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ORIGINAL ARTICLE

# Span 80 effect on the solvent extraction for heavy oil recovery

**Jinjian Hou [a,b,c,*], Mingyao Cao [d,*], Keyi Duan [d], Lingyu Sun [a,b,c], Shuanglong Lin [e], Ming Zhang [f], Wei Li [f]**

[a] *School of Chemical Engineering and Technology, Tianjin University, Tianjin, China*
[b] *National Engineering Research Centre of Distillation Technology, Tianjin, China*
[c] *Collaborative Innovation Center of Chemical Science and Engineering (Tianjin), China*
[d] *School of Management, Universiti Sains Malaysia, 11800 USM Penang, Malaysia*
[e] *College of Chemical Technology, Shijiazhuang University, Shijiazhuang, China*
[f] *College of Chemical Engineering, China University of Petroleum-Beijing (CUP), Beijing, China*

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**Abstract** In this study, we used the Span 80 to enhance solvent extraction process, and we explored the mechanism. The results indicated different solvents would obtain different oil recovery, and toluene showed the optimal oil recovery, and the n-heptane showed the lowest oil recovery. The complex solvents could improve oil recovery. Toluene could make the heavy oil show the lowest viscosity (89.6 Pa.S), and n-heptane make the heavy oil show the highest viscosity (176.3 Pa.S). Complex solvents could decrease the heavy oil viscosities. The higher C/H was, the higher heavy oil recovery was, and when the asphaltene and resins content increase, the C/H would increase. The C/H showed the highest value (9.09, by toluene) and the lowest value (8.15). In this study, Span 80 could increase heavy oil C/H ratio, decrease heavy oil viscosity. Span 80 could make the sands surface more hydrophilic, and then the solvent loss would decrease. The oil recovery was high after 10 times recycle use.



## 1. Introduction

Unconventional oils were the important resources which were different from the conventional crudes (Isaac et al., 2022). There were many characteristics for the unconventional crudes, for instance, the high density, high viscosity, chemical complex, etc. The unconventional oils were usually combined with the rocks, and difficult to liberate from minerals surface (Zolfaghari et al., 2022). The unconventional oils included the (extra) heavy oil, oil sands, tar sands, tight shale oil and other oils. Comparing with the unconventional oils, the conventional oils were low density, high heating value and liquid state. Besides, the conventional oils would be easy to use (Markey et al., 2022).

* Corresponding authors at: School of Chemical Engineering and Technology, Tianjin University, Tianjin, China (J. Hou).
E-mail addresses: houjinjian@tju.edu.cn (J. Hou), mingyaocao1234@163.com (M. Cao).

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As was known to us all, unconventional oils take up huge ratio in the petroleum resources (Ahsaei et al., 2019; Azum et al., 2022), and many methods were used to extract the heavy oil from the unconventional oils, for instance, the solvent extraction (Zhao et al., 2015, Lin et al., 2017), hot water based extraction (Dai and Chung 1996, Lin et al., 2019), pyrolysis (Liu et al., 2012, Shin et al., 2017), etc. Comparing to other methods, solvent extraction had many advantages, for instance, the oil recovery was high, and the solvent residue was low, and the method had widely adaptability (for oil-wet rock or water-wet rock), the solvents could be recovered.

The solvent extraction process included the dissolution process and heavy oil recovery process (Khammar and Xu, 2017a, 2017b). According to the principle that the similar substance is more likely to be dissolved by each other, different solvents would show different effect on the extraction effect (Khammar and Xu, 2017a, 2017b). Besides, there exist many problems during the solvent extraction process, for instance, the solvent residue amount was high, and the solvent extraction mechanism was not clear. Therefore, the solvent extraction should be further studied, and other work should be done.

There are many disadvantages for the solvent extraction, and the disadvantages were as follows (Zhu et al., 2020). On the one hand, the oil recovery was low by solvent extraction, and there was much residual solvent onto the sands surface. On the other hand, the solvent recovery was difficult by the solvent extraction (Nikakhtari et al., 2013).

In recent years, the surfactants were used to enhance the heavy oil recovery (Isaac et al., 2022, Yahya et al., 2022, Zhao et al., 2022). The surfactants could effectively decrease the oil–water interfacial tension, and solubilize organic compounds (Azum et al., 2022, Dai et al., 2022, Senthilkumar et al., 2022). Besides, the ionic liquids could effectively increase the oil recovery, the ionic liquids could increase the heavy oil recovery and decrease the oil content (Rodriguez-Palmeiro et al., 2015, Bera and Belhaj 2016, Manshad et al., 2017).

Therefore, the purpose of this work was as follows: (i) to study the single solvent and complex solvents extraction effect on the heavy oil recovery; (ii) to study the Span 80 effect on the oil recovery process was put forward; (iii) to study the Span 80 role mechanism.

## 2. Materials and methods

### 2.1. Materials

Toluene, n-heptane, cyclohexane, n-octane, xylene, Span 80 were of analytical grade and were purchased from Aladdin Co., Ltd., Shanghai. The Seoul heavy oil samples were from Seoul, South Korea.

### 2.2. Solvent extraction process

The solvent extraction process was as follows. The toluene was mixed with the Seoul heavy oil samples, and then the stirring process was conducted. The temperature, stirring rate and stirring time were optimized. After the extraction process, the heavy oil was obtained, and the solvent was replaced by other solvent. Then the complex solvents were used to replace the single solvent. Then the Span 80 surfactant was used to enhance the solvent extraction process.

