Phase split of oil-water two phase flow at double-layer T-junctions pipes

Lele Yang 1,2, Jing Wang 1,2, Yong Ma 1,2 and Li Zou 3,*

1Marine Engineering and Technology, Sun Yat-sen University, Guangzhou, China
2Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai, China
3School of Naval Architecture, Dalian University of Technology, Dalian, China

*Corresponding author e-mail: zoulidut@126.com

Abstract. Offshore oil and gas production systems are in urgent need of a more compact, high-efficient oil-water separator. T-junction pipes are a potential solution to the need. Combining dynamic separation principle of T-junctions pipes with shallow pond theory, this paper presents a novel design of double-layer T-junctions pipes to realize high-efficient oil-water separation. The separation system consisted of upper and lower double-layer pipes that are connected by two vertical pipes. There exists an axially floating oil pipe along the top of the upper outer pipe. This design makes the Reynolds number decrease, which is beneficial to the formation of oil-water stratified flow. The slender seam at the bottom of inner pipe reduces the turbulence intensity, thus avoiding remixing oil with water. The influence of mixture velocity, oil content, water superficial velocity, oil superficial velocity, and inlet flow pattern on the phase split of oil-water two phase flow at double-layer T-junctions pipes has been investigated. Experimental results showed that the separation performance was less affected by the inlet oil content than by the inlet mixture velocity. Additionally, the phase split in the separation system was very sensitive to the inlet flow pattern. For separated flow pattern, oil-water can be well separated. But for dispersed flow pattern, the oil-water separation efficiency was low. Besides, the using of floating oil pipe can increase the system separation efficiency.

Keywords: Oil-water, phase split, double-layer, T-junctions.

1. Introduction
T-junctions pipes exist widely in the oil and gas industry. When two phases flowing in a pipe encounter a T-junction, phase maldistribution takes place between the run and the branch arms. If the degree of phase maldistribution get enhanced, T-junctions pipes can be used as a two-phase preseparator. Nowadays, T-junction pipes are mainly used for gas-liquid separation. The major structural parameters that affect the separation performance include the diameter ratio of run and branch arms [1], the branch angle [2], the inclination angle of the branch arm [3] and the number of branch arms [4]. The major operational parameters that affect the separation performance include the inlet flow pattern [5], the superficial velocities of two-phase [6] and the system pressure [7]. When all the structural and
operational parameters are determined, the separation performance at T-junctions pipes can be further
controlled by adjusting the split ratio. Yang et al. [8] proposed that T-junctions pipes could be used for
oil-water separation. However, owing to the small difference in density between oil and water, it is
difficult to realize high-efficient oil-water separation by using regular T-junctions pipes.

In the present study, the innovation design of double-layer T-junctions pipes was proposed by
combining dynamic separation principle of T-junctions pipes with shallow pond theory. The separation
characteristics at double-layer T-junctions pipes were investigated via experimental tests.

2. Experiments
In this study, water and LP-14 white oil were chosen as experimental fluids, and their physical properties
under experimental conditions were as follows: \( \rho_w = 998.0 \text{ kg/m}^3 \), \( \mu_w = 1.0 \text{ mPa·s} \), \( \rho_o = 836\text{kg/m}^3 \), \( \mu_o = 36\text{mPa·s} \). Fig. 1 is the schematic diagram of experimental setup. The water mixed with potassium
permanganate and LP - 14 were measured by turbine flowmeters and mixed in a T-junction. After
separation, the flow rate of the mixtures emerging from the water outlet was measured by a turbine
flowmeter, and the oil content was measured by sampling test. The mixture flow rate and oil content at
the oil outlet were measured by Coriolis mass flowmeters. The flow rate emerging from the floating oil
pipe was measured by gear flowmeter, and the oil content was measured by sampling test.

The double-layer T-junctions pipes used in the experiment included upper and lower double-layer
pipes that were connected by two vertical pipes. The floating oil pipe was arranged along the axial
direction at the top of the upper outer pipe. The central axis of the upper inner pipe was vertically above
the central axis of the upper outer pipe, and the central axis of the lower inner pipe was vertically below
the central axis of the lower outer pipe. The upper and lower outer pipe had a 80-mm inner diameter,
and the upper and lower inner pipe had a 50-mm inner diameter. The internal diameter of the floating
pipe diameters was 80mm. All the pipes were made of plexiglass to enable visual observation.

When oil-water two phase flowed into the separation system, water with a small amount of oil flow
into the upper outer pipe from the slender seam located at the bottom of the upper inner pipe, and then
flowed into the lower outer pipe through the vertical pipe. The water would settle down to the bottom
of the lower outer pipe and flowed into the lower inner pipe through the slender seam located at the
bottom of the lower inner pipe. Pure water flowed out of the separation system through the lower inner
pipe while pure oil flowed out of the separation system through the upper inner pipe. A small amount
of floating oil flowed into the floating oil pipe through the hole located at the top of the upper outer pipe.
Finally, the separation of two phase was realized. This design of "pipe-in-pipe" contributed to the
shallow pool effect. The eccentric placement between the inner and outer pipes made the cross-sectional
area of oil-water two-phase flow decrease gradually. Thus, the Reynolds number also decreased, which
can reduce the turbulence intensity and facilitate the formation of stratified flow.

![Figure 1. Schematic diagram of experimental setup](image_url)
3. Results and discussions

The water superficial velocity, oil superficial velocity and mixture velocity at the inlet are calculated as:

\[
V_{wi} = \frac{Q_{wi}}{\pi d^2 / 4}
\]

(1)

\[
V_{oi} = \frac{Q_{oi}}{\pi d^2 / 4}
\]

(2)

\[
V_{m} = \frac{Q_{wi} + Q_{oi}}{\pi d^2 / 4}
\]

(3)

To evaluate the separation performance of double-layer T-junctions pipes, the separation efficiency proposed by Yang et al. [8] is applied:

\[
\eta = \frac{Q_{ob} - Q_{wb}}{Q_{oi} - Q_{wi}}
\]

(4)

Where \(Q_{oi}\) is the oil flow rate at the inlet, \(Q_{wi}\) is the water phase flow at the inlet, \(Q_{ob}\) is the oil phase flow at the oil outlet, and \(Q_{wb}\) is the water phase flow at the oil outlet.

Split ratio is defined as the ratio of the mixture flow rate at the oil outlet to that at the inlet, i.e.:

\[
F_b = \frac{Q_{ob} + Q_{wb}}{Q_{oi} + Q_{wi}}
\]

(5)

![Figure 2](image-url). Effect of the mixture velocity on the separation efficiency

3.1. Effect of the mixture velocity

Fig. 2 shows the effect of the mixture velocity on the separation efficiency. As can be seen, the optimal separation efficiency decreased with the increase in the mixture velocity. As the mixture velocity increased, the residence time of oil and water two-phase at the double-layer T-junctions pipes became shorter, which made it difficult for the water phase to completely settle to the lower horizontal pipe. More oil was carried out of the separation system with the water. When the mixture velocity was low, the double-layer T-junctions pipes can basically realize the complete separation of oil and water, as shown in Fig. 3. After the oil phase was carried out from the seam in the upper inner pipe, part of them floated up to the top of the upper outer pipe, while the residual oil entered the lower outer pipe and
floated up to the top of the lower outer pipe. When they accumulated to a certain extent, they re-floated up to the upper pipe through the vertical pipe, which largely prevented the oil phase entering the lower pipe from flowing away from the water outlet directly. Additionally, owing to eccentric placement, the annulus area at the oil outlet of the upper outer pipe and the water inlet of the lower inner pipe was small, which can prevent the water phase from entering the floating pipe and the oil phase from entering the lower inner pipe. This can avoid the re-mixing of oil and water after separation.

![Image](image.jpg)

**Figure 3.** Photograph of complete oil-water separation

### 3.2. Effect of the oil content

Fig. 4 shows the effect of the oil content on the separation efficiency. Under high mixture velocity, lower oil content contributed to higher optimal separation efficiency. But under low mixture velocity, the oil content had little effect on the optimal separation efficiency, and good separation performance can be achieved under different working conditions. This indicated that the mixture velocity had a greater effect on the separation performance of double-layer T-junctions pipes than the oil content.

![Graph](graph.png)

**Figure 4.** Effect of the oil content on the separation efficiency

### 3.3. Effect of the water superficial velocity

Fig. 5 shows the effect of the water superficial velocity on the separation efficiency. As shown, when the oil superficial velocity was low, the water superficial velocity had little effect on the separation efficiency. This was because only a small amount of water entered the lower horizontal pipe when the oil superficial velocity was low. These water tended to accumulate at the top of the lower outer pipe and returned to the upper horizontal pipe through the vertical pipe. However, under high oil superficial
velocity, more oil entered the lower horizontal pipe. It became difficult to accommodate all these oil in the limited annulus volume between the inner pipe and outer pipe. Part of these oil entered the lower inner pipe and flowed out from the water outlet, which made the separation efficiency decrease obviously.

![Figure 5](image1)

**Figure 5.** Effect of the water superficial velocity on the separation efficiency

3.4. Effect of the oil superficial velocity

Fig. 6 shows the effect of the oil superficial velocity on the separation efficiency. As can be seen, the optimal separation efficiency decreased as the oil superficial velocity increased. At the same time, when the oil superficial velocity increased to a certain level, the separation efficiency decreased sharply. This was because the inlet flow pattern of oil-water two-phase gradually changed from stratified flow or stratified flow pattern with mixed layer on the phase interface to oil-in-water dispersion flow. This indicated that the separation performance of double layer T-junctions pipes was sensitive to the inlet flow pattern, which is unexpected in the practical engineering applications. This problem can be solved by increasing the number of vertical branches at a fixed interval along the horizontal pipe.

![Figure 6](image2)

**Figure 6.** Effect of the oil superficial velocity on separation efficiency

3.5. Effect of the floating oil pipe

The above experimental data was obtained without using the floating oil pipe. To study whether the use of floating oil pipe is beneficial to the oil-water separation, this study compared and analyzed the maximum separation efficiency with and without the floating oil pipe under the same inlet condition, as shown in Fig.7. Obviously, the use of floating oil pipe can further improve the separation efficiency of the separation system. Experimental observation showed that part of the oil carried out from the slender seam of the upper inner pipe rised to the top of the upper outer pipe and entered the floating oil pipe.
through the hole located at the top of the upper outer pipe. This can greatly reduce the oil phase entering the lower pipe and thus avoid the oil phase flowing out from the water outlet.

Figure 7. Effect of the floating oil pipe on the separation efficiency

4. Conclusion
The design of double-layer T-junctions pipe had the structural features of "pipe in pipe" and eccentric placement, which was beneficial to the forming of stratified flow for oil and water. This design can also reduce the settlement time, and avoid the re-mixing of oil and water after separation. The experimental results showed that the two-layer T-junctions pipes can maintain a stable and good working condition by adjusting the split ratio, and the separation efficiency was related to the mixture velocity, oil content, water superficial velocity, and oil superficial velocity. The separation performance of double-layer T-junctions pipes was very sensitive to the two-phase flow pattern at the inlet. For separated flow pattern, oil-water can be well separated. But for dispersed flow pattern, the oil-water separation efficiency is low. Besides, the floating tube can increase the system separation efficiency.

Acknowledgments
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