

Gas-liquid flow splitting at T-junctions tubes with inclined branch arms

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ABSTRACT: Gas and liquid separation at T-junctions tubes was investigated to explore whether it is feasible to keep T-junctions in good operation condition by pressure control. Experimental data reveal that, there exists a critical value for pressure drop ratio to make the system perform best. Furthermore, a prediction relationship between the separation efficiency and the dimensionless pressure was developed.

KEY WORDS: air–water; separation; T-junctions; pressure control

INTRODUCTION

For gas and liquid separation, the T-junction tubes can be used as an alternative to conventional vessel-type separators, and they are small, low weight, low cost, and efficient^[1, 2]. The phase split at a tee junction is primarily affected by the orientations of inlet and outlets^[3], the inlet phase superficial velocities^[4, 5], the flow patterns upstream of the junctions^[6, 7], the system pressure^[8, 9], the branch angle^[10] and so on.

Due to the fact that a tee junction may not achieve full separation, combining tee junctions are necessary for a high degree of separation^[11, 12]. When the geometry of T-junctions separator is optimal, regulating the split ratio can further enhance the natural phase separation^[13]. However, in real production, the mixture flows are not at steady state, and the flowrates and gas-liquid ratio always vary with time so that it is very difficult to ensure the separation system in optimum by regulating the split ratio. Therefore, the objective of this work is to design a compact T-junctions separator by combining several junctions in series, and present a pressure control scheme instead of flowrates control to maximize the separation performance over a wide range of inlet flow conditions.

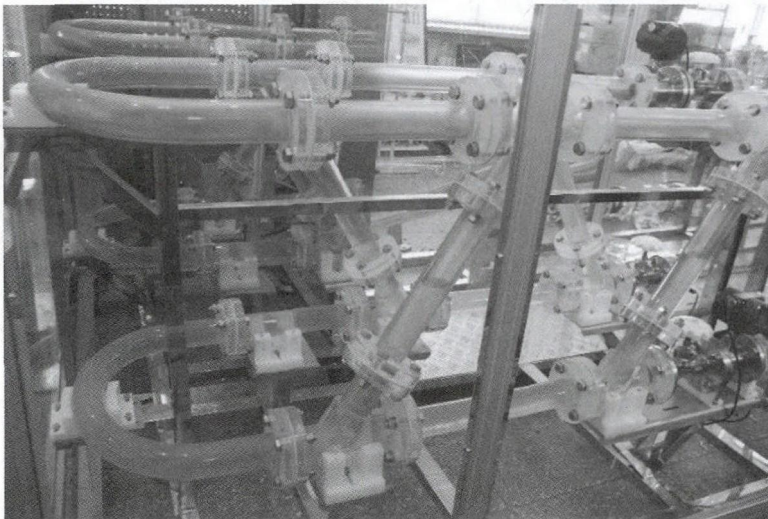


Fig. 1 Photograph of T-junctions

EXPERIMENTAL INVESTIGATION

In the experiment, air was chosen as the gas phase while water chosen as the liquid phase. The physical properties under experimental conditions were as follows: $\rho_g=1.205\text{kg/m}^3$, $\mu_g=1.81 \times 10^{-3}\text{mPa}\cdot\text{s}$, $\rho_w=998.0\text{kg/m}^3$, $\mu_w=1.0\text{mPa}\cdot\text{s}$. The experiment covered a wide range of the inlet volume void fraction between 0.17 and 0.61. The T-junctions tubes used in this experiment consisted of four junctions, as shown in Fig. 1. Here, all the branch arms were orientated in the same direction with 60° upwards to avoid the angle range where the change of inclination angles showed a great influence on the separation performance^[14]. All the tubes with plexiglass to enable visual observation were 50mm in diameter.

RESULTS AND DISCUSSION

Effects of pressure drop ratio on phase split

The separation efficiency (η) is defined to evaluate the performance of T-junctions tubes in Eq.1.

$$\eta = 1 - \frac{Q_{l3}}{Q_{l1}} \quad (1)$$

where Q_{l1} is the total amount of the liquid at the inlet, and Q_{l3} the amount of the liquid entrained in the outlet gas stream.

The pressure drop ratio is defined as the ratio of the inlet-to-branch pressure drop to the inlet-to-run pressure drop as follows:

$$\overline{\Delta P} = \frac{P_1 - P_3}{P_1 - P_2} \quad (2)$$

where the subscripts 1, 2 and 3 refer to the inlet, the run and the branch.

The gas fraction at the run is expressed as follows:

$$F_{g2} = \frac{Q_{g2}}{Q_{l2} + Q_{g2}} \quad (3)$$

where Q_{g2} is the gas flow rate at the run, and Q_{l2} the liquid flow rate at the run.