### 2.3. Recycle use

After the solvent extraction process, the Span 80 was still to be used again. In other words, the Span 80 could be recycled use. Therefore, the heavy oil could be recovered, and the oil recovery would be enhanced.

### 2.4. Viscosity measurement and C/H analysis

The heavy oils were extracted from the Seoul heavy oil by solvents and Span 80 enhanced solvents. And then the heavy oil viscosity was measured by the viscometer (NDJ-5S, Shanghai Youyi Instrument Co. Ltd., Shanghai, China), and the heavy oil element was measured by Elemental analyzer (vario micro cube, Elementar, Langenselbold, Germany).

### 2.5. SARA analysis

In order to analyze the differences among single solvents, complex solvents and Span 80 enhanced solvents, the heavy oils were conducted the SARA analysis. The detailed experiment procedure followed the literature (Marufuzzaman and Henni 2014, Wang et al., 2020).

### 2.6. Wettability analysis

The sands were extracted from the Seoul heavy oil by solvents and Span 80 enhanced solvents. And then the water drops were dripped onto the sands surface, and the contact angles were measured by the instrument (pendant drop method, SL200B, Kono, Seattle, WA, USA). Besides, the water drop retention time was measured.

### 2.7. Zeta potential measurement

Double layer theory indicated that the two layers onto the solids surface (Wu et al., 1999). The first layer was mobile layer, which was the ions adsorption onto the object surface because of the surface charge adsorption. The second layer was slipping plane, which was the opposite charge. The DLVO theory followed the double layer theory (Carstens et al., 2019). Zeta potential was the electrical potential in the slipping plane, but the slipping plane could effectively separate the mobile plane and the solids surface. The zeta potential was the electric potential in the slipping plane and corresponding to the point in the bulk fluid away from the interface. The zeta potential measurement was used to value the heavy oil and sands charges. In this study, we explored the heavy oil and sands zeta potentials in different solution.

## 3. Results and discussion

### 3.1. Single solvent extraction experiment

Fig. 1 showed the temperature, stirring rate and stirring time effect on the heavy oil recovery. Fig. 1(a) showed the increase temperature would increase the heavy oil recovery, and then the oil recovery would remain stable. When the temperature increased from 20 °C to 50 °C, the oil recovery increase was high. When the temperature increased from 50 °C to 70 °C, the oil recovery would remain stable. Fig. 1(b) showed the oil recovery would increase when the stirring rate would increase. When the stirring rate increased from 300 rpm to 500 rpm, the oil recovery increase would be larger. When the stirring rate 500 rpm to 700 rpm, the oil recovery would become stable. Fig. 1(c) showed that the oil recovery would increase when the stirring time increased, and then the oil

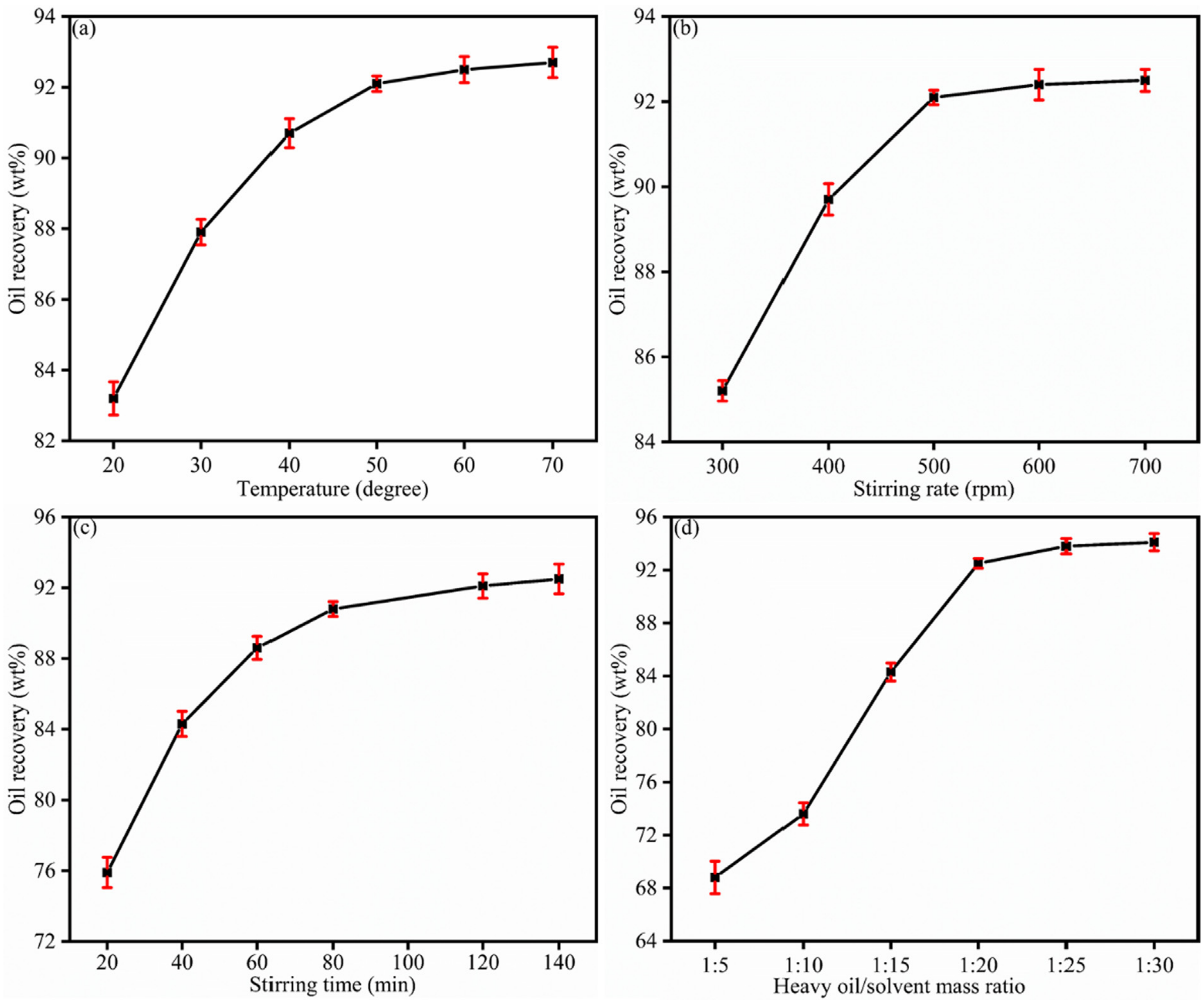


**Fig. 1** The (a) temperature (°C); (b) stirring rate (rpm); (c) stirring time (min); (d) heavy oil/solvent mass ratio effect on oil recovery (wt %).

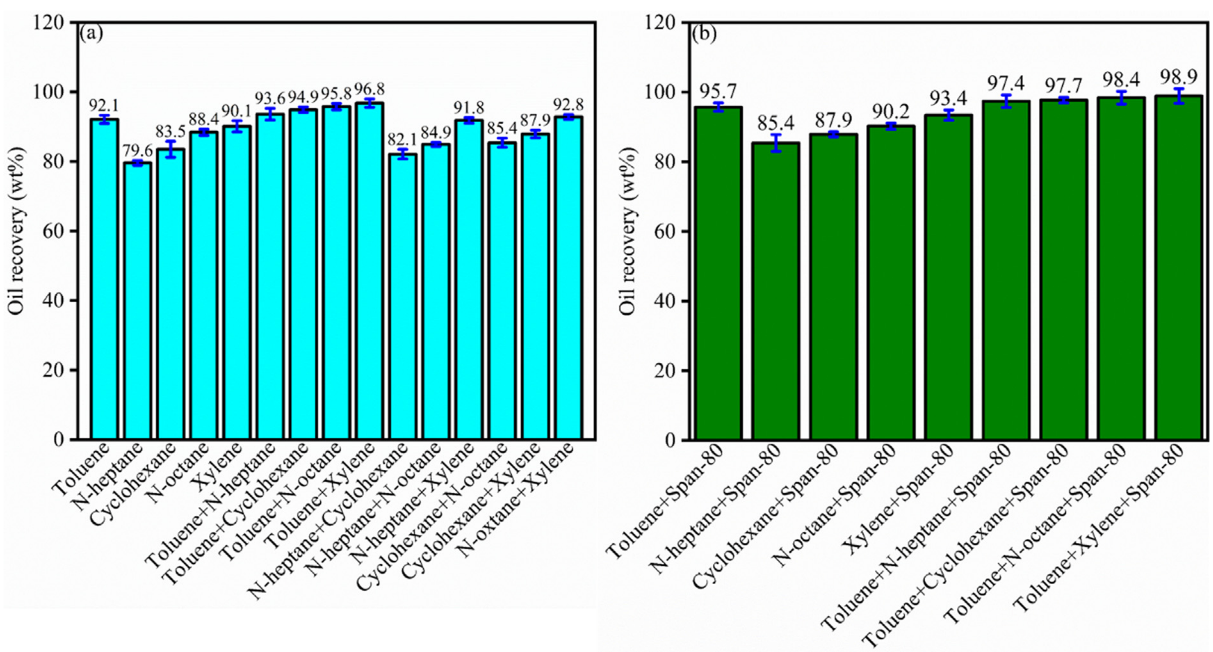


**Fig. 2** (a) Single/complex solvents; (b) Span 80 enhanced single/complex solvents extraction for oil recovery.

recovery would remain stable. Before 80 min, the oil recovery would increase with the stirring time increase. Then the oil recovery would remain stable. Fig. 1(d) showed that the oil recovery would increase when the heavy oil/solvent mass ratio decreased, when the value decreased to 1:20, the oil recovery remained stable.

### 3.2. Heavy oil recovery analysis

Fig. 2(a) showed that the oil recovery by toluene was the highest(Wang et al., 2014, Lin et al., 2017), and the oil recovery was 92.1 wt%. The oil recovery followed the rule: 92.1 wt% (toluene) > 90.1 wt% (Xylene) > 88.4 wt% (N-octane) > 83.5 wt% (Cyclohexane) > 79.6 wt% (N-heptane). The reason was that different solvents showed different solubility parameters. When toluene was combined with n-heptane, cyclohexane, n-octane, xylene, the oil recovery was 93.6 wt %, 94.9 wt%, 95.8 wt%, 96.8 wt%, respectively, and the oil recovery was higher than the individual solvent. The complex solvents could improve the oil recovery. As was shown in Fig. 2(b), the Span 80 could improve the oil recovery by single/complex solvent extraction. When toluene, n-heptane, cyclohexane, n-octane, xylene was combined with Span 80, the oil recovery would increase to 95.7 wt%, 85.4 wt%, 87.9 wt%, 90.2 wt%, 93.4 wt%, respectively, which was higher than the oil recovery extracted by single solvents alone. The highest oil recovery was 98.9 wt% (by toluene + xylene + Span 80).

### 3.3. Heavy oil C/H analysis

As was shown in Fig. 3(a), the C/H of bitumen extracted by toluene was the highest (9.09), and the C/H of bitumen extracted by n-heptane was the lowest (8.15). The higher C/H ratio would be helpful to the oil recovery. Toluene could dissolve most heavy oil components, and therefore the oil recovery would increase, but n-heptane can't dissolve n-heptane, therefore, the C/H ratio would decrease. As was shown in Fig. 3(b), Span 80 could increase the C/H, the results indicated that Span 80 was helpful for the heavy components liberation. When Span 80 was used to enhance the toluene + xylene, toluene extraction, the C/H ratio were 10.17, 9.37, respectively.

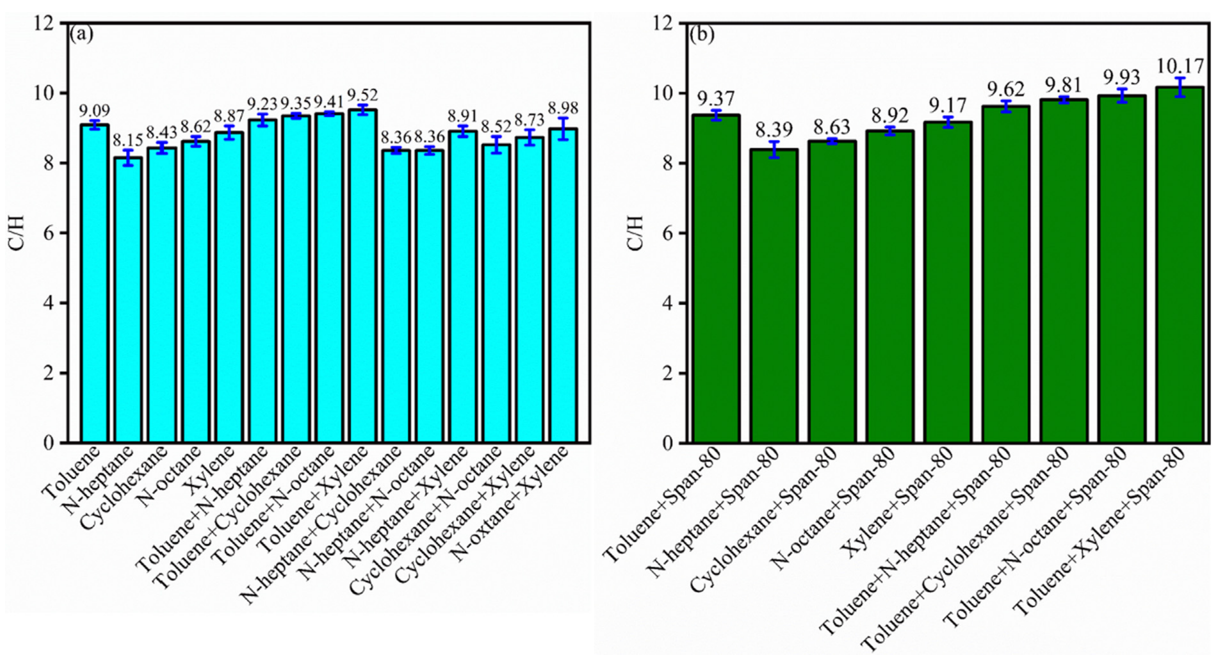


**Fig. 3** The C/H ratio of heavy oil extracted by (a) Single/complex solvents; (b) Span 80 enhanced single/complex solvents.

**Table 1** SARA analysis of the heavy oil extracted by single/complex solvents and Span 80 enhanced solvents.

| Solvents | Saturates (wt%) | Aromatics (wt%) | Resins (wt%) | Asphaltenes (wt%) |
|---|---|---|---|---|
| Toluene | 19.45 | 31.96 | 27.13 | 21.46 |
| N-octane | 19.72 | 32.18 | 26.87 | 21.23 |
| N-heptane | 20.23 | 32.54 | 26.42 | 20.81 |
| Toluene + N-octane | 19.34 | 31.78 | 27.26 | 21.62 |
| Toluene + N-heptane | 19.18 | 31.66 | 27.42 | 21.74 |
| Toluene + Span 80 | 19.11 | 31.34 | 27.69 | 21.86 |
| N-octane + Span 80 | 19.34 | 32.02 | 27.18 | 21.46 |
| N-heptane + Span 80 | 20.07 | 32.29 | 26.68 | 20.96 |
| Toluene + N-octane + Span 80 | 19.14 | 31.64 | 27.44 | 21.78 |
| Toluene + N-heptane + Span 80 | 18.88 | 31.58 | 27.66 | 21.88 |

*3.4. SARA analysis*

The SARA analysis of the heavy oil extracted by single/complex solvents and Span 80 enhanced solvents was shown in Table 1. When the toluene was used to extract heavy oil, the saturates, aromatics, resins and asphaltenes content were 19.45 wt%, 31.96 wt%, 27.13 wt%, 21.46 wt%, respectively. When the n-octane was used to extract heavy oil, the saturates, aromatics, resins and asphaltenes content were 19.72 wt%, 32.18 wt%, 26.87 wt%, 21.23 wt%, respectively. The complex solvents were used, the resins content and asphaltenes content would increase, the saturates and aromatics content would decrease. When Span 80 was used, the resins and asphaltenes content would increase, the saturates and aromatics content would decrease.

*3.5. Wettability analysis*

As was shown in Fig. 4(a), the contact angle of the sands extracted by toluene would be 36.8°, lower than other sands, which meant that the toluene could make sands surface more

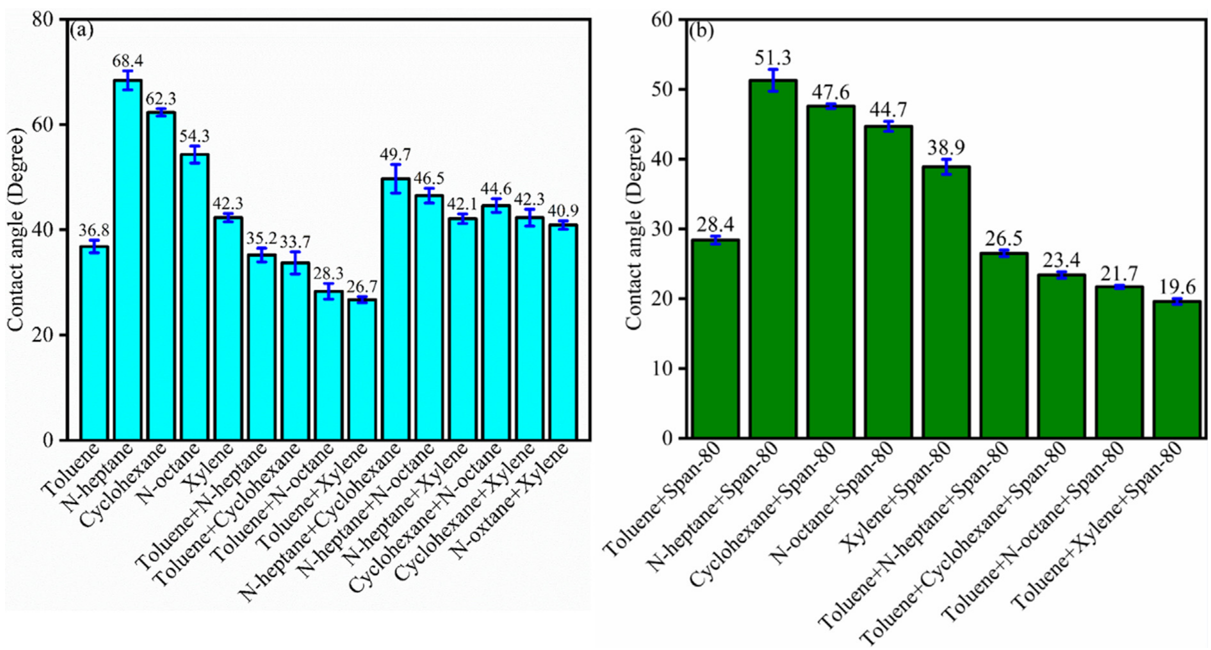


**Fig. 4** The contact angle of the sands extracted by (a) Single/complex solvents; (b) Span 80 enhanced single/complex solvents.

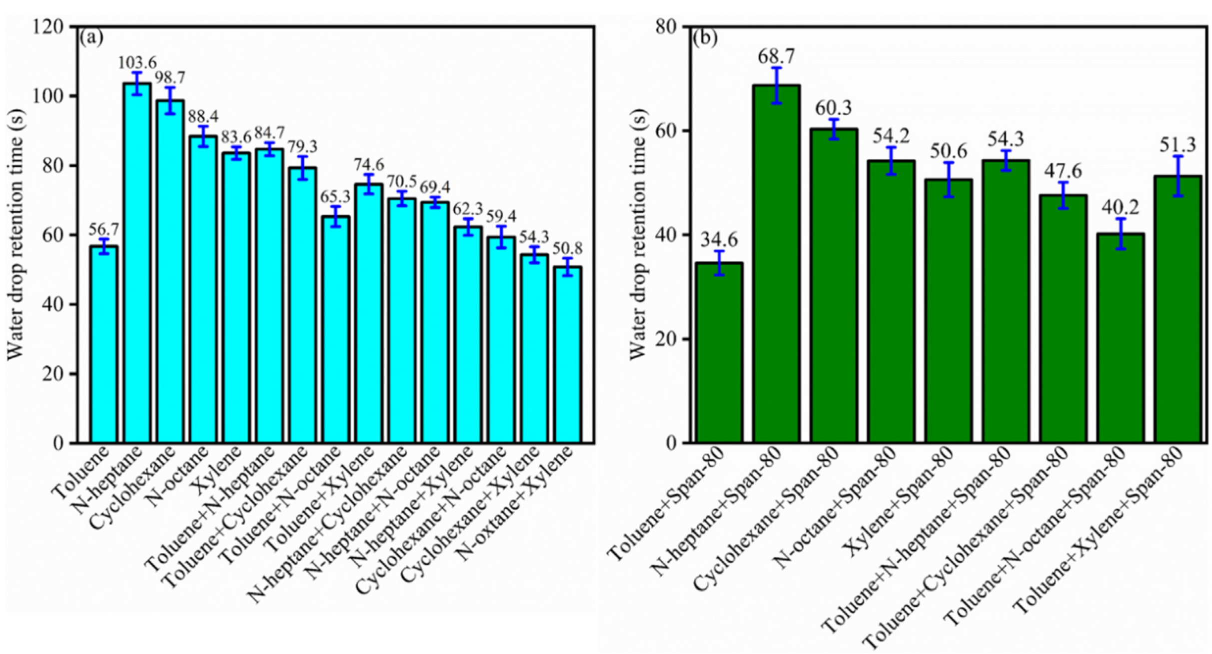


**Fig. 5** The water drop retention time (s) of the sands extracted by (a) single/complex solvents; (b) Span 80 enhanced single/complex solvents.

hydrophilic, and the wettability influence the oil recovery. The highest contact was 68.4° (for n-heptane). When the complex solvents were used extract heavy oil, the contact angle of sands would decrease (Xu et al., 2021). When the sands surface became more hydrophilic, the oil recovery would increase (Ahsaei et al., 2019: Haghighi et al., 2020). The complex solvents could decrease the interaction force between sands and solvents, which decrease the contact angle. Span 80 could make the sands surface more hydrophilic (Fig. 6(d)), namely, the contact angles of viscosities extracted by toluene, cyclohexane, toluene + cyclohexane, toluene + Span 80, cyclohexane + Span 80, toluene + cyclohexane + Span 80 were 36.8°, 62.3°, 33.7°, 28.4°, 47.6°, 23.4°, respectively.

The water drop retention time of water drops was shown in Fig. 5. As was shown in Fig. 5(a), for the single solvents, toluene, n-heptane, cyclohexane, n-octane and xylene could make the sands water drop retention time as 56.7 s, 103.6 s, 98.7 s, 88.4 s, 83.6 s, respectively. The complex solvents could decrease the water drop retention time. As was shown in Fig. 5(b), the Span 80 could decrease the water drop retention time, which meant that Span 80 could make the sands surface more hydrophilic.

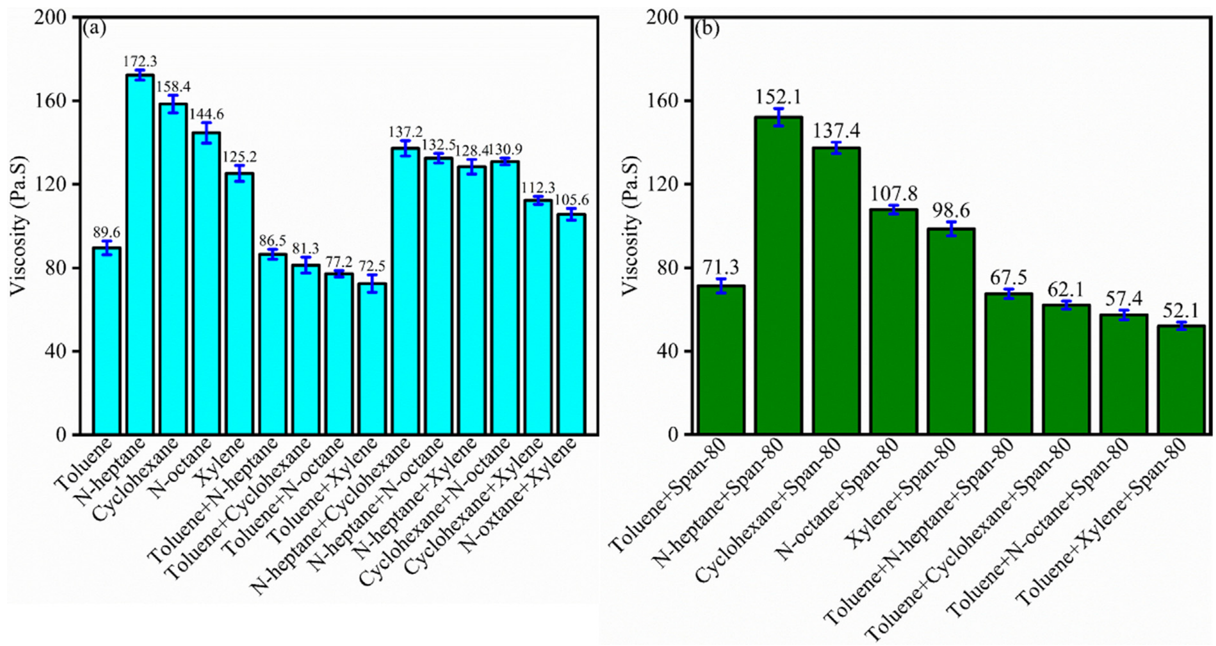


**Fig. 6** The viscosity of heavy oil extracted by (a) Single/complex solvents; (b) Span 80 enhanced single/complex solvents.

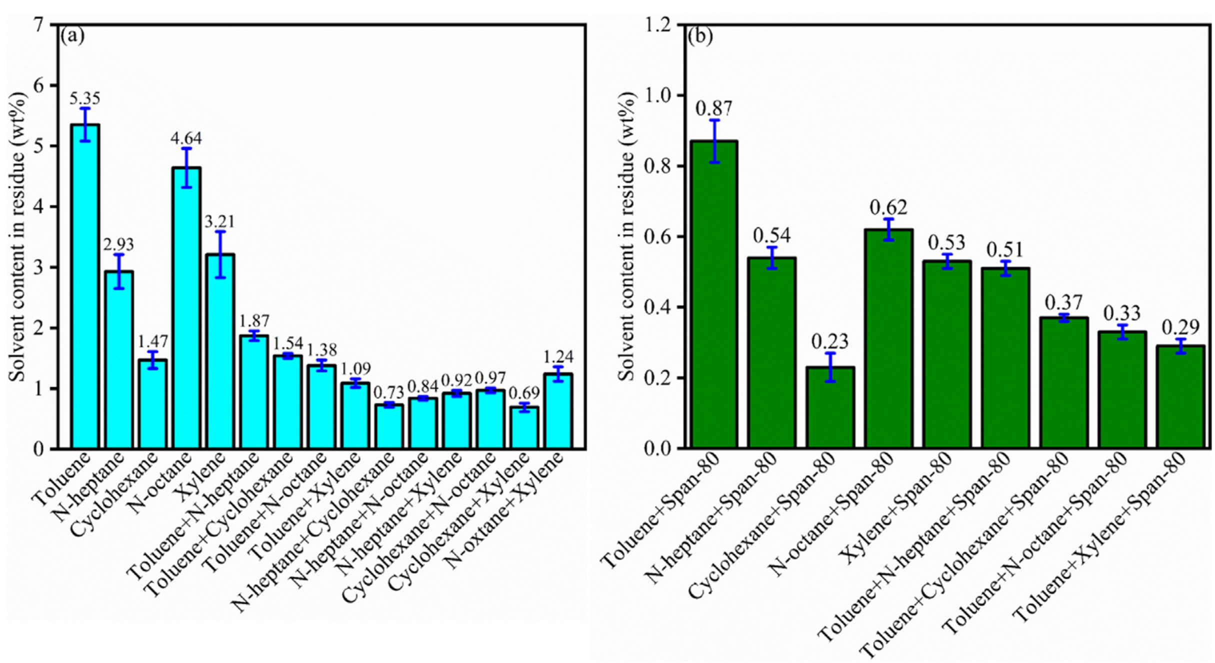


**Fig. 7** (a) Single/complex solvents; (b) Span 80 enhanced single/complex solvents residue content in sands.

*3.6. Viscosity analysis*

As was shown in Fig. 6(a), the heavy oil extracted by toluene, n-heptane, cyclohexane, n-octane, xylene were 89.6, 172.3, 158.4, 144.6, 125.2 Pa.S, respectively. The lowest viscosity was 72.5 Pa.S, which extracted by toluene and xylene at a ratio of 1:1. When the heavy oil viscosities decreased, the heavy oil recovery would increase, because the lower viscosity would be helpful for the heavy oil liberation (Hua 2020, Liu et al., 2021, Zhang et al., 2021). The results indicated that Span 80 could effectively enhance the solvent extraction process. The Span 80 could decrease the heavy oil viscosities (Fig. 6(b)), and the heavy oil viscosities followed the order that single solvent followed. The lowest viscosity was 52.1 Pa.S (toluene + Xylene + Span 80). Span 80 could decrease oil–water interfacial tension, and Span 80 could dissolve into the heavy oil phase, therefore the heavy oil viscosities would decrease.

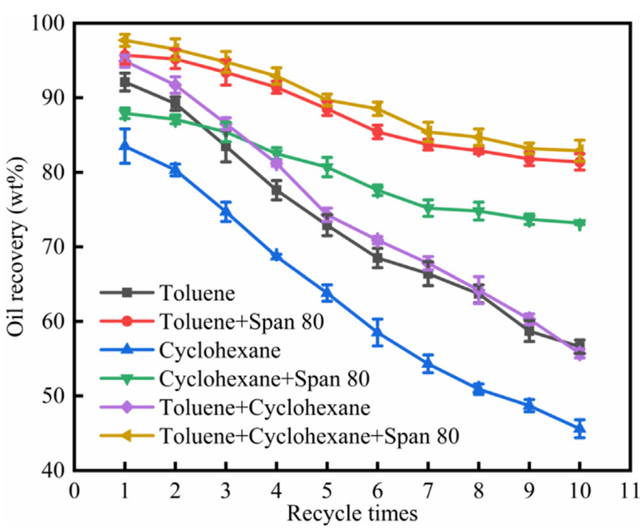


**Fig. 8** The oil recovery versus recycling times.

*3.7. Solvents residue in sands*

The solvents residue in the sands was shown in Fig. 7. Different solvents would remain in the sands, and the amount would be different. Toluene, n-heptane, cyclohexane, n-octane, xylene solvents residue was 5.35 wt%, 2.93 wt%, 1.47 wt%, 4.64 wt %, 3.21 wt%, respectively (Fig. 7(a)). Cyclohexane showed the lowest solvent residue, which was that cyclohexane showed low interaction force with the sands. Besides, toluene showed the highest solvent residue among other solvents. When complex solvents were used extract the heavy oil, the solvents residue would decrease. The complex solvents would decrease the solvents and sands interaction force. The lowest solvents residue was 0.69 wt% (by cyclohexane + xylene).

*3.8. Recycle use*

Recycle use efficiency could be used to value the Span 80 effect. Fig. 8 showed the oil recovery value with different recycling times. Without Span 80, the oil recovery decreased a lot when the recycling times increase. When the recycling times increased to 5, the heavy oil recovery by toluene, cyclohexane, toluene + cyclohexane were 72.9 wt%, 63.8 wt%, 74.3 wt%, respectively, and the heavy oil recovery by toluene + Span 80, Cyclohexane + Span 80, toluene + cyclohexane + Span 80 were 88.5 wt%, 80.7 wt%, 89.7 wt%, respectively. The heavy oil recovery extracted by solvents only was much higher than that extracted by solvents and Span 80. Besides, when the recycle times reached 7, the oil recovery by solvents and Span 80 remained stable, but the recovery by solvents only would

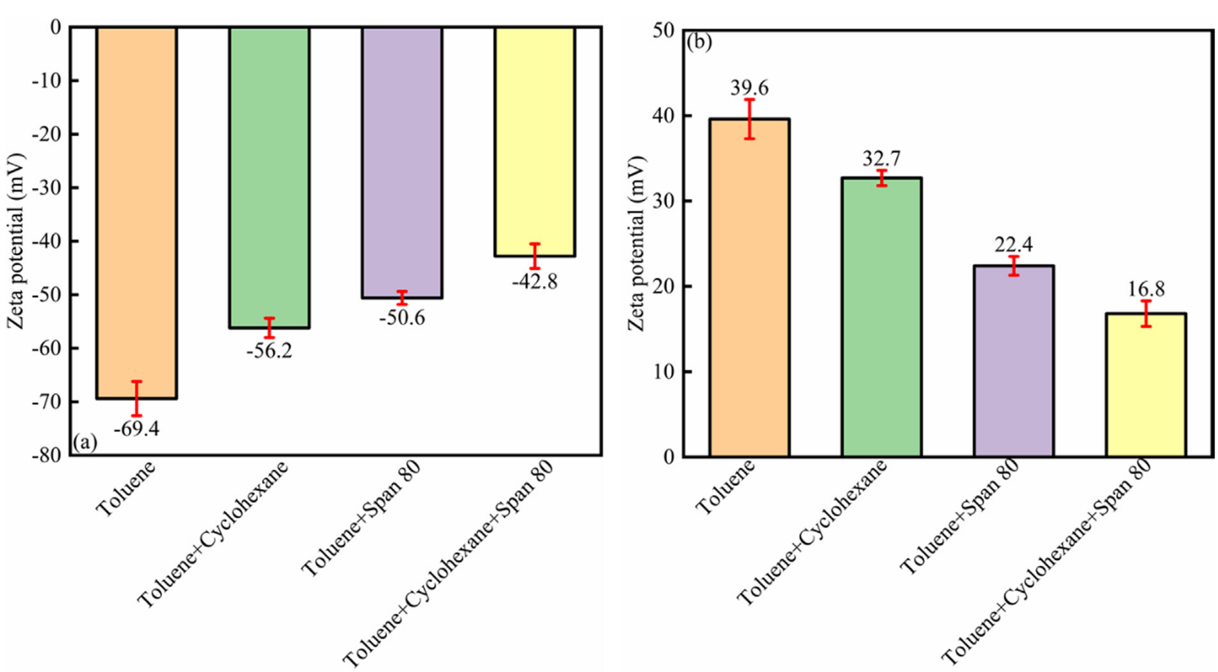


**Fig. 9** The zeta potentials of (a) heavy oil; (b) sands extracted by different methods in deionized water.

decrease further. The results showed that Span 80 could obtain high oil recovery after many recycle times. Only the surfactant could be recycled use, the process could become industrialized (Xu et al., 2018, Liu et al., 2022).

### *3.9. Zeta potential measurement*

Zeta potentials could measure the surface charges of solution system (Liu et al., 2006, Yahya et al., 2019). Fig. 9 showed that the heavy oil and sands zeta potentials. For heavy oils, when different solvents were used to heavy oil, the zeta potentials were different. When toluene, toluene + cyclohexane, toluene + Span 80, toluene + cyclohexane + Span 80 were used, the heavy oil zeta potentials were −69.4 mV, −56.2 mV, −50.6 mV, −42.8 mV, respectively. When these solvents were used to extract the heavy oil, the sands zeta potentials were −39.6 mV, 32.7 mV, 22.4 mV, 16.8 mV, respectively. The results showed that Span 80 could decrease the zeta potentials absolute value, which decrease the corresponding heavy oil and sands charges (Tang et al., 2021). Then the interaction force between heavy oil and sands would decrease, because the attraction force would decrease (Cui and Pang 2017).

## 4. Conclusions

In this study, the Span 80 effect on solvent extraction for heavy oil recovery, and the detailed conclusions were as follows:

(1) Both single solvent and complex solvents could help enhance oil recovery, and the complex solvents could increase the heavy oil recovery, increase heavy components content (resins, asphaltenes).
(2) Span 80 could effectively alter the oil–water interfacial property, and decrease the oil–water interfacial tension. The Span 80 could increase the heavy oil recovery. The Span 80 surfactants could be recycled use, and the oil recovery could remain high after several times.
(3) The Span 80 could be used to decrease the solvents residue in sands, and make the sands surface more hydrophilic, and the Span 80 could decrease the absolute value of the sