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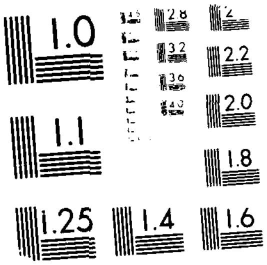

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B J Azzopardi, A Purvis and A H Govan

Thermal Hydraulics Division
Harwell Laboratory, Oxfordshire OX11 0RA

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FLOW SPLIT OF CHURN FLOW AT A VERTICAL IMPACTING T

B. J. Azzopardi, A. Purvis and A. H. Govan

ABSTRACT

Measurements have been made of the flow split which occurs when churn flow arrives at a vertical impacting T. The results show similar trends to data for annular flow obtained by Azzopardi et al. (1986). A simple modification of the model of Azzopardi et al. has been produced which correctly predicts the data.

Thermal Hydraulics Division
Harwell Laboratory
Oxon OX11 ORA

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CONTENTS

TABLES

ILLUSTRATIONS

1. INTRODUCTION

Flow split at pipe junctions occurs in many industrial processes ranging from nuclear reactors to oil fields. When the flow consists of more than one phase, prediction of the flow split is made more difficult as either phase can emerge preferentially through one exit. Azzopardi (1986a) has reviewed the information available for gas/liquid flow split. He concludes that only Azzopardi and Whalley (1982) give a physically based model for the flow split though this was limited to a junction formed by a side arm emerging from a vertical main pipe, annular flow approaching the junction and low take off through the side arm. Subsequently, Azzopardi (1986b) has extended the model to handle this geometry and flow pattern over the entire range of take off.

In some designs, equipment to process the entire feed stream would be impractically large and two parallel streams are necessary. For gas/liquid flow, the junction must be designed to give the same quality at each outlet. Two approaches have been suggested to effect this division. Hong (1978) 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, Figure 1. All his pipes were horizontal and the data shows 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 less than 20% (or greater than 80%) of the flow entering the junction. Hong presented data for one set of inlet conditions. Azzopardi et al. (1986) have carried out experiments on a similar junction though in this case the inlet pipe was vertical and the outlet pipes horizontal. The proportion of gas to liquid from each exit was only the same when the split is 50/50, Figure 2. For smaller take off there was a larger liquid fraction than in the inlet pipe. Azzopardi et al. also proposed a model to describe this flow split, based on the assumption that the gas and film from the same segment of the main pipe were taken off. The drops impacted on the stagnation surface and were then driven into the outlet lines by pressure gradients from the stagnation point. This model gives good predictions of the flow split. An alternative geometry has been produced by Fouda and Rhodes (1972) who 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 take off rates produced different responses in the amount of gas and liquid taken off.

This report extends the experimental measurements of Azzopardi et al. (1986) to churn flow.

2. EXPERIMENTAL ARRANGEMENT

The experiments described below were carried out in the same apparatus as used by Azzopardi et al. (1986). This is shown schematically in Figure 3. Filtered, metered air at constant pressure was provided from the laboratory compressed air main. 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 flowrate 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 internal diameter), through an entrance section 0.5 m long. Water is then introduced 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 vertical 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 gas meter, the water flowrate 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 the two side arms were used to control the division of the flow and maintain the pressure at the junction at 1.7 bar.

3. RESULTS AND DISCUSSION

Measurements have been made of the flow split at an impacting junction using the apparatus described in section 2. Data was obtained for eight sets of inlet conditions - gas mass fluxes of 3.2 and 8 kg/m²s and liquid mass fluxes of 80, 160, 320 and 800 kg/m²s. The conditions at which the data were taken are plotted on a flow pattern map, Figure 4. Also shown are the conditions at which data were taken by Azzopardi et al. (1986) and the lines delineating flow pattern boundaries from the models of Taitel et al. (1980). All the runs in the present work were observed to be in churn flow which agrees with the predictions of Taitel et al.

The results are listed in table 1 and are shown in Figures 5 and 6. As can be seen, measurements were made over the entire range of take off, from all flow coming out of one side arm to all coming out of the other. Data was 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. It can be seen in Figures 5 and 6 that the arm with the lower air flow had proportionally more liquid. However, when the gas flow splits 50/50, then the liquid is also equally split. When more than half of the fluids were taken off, the symmetry of the junction asserts itself and the take off is now a mirror image of the low take off region. Figure 5 and 6 show that there is very little difference between the results from different inlet flowrates. The trend of the results is very similar to those obtained by Azzopardi et al. (1986) with annular flow at inlet.

Observations of churn flow, particularly those with mass flows within the range studied here, lead one to suggest that all of the liquid could be taken as a thick film on the tube walls. This is based on (i) observations made, in the present experiments, through the tube walls, (ii) axial view cine film taken by Rhodes (1981) which show that for reasonably long periods of time there is a continuous gas core (occasionally the liquid bridges the entire pipe cross section) and (iii) measurement of radial variations of void fraction which indicate that there is a peak at the tube centre.

If all of the liquid can be taken as being in the film, then a simplified version of the model of Azzopardi et al. (1986) could be used. In this it is assumed that the liquid and gas taken off both come from the same segment of the inlet pipe. The relationship between the fraction of gas taken off and the fraction of liquid taken off can then be written, from geometric considerations, as

$$G' = \frac{1}{2\pi} (2 \pi L' - \sin 2 \pi L') \qquad (1)$$

The curve corresponding to equation (1) has been plotted on Figures 5 and 6. There is good agreement with most of the data though some points show that there is scatter amongst the data. In Figure 6 it can be seen that the fraction of liquid taken off is slightly underpredicted at fractional gas take offs upto 0.3.

The model presented by Azzopardi et al. (1986) and as modified above provides an appropriate prediction method for annular or churn flow at a vertical impacting T. Obviously further work is necessary to understand the processes that occur with other flow patterns and with other orientations.

4. CONCLUSIONS

From the above work it can be concluded that:

(1) For vertical churn flow entering an impacting junction the qualities in each of the outlet tubes are only equal when half the fluids pass into each outlet. An adaptation of the simple model proposed by Azzopardi et al. (1986) successfully predicts the partition of the phase.

(2) The flow split in the present experiments is insensitive to inlet gas and liquid flowrates. This result is similar to that found by Azzopardi et al. (1986).

(3) Further work is necessary to extend this work to other flow patterns and orientations.

ACKNOWLEDGEMENTS

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TABLE 1

MEASURED FLOW SPLIT

INLET		OUTLET		Fraction of Gas Taken Off	Fraction of Liquid Taken Off
Air Flow (g/s)	Water Flow (g/s)	Air Flow (g/s)	Water Flow (g/s)		
2.48	66.3	2.49	66.9	1.003	1.009
2.58	62.7	2.54	56.1	0.986	0.89
2.46	63.9	2.03	50.3	0.83	0.79
2.46	60.2	1.36	33.0	0.55	0.55
2.46	66.3	0.80	28.8	0.32	0.435
2.49	73.7	0.0	19.0	0.0	0.26
2.59	60.2	2.65	48.1	1.025	0.799
2.70	61.1	1.04	29.5	0.385	0.484
2.55	61.4	0.88	28.8	0.345	0.470
2.59	62.4	0.53	30.3	0.204	0.485
2.59	129.1	2.64	130.7	1.02	1.01
2.52	129.1	2.20	90.4	0.873	0.7
2.52	129.1	1.50	68.1	0.597	0.527
2.55	125.2	1.11	64.9	0.0	0.518
2.54	126.0	0.51	48.2	0.202	0.383
2.54	128.5	0.29	39.4	0.114	0.307
2.54	128.5	0.0	30.7	0.0	0.239
2.55	129.8	1.69	77.5	0.633	0.597
2.54	129.8	0.33	41.3	0.129	0.318
2.57	258.3	2.47	202.0	0.963	0.781
2.59	254.5	0.70	99.8	0.270	0.392
2.27	252.0	2.33	250.0	1.02	0.992
2.71	252.0	2.71	221.5	1.00	0.879
2.66	252.0	2.35	185.2	0.882	0.735
2.70	252.0	2.10	160.4	0.779	0.636
2.68	252.0	1.66	143.2	0.619	0.568
2.70	252.0	1.34	127.3	0.498	0.505
2.68	252.0	0.80	93.3	0.30	0.370
2.58	252.0	0.16	68.8	0.063	0.273
2.58	252.0	0.0	44.4	0.0	0.176
2.60	624.0	0.0	53.0	0.0	0.084
2.51	622.0	0.0	17.0	0.0	0.038
2.52	617.0	0.06	86.0	0.024	0.139
2.51	617.0	0.02	118.0	0.008	0.190
2.53	611.0	0.08	144.0	0.03[illegible]	0.235
2.51	617.0	0.16	163.0	0.063	0.264
2.53	624.0	0.22	218.0	0.088	0.349
2.57	621.0	0.20	264.0	0.080	0.426
2.57	617.0	0.86	273.0	0.333	0.442

TABLE 1

MEASURED FLOW SPLIT
(Continued)

INLET		OUTLET		Fraction of Gas Taken Off	Fraction of Liquid Taken Off
Air Flow (g/s)	Water Flow (g/s)	Air Flow (g/s)	Water Flow (g/s)		
6.14	65.5	0.0	14.0	0.0	0.214
5.99	60.2	2.29	28.6	0.382	0.476
6.01	63.9	4.72	42.9	0.786	0.672
6.10	66.1	6.05	65.9	0.992	0.996
6.09	65.5	5.28	47.0	0.867	0.718
6.10	66.1	4.60	39.6	0.762	0.599
6.15	65.5	3.72	36.9	0.606	0.563
6.15	64.9	3.14	35.5	0.510	0.548
6.14	65.8	2.23	30.8	0.362	0.468
6.14	65.8	1.75	49.4	0.285	0.458
6.15	65.8	1.33	26.9	0.217	0.408
6.14	65.5	0.53	20.8	0.087	0.317
6.35	131.0	1.29	53.9	0.203	0.411
6.34	131.0	0.58	42.9	0.091	0.328
6.35	131.0	0.0	23.5	0.0	0.179
5.98	127.3	4.0	72.1	0.669	0.566
6.00	128.5	1.52	53.7	0.254	0.418
6.34	129.8	6.30	132.4	0.993	1.020
6.35	129.1	6.21	108.5	0.978	0.840
6.35	128.5	5.04	81.4	0.794	0.633
6.35	129.8	4.62	78.7	0.727	0.606
6.34	129.1	4.10	72.8	0.646	0.564
6.35	128.5	3.68	71.4	0.60	0.556
6.35	129.8	2.92	65.4	0.460	0.504
6.35	131.0	2.57	63.3	0.405	0.483
6.36	132.3	1.84	57.6	0.289	0.436
6.41	252.0	6.32	249.7	0.985	0.991
6.42	252.0	5.89	179.7	0.917	0.713
6.42	249.6	5.37	158.7	0.836	0.636
6.42	252.0	5.16	149.6	0.804	0.594
6.41	248.8	4.40	133.6	0.686	0.537
6.39	249.6	3.67	131.8	0.575	0.527
6.38	252.0	2.80	122.1	0.439	0.485
6.37	249.6	2.19	110.5	0.344	0.443
6.38	249.6	1.25	96.9	0.195	0.388
6.39	252.0	0.0	44.4	0.00	0.176
6.03	252.0	5.54	179.7	0.919	0.713
5.97	252.0	3.15	129.7	0.528	0.515
5.99	252.0	1.93	111.7	0.323	0.443
63.5	623.7	0.0	95.7	0.0	0.153
6.13	617.4	0.16	182.0	0.026	0.295
6.14	614.2	0.80	231.6	0.131	0.377
6.10	617.4	1.44	267.6	0.237	0.433

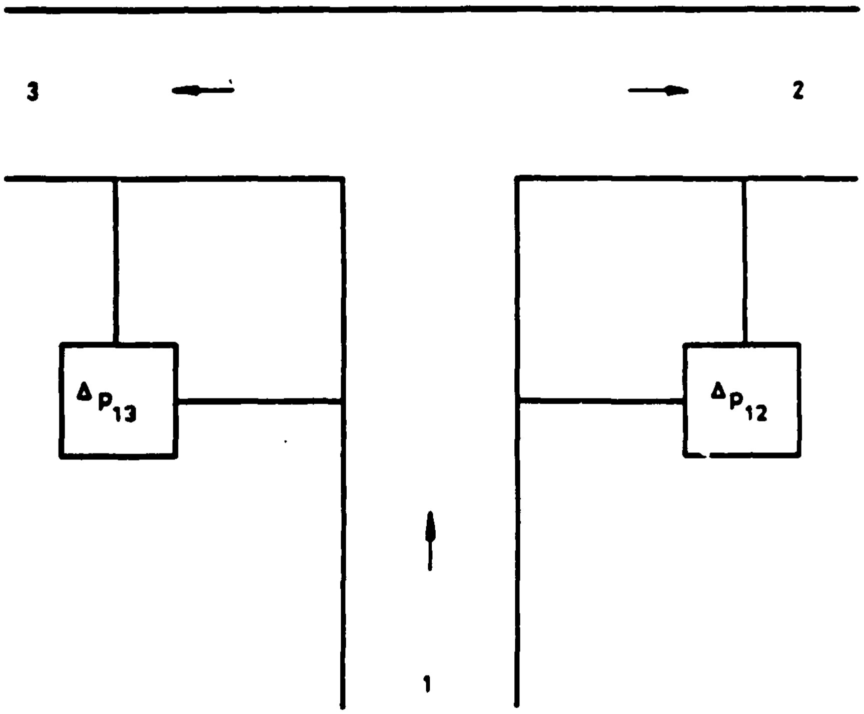

FIG.1. IMPACTING JUNCTION.

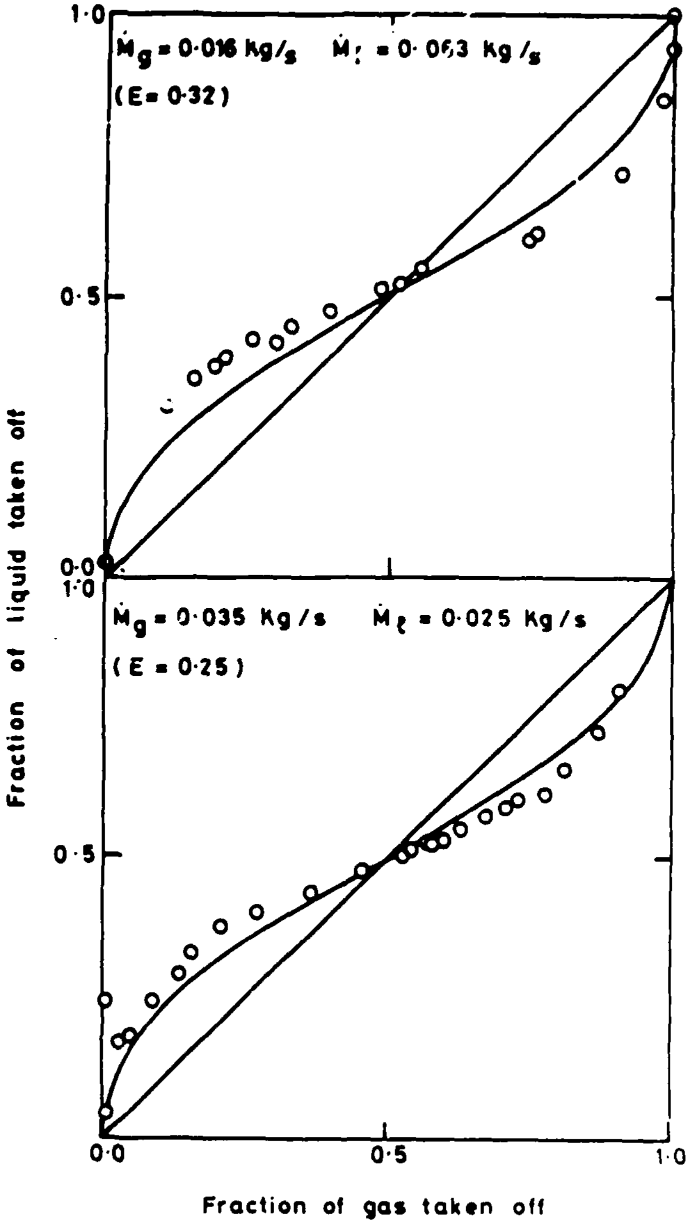

FIG. 2. EXAMPLE OF DATA AND PREDICTIONS FOR ANNULAR FLOW AZZOPARDI ET AL (1986)

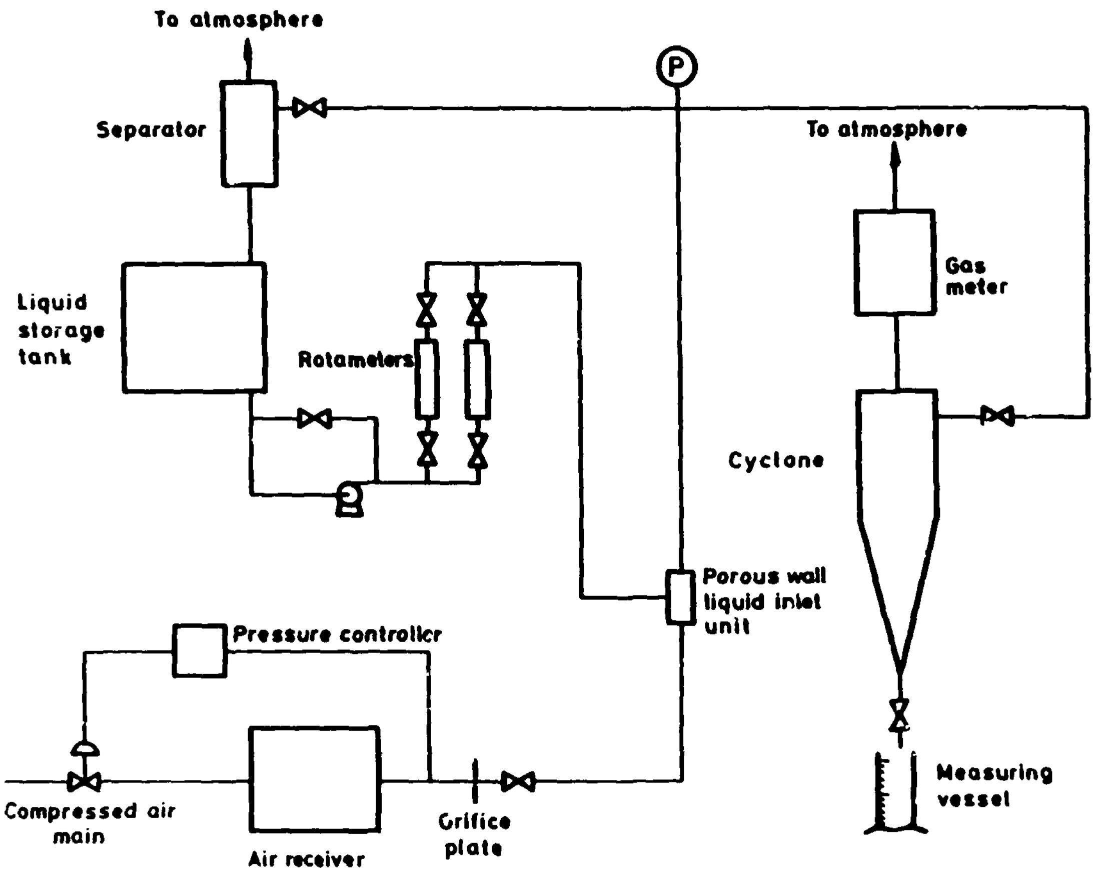

FIG. 3. EXPERIMENTAL ARRANGEMENT.

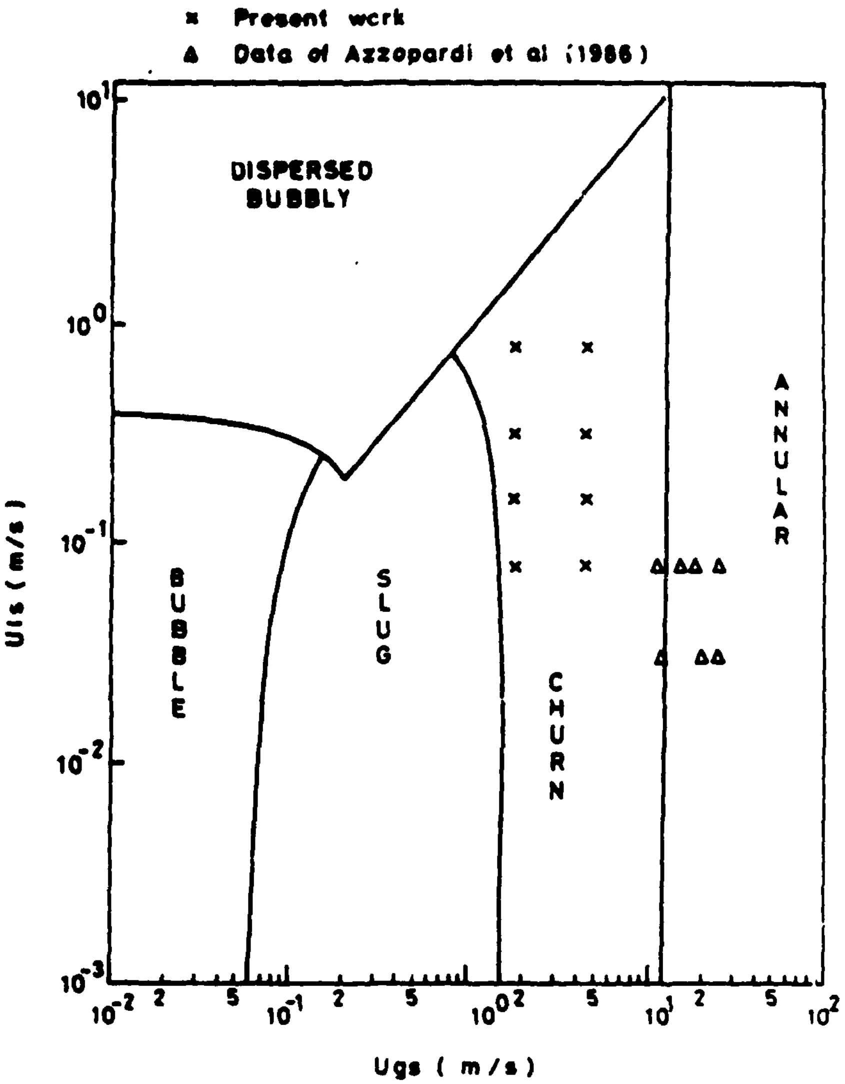

FIG. 4. FLOW PATTERN MAP SHOWING CONDITIONS AT WHICH DATA HAS BEEN TAKEN.

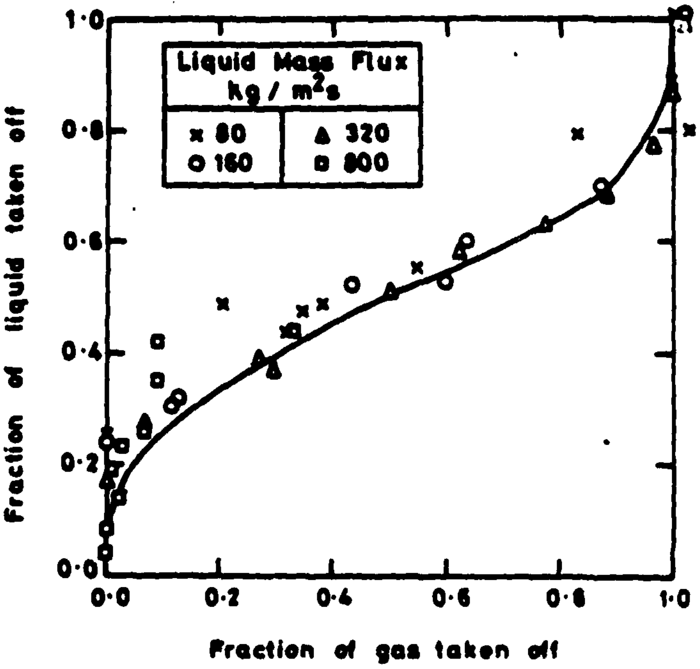

FIG. 5. FLOW SPLIT- GAS MASS FLUX 3·2 Kg /m²s.

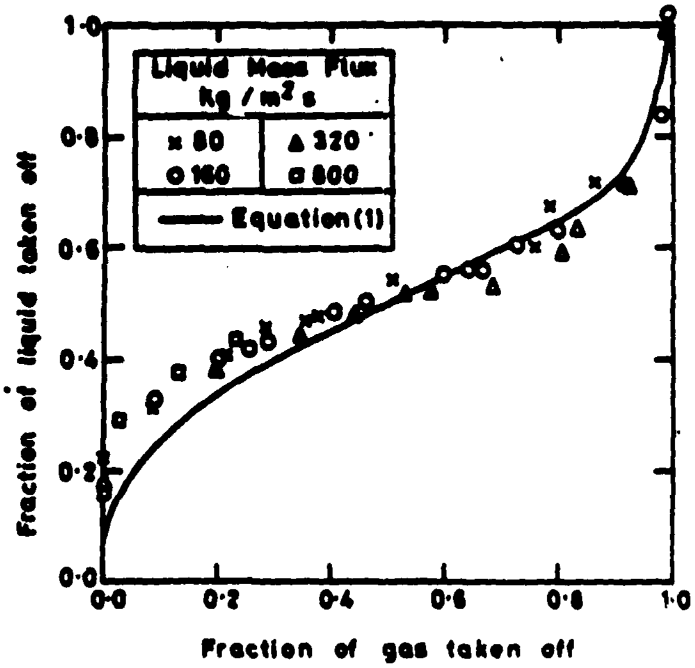

FIG. 6. FLOW SPLIT - GAS MASS FLUX, 8 kg/m² s.

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