The change of separation efficiency with the pressure drop ratio was depicted in Fig. 2. As can be seen, the separation efficiency decreases as pressure drop ratio increases. The reason is that the fluids will be more likely to flow out through the run when the back-pressure at the run drops or at the branch increases, whereas the liquid level in the T-junctions tubes keeps a certain value providing a barrier against the gas at the branch flowing into the run. At the same time, the liquid falls into the run more easily from the T-junctions tubes for the residence time of the liquid at the branch increases. Thus, the gas stream generated at the branch will become less contaminated with liquid. However, when the pressure drop ratio decreases to a certain extent, the gas fraction at the run will rapidly increase due to the lowering of the liquid level, as shown in Fig. 3. It can be obtained that there exists a critical value for pressure drop ratio to make the T-junctions tubes perform best.

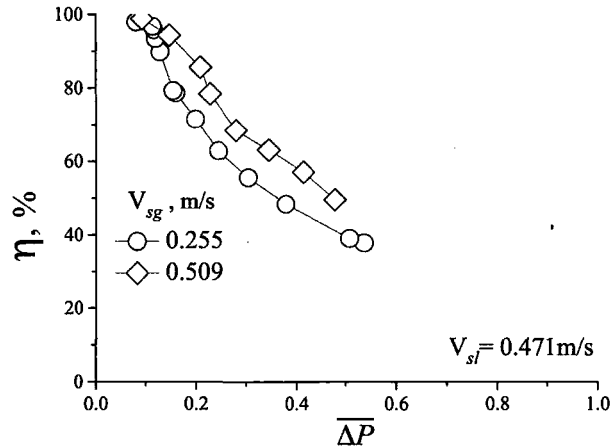


Fig. 2 Effects of pressure drop ratio on separation efficiency

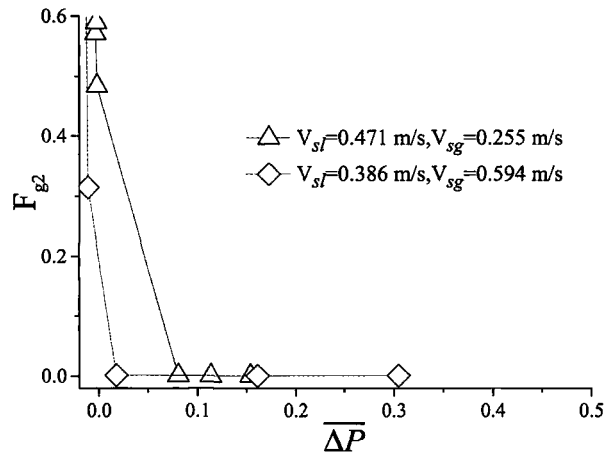


Fig. 3 Effect of pressure drop ratio on gas fraction at the run

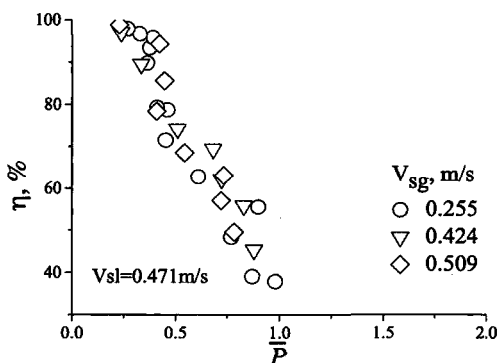
Effects of the dimensionless pressure on phase split

In the present study, the dimensionless pressure is defined as the ratio of the inlet-to-branch pressure drop to the pressure at the run as follows:

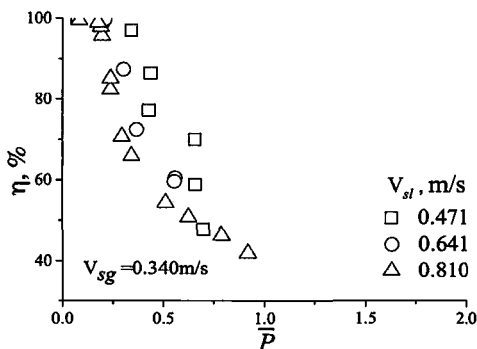
$$\bar{P} = \frac{P_1 - P_3}{P_2} \tag{4}$$

where the subscripts 1, 2 and 3 refer to the inlet, the run and the branch.

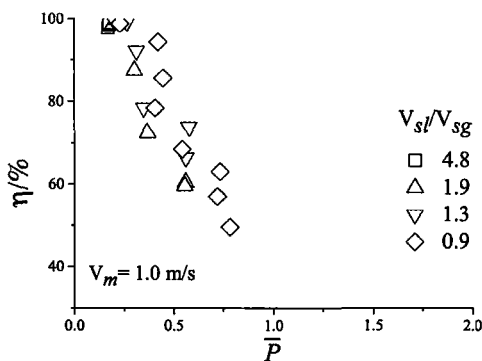
The system pressure is found to have a great influence on the separation performance of the systems. Therefore, the dimensionless pressure (\bar{P}) is proposed by considering the system pressure to reflect the physical laws more exactly. For various combinations of superficial gas and liquid velocities, the separation efficiency versus the dimensionless pressure is depicted in Fig. 4. A distinct observation is that all the data are concentrated around a certain curve, independent of the inlet superficial velocities. This means that the phase split at T-junctions is strongly dependent of the pressures at the inlet and both outlets. In addition, the data points in Fig. 4(a) are more compact than those in Figs. 4(b) and 4(c). Thus, the separation performance of the T-junctions system is more affected by inlet liquid superficial velocity than inlet gas superficial velocity.



(a) Constant inlet liquid flow rate and different inlet gas flow rates



(b) Constant inlet gas flow rate and different inlet liquid flow rates



(c) Constant inlet mixture flow rate.

Fig. 4 Separation efficiency with dimensionless pressure for various inlet conditions

Prediction relationship

In this work, the optimal pressure control strategy can be defined as that the separation efficiency almost reaches its maximum while the gas fraction at the run is near zero. The optimum dimensionless pressure (\bar{P}_{opt}) for various inlet conditions is shown in Fig. 5. For all the cases, more than 97% of the data are located at a relatively narrow range from 0.176 to 0.269. This also demonstrates that a pressure control strategy for the operation of T-junctions is feasible.

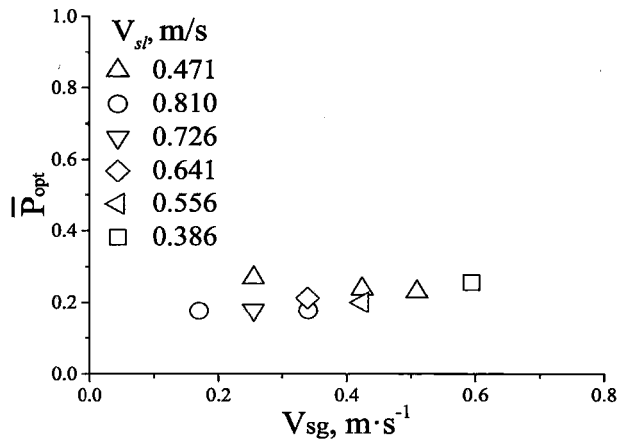


Fig. 5 Optimum dimensionless pressure for various inlet conditions

Fig. 6 shows the change of separation efficiency with dimensionless pressure. The relationship between the separation efficiency and the dimensionless pressure can be re-extracted from the data of the present test as:

$$\eta = 0.35 + \frac{0.65}{1 + (\bar{P} / 0.54)^{4.4}} \quad (5)$$

where, the number of experimental points used is about 94, and the developed prediction relationship gives a reasonable performance with 94% of the data having an average absolute error less than 20%. This empirical equation can help set the pressures at the inlet and both outlets to maximize the fractional amount of inlet liquid extracted into the run. Meanwhile, the component content of gas-liquid mixture after separation can be known approximately through this empirical equation.

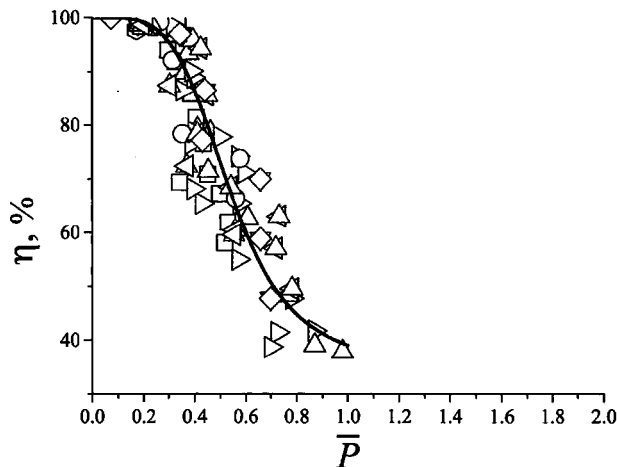


Fig. 6 The curve obtained by fitting all the data

CONCLUSION

From the current study it can be concluded that:

For a gas and liquid separation by the T-junctions tubes, there exists a critical value for pressure drop ratio to make the system perform best. And the pressures at the inlet and both outlets play a significant role on the separation efficiency. Compared with the superficial gas velocity, the superficial liquid velocity shows more

seriously effects on the phase split.

Base on the test data, a relationship between the separation efficiency and the dimensionless pressure was developed for the prediction of phase split at T-junctions tubes. Considering that a more accurate prediction is greatly complicated and difficult, the model suggested might be helpful for practical application in oil and gas industry, especially for the design of tube separator.

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