energies

Supplementary Materials

Study on Asymmetry Concentration of Mixed Oil in Products Pipeline

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1. The influence of the polar adsorption coefficient

The influence of the polar adsorption layer on the asymmetric distribution is mainly reflected in the influence of the adsorption coefficient a and desorption coefficient b on the distribution of mixed oil concentration. This paper compares the variation of the mixed oil length, mixed oil head length, mixed oil tail length, mixed oil tail trace length and dimensionless deviation volume with the running length under different adsorption coefficient a and desorption coefficient b. Figure S1 shows the effect of adsorption coefficient a and desorption coefficient b on the length of mixed oil. The values of a and b are both between 0 and 1, and their influence on oil mixing is still uncertain. Suppose the saturated adsorption concentration is 1, and the two values are respectively taken as 0.1, 0.3, 0.5, 0.7 and 0.9 for simulation. In general, within a reasonable range of values, the coefficients a and b do not affect the general trend of mixed oil growth, and can only play a role in revising the model. When the running length is small, several curves overlap each other. As the running distance increases, the influence of the two on the mixing becomes more obvious. When the running distance is long enough (when the running distance is 1km in the figure), compared with the curve in the figure, it can be seen that when the values of a and b increase from 0.1 to 0.3, the amount of mixed oil increases, and the adsorption effect is greater than the desorption effect. When the values of a and b increase from 0.5 to 0.9, the amount of mixed oil gradually decreases, and the effect of desorption coefficient b gradually increases. When the values of a and b are between 0.3 and 0.5, the effects of the adsorption coefficient a and the desorption coefficient b are more balanced.

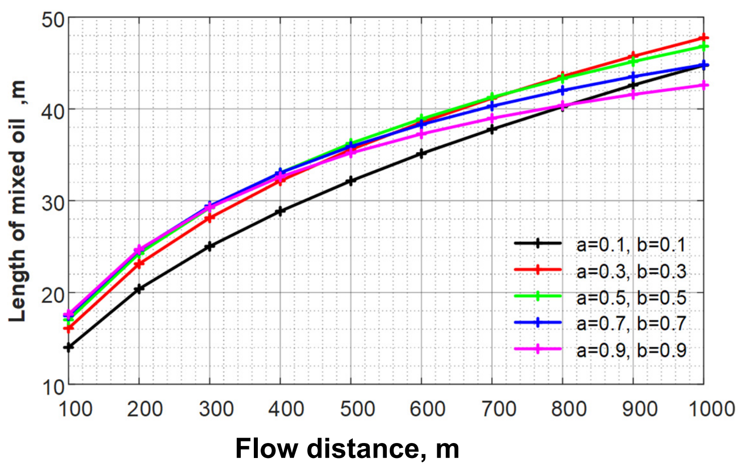


Figure S1. Effect of adsorption and desorption coefficient a and b to the length of mixed oil

Figure S2 shows the effect of adsorption coefficient a and desorption coefficient b on the length of the mixed oil head. The curve with a value of 0.7 for a and b exceeds the curve with a value of 0.9 at a running length of 1km. Comparing Figure S1, it can be seen that the overall impact of the two on the mixed oil head is smaller than the overall impact on the mixed oil section.

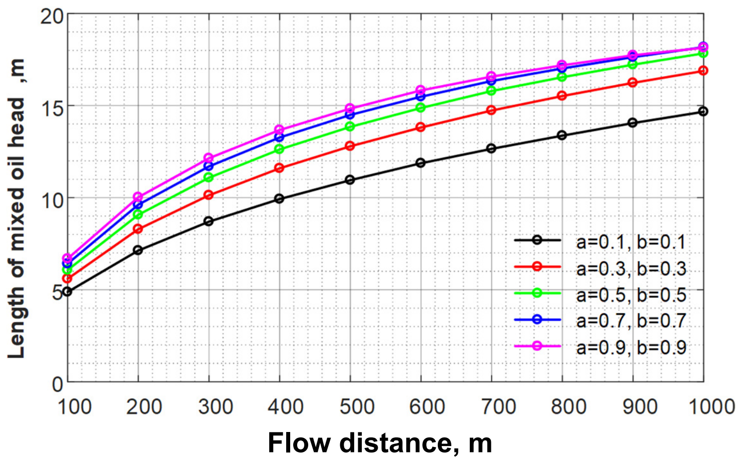


Figure S2. Effect of adsorption and desorption coefficient a and b to the length of front part of mixed oil

Figure S3 shows the influence of adsorption coefficient a and desorption coefficient b on the length of mixed oil tail and mixed oil tail trace. The mixed oil tail trace (the part with the front oil concentration greater than or equal to 95%) occupies most of the length of the mixed oil tail (the part with the front oil concentration greater than or equal to 90%), and the ratio exceeds 50%. Comparing Figure S1, the effect of the two on the mixed oil tail and the mixed oil tail trace is similar with the effect on the whole mixed oil section.

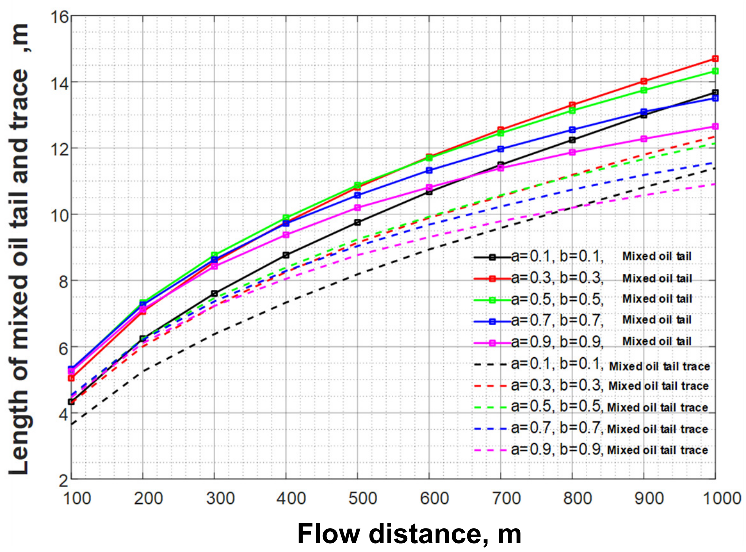
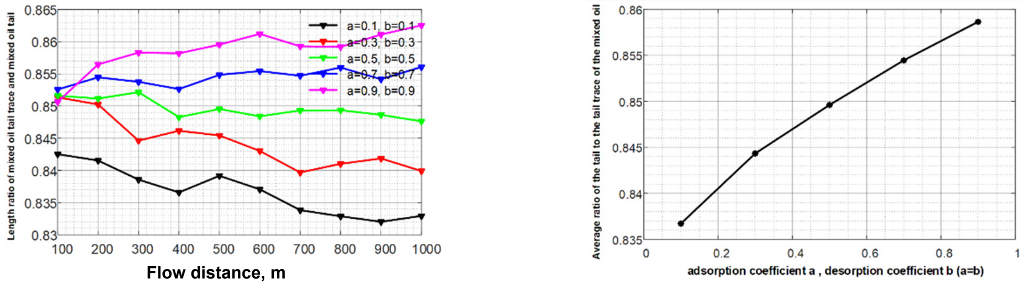


Figure S3. Effect of coefficient a and b to the length of tail and trail part of mixed oil

Figure S4 shows the effect of adsorption coefficient a and desorption coefficient b on the ratio of mixed oil tail trace and mixed oil tail length. Figure S4(a) shows the change of the ratio of the mixed oil tail trace to the mixed oil tail length with the running length under different adsorption coefficient a and desorption coefficient b. The running length has little effect on the ratio of the two. The mixed oil tail trace accounts for about 85% of the length of the mixed oil tail. Figure S4(b) is obtained by averaging each curve in the figure. As the values of adsorption coefficient, a and desorption coefficient b increase, the ratio of mixed oil tail trace to the length of mixed oil tail gradually increases. The rate of increase gradually slows down.



(a) Variation with flow distence (b) Average value

Figure S4. Ratio of trail length and tail length changing with time for different a and b

Figure S5 shows the effect of adsorption coefficient a and desorption coefficient b on the ratio of the length of the mixed oil head to the mixed oil tail. The ratio decreases as the two values increase. That is, when the two values are larger, the length of the mixed oil head is longer than the mixed oil tail. At this time, the influence of the desorption coefficient b is greater, and the front oil adsorbed on the pipe wall is separated from the pipe wall under the strong desorption action, which makes the mixing of the rear oil easier. From this point of view, the values of the two need to be within a certain range to ensure the simulation effect of adsorption.

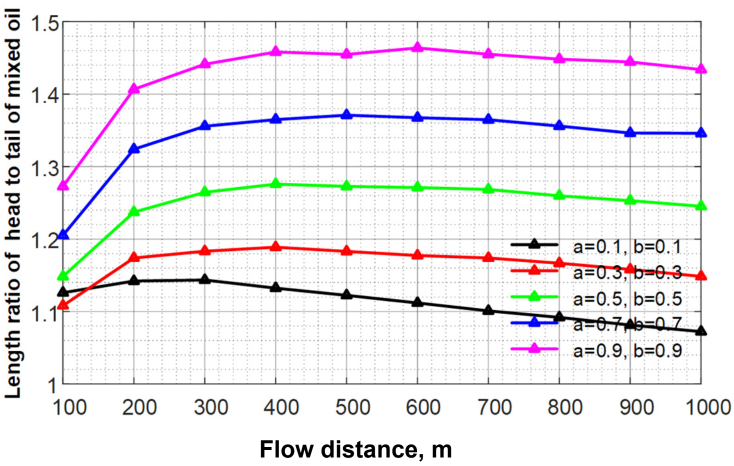


Figure S5. Effect of coefficient a and b to the ratio of front length and tail length

Figure S6 shows the variation of the ratio of the mixed oil tail trace to the length of the mixed trace tail under different adsorption coefficient a and desorption coefficient b with the running length. The deviation volume X can reflect the asymmetry of the mixed oil concentration curve, and its physical meaning is the difference between the volume of the rear oil contained in the first half of the mixed oil (The concentration of front oil is greater than or equal to 50%) and the volume of the front oil contained in the second half of the mixed oil (The concentration of rear oil products is greater than 50%). The deviation volume in the figure is dimensionless treated with the characteristic length of the pipe.

When the values of a and b are 0.1 and 0.3, as the running length increases, the asymmetry of the mixed oil concentration curve gradually increases, and the difference between the mixed oil head and the mixed oil tail gradually increases. This is because when the two values are smaller, the adsorption effect is stronger, and the influence of the mixed oil tail trace gradually manifests. When the values of a and b are greater than or equal to 0.5, the deviation volume is a negative value. A negative deviation volume indicates that the volume of the downstream oil contained in the first half of the mixed oil is greater than the volume of the front oil contained in the latter half of the mixed oil.

Currently, the increase of the desorption coefficient b leads to an increase in the degree of desorption in the simulation process, which is reasonable in the numerical calculation process. However, in the actual process, the front oil contained in the second half of the mixed oil is usually greater than the rear oil contained in the first half of the mixed oil. Therefore, when the limit adsorption concentration is 1 (when the coefficients a and b take the same value), the values of a and b are recommended to be less than 0.5.

The deviation volume $V_d^{0.1}$ can reflect the difference between the curve of the mixed oil head and the curve of the mixed oil tail. Comparing the dashed line and the solid line in Figure S7, the difference between the curve of the mixed oil head part and the curve of the mixed oil tail part is not the main reason for the overall asymmetry of the mixed oil concentration curve.

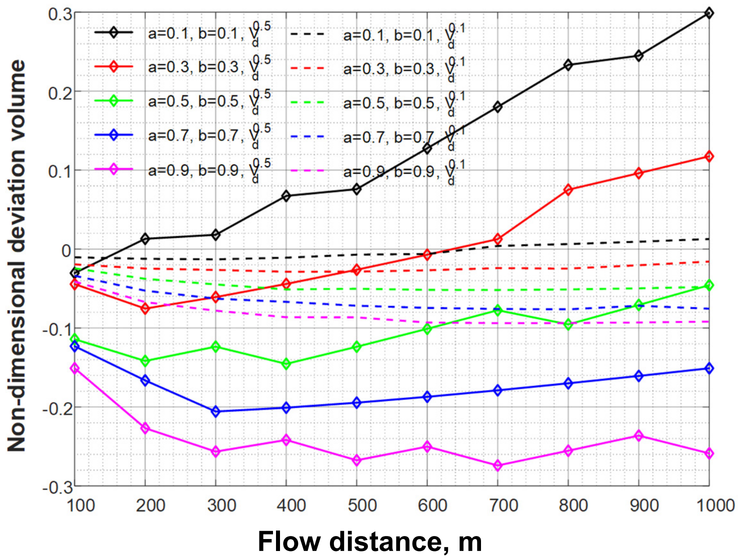
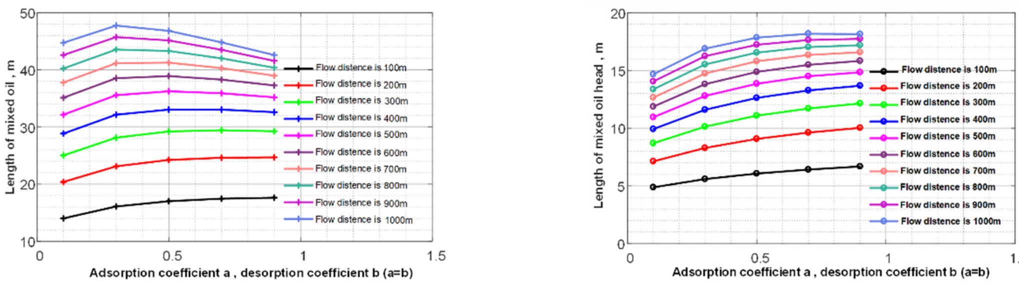
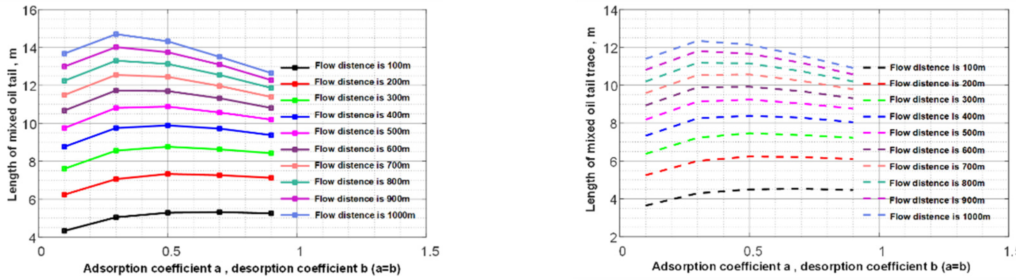


Figure S7. Deviation volume changing with time for different *a* and *b*

Figure S8 shows the influence of the adsorption coefficient *a* and desorption coefficient *b* on the length of the mixed oil, mixed oil head, mixed oil tail and mixed oil tail trace. Both have similar effects on mixing length, mixed oil tail length and mixed oil tail trace length. When the running distance is long enough, the mixed oil length, mixed oil tail length, and mixed oil tail trace length show a trend of first increasing and then decreasing with the increase of the coefficient, and reach the maximum when the two values are 0.3. The influence on the mixed oil head is slightly different. When the values of the two coefficients increase, the mixed oil length also increases, but the increasing speed gradually slows down.



(a) Effect on mixed oil length (b) Effect on the length of the mixed oil head



(c) Effect on the length of mixed oil tail (d) Effect on the length of mixed oil tail trace

Figure S8. Effect of a and b to length of mixed oil, front part, tail part and trail part of mixed oil

Figure S9 shows the influence of adsorption coefficient a and desorption coefficient b on the deviation volume. The change trend of the curve when the running distance is 100m is slightly different from other curves. This is because the running distance is too short. The influence of the two coefficients on the oil mixing is continuously accumulated with the increase of the travel distance, and the simulation results are not stable when the travel distance is short. When the running distance is 1000m, with the increase of the two values, the mixed oil head part gradually exceeds the mixed oil tail part. The deviation volume should be a positive value during the actual operation of the products pipeline. Therefore, it is recommended that the values of adsorption coefficient a and desorption coefficient b be less than or equal to 0.4, which is consistent with the analysis in the previous article.

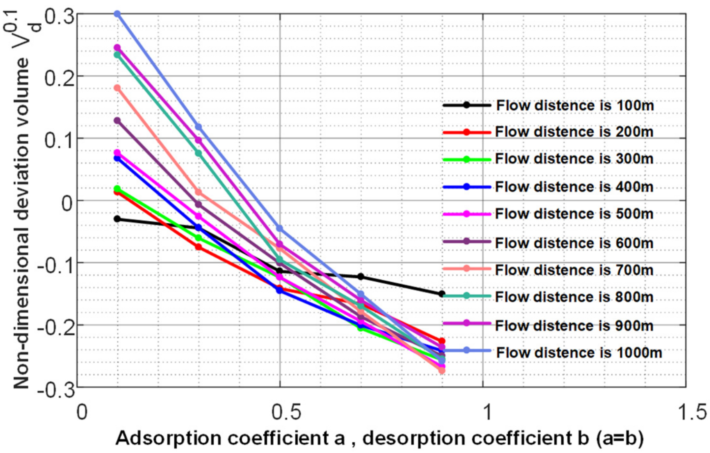


Figure S9. Effect of a and b on deviation volume (0.1)

Figure S10 shows the influence of the adsorption coefficient a and the desorption coefficient b on the deviation volume $V_d^{0.5}$. When the two values are greater than 0.5, its influence on the overall mixed oil concentration curve gradually decreases as the two values increase. When the two values are less than or equal to 0.3, the deviation volume $V_d^{0.5}$ is a negative value, which does not fit the experimental and field data well. In summary, when the limit adsorption concentration is 1, the values of the adsorption coefficient *a* and the desorption coefficient *b* are 0.4.

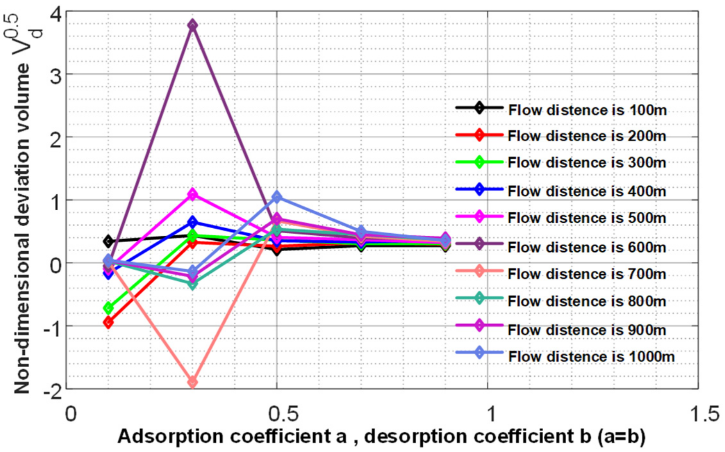


Figure S10. Effect of a and b on deviation volume (0.5)

2. Influence of oil viscosity

The viscosity of oil is related to Reynolds number and wall shear stress. Figure S11 shows the effect of oil viscosity on the total length of mixed oil. As the viscosity decreases, the mixed oil length increases under the same running length, but the increasing speed gradually slows down. When the running length exceeds 500m, the mixed oil length, mixed oil head, mixed oil tail and mixed tail trace length will not change much with the running length. Figure S12 and Figure S13 respectively show the influence of oil viscosity on the length of the mixed oil head, the length of the mixed oil tail and the length of the mixed oil tail trace. The change trend is almost the same as that in Figure S11. Comparing the length of the mixed oil tail and the length of the mixed oil tail trace in Figure S13, the length of the mixed oil tail trace always accounts for most of the length of the mixed oil tail. The ratio of mixed oil head to mixed oil tail length is shown in Figure S14(a). When the running distance is long enough, the ratio fluctuates around 88.5%. Figure S14(b) shows the change in the ratio of the length of the mixed oil head to the mixed oil tail with the running length for different oil viscosity. The diffusion coefficient has little effect on this ratio. Under the viscosity of the five oils, the ratio increases with the increase of the running distance, and increases rapidly in the initial stage of the operation. When the running length reaches about 500m, the ratio is stable at about 93%, but it is always less than 1. The length of the mixed oil tail is always greater than the length of the mixed oil head.

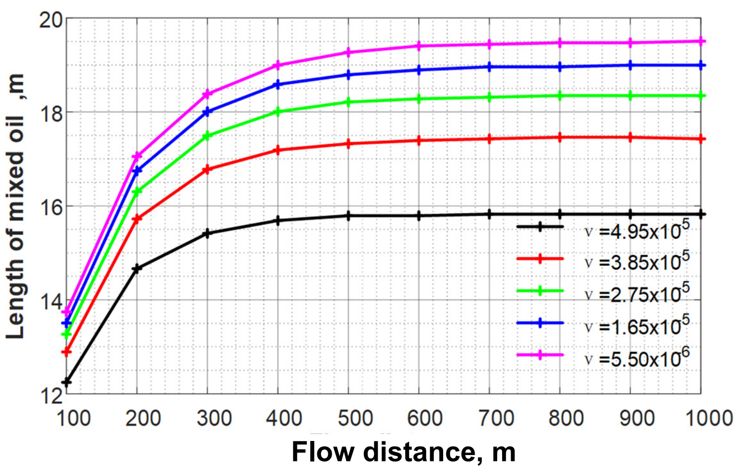


Figure S11. Effect of viscosity on the length of mixed oil

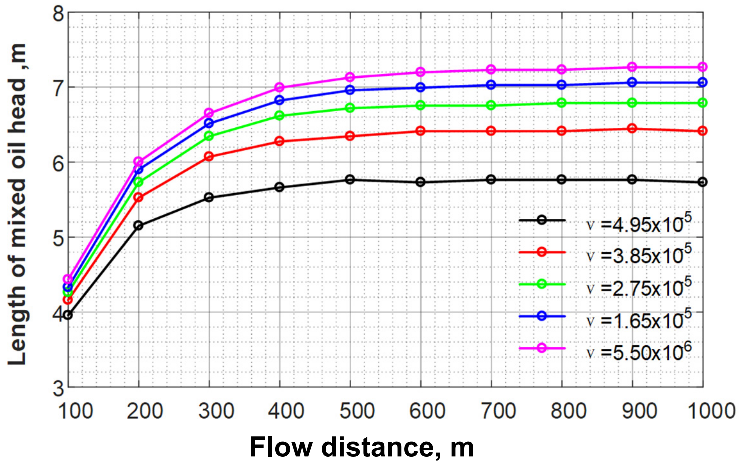


Figure S12. Effect of viscosity on front part of mixed oil

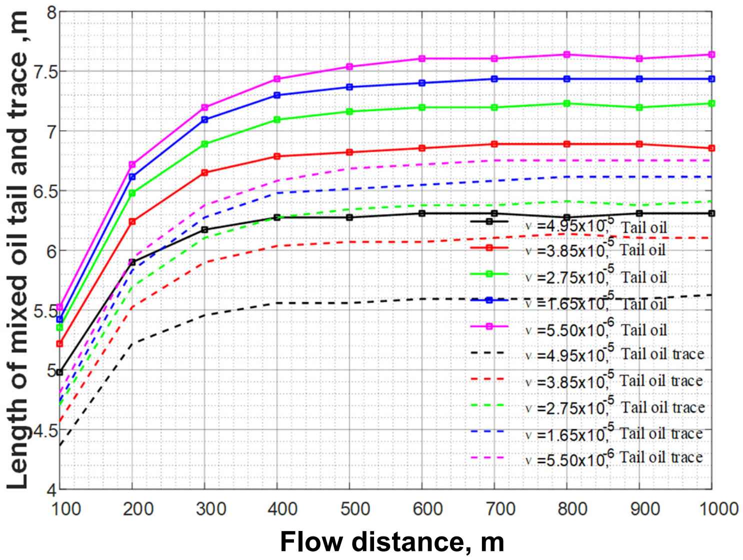
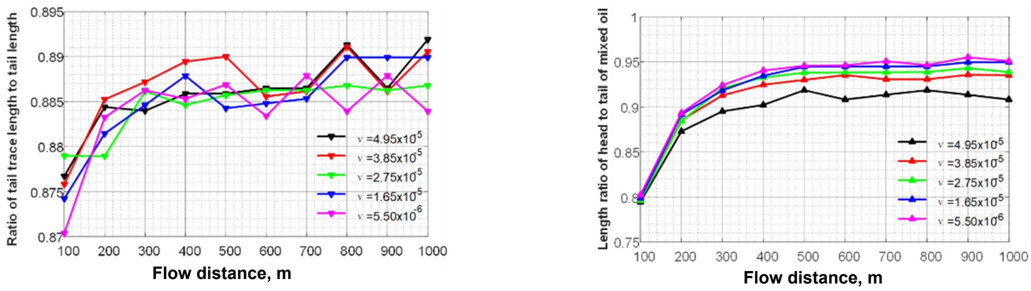


Figure S13. Effect of viscosity on tail and tail part of mixed oil

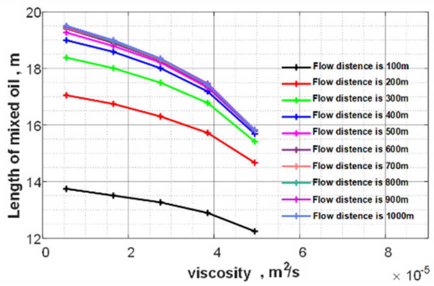


(a) The ratio of mixed oil tail trace to the length of mixed oil tail

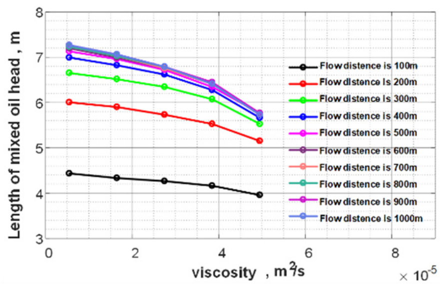
(b) The ratio of the length of the mixed oil head to the mixed oil tail

Figure S14. Ratio of mixed oil length changing with time for different viscosity

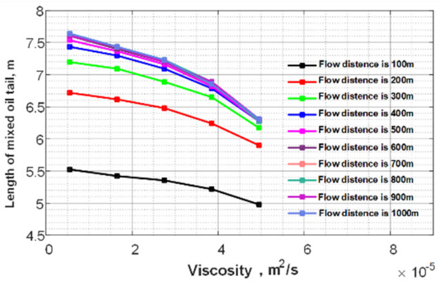
Figure S15 shows the effect of oil viscosity on the length of mixed oil, oil head, mixed oil tail and mixed oil tail trace length. The four have the same trend. When the viscosity of the oil increases, the length of the mixed oil, the mixed oil head, the mixed oil tail, and the length of the mixed oil tail decrease. Figure S16 shows the effect of oil viscosity on the deviation volume. When the value of the diffusion coefficient changes, $V_d^{0.1}$ and $V_d^{0.5}$ fluctuate up and down, there is no upward or downward trend, and the fluctuation is relatively large. $V_d^{0.1}$ fluctuates between 0.03 and 0.07, and $V_d^{0.5}$ fluctuates between 0.2 and 0.5.



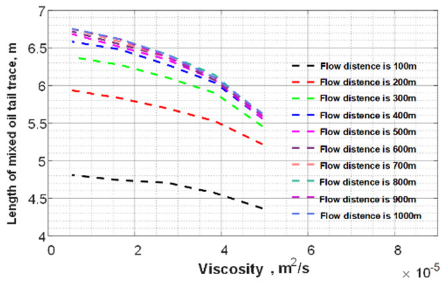
(a) Effect on the length of mixed oil



(b) Effect on the length of the mixed oil head

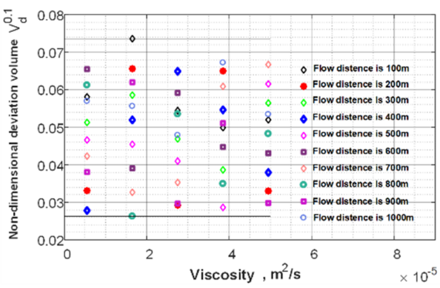


(c) Effect on the length of mixed oil tail

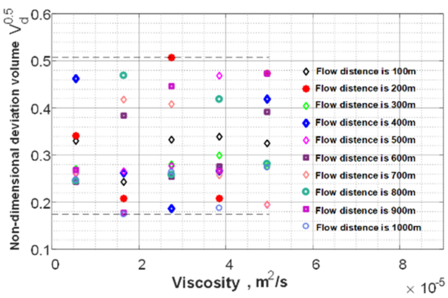


(d) Effect on the length of mixed oil tail trace

Figure S15. Effect of viscosity to length of mixed oil, front part, tail part and trail part of mixed oil



(a) Deviation volume $V_d^{0.1}$



(b) Deviation volume $V_d^{0.5}$

Figure S16. Effect of viscosity on deviation volume

3. Influence of diffusion coefficient

The diffusion coefficient mainly affects the process of diffusion. The Peclet number is positively correlated with the characteristic length of the pipeline and the average flow velocity of the pipeline, and negatively correlated with the diffusion coefficient. Its physical meaning is the relative proportion of convection and diffusion. When Peclet's number is much greater than 1, convection is dominant. This section simulates the asymmetry distribution of the corresponding Peclet numbers respectively impact when the diffusion coefficients are 1×10^{-3}, 2×10^{-3}, 3×10^{-3}, 4×10^{-3}, and 5×10^{-3}. The corresponding Peclet numbers are: 6.36×10^{2}, 3.18×10^{2}, 2.12×10^{2}, 1.59×10^{2} and 1.27×10^{2}.

Figure S17-Figure S19 respectively show the influence of diffusion coefficient on the total length of the mixed oil, the length of the mixed oil head, the length of the mixed oil tail and the mixed oil tail trace. The growth trends in the three graphs are consistent. The larger the diffusion coefficient, the stronger the effect of convection, and the greater the amount of mixed oil under the same running length. The comparison of the two sets of curves in Figure S19 shows that the mixed oil tail still occupies most of the mixed oil tail.

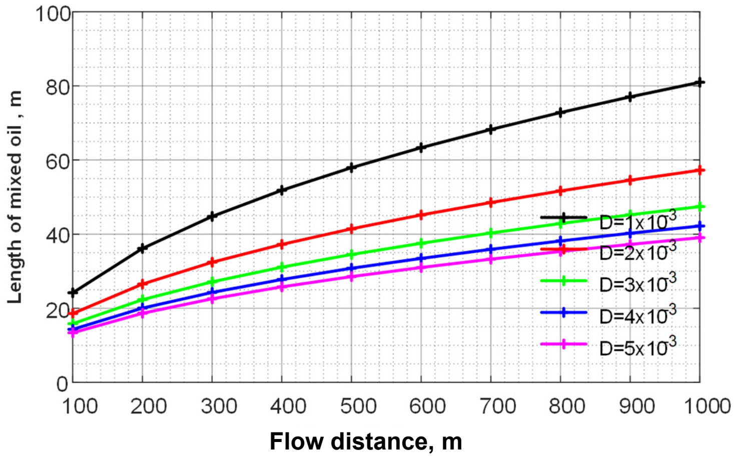


Figure S17. Effect of D on mixed oil

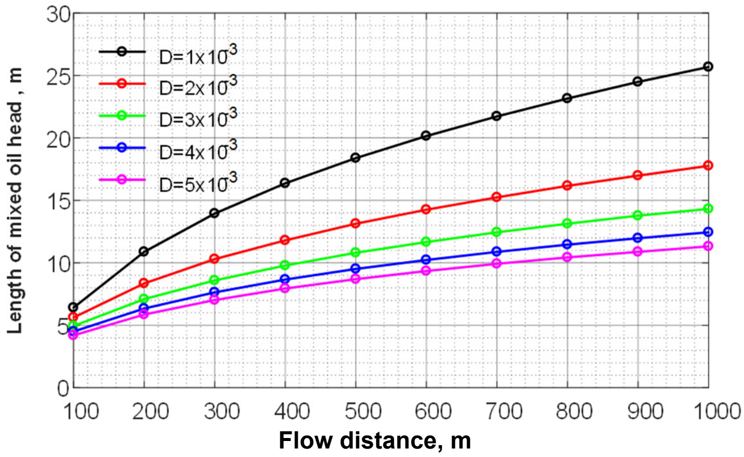


Figure S18. Effect of D on front part

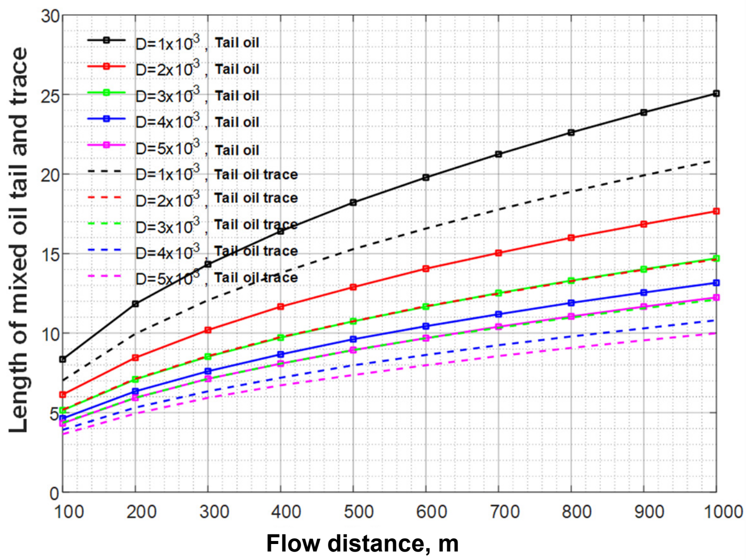


Figure S19. Effect of D on the length of tail and trail part of mixed oil

Figure S20 shows the variation of the ratio of the mixed oil tail trace to the length of the mixed oil tail with the running length under different diffusion coefficients. When the running length is the same, as the diffusion coefficient increases, the ratio decreases. When the conveying distance is the same, the larger the diffusion coefficient, the smaller the proportion of the mixed oil tail trace occupying the mixed oil tail section.

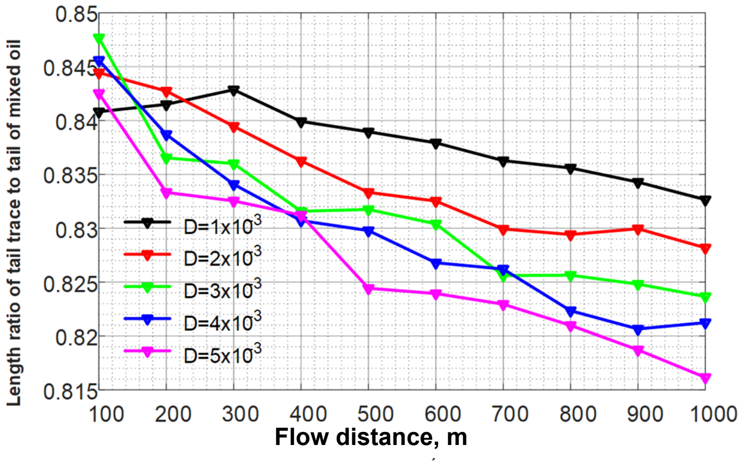


Figure S20. Ratio of trail length and tail length changing with time for different D

Figure S21 shows the variation of the ratio of the length of the mixed oil head to the mixed oil tail with the running length under different diffusion coefficients. When the running length is long enough, as the diffusion coefficient increases, the ratio decreases. That is, when the running length is long enough, the larger the diffusion coefficient, the smaller the ratio of the mixed oil head to the mixed oil tail length, and sometimes the mixed oil head is longer than the mixed oil tail. The larger the diffusion coefficient, the smaller the relative change between the mixed oil head and mixed oil tail length as the running distance increases. This is because the diffusion along the radial direction of the pipeline inhibits the axial development of the mixed oil.

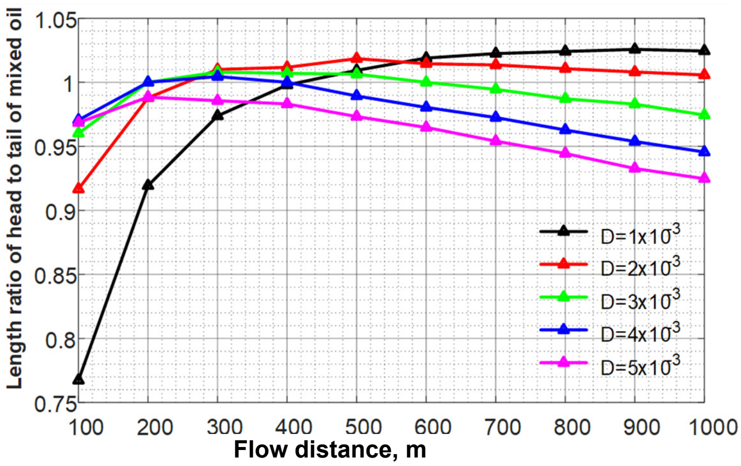
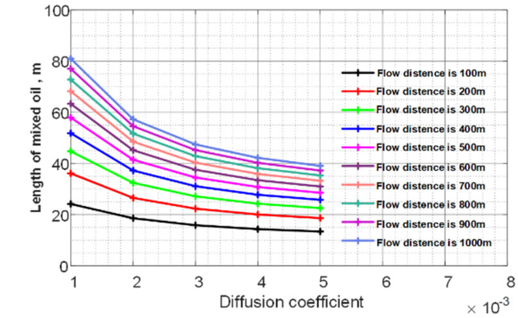
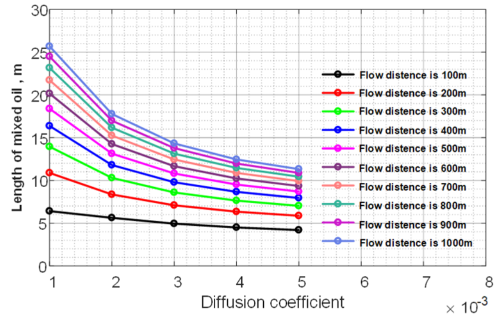


Figure S21. Ratio of front length and tail length changing with time for different D Diffusion coefficient distribution

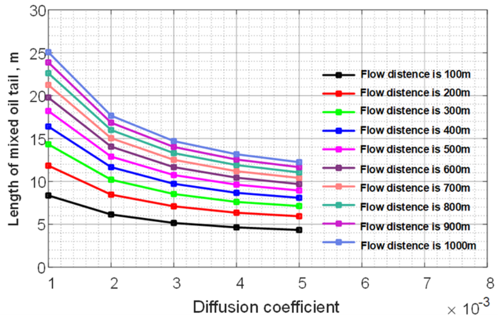
Figure S22 shows the influence of diffusion coefficient on the length of the mixed oil, the mixed oil head, the mixed oil tail, and the length of the mixed oil tail trace. The four have the same downward trend. As the diffusion coefficient increases, the descending speed decreases slightly.



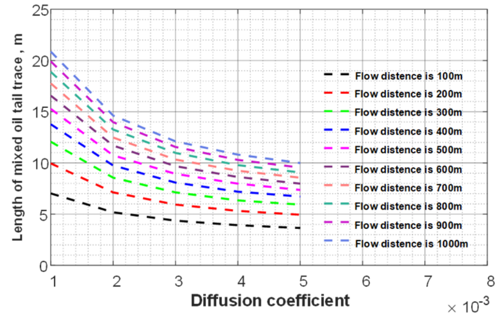
(a) Effect on the length of mixed oil



(b) Effect on the length of mixed oil head



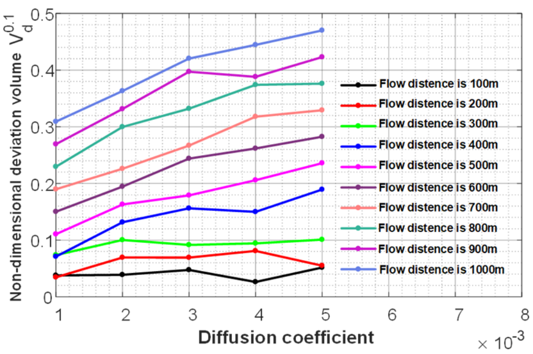
(c) Effect on the length of mixed oil tail



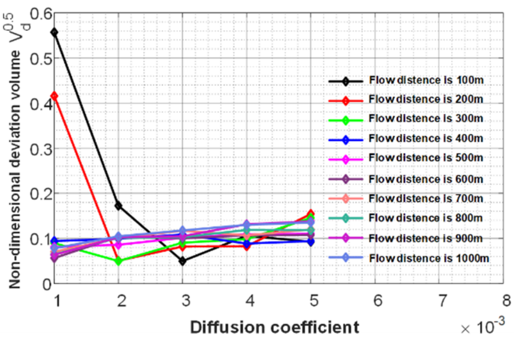
(d) Effect on the length of mixed oil tail mark

Figure S22. Effect of D on length of mixed oil, front part, tail part and trail part of mixed oil

Figure S23 shows the effect of diffusion coefficient on deviation volume. When the running length is long enough, both increase with the increase of the diffusion coefficient. In Figure S23(b), when the running distance is 100m and 200m, there is a large deviation of the value. This is because the running length is too short and the oil mixing process has not yet reached stability.



(a) deviation volume $V_d^{0.1}$



(b) deviation volume $V_d^{0.5}$

Figure S23. Effect of D on deviation volume

4. Effect of temperature

This section simulates the effect of temperature on the asymmetric distribution. Figure S24-Figure S26 are the effects of temperature on the total length of the mixed oil, the length of the mixed oil head, the length of the mixed oil tail and the mixed tail trace. The growth trends in the three graphs are consistent. As the temperature increases, the mixed oil length, mixed oil head length, mixed oil tail length and mixed oil tail trace length all increase slightly.

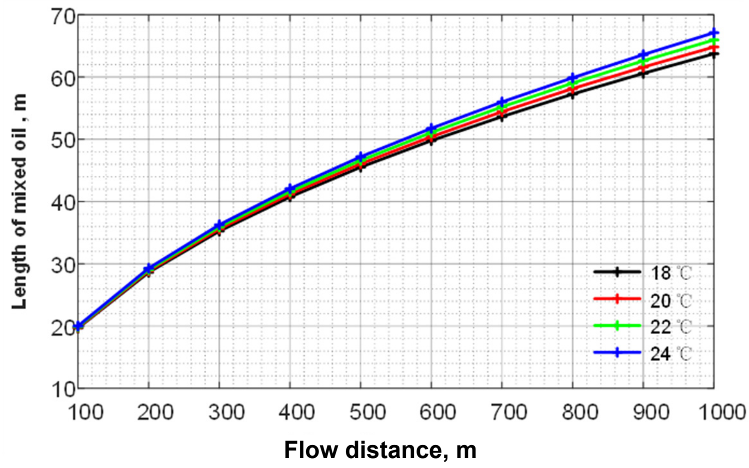


Figure S24. Effect of temperature on the length of mixed oil

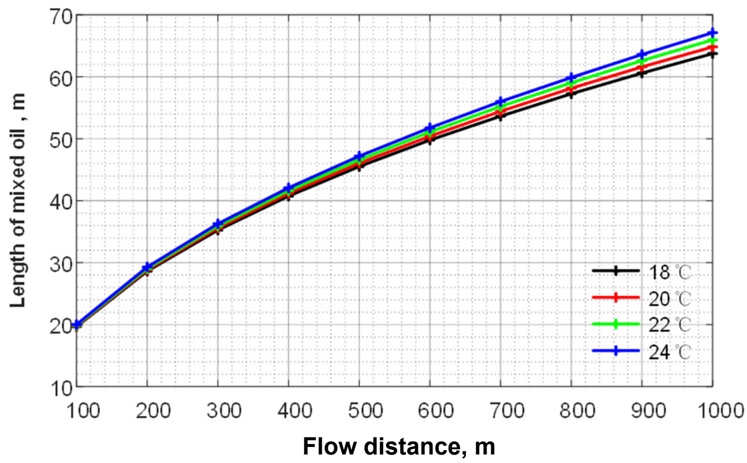


Figure S25. Effect of temperature on front part

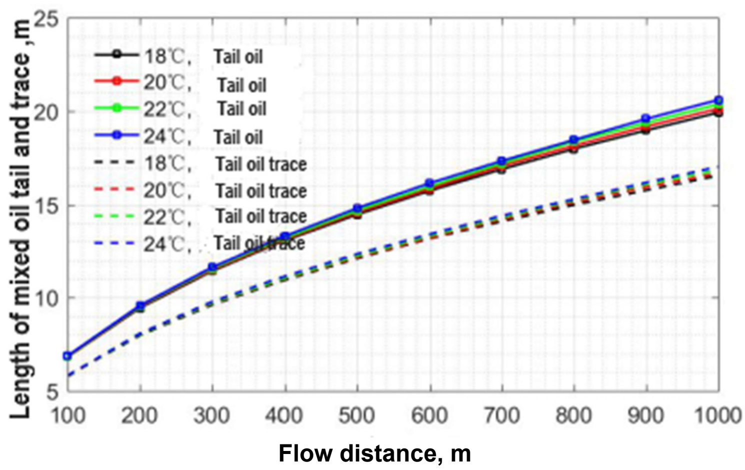


Figure S26. Effect of temperature on the length of tail and trail part of mixed oil

Figure S28 shows the variation of the ratio of mixed oil tail trace to mixed oil tail length with running length at different temperatures. Comparing several curves, the temperature has little effect on the ratio, the temperature has little effect on the mixed oil tail trace. The proportion of the mixed oil tail has little effect. Figure S29 shows the variation of the ratio of the length of the mixed oil head to the mixed oil tail with the running length at different temperatures. The effect of temperature on this ratio is also small. Figure S30 shows the effect of temperature on the length of mixed oil, mixed oil head, mixed oil tail and mixed oil tail trace length. The influence of temperature on the four is relatively small. As the temperature increases, the length of the four increases slightly, but the magnitude is small.

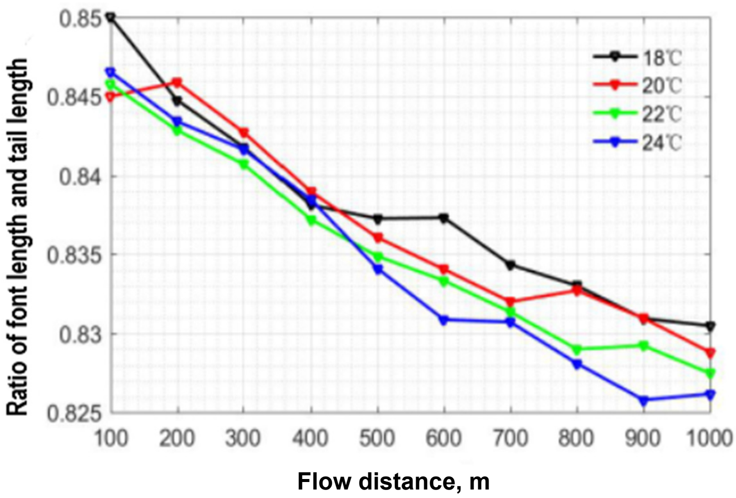


Figure S27. Ratio of trail length and tail length changing with time for different temperature

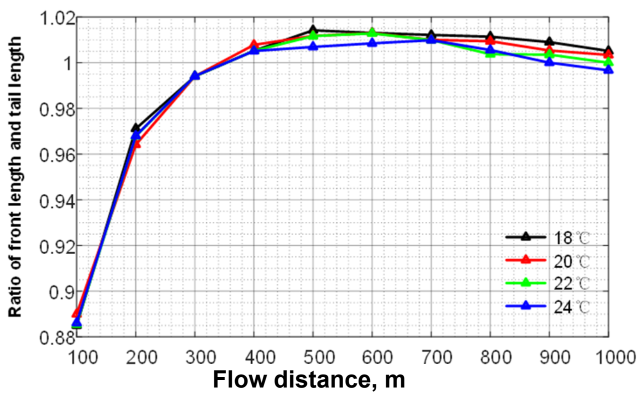
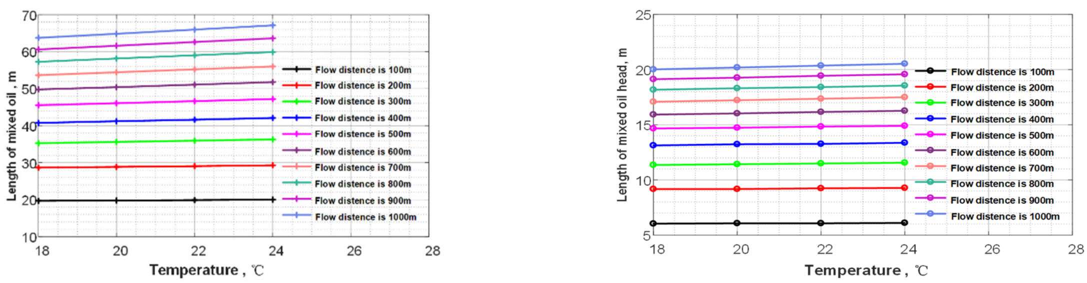
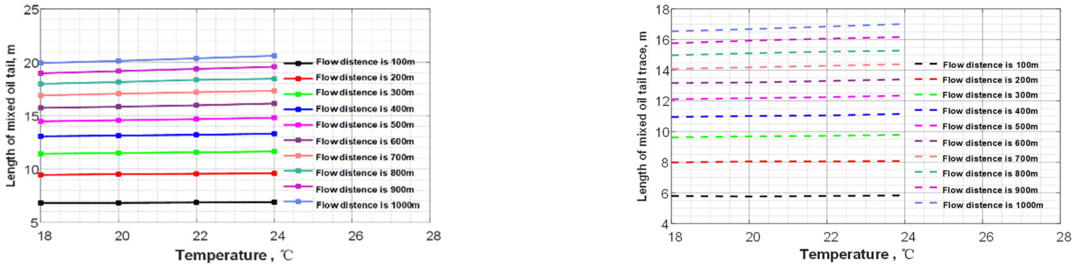


Figure S28. Ratio of front length and tail length changing with time for different temperature



(a) Effect on length of mixed oil

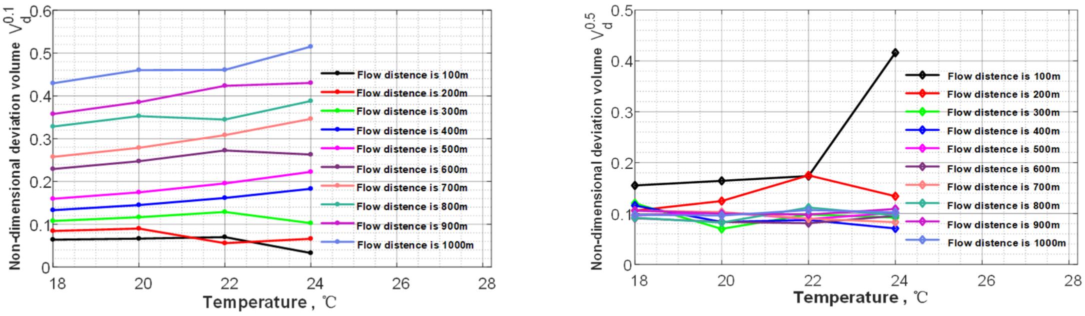
(b) Effect on length of mixed oil head



(c) Effect on length of mixed oil tail (d) Effect on length of mixed oil tail trace

Figure S29. Effect of temperature on the length of mixed oil, front part, tail part and trail part of mixed oil

Figure S30 shows the effect of temperature on the deviation volume. The simulation is unstable when the running length is short, and the simulation results currently are not for reference. When the running distance is long, the two deviation volumes change little with temperature, but generally there is a slight upward trend as the temperature rises.



(a) deviation volume$V_d^{0.1}$ (b) deviation volume$V_d^{0.5}$

Figure S30. Effect of temperature on deviation volume

From the analyses, it can be clearly seen that the lengths and deviation volume of mixed oil are not sensitive to temperature, regardless of which flow distance.

5. Effect of pipe diameter

This section simulates the influence of pipe diameter on the asymmetric distribution, keeping the average flow velocity in the pipe constant during the analysis. Figure S31-Figure S33 respectively show the influence of pipe diameter on the total length of the mixed oil, the length of the mixed oil head, the length of the mixed oil tail and the mixed oil tail trace. The growth trends in the three graphs are consistent. The mixing length decreases as the pipe diameter increases. When the pipe diameter changes from 0.28m to 0.32m, the growth rate of the mixed oil length decreases rapidly with the running distance.

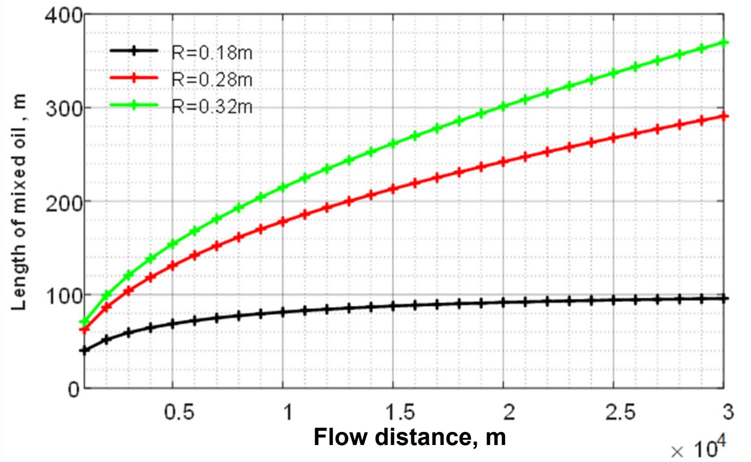


Figure S31. Effect of radius on the length of mixed oil

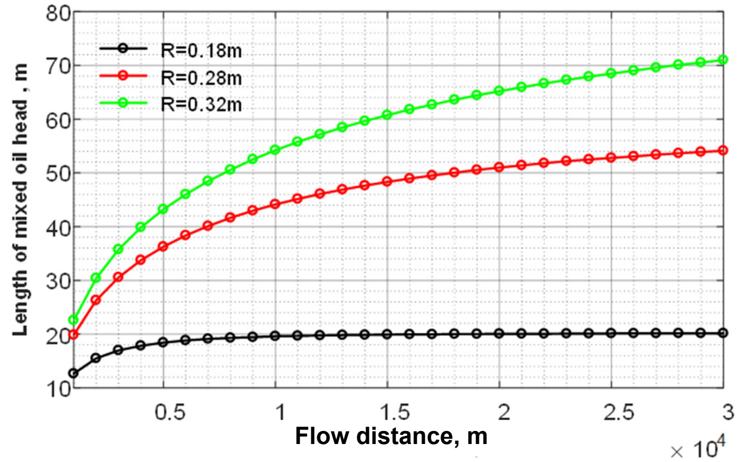


Figure S32. Effect of radius on front part

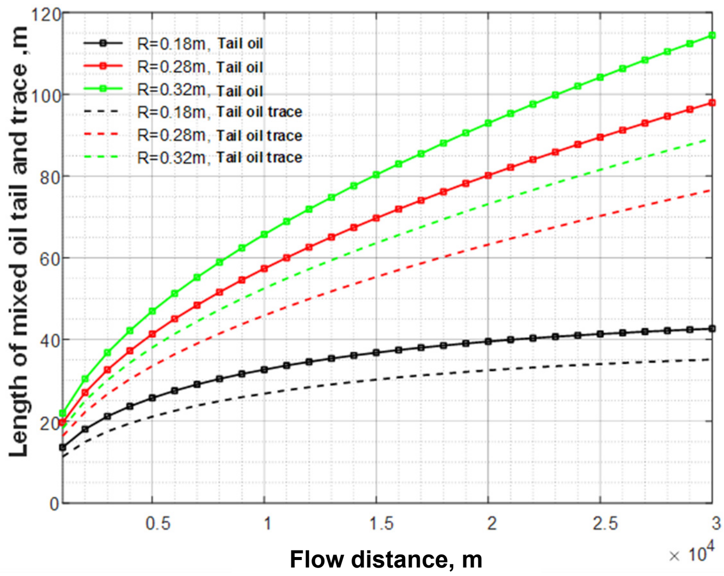


Figure S33. Effect of radius on the length of tail and trail part of mixed oil

Figure S34 shows the variation of the ratio of the mixed oil tail trace to the length of the mixed oil tail under different pipe diameters with the running length. When the pipe diameter is reduced to 0.18m and the running distance is long enough, the mixed oil tail trace occupies the mixed oil. The proportion of mixed oil tail length basically does not change with the running length. When the pipe diameter is 0.28m and 0.32m, as the running length increases, the ratio of mixed oil tail trace to the mixed oil length decreases, but the decreasing speed gradually slows down.

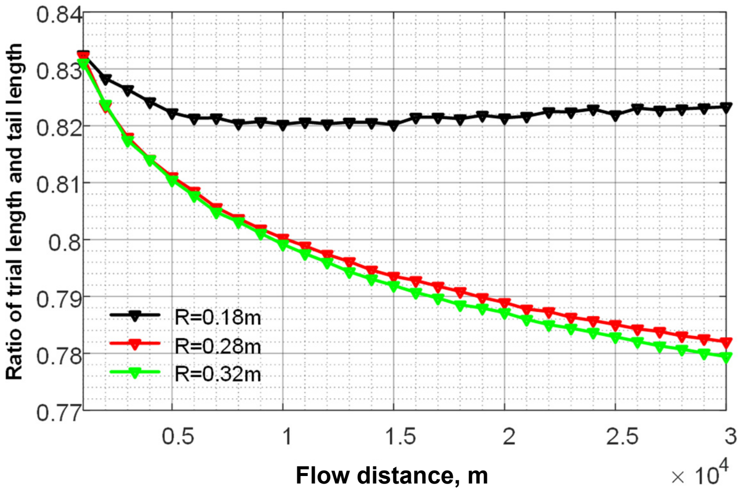


Figure S34. Ratio of trail length and tail length changing with time for different radius Effect of a and b on deviation volume (0.5)

Figure S35 shows the variation of the ratio of the mixed oil tail trace to the length of the mixed oil tail under different pipe diameters with the running length. All three curves show a downward trend. As the running distance increases, the ratio of mixed oil head to mixed oil tail length decreases continuously. Under the same running length, the smaller the pipe diameter, the smaller the ratio.

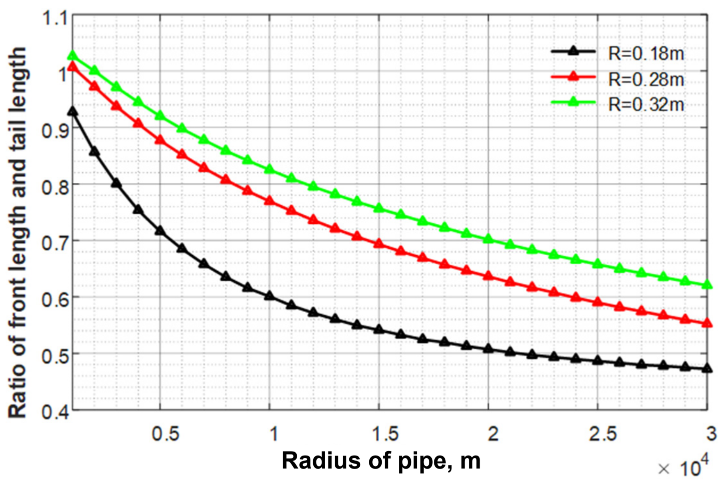
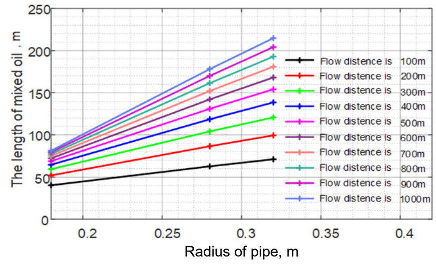
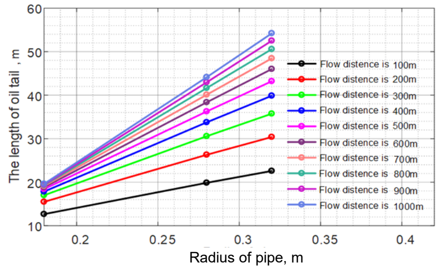


Figure S35. Ratio of front length and tail length changing with time for different radius

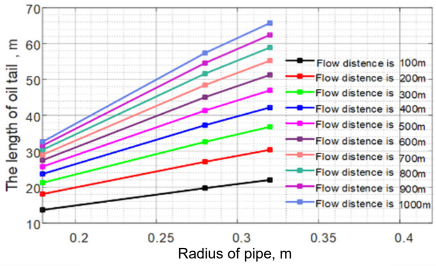
Figure S36 shows the influence of pipe diameter on the length of mixed oil, mixed oil head, mixed oil tail and mixed oil tail trace length. As the pipe diameter increases, the length of the four increases. The pipe diameter has basically the same effect on the length of the mixed oil, the mixed oil head, the mixed oil tail and the length of the mixed oil tail trace. Figure S37 shows the effect of pipe diameter on deviation volume. The deviation volume $V_d^{0.5}$ increases as the pipe diameter increases. When the running distance is long enough, $V_d^{0.1}$ reaches the maximum when the pipe diameter is 0.28.



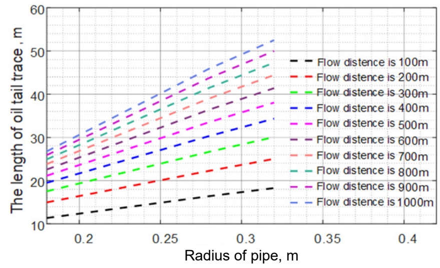
(a) Effect on length of mixed oil



(b) Effect on length of mixed oil head

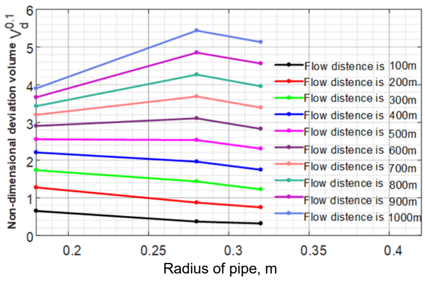


(c) Effect on length of mixed oil tail

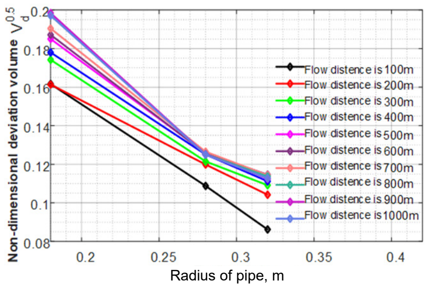


(d) Effect on length of mixed oil tail trace

Figure S36. Effect of radius on the length of mixed oil, front part, tail part and trail part of mixed oil



(a) deviation volume $V_d^{0.1}$



(b) deviation volume $V_d^{0.5}$

Figure S37. Effect of radius on deviation volume

6. Effect of velocity

This section simulates the effect of flow velocity on the asymmetric distribution. Figure S38-Figure S40 respectively show the influence of pipe diameter on the total length of the mixed oil, the length of the mixed oil head, the length of the mixed oil tail and the mixed oil tail trace. The growth trends in the three graphs are consistent. As the flow rate increases, the mixing length under the same operating conditions increases.

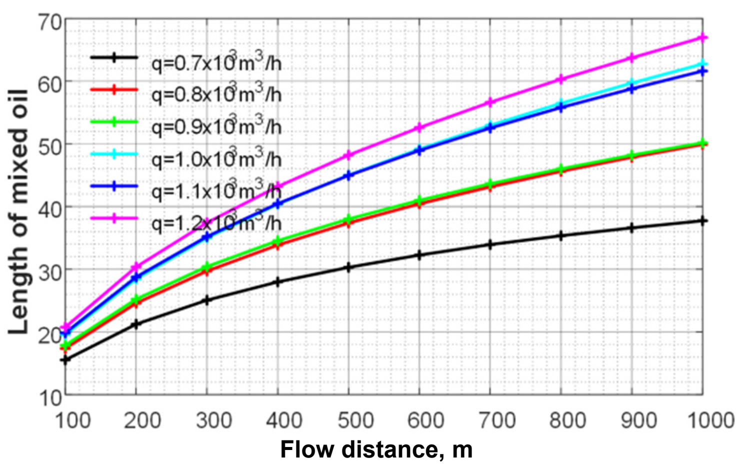


Figure S38. Effect of velocity on the length of mixed oil

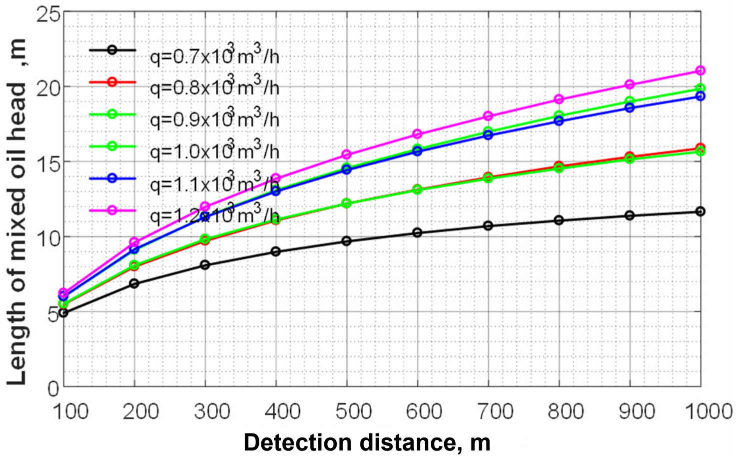


Figure S39. Effect of velocity on front part

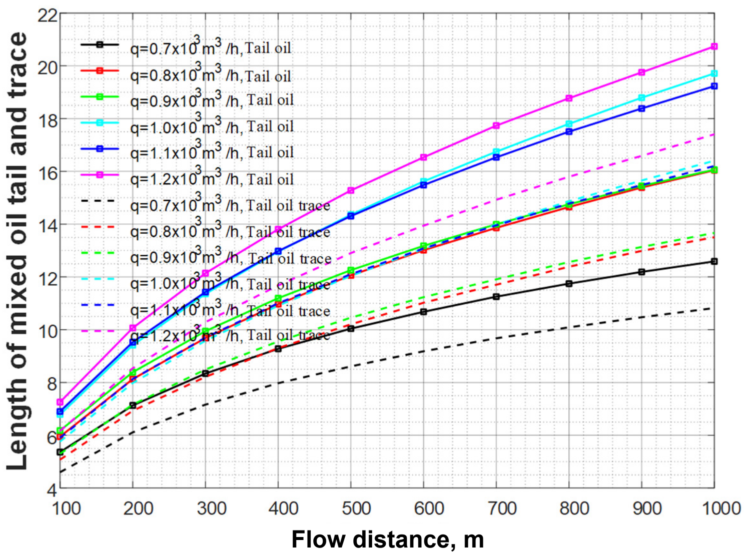


Figure S40. Ratio of trail length and tail length changing with time for different velocity

Figure S41 shows the variation of the ratio of the mixed oil tail trace to the mixed oil tail length with the running length at different flow rates. With the increase of the flow rate, the proportion of the mixed oil tail traces in the length of the mixed oil tail shows a downward trend. Figure S42 shows the variation of the ratio of the length of the mixed oil head to the mixed oil tail with the running length at different flow rates. When the running distance is long enough, as the flow rate increases, the ratio of the length of the mixed oil head to the mixed oil tail increases.

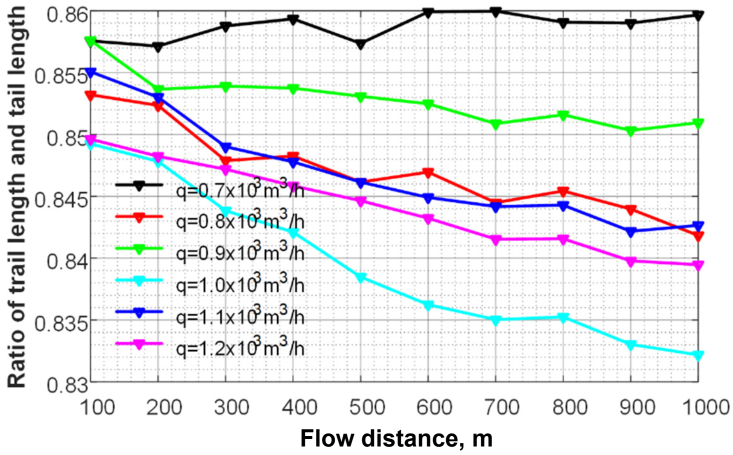


Figure S41. Ratio of trail length and tail length changing with time for different velocity

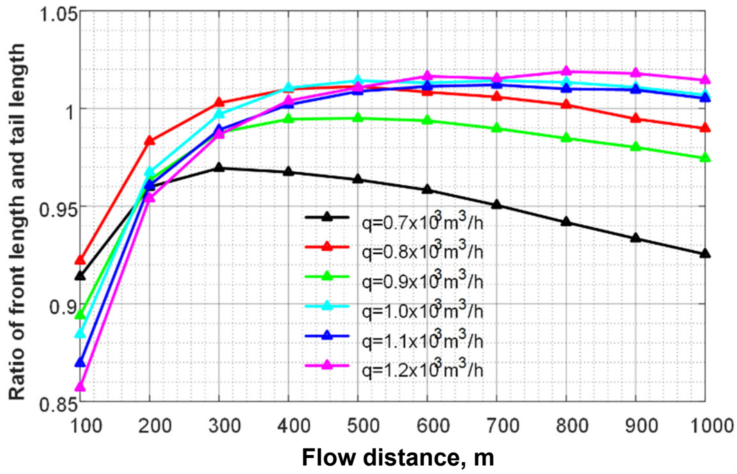
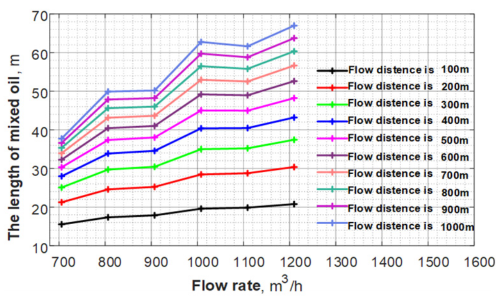
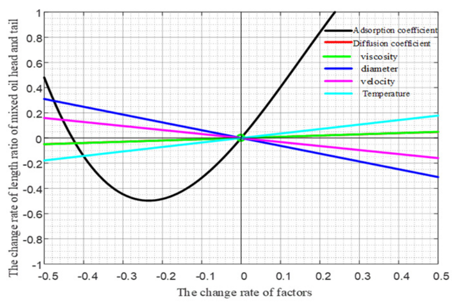


Figure S42. Ratio of front length and tail length changing with time for different velocity

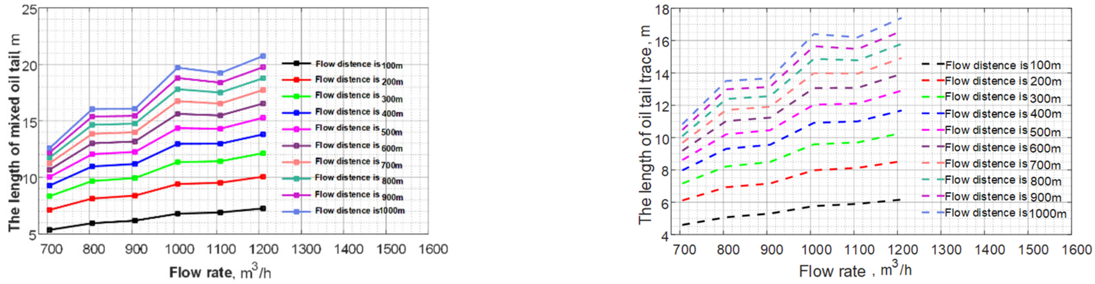
Figure S43 shows the effect of flow velocity on the length of mixed oil, mixed oil head, mixed oil tail and mixed oil tail trace length. With the increase in traffic, the four are showing an upward trend overall. Figure S44 shows the effect of temperature on the deviation volume. The deviation volume $V_d^{0.1}$ decreases as the flow rate increases. When the running distance is long enough, $V_d^{0.5}$ does not change much with the increase of flow.



(a) Effect of the length of mixed oil

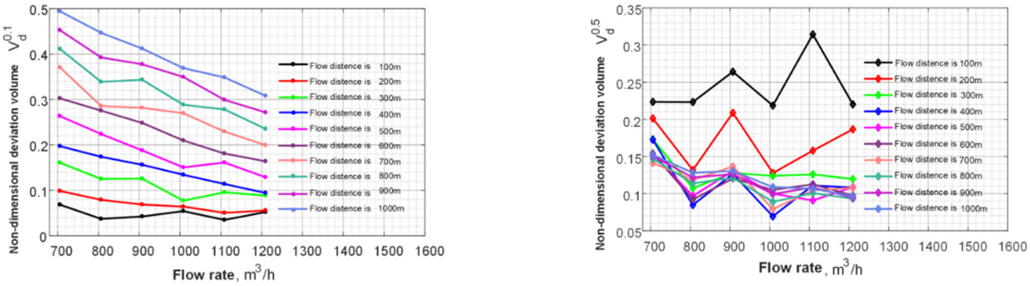


(b) Effect of the length of mixed oil head



(c) Effect of the length of mixed oil tail (d) Effect of the length of mixed oil tail trace

Figure S43. Effect of velocity on the length of mixed oil, front part, tail part and trail part of mixed oil



(a) deviation volume$V_d^{0.1}$ (b) deviation volume$V_d^{0.5}$

Figure S44. Effect of velocity on deviation volume