Controlling the Phase Separation of Gas–Liquid Flows at Horizontal T-Junctions

G. Baker, W. W. Clark, B. J. Azzopardi, and J. A. Wilson
School of Chemical, Environmental and Mining Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, U.K.

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The phase split that occurs naturally at T-junctions has been further enhanced to provide a viable partial gas–liquid separator. Previous experimental investigations have mainly considered only single junctions but here the performance of a separator system consisting of two T-junctions in series is reported. The addition of control valves on the exit pipes extends previous fundamental studies and incorporates the concept of control and flexibility. A simple active control strategy is proposed on the basis of two control valves, one associated with an automatic level control, the other optimizing liquid residence time, leading to the development of a conceptual T-separator. Experiments were performed in the stratified and slug flow patterns using air and kerosene at ambient temperatures. © 2007 American Institute of Chemical Engineers *AIChE J,* 53: 1908–1915, 2007
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Introduction

The physical separation of gas–liquid flows is an integral part of many industrial processes. Such separations are desirable to reduce the problems associated with handling two-phase mixtures downstream since single-phase streams are safer and easier to transport. Traditionally this is achieved under the effect of gravity making for large vessels which are costly, heavy, and require much more expensive support steelwork when used offshore. Furthermore, they contain large inventories of toxic and/or flammable materials, which in light of ever increasing safety requirements, need to be minimized. Thus, there is a desire to seek alternative phase separation technologies. It is well known that when a gas–liquid flow divides at a pipe junction it undergoes a partial phase separation, producing a gas-rich and a liquid-rich stream.[1-4] It was suggested[5] that junctions could be employed as phase separators. Indeed, one design[6] has been installed in a petrochemical plant in the United Kingdom and has operated successfully since about 2000. This unit has a volume one to two order of magnitude smaller than the equivalent conventional separator that was the alternative. This compact size is one of the main advantages of a junction as a separator, enabling it to be installed where space is at a premium. Thus, although total phase separation would not necessarily be achieved, a junction could be incorporated into an intensified phase separation system, where the phase-rich streams are fed downstream to smaller secondary conventional gravity separator units. Such an approach would place limits on the fraction of the second phase in each product stream. For a good partial separation system, a suggested target separation criterion is that the product streams would each contain less than 10% v/v of the unwanted phase.

In seeking the optimal geometry for this concept of using T-junctions as partial phase separators, research concentrated on trying to enhance the natural phase separation. One simple approach is to reduce the diameter of the side arm. This has been shown, for fully horizontal T-junctions,[7,8] to significantly increase the gas velocity in the take-off side-arm and hence increase the inlet/side-arm pressure drop, promoting gas take-off. However, the acceleration of the gas would have a strong inertial influence on the liquid, essentially dragging it into the side-arm. There is a disadvantage to this, first suggested by Azzopardi,[9] related to the reduced axial

Correspondence concerning this article should be addressed to B. J. Azzopardi at barry.azzopardi@nottingham.ac.uk.

take-off distance. Here the time available for liquid to flow into the side arm is physically reduced, so also reducing the likelihood that liquid is dragged into the side-arm by the gas. It has also been suggested[10,11] that with a horizontal reduced side-arm, liquid flowing at the bottom of the pipe will not be directly influenced by the side-arm diameter but by the difference in main pipe/side arm diameters since any liquid entering the side arm would first have to rise up the pipe wall. However, Azzopardi et al.[10] showed that for high gas take-off this side-arm climbing effect becomes negligible, explained by the existence of a hydraulic jump effect as further described by Azzopardi and Smith.[12] This phenomenon is characterized by a very sharp increase in the liquid take-off beyond a critical gas take-off value and is caused by a reduction in the liquid momentum and an increase in the liquid height at the junction, allowing the liquid to be more readily diverted into the side arm. To maximize the operational range of a T-junction separator there is a requirement to try and eliminate any hydraulic jump.

The next idea is to rotate the side-arm relative to the main horizontal pipe, to enhance the separation by the use of gravity and fluid density differences. Penmatcha et al.[13] reported a systematic study for stratified air-water flows where the side-arm was rotated from angles of $+35^\circ$ above the horizontal to -60° below. For downward side arms it was found that the liquid take-off increased with the angle of declination, while for upward inclinations a significant proportion of gas had to be diverted into the side arm before any liquid was extracted. As the side arm inclination angle increased, the proportion of gas initially diverted into it before any liquid was extracted also increased. However, once liquid pick-up starts there need only be a relatively small increase in the gas take-off to get the majority of the liquid drawn off with it. This is seen as further evidence of the hydraulic jump phenomenon. Both Seeger et al.[14] and Reimann et al.[15] note how the inlet flow pattern could influence the phase split at a vertically upward and downward T-junction. For example, with a vertically upward side arm it is assumed that it is the flow within the top section of the pipe that would be influenced by the branch. Thus, if the void fraction is high within that region, as for stratified flows, then the side arm take-off void fraction would also be expected to be high. Conversely, for downward side arms, a liquid dominated take-off would be expected since the denser liquid phase, flowing along the bottom section of the pipe, will be most affected by gravity. Peng et al.[16] also suggested that before gas could be extracted into a vertically downward side arm it would have to break through the liquid layer. The thinner this liquid layer, the easier it is for the gas phase to break through. According to the stratified flow model of Taitel and Dukler,[17] for a fixed inlet liquid flowrate, as the gas inlet flowrate increases the liquid layer will become thinner and flow faster and less liquid will be extracted downward prior to gas pull-through occurring.

Thus, since the flow split can be enhanced by reorienting the side arm from upwards, for gas dominated take-off, to downwards, for liquid dominated take-off, the next extension in the development of T-junction separators is the combination of two or more junctions in series. A study reported by Bevilacqua et al.[18] combined three junctions in series, all with vertically upward side arms, to form what they termed a *Comb Separator*. When manifolding the three side-arm flows together it was found that manipulating the pressure difference across the two outlets changed the separation performance of the system. By increasing the pressure drop in the liquid-dominated run exit stream, the gas content of the stream was further reduced but more liquid was forced to leave in the combined gas-rich exit. Hence, there was a balance required based on the need for clean gas and liquid flows exiting the combined branch and run pipes, respectively.

Further work by Wren and Azzopardi[19] described the application of two vertically opposing side-arms placed in series on a horizontal main pipe. Here, a T-junction with a vertically downward side-arm is placed downstream of a junction with a vertically upward side-arm. They showed that by combining the up and run arms it was possible to produce a gas-rich product stream. Further, by manipulating valves on the three exit-streams it was found that the phase separation could be optimized more fully when compared with a single downward side arm junction. This was mainly attributed to the elimination of the detrimental hydraulic jump, with the down arm acting as a liquid drain. Using this geometry they attained one of the target criterion, defined for this work, namely, less than 10% v/v liquid in the gas-rich product stream but they could not resolve the problem of a high gas content within the liquid-rich product stream.

In this current study the concept of Wren and Azzopardi[19] is coupled with an active control system, as implied by the pressure difference balancing approach first suggested by Bevilacqua et al.[18] Control valves are placed on two of the three outlets of a horizontal dual T-junction system to maximize the separation performance over a wide range of inlet flow conditions. It is envisaged that such a design would form the first step in a more intensive phase separation system, designed to minimize inventory while still maintaining efficient phase separation over a wide range of inlet flow conditions.

Experimental Arrangement

To investigate the separation performance of T-junctions in series two equal 38-mm internal diameter T-junctions were used. Air and a high-flashpoint kerosene were chosen as experimental fluids, both to closer replicate industrial situations and also to allow the application of electrical capacitance tomography in the determination of flow patterns.

Figure 1 shows a schematic diagram of the two-junction arrangement. Air at a pressure of 6 bar is taken from the laboratory supply line and kerosene is pumped from a storage tank. The flow rates of each phase were metered using a calibrated orifice plate. The phases are combined in a mixer where the gas enters axially and the liquid is introduced through a porous wall section. The two-phase mixture then flows through 6.6 m of transparent acrylic pipe to an electrical capacitance tomography sensor. There is a further 6 m of pipework beyond the sensor to the first T-junction, which has a vertically upward side arm. This gives a $\sim$330 pipe diameter development length. The second T-junction, with a vertically downward side-arm, is located a further 1.9 m (50D) downstream of the first. Both side-arms have a significant length of vertical pipe section, 1.0 m (26D), followed by a

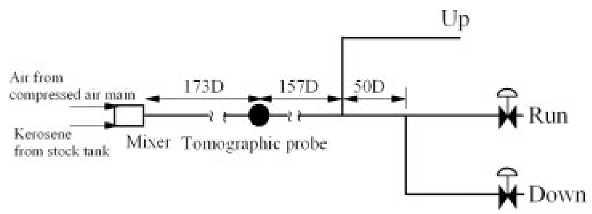

Figure 1. Schematic of dual T-junction arrangement.

bend and further pipework leading to their respective test separators, i.e., phase separation/measurement tanks. The liquid flow rates of all three discharge streams are determined from the timed rise in liquid height in these constant cross-sectional area vessels.

The system pressure was recorded, using a pressure transducer, placed 0.10 m upstream of both T-junctions. The air was metered continuously by measuring the differential pressures across orifice plates placed in each of the three gas discharge streams. The modular design of the system meant that either T-junction could be examined in isolation. Flow resistances around the junctions were provided by pneumatically actuated control valves with linear characteristics. By varying the setting of each control valve across its full operational range the flow split characteristics of the T-junction system could then be determined. Baker[20] provides more detailed information on the layout of the experimental facility. Figure 2 shows the range of gas and liquid superficial velocities investigated plotted in terms of the observed flow pattern, superimposed on the theoretical flow map for the experimental facility based on the work of Taitel and Dukler[15] modified using the alternative suggestion for the slug/annular transition of Barnea et al.[21] As can be seen there is good agreement between our observations and the predictions of the models.

It has been shown[20] that the flow pattern approaching a T-junction can have a significant effect on the expected flow split at that junction. Thus knowledge of the flow pattern would be an important prerequisite in the operation of a T-junction partial phase separator. Here electrical capacitance tomography (ECT), a nonintrusive technique, was used to image the phase distribution across the interior cross-section of the inlet pipe. Eight electrodes are evenly distributed around the exterior circumference of the acrylic pipe and an electronic system interrogates each possible pair of these and can provide cross-sectionally resolved images at a maximum sample rate of 100 Hz. Full details of the sensor design are given by Jeanmeure.[22] Traditionally, flow pattern identification using ECT would be on the basis of the reconstructed images, however recent work[23,24] has shown that this need not be the case. Knowing that horizontal flow patterns exhibit fundamental geometric properties it followed that the raw capacitance data, used for the image reconstruction, must also contain geometric trends. Thus, three principal identifiers have been proposed on the basis of the geometrical nature of the flow patterns. For annular flow, where the liquid film is distributed around the pipe wall, adjacent electrode pairs are expected to give similar capacitance measurements, while for stratified flows, where the liquid flows along the bottom of the pipe, the balance between the measurements from the electrode pairs at the upper and lower pipe sections is considered. The final identification parameter is associated with the measured liquid hold-up, determined by analysis of the capacitance measurements between opposite electrode pairs, with high values indicating a pipe full of liquid, implying slug flow.

Results and Discussion

Initial experiments considered the individual T-junctions with side arms orientated either vertically upward or downward. These flow split results are then compared with those for the same flow conditions approaching the dual T-junction system with no resistance on the down arm, so acting as a simple drain. When two horizontal T-junctions are combined in series it has been found that it is not enough to simply assume that they can be considered as individual components.[19] If the junctions are not separated by a significant distance of pipeline there will be some interaction between them, with a subsequent influence on the resultant phase split. The comparisons made in the present study allow for a better understanding of how combined T-junctions can add flexibility and control. Figure 3 shows such comparisons for flow conditions within the stratified and slug flow patterns. Here, for both stratified and slug flows, the effect of having the down arm acting as a drain is clearly visible. The hydraulic jump effect[12] is seen in the present single junction data for stratified flow as a sharp increase in the liquid take-off. In the presence of the down arm this effect is eliminated. Thus, in the stratified flow data here, total gas extraction in the up arm is achieved with approximately 8% liquid take-off when two T-junctions are used, compared with a gas take-off of 88% for the single junction at an equivalent liquid take-off. A similar result is also seen for slug flow, especially with low gas take-off values when the liquid extraction can be reduced by up to 50% in the presence of the downward junction.

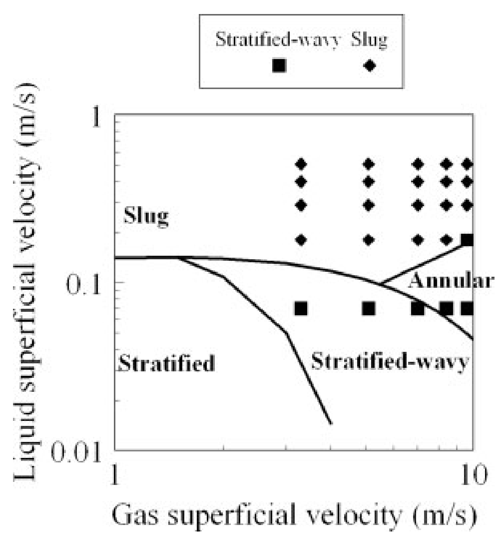

Figure 2. Flow map for experimental facility showing experiment conditions and observed flow patterns.

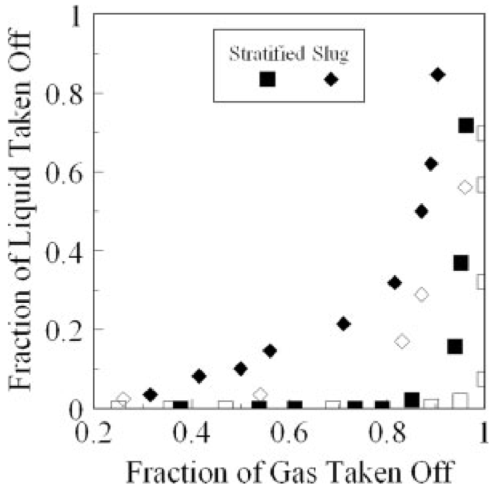

Figure 3. Effect of vertically downward side arm on the phase split at a vertically upward side arm.

Stratified flow: Gas superficial velocity = 5.1 m/s, liquid superficial velocity = 0.07 m/s, slug flow: Gas superficial velocity = 3.3 m/s, liquid superficial velocity = 0.18 m/s. Closed symbols – up only; open symbols – up followed by down.

Figure 4 shows the flow split of slug flow at both the upward and downward T-junctions obtained by manipulating valves around the downward junction only. The data shows the same trends as observed in the studies of both Penmatcha et al.[13] and Wren[25] in that once gas starts to enter the down leg, small increases in the liquid take-off are associated with much larger increases in the gas take-off. This is directly comparable to the vertically upward T-junction situation, as illustrated by Figure 3, where once liquid starts to be entrained upward with the gas the hydraulic jump effect dominates and the liquid take-off increases rapidly. One possible explanation for the behavior at the downward junction, suggested by both Wren[25] and Reimann et al.,[15] is the formation of a vortex in the down arm at the onset of gas pull-through, beyond a critical liquid take-off value. This vortex would then create a lower pressure region in the down arm that would then encourage gas to preferentially flow into it.

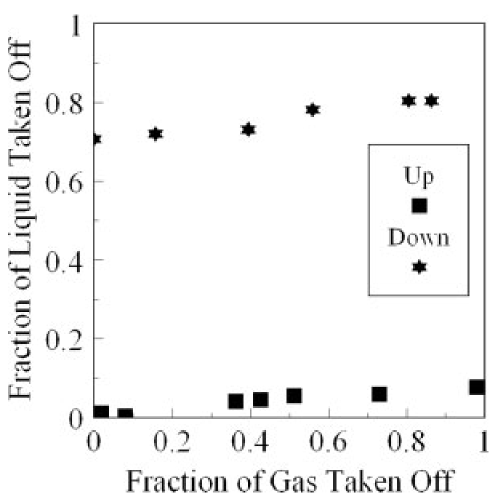

Figure 4. The flow split of a dual T-junction separator under slug flow conditions: gas superficial velocity = 3.3 m/s, liquid superficial velocity = 0.35 m/s.

Down arm liquid level control

Previous work[19] has already highlighted that, for a dual T-junction geometry, the up and run streams can be combined to provide a gas-rich product stream capable of achieving the separation target of less than 10% v/v liquid-in-gas for the low liquid flowrates they investigated. The problem still remains of how to overcome the problem of high gas content in the other product stream. Analysis of work undertaken by Wren[24] identifies the temporary existence, under certain conditions, of an aerated liquid plug in the down arm above the valve. This plug creates a physical barrier preventing gas leaving through this exit stream. Such a phenomenon was also observed in the current study. Evidence of this can be seen in Figure 4, where there is a significant period of liquid only take-off in the down arm prior to the onset of gas extraction.

This constant liquid presence in the down arm can be artificially created and sustained by the use of an automatic level control system. Such a liquid level control (LC) is shown in Figure 5. Here a pneumatically actuated control valve in the down arm pipework is connected to a level sensor under proportional control maintaining the liquid level around a predefined set point value. Experiments indicated that this level control system, once sufficiently tuned, provided a liquid level around the set point value over the wide range of gas and liquid inlet flow conditions investigated. Figure 6 shows typical temporal variations for both the measured liquid level and the control valve movements, with a set point of 400 mm while operating within the slug flow pattern. The graphs show that the control system was responding effectively and quickly to the changes in the measured liquid height, maintaining it around the set point. As expected there is a direct relationship between the valve movement response and the measured liquid level. The distributed peaks in the measured liquid level output are indicative of the slug flow pattern, where there are periodic liquid surges due to the nature of that flow pattern, these are compensated by the control valve opening fully, to allow the liquid level to fall rapidly, and then closing fully, to re-establish the liquid plug.

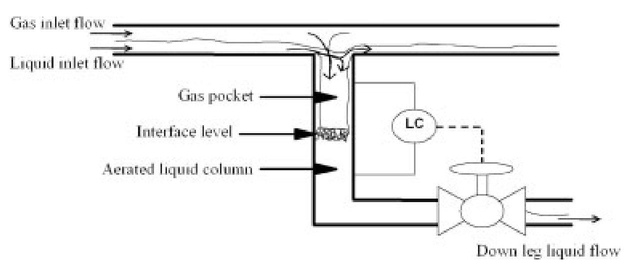

Figure 5. Schematic of the automatic liquid level control in down arm.

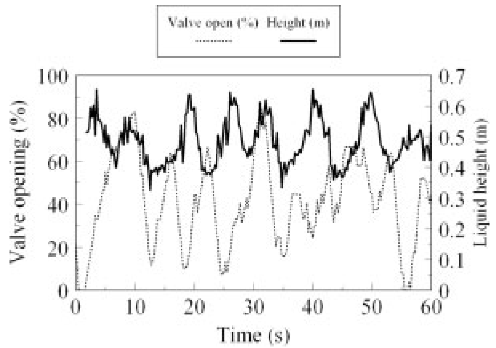

Figure 6. Typical response of automatic level control under slug flow conditions: gas superficial velocity = 3.3 m/s, liquid superficial velocity = 0.35 m/s.

Figure 7 shows typical flow split plots obtained for both stratified and slug flows with the automatic liquid level control in operation. These graphs clearly highlight the effectiveness of the level control in maintaining an adequate gas-seal within the down arm for both flow patterns. Since the liquid plug created prevents gas from leaving the system through this exit stream the data for the down arm all lie along the ordinate. As would be expected there are differences between the fractions of liquid recovered in the down leg for stratified and slug flows, attributed to the differences in the relative phase velocities and the liquid distribution across the pipe cross-section for the two cases. In the case of stratified flow, the liquid phase travels relatively slowly along the bottom of the horizontal pipe and has insufficient momentum to allow it to by-pass the down arm opening, so it simply flows down into it. Conversely, for the slug flow pattern the majority of the liquid travels as fast moving plugs that fill the entire pipe cross section. Hence, not only does the liquid have increased momentum to effectively jump over the down leg opening but a significant proportion also travels along the top-half of the pipe. This means that the liquid is influenced more the up arm and less by the down arm. Thus, a greater fraction of the inlet liquid is recovered for stratified flow than for slug flow, even though the actual mass flow of liquid recovered in the down arm is significantly higher in the latter case.

The up arm data follows very similar trends as already observed in Figure 3 with the down arm again acting effectively as a drain eliminating the hydraulic jump phenomenon. As before, the differences between the stratified and slug flow phase split results in the up arm are functions of the void fraction distributions within the pipe cross section as well as the relative velocities of the phases within each pattern. So, for the stratified flow case, gas easily diverts into the up arm but without the hydraulic jump effect the liquid is not so readily transported upwards with it. However, within the slug flow pattern it is much easier for the gas to convey the liquid flowing along the top section of the horizontal pipe upwards.

Controlling the liquid recovery in the down arm

To maximize the gas–liquid separation performance of the dual T-junction separator system there was a requirement to maximize the liquid recovery through the liquid-only product stream and hence minimize the liquid content of the gas-rich product stream. By placing a control valve downstream of the second T-junction it was hoped that it would be possible to regulate the residence time of the liquid in the pipe between the two junctions. Thus, it was anticipated that some level of control could be established on the liquid hold-up at the downward junction, increasing the potential for liquid to fall into the down arm, especially when considering the high momentum liquid slugs encountered. Such a concept is loosely based on the method employed by Bevilacqua et al.[18] on their multiple junction system. In that case, by varying the pressure difference between the two product streams, the required liquid product stream would become more or less contaminated with gas and conversely, the mainly gas product stream would become more or less contaminated with liquid.

To evaluate the effect this liquid hold-up control valve had on the system performance a systematic study was performed for the grid of gas and liquid superficial velocities previously shown in Figure 2. For these investigations this second control valve was manually set at incremental positions across its entire operating range (0–100% open) and the automatic liquid level control on the down arm operated independently and continually, to prevent gas leaving in the liquid product stream. For each set of flow conditions phase split measurements were obtained over a significant length of time so as to provide a reliable and repeatable set of results. In each case, the fraction of inlet liquid recovered in the down arm product stream is plotted against the run arm control valve position. Two such plots are presented in Figures 8 and 9 for stratified and slug flows, respectively.

Overall, it is clear from Figures 8 and 9 that the valve on the run arm has a significant influence on the amount of liquid extracted in the down arm regardless of the upstream flow pattern. Similar to the work of Bevilacqua et al.,[18] here there is an operational point that allows the maximum amount of liquid to be extracted in the down arm for both stratified and slug flow accounting for the curved nature of the data. At one extreme, when the run valve is fully open, the fraction of the liquid travelling with the greatest momen-

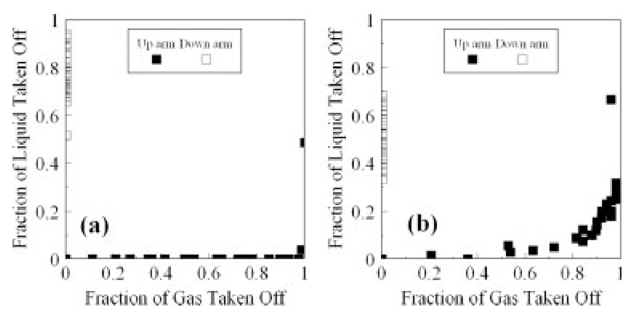

Figure 7. Effect on the flow split of the automatic level control maintaining a constant liquid level in the down arm of a dual T-junction system.

(a) Stratified flow: gas superficial velocity = 5.1 m/s, liquid superficial velocity = 0.08 m/s; (b) slug flow: Gas superficial velocity = 3.3 m/s, liquid superficial velocity = 0.35 m/s.

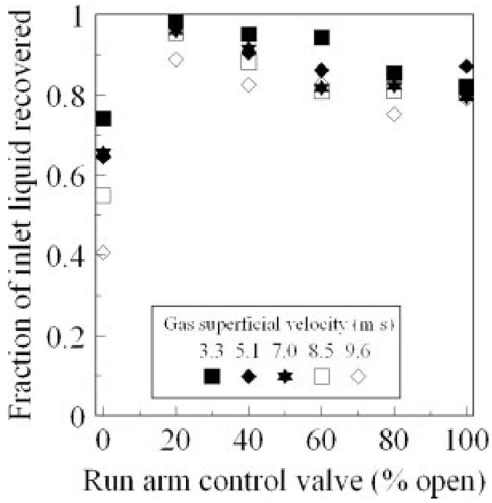

Figure 8. Fraction of inlet liquid recovered in down arm for stratified flows with a constant liquid superficial velocity, liquid superficial velocity = 0.07 m/s.

tum more readily by-passes the down arm opening. Thus, the fractional amount of inlet liquid extracted in the down arm is low. While for the other extreme situation, when the run arm valve is completely closed, the result in terms of fractional recovery in the down arm is similar but the action is considerably different. In this case, closing the run arm dictates that there are now only two possible outlets, through the up or down arms. However, because of the action of the automatic control valve, the gas has only one route through the system, namely the up arm. This produces a significant negative pressure gradient along the pipework between the two outlets, which increases in severity as either one, or both, of the phase superficial velocities increase. In extreme cases of slug flow, high liquid and low gas flowrates, the liquid is seen to oscillate within this connecting pipe, as the pressure fluctuates at the first T-junction in response to each liquid slug. At this operational point, there is considerable hold-up of liquid at the first junction, similar to that seen during the onset of the hydraulic jump phenomenon, and so there is a greater potential for the liquid to be dragged upwards by the gas.

Another observation from Figures 8 and 9 is the distinct difference between the shape of the two data sets, indicative of the distinct differences between the two flow patterns and the mechanisms that govern their phase split at T-junctions. For stratified flows, Figure 8, at a constant liquid superficial velocity, as the gas superficial velocity is increased the fractional liquid take-off in the down arm decreases. This can be attributed to the fact that as the actual velocity of the gas above the liquid increases, the liquid layer thins and flows faster, as suggested by Taitel and Dukler.[17] Thus, the liquid travels with increased momentum and a greater fraction can by-pass the down arm opening. In the case of slug flow, Figure 9, similar trends to those observed for stratified flow are seen, when the liquid superficial velocity increases, at a constant gas superficial velocity, the fractional liquid recovery decreases. This is attributed to the effect that the increasing liquid velocity has on the momentum and frequency of liquid slugs and on the liquid distribution across the pipe cross-section liquid. These both increase the likelihood of liquid by-passing the down arm and also the chances of liquid being transported by the gas into the up arm.

An overriding and important concept illustrated by Figures 8 and 9 was the apparent existence of an optimal run control valve setting, which was seen to be dependent not on the gas or liquid inlet superficial velocities but solely on the flow pattern within the inlet pipe. Quantification of this optimal control valve setting was also dependent on the flow pattern under consideration. For stratified this optimum valve setting can be determined by simple visual inspection of the data presented as in Figure 8. The pronounced peak that relates to the maximum fractional liquid recovery and is directly indicative of the optimum control valve setting always occurred when the valve was 20% open. Since there was not the same sharp deviation present in any of the slug flow data, see Figure 9, the analysis has to be performed differently. Interestingly, for slug flow, each data set could be adequately represented by a unique second-order polynomial. As for any polynomial the maximum value can be found when the gradient of the curve is equated to zero. In this case, the calculated maximum value relates to the maximum fractional liquid recovery in the down arm and by simple substitution back into the original equation it can be directly related to the optimum control valve setting. So for the cases presented in Figure 9, the optimum control valve settings lie within a narrow range of between 54% and 60% open.

By extending this analysis to include all the preselected combinations of gas and liquid inlet superficial velocities, plotted in Figure 2, an overall control methodology can be established. The result of this analysis is shown in Figure 10, where the optimal run arm control valve setting for each set of inlet flow conditions is plotted against the gas inlet superficial velocity for constant values of liquid inlet superficial velocity. As expected from the results previously shown in Figures 8 and 9 the data are grouped into distinct zones,

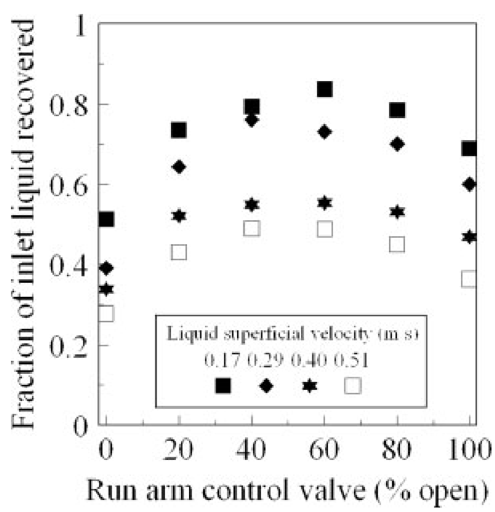

Figure 9. Fraction of inlet liquid recovered in down arm for slug flow with a constant gas superficial velocity, gas superficial velocity = 3.3 m/s.

strongly dependent on the inlet flow pattern. From Figure 10, it is seen that for stratified flows the optimal run arm control valve setting is always 20% open, with the data showing no scatter. In the case of slug flow, the data does show some minor scattering within relatively tight limits. The calculated mean run arm control valve setting was found to be 55% open, indicated by the horizontal line on Figure 10, with a range of 12%, highlighted by the shaded region.

Since it is relatively simple to identify the probable flow pattern within a pipe it is a clear advantage to base the control strategy on such a parameter rather than actual phase velocities, which are substantially more difficult to quantify. From the results obtained it is feasible to propose a control strategy for the operation of a dual T-junction separator based on a combination of level control and flow pattern identification. Coupling this idea with the previously established notion of combining the up and run arms to provide a gas-rich product stream, it is possible to assess the overall separation performance of the T-junction system. Recall that for a primary partial separation stage, the criterion for a good separation was to deliver two phase-rich product streams each with less than 10% v/v of unwanted phase contaminate. If the flows from the up and run branches are combined a gas rich stream is produced. On the basis of this, Figure 11 demonstrates the described system could feasibly perform as required over the entire range of flow conditions investigated. Indeed, Figure 11 shows that for stratified flow the amount of liquid in the gas-rich product stream is considerably less than 0.05% v/v in all cases. This has to be primarily due to the nature of that flow pattern. However, even for slug flow conditions, the gas-rich stream usually contains less than 5% v/v liquid, only increasing above 6% for the very highest liquid loading, where slugging will be most intensive. It is noted that for these cases the down branch with its level control gave essentially an all liquid flow.

The results shown above indicate that the two junction arrangement as illustrated in Figure 1 can be an effective phase separator system. Estimates reveal that it would have a volume at least an order of magnitude lower than the equivalent conventional vessel separator. The liquid stream, usually

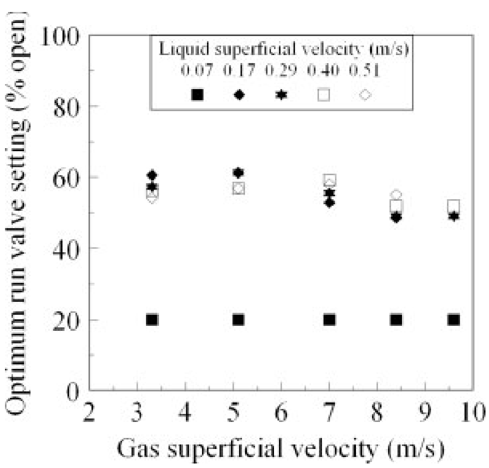

Figure 10. Dependency of the optimum run arm control valve setting on the inlet phase superficial velocities.

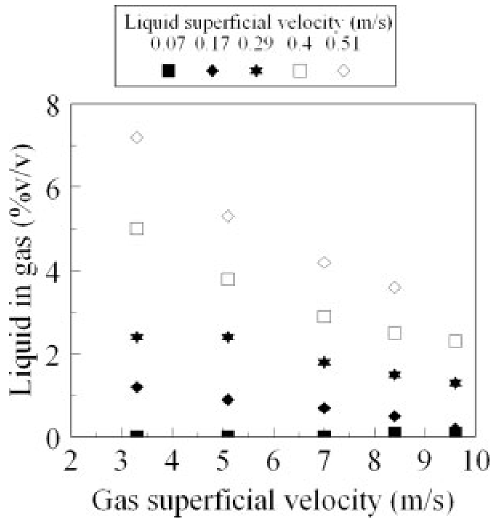

Figure 11. Amount of liquid in combined gas stream based on determined optimum run arm control valve settings (stratified flow: 20% open, slug flow: 55% open).

an oil/water mixture would have to be separated downstream. However, this too could use pipe work/junctions as indicated by the research of Yang et al.[26,27] Obviously, the efficacy of the proposed will decrease with increasing system pressure but then so will that of the conventional separator. The proposed arrangement requires two control circuits as do conventional separators. Because of the smaller volumes involved, the arrangement described earlier requires more reactive control.

Conclusions

From the current study it can be concluded that:

(1) Two oppositely orientated T-junctions placed in series on a horizontal main pipe can be effectively utilized as a compact partial phase separator capable of producing a gas-free product stream and a gas-rich product stream, containing less than 10% v/v liquid over a wide range of inlet conditions.

(2) A vertically downward side-arm can act as a constant liquid drain and reduce the phenomenon of hydraulic jump at an upstream vertically upward side-arm, promoting a greater degree of phase separation through the system.

(3) Inclusion of a liquid level control system on the vertically downward T-junction side arm was shown to be effective in preventing any measurable gas take-off through a liquid-only product stream.

(4) The two-phase flow pattern in the separator feed has been identified as a prime factor in the active control of phase separation through a dual T-junction system, irrespective of the individual phase superficial velocities.

Acknowledgments

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