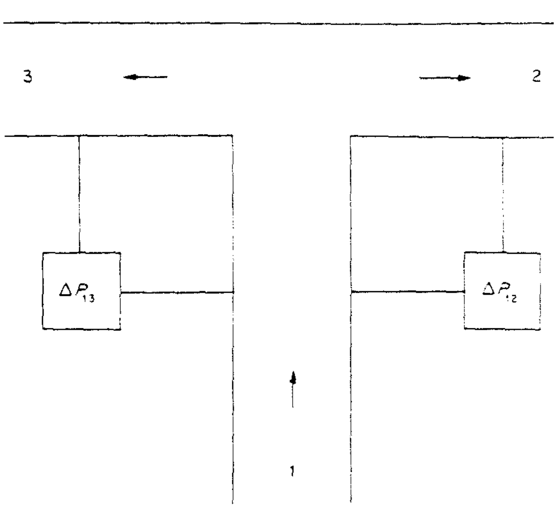

Figure 2. An impacting junction.

the junction, $\Delta P_{12}, \Delta P_{13}$. Normally three of these parameters are specified, e.g. $\dot{M}_{1G}$, $\dot{M}_{1L}$ and, say ΔP_{13}. Therefore there are five unknowns and five equations are necessary to specify the problem. Four of these equations are easily obtained from total and phase mass balances and from momentum balances across the exits. The fifth equation, which defines the flow split, is much more difficult to specify and is the subject of this paper. In the momentum equations loss coefficients must be defined. To date, only Morikawa *et al.* (1978) have produced an equation for this geometry:

$$k_{1i} = 0.548 + 0.988q - 0.427q^2, \qquad [1]$$

where

$$q = \frac{\dot{M}_3}{\dot{M}_1}.$$

Geometric constraints can force designers to specify a bend just before the impacting junction. The centrifugal effects in the bend can distort the phase distribution at the inlet to the junction and hence the flow split. However, information on the behaviour of two-phase flow in bends is very limited. For example, Gardner & Neller (1969) have studied bubble/slug flow in a bend from a vertical to a horizontal pipe. They found that gas can flow either on the outside or the inside of the bend depending on the balance between centrifugal forces (tending to push the water to the outside) and gravity (tending to pull it to the inside). They proposed a critical Froude number, $\mathrm{Fr}_\theta = V^2/gR_c \sin\theta = 1$, where V is the mixture mean velocity, R_c is the radius of curvature of the bend and θ is the angle of the bend, to distinguish the two types of behaviour.

Kooijman & Lacey (1968), Anderson & Hills (1974) and Maddock *et al.* (1974) have studied annular flow in 90° bends between vertical and horizontal pipes. They observed that the film flows predominantly on the inside of the bend. They suggested that this indicates that the radial pressure gradients and gravity are stronger than the centrifugal forces. Only Chakrabati (1976) has studied bends in a horizontal plane, though Banerjee *et al.* (1967), Hewitt & Dell (1968) and Whalley (1980) have made observations and measurements on tubes coiled about a vertical axis. However, it is believed that this information can be used to assess the flow behaviour in bends, as Kooijman & Lacey (1968) have observed that the flow is very similar at 90° and 360° into a coil. These studies present clear evidence that, whereas one would expect centrifugal forces to cause a separation of the phases with the denser phase flowing around the outer part of the duct perimeter, under certain conditions it may flow mainly along the inner part. Banerjee *et al.* (1967) showed that this behaviour, which they called film inversion, could be quantitatively accounted for solely by differences in radial pressure gradients in the fast moving gas and the slower liquid film. They presented a criterion based on a balance of centrifugal and gravitational forces. The subsequent studies of Hewitt & Dell (1968) and Whalley (1980) show qualitative but not clear quantitative confirmation of this analysis. Under certain other conditions, particularly higher liquid flow rates, the liquid in the film flows on the outside of the bend. However, no theoretical models exist which can predict the circumferential variation of film flow rate.

2. MODEL OF THE FLOW SPLIT

As with other junctions which consist of a side arm coming off a main tube, the division of annular flow at an impacting T can be analysed by considering the behaviour of the liquid drops, the liquid film and the gas phase. The important physical processes are probably that the gas drags the film into the outlet whilst the drops impact on the stagnation surface and the resulting film is forced into the outlet pipes by the pressure gradient between the point of maximum stagnation pressure (not necessarily the point of geometric symmetry) and the outlet pipes.

In the case of the film, the methodology of Azzopardi & Baker (1981) can be followed. This employs the observation of McNown (1954) that fluid taken off comes from the segment of the main pipe nearest the exit pipe. As the momentum fluxes of the phases differ (and that of the gas is often low), the probability that the liquid will be diverted with the gas is assumed to depend on the ratio of momentum fluxes. The liquid taken off is then the integral of the product of the probability times the local liquid flow rate:

$$\dot{M}_{3\mathrm{LF}} = \int_{\psi - 1/2\Phi}^{\psi + 1/2\Phi} \int_{R - \Delta(\phi)}^{R} P_{\mathrm{L}} \rho_{\mathrm{L}} U_{\mathrm{L}}(r^{1})[1 - \epsilon_{\mathrm{G}}(r)] r \, \mathrm{d}r \, \mathrm{d}\phi. \qquad [2]$$

The equivalent equation for the gas can be integrated assuming a uniform gas flow rate across the cross-section to yield

$$\frac{\dot{M}_{\mathrm{G3}}}{\dot{M}_{\mathrm{G1}}} = G^{1} = \frac{1}{2\pi}(\Phi - \sin \Phi), \qquad [3]$$

where the number subscripts are defined in figure 2. For annular flow the probability, P_{L}, can be written separately for the film on the walls and for the drops:

$$P_{\mathrm{L}} = K \frac{\rho_{\mathrm{G}} \bar{U}_{\mathrm{G}}^{2}}{\rho_{\mathrm{L}} \bar{U}_{\mathrm{LF}}^{2}} \quad \text{for} \quad R > r > R - \delta \qquad [4]$$

and

$$P_{\mathrm{L}} = K^{1} \frac{\rho_{\mathrm{G}} \bar{U}_{\mathrm{G}}^{2}}{\rho_{\mathrm{L}} \bar{U}_{\mathrm{LD}}^{2}} \quad \text{for} \quad 0 > r > R - \delta. \qquad [5]$$

Assuming $K \sim K^{1}$ and remembering $\bar{U}_{\mathrm{G}} \gg \bar{U}_{\mathrm{LF}}$ and $\bar{U}_{\mathrm{G}} \sim \bar{U}_{\mathrm{LD}}$, then

$$\frac{K \rho_{\mathrm{G}} \bar{U}_{\mathrm{G}}^{2}}{\rho_{\mathrm{L}} \bar{U}_{\mathrm{LF}}^{2}} \gg K^{1} \frac{\rho_{\mathrm{G}} \bar{U}_{\mathrm{G}}^{2}}{\rho_{\mathrm{L}} \bar{U}_{\mathrm{LD}}^{2}}. \qquad [6]$$

As the maximum possible value is 1.0, P_{L} can be approximated by

$$P_{\mathrm{L}} = 0 \quad \text{for} \quad r < R - \delta$$

and

$$P_{\mathrm{L}} = 1.0 \quad \text{for} \quad R < r < R - \delta. \qquad [7]$$

As

$$\epsilon_{\mathrm{G}} = 0 \quad \text{for} \quad R > r > R - \delta,$$

[2] becomes

$$\dot{M}_{3\mathrm{LF}} = \int_{\psi - 1/2\Phi}^{\psi + 1/2\Phi} \int_{R - \delta}^{R} \rho_{\mathrm{L}} U_{\mathrm{L}}(r) r \, \mathrm{d}r \, \mathrm{d}\phi. \qquad [8]$$

Now $(R - \delta)/R \sim 1.0$ so the velocity can be set equal to $\bar{U}_{\mathrm{LF}}(\phi)$. Equation [8] can then be integrated, using the definition of the film flow rate per unit periphery, $\Gamma(\phi) = \rho_{\mathrm{L}}(\phi) U_{\mathrm{LF}}(\phi) \delta(\phi)$, to yield

$$\dot{M}_{3\mathrm{LF}} = R \int_{\psi - 1/2\Phi}^{\psi - 1/2\Phi} \Gamma(\phi) \, \mathrm{d}\phi. \qquad [9]$$

If $\Gamma(\phi)$ is known, the liquid taken off from the film can be determined by integrating [9], using [3] to define Φ.

For the case where the main tube is vertical Γ is independent of ϕ so that [9] becomes

$$\dot{M}_{3\mathrm{LF}} = \frac{R}{\Gamma\Phi} \qquad [10]$$

When $\Phi = 2\pi$ this is the film flow rate:

$$\dot{M}_{1\mathrm{LF}} = \dot{M}_{1\mathrm{L}}(1 - E) = 2\pi R\Gamma \qquad [11]$$

Combining [10] and [11] defines the liquid film taken off in terms of Φ,

$$\Phi = \frac{2\pi M_{3\mathrm{LF}}}{M_{1\mathrm{L}}(1 - E)}, \qquad [12]$$

which can be combined with [3] to yield

$$G^1 = \frac{1}{2\pi}\left[\frac{2\pi L^1_{\mathrm{F}}}{(1 - E)} - \sin\frac{2\pi L^1_{\mathrm{F}}}{(1 - E)}\right]. \qquad [13]$$

Consider now the film formed by the impact of the entrained droplet flow. This is assumed to be spread uniformly and the peak pressure occurs at the projection of the chord bounding the segment from which the gas is diverted. The fraction of entrained liquid taken off can then be written, using a simple geometrical argument, as

$$\frac{\dot{M}_{3\mathrm{LD}}}{\dot{M}_{1\mathrm{LD}}} = \frac{1}{2}\left(1 - \cos\frac{\Phi}{2}\right). \qquad [14]$$

As $\dot{M}_{1\mathrm{LD}} = E\dot{M}_{1\mathrm{L}}$, and defining L^1 as $\dot{M}_{3\mathrm{L}}/\dot{M}_{1\mathrm{L}}$, [14] can be rewritten as

$$L^1_{\mathrm{D}} = \frac{E}{2}\left(1 - \cos\frac{\Phi}{2}\right), \qquad [15]$$

where Φ is related to G^1 by the relationship given in [3]. The total liquid taken off can be written as

$$L^1 = L^1_{\mathrm{F}}(G^1) + \mathrm{L}^1_{\mathrm{D}}(G^1), \qquad [16]$$

where $L^1_{\mathrm{F}}(G^1)$ and $L^1_{\mathrm{D}}(G^1)$ are determined from the solution of [13] and [15].

3. EXPERIMENTAL ARRANGEMENT

The apparatus used in the experiments described below is shown schematically in figure 3. Filtered, metered air at constant pressure was provided as described by Fryer & Whalley (1980). Water was drawn from a receiver by means of a centrifugal pump. Correct water pressure was attained by bypassing part of the flow and the flow was monitored by one of a number of calibrated rotameters. The air entered the flow tube, which was made from sections of acrylic resin tubing (0.0318 m i.d.), through an entrance section 0.5 m long. Water then entered through a section of porous wall.

The junction, which was machined out of a block of acrylic resin, was placed at the top of the flow tube, 3.84 m from the liquid entry point. The side arms consisted of at least 1.5 m of straight acrylic resin tubing followed by lengths of flexible tubing. The air and water emerging from one side arm were separated in a cyclone and metered. The air flow was measured using a calibrated turbine meter, the water flow rate was determined from weighing a timed efflux. The two-phase flow emerging from the second side arm was also separated, though not metered. The water was returned to the stock tank, the air being released to atmosphere. Valves in two side arms were used to control the division of the flow and maintain the pressure at the junction at 1.7 b.

4. RESULTS AND DISCUSSION

Measurements have been made of the flow split at an impacting junction, using the apparatus described in section 3. Data were obtained for seven sets of inlet conditions over the range of mass

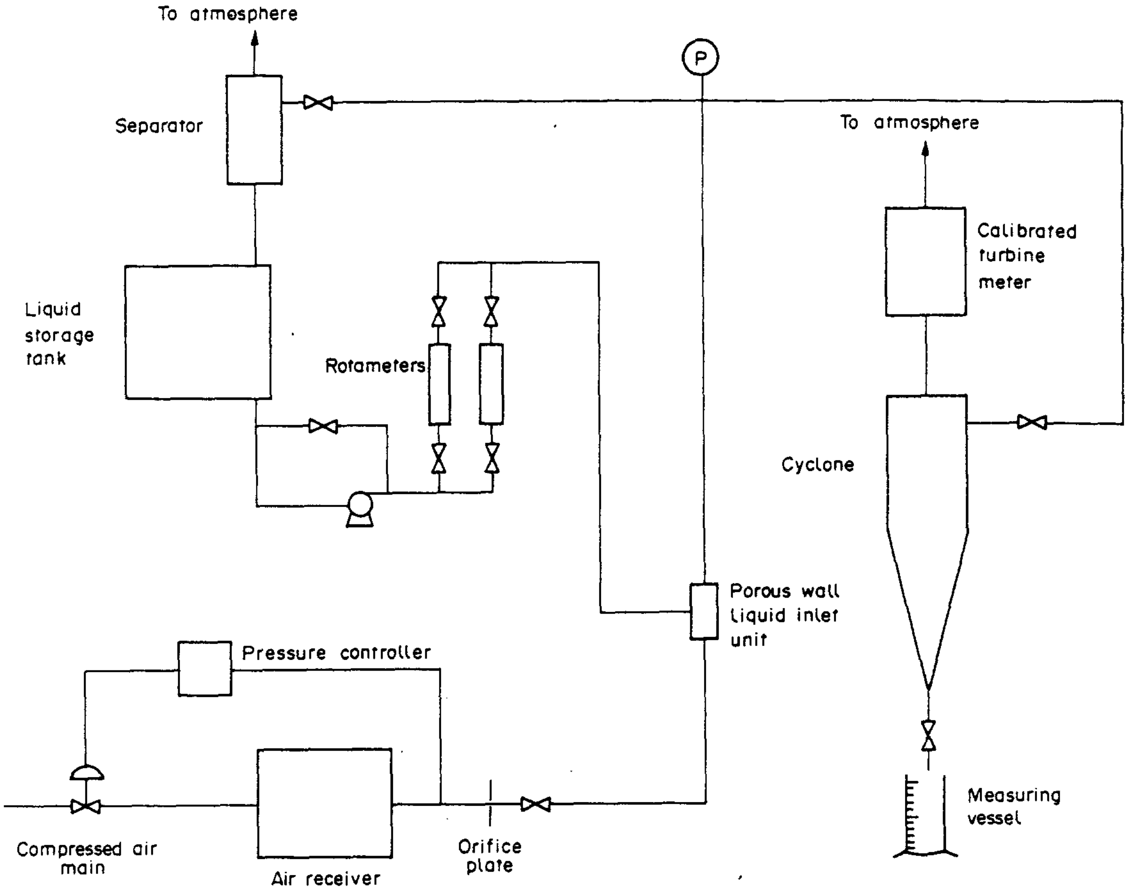

Figure 3. Experimental arrangement.

fluxes 52.4–123 kg/m^2 s and qualities between 0.21 and 0.58. In all cases a pressure of 1.7 b was maintained at the junction.

The results are listed in table 1 and are shown in figures 4 and 5. As can be seen, measurements were made over the entire range of take-off, from all flow coming out of one exit to all coming out of the other. Data were taken in order of increasing take-off and in order of decreasing take-off, but no difference was found in the results. In addition, data taken on two separate occasions were indistinguishable.

An assessment has been made of the degree of error or uncertainty present in these experimental results. In the case of the fraction of liquid taken off, the uncertainties are due to the closeness to which the inlet liquid rotameter and the weighing balance and stop clock used to measure the outlet flow could be read. These gave a maximum value to the combined uncertainty of 0.024 in the fraction of liquid taken off. In the case of the gas, uncertainties occurred in the reading on the calibrated gas turbine meter and in the manometer measuring pressure drop across the orifice plate. Their combined effect was calculated to be 0.015 in the fraction of gas taken off. In fact the size of the symbols used in figures 4 and 5 gives a good indication of the uncertainties or errors present in this data.

It can be seen in figures 4 and 5 that the arm with the lower air flow has proportionately more liquid. However, when the gas flow splits 50/50, then the liquid flow is also equally split. When more than half of the fluids are taken off, the symmetry of junction asserts itself and the take-off is now a mirror image of the low take-off region.

The predictions of the theoretical model described in section 2 are also shown in figures 4 and 5. In these predictions the entrainment fraction was determined from interpolation of the data of Gill & Hewitt (1962), who made measurements on a tube of the same diameter as in the present experiments and at flow rates which span the flow rates examined here. The predictions follow the

Table 1. Flow split at an impacting junction

Gas flow rate $=0.0164\ \mathrm{kg\,s^{-1}}$ Liquid flow rate $=0.0252\ \mathrm{kg\,s^{-1}}$		Gas flow rate $=0.0277\ \mathrm{kg\,s^{-1}}$ Liquid flow rate $=0.0252\ \mathrm{kg\,s^{-1}}$		Gas flow rate $=0.0346\ \mathrm{kg\,s^{-1}}$ Liquid flow rate $=0.0252\ \mathrm{kg\,s^{-1}}$		Gas flow rate $=0.0157\ \mathrm{kg\,s^{-1}}$ Liquid flow rate $=0.0630\ \mathrm{kg\,s^{-1}}$		Gas flow rate $=0.0208\ \mathrm{kg\,s^{-1}}$ Liquid flow rate $=0.0630\ \mathrm{kg\,s^{-1}}$		Gas flow rate $=0.0252\ \mathrm{kg\,s^{-1}}$ Liquid flow rate $=0.0630\ \mathrm{kg\,s^{-1}}$		Gas flow rate $=0.0346\ \mathrm{kg\,s^{-1}}$ Liquid flow rate $=0.0630\ \mathrm{kg\,s^{-1}}$	
Liquid take-off ($\mathrm{kg\,s^{-1}}$)	Gas take-off ($\mathrm{kg\,s^{-1}}$)	Gas take-off ($\mathrm{kg\,s^{-1}}$)	Liquid take-off ($\mathrm{kg\,s^{-1}}$)	Gas take-off ($\mathrm{kg\,s^{-1}}$)	Liquid take-off ($\mathrm{kg\,s^{-1}}$)	Gas take-off ($\mathrm{kg\,s^{-1}}$)	Liquid take-off ($\mathrm{kg\,s^{-1}}$)	Gas take-off ($\mathrm{kg\,s^{-1}}$)	Liquid take-off ($\mathrm{kg\,s^{-1}}$)	Gas take-off ($\mathrm{kg\,s^{-1}}$)	Liquid take-off ($\mathrm{kg\,s^{-1}}$)	Gas take-off ($\mathrm{kg\,s^{-1}}$)	Liquid take-off ($\mathrm{kg\,s^{-1}}$)
0.0251	0.0167	0.0266	0.0249	0.0256	0.0148	0.0164	0.0654	0.0210	0.0596	0.0100	0.0287	0.0281	0.0360
0.0111	0.0065	0.0253	0.0211	0.0237	0.0142	0.0145	0.0459	0.0208	0.0574	0.0078	0.0272	0.0269	0.0356
0.0123	0.0080	0.0224	0.0171	0.0210	0.0132	0.0121	0.0391	0.0197	0.0470	0.0063	0.0261	0.0255	0.0350
0.0098	0.0051	0.0201	0.0151	0.0189	0.0128	0.0088	0.0349	0.0174	0.0412	0.0051	0.0253	0.0241	0.0343
0.0077	0.0036	0.0158	0.0146	0.0161	0.0118	0.0077	0.0323	0.0160	0.0386	0.0039	0.0239	0.0228	0.0333
0.0041	0.0013	0.0127	0.0127	0.0127	0.0110	0.0063	0.0300	0.0128	0.0347	0.0027	0.0221	0.0216	0.0340
0.0015	0.0000	0.0091	0.0111	0.0095	0.0100	0.0052	0.0280	0.0117	0.0334	0.0011	0.0175	0.0209	0.0337
0.0178	0.0135	0.0066	0.0101	0.0074	0.0093	0.0044	0.0265	0.0102	0.0333	0.0000	0.0095	0.0191	0.0322
0.0143	0.0110	0.0041	0.0075	0.0055	0.0082	0.0160	0.0522	0.0089	0.0317	0.0067	0.0260	0.0175	0.0312
0.0127	0.0087	0.0019	0.0050	0.0002	0.0055	0.0121	0.0370	0.0073	0.0291	0.0263	0.0475	0.0158	0.0302
0.0076	0.0036	0.0000	0.0016	0.0000	0.0012	0.0084	0.0319	0.0059	0.0280	0.0252	0.0587	0.0218	0.0325
0.0198	0.0144	0.0068	0.0097	0.0000	0.0013	0.0049	0.0255	0.0025	0.0223	0.0235	0.0399	0.0174	0.0312
		0.0114	0.0116	0.0318	0.0198	0.0032	0.0231	0.0014	0.0190	0.0225	0.0380	0.0154	0.0301
		0.0139	0.0126	0.0305	0.0172	0.0025	0.0224	0.0000	0.0074	0.0200	0.0356	0.0137	0.0289
		0.0156	0.0132	0.0285	0.0158	0.0035	0.0239			0.0189	0.0350	0.0127	0.0283
		0.0162	0.0136	0.0272	0.0158	0.0017	0.0192			0.0174	0.0335	0.0118	0.0277
		0.0209	0.0154	0.0250	0.0150	0.0000	0.0015			0.0163	0.0350	0.0108	0.0272
		0.0278	0.0251	0.0206	0.0132	0.0170	0.0596			0.0079	0.0262	0.0102	0.0276
				0.0222	0.0141					0.0129	0.0334	0.0088	0.0266
				0.0203	0.0133					0.0131	0.0319	0.0072	0.0259
				0.0185	0.0128					0.0116	0.0300	0.0060	0.0246
				0.0047	0.0074					0.0257	0.0502	0.0052	0.0242
				0.0031	0.0061					0.0233	0.0405	0.0047	0.0238
				0.0017	0.0045					0.0212	0.0388	0.0040	0.0231
				0.0010	0.0043					0.0167	0.0343	0.0072	0.0271
										0.0011	0.0173	0.0058	0.0255
												0.0038	0.0238
												0.0030	0.0227
												0.0025	0.0222
												0.0013	0.0193
												0.0000	0.0114

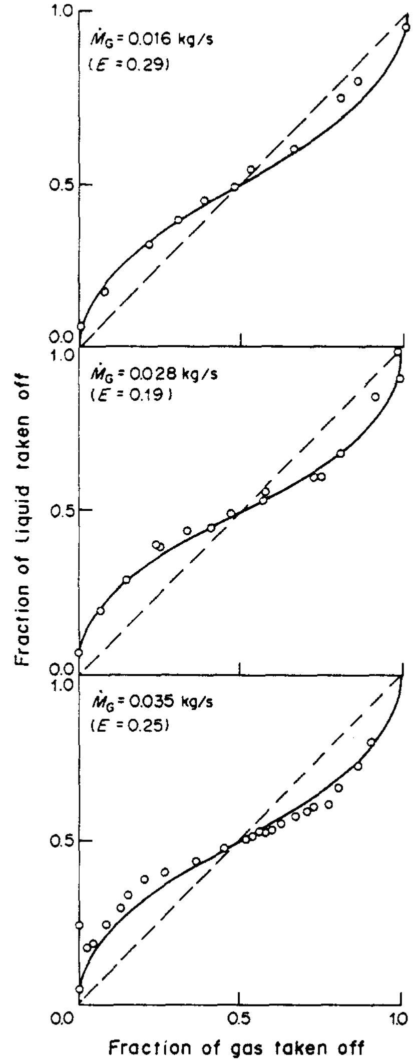

Figure 4. Flow split at an impacting junction (liquid flow rate = 0.025 kg/s). ——, Theory; ---, equal quality split.

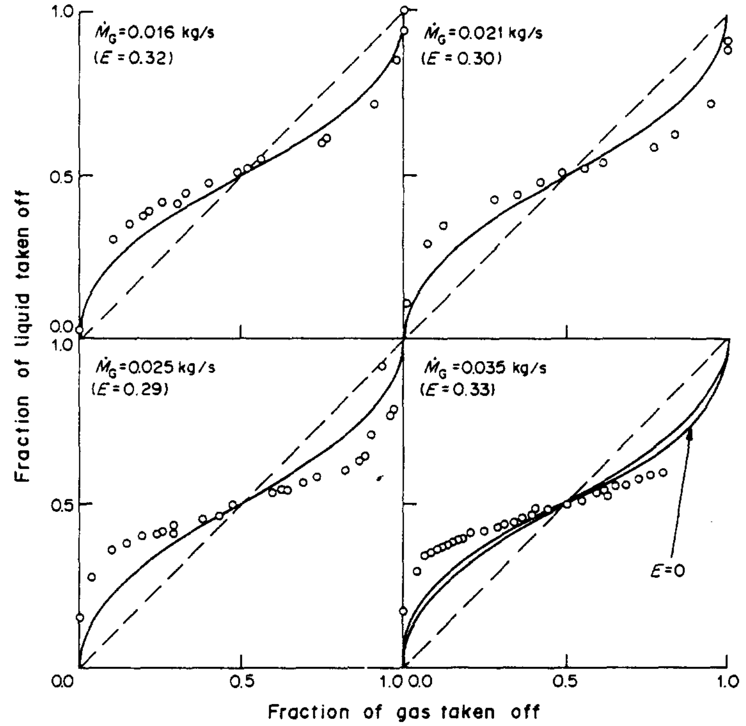

Figure 5. Flow split at an impacting junction (liquid flow rate = 0.063 kg/s). ——, Theory; ---, equal quality split.

experimental data very accurately, particularly at the lower liquid flow rate. As yet, no reason has been found to explain the deviation at higher liquid flow rates. It has been found that the predictions are not sensitive to the value of the entrained fraction, E. For example, for one of the cases shown in figure 5 predictions are shown with $E = 0$. These are very close to the predictions using the value of E derived from the data of Gill & Hewitt (1962).

Calculations have been made for a case in which the pipe leading to the impacting junction is not vertical but horizontal. Here, information is required on the circumferential variation of film flow rate, $\Gamma(\phi)$. This could be calculated from the model of Laurinat *et al.* (1985). In our laboratory, Butterworth & Pulling (1973) have measured both $\Gamma(\phi)$ and the film thickness. From this data it has been determined that the film momentum is less than the gas momentum all around the tube periphery. Therefore the approximation given [7] is valid and [9] can be used. The data of Butterworth & Pulling (1973) can be well-described by

$$\Gamma(\phi) = \frac{1.66}{\cos^2\phi + 4.6\cos\phi + 4.55}. \qquad [17]$$

Substituting this into [9] enables a solution of [16] to be provided. The predictions are shown in figure 6, together with predictions for the vertical upflow case at the same flow rates. The entrained

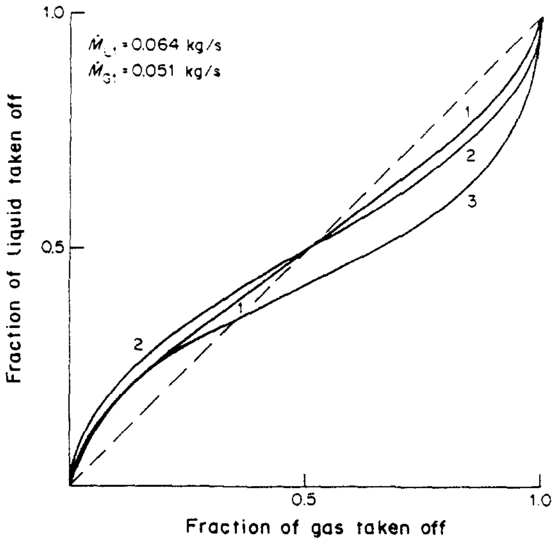

Figure 6. Prediction of flow split for flows with circumferentially varying film flow rate. 1, Horizontal pipe ($E = 0.05$); 2, vertical pipe ($E = 0.45$); 3, horizontal bend ($E = 0.09$); ---, equal quality split.

fraction differs noticeably in these two cases (horizontal $E = 0.05$; vertical $E = 0.45$). It can be seen that the horizontal case shows less separation than the vertical case in spite of having a lower entrained fraction which usually produces greater phase separation (see figure 5). This initially lower liquid take-off is due to the fact that the liquid film flow rate at the sides of the tube (where it is taken off first) is less than in the vertical pipe.

In order to assess the effect of a bend on the flow split at the impacting T, the data of Whalley (1980) has been used to specify $\Gamma(\phi)$. Data was chosen from a run at the same gas and liquid mass fluxes as the horizontal flow case discussed above. The data is well-described by

$$\Gamma(\phi) = 0.35 + 0.19 \sin(\phi - 120). \qquad [18]$$

This could be substituted into [9] which is then used in conjunction with [16] to specify the whole range of flow split. The predicted take-off rates for the outlet pipe on the outside of the bend are shown in figure 6. It can be seen that at low gas take-off, the deviation from the 45° line (indicating equal quality split) is much less than at high take-off. In this case equal quality does not occur when half the fluids have been taken off but at about 34% gas take-off, i.e. more liquid is taken off the inside of the bend. This is as expected since [18] indicates that most of the liquid film is on the inside wall of the bend, an example of the film inversion discussed in section 1.

The model described here has been shown capable of calculating the flow split at an impacting T for annular flow in vertical and horizontal pipes or bends. The results and their interrelations are explicable by arguments based on the physics of the process occurring. However, only when the inlet pipe to the T is vertical has experimental verification been carried out. There is now a need to carry out experiments to measure the flow split when the inlet pipe is horizontal or contains a bend close to the junction. However, a description of the circumferential variation of film flow rate will also be necessary. These experiments are planned.

It is noted that the present model gives phase splits which are completely different from those published by Hong (1978). Because the circumferential distribution of film flow is not known for Hong's conditions, exact predictions could not be made. Moreover, the paper does not give the experimental points nor provides any information about the experimental accuracy. However, the experiment was carried out in a tube whose diameter is much smaller than that used in the current experiments. It is therefore possible that surface tension effects were stronger in Hong's experiments than in this work and this caused the difference between his results and those in the present paper. (We would like to thank one of the referees for suggesting this mechanism.)

5. CONCLUSIONS

From the above work it can be concluded that:

1. For vertical annular flow entering an impacting junction the qualities in each of the outlet tubes are only equal when half the fluids pass into each outlet. A simple model has been proposed which successfully predicts the partition of the phases.
2. The above model can be extended to predict the flow split when an annular flow enters an impacting junction from a straight horizontal tube or a bend. However, no experimental data exists with which the accuracy of these predictions can be checked.
3. Further work is necessary to extend this work to other flow patterns.

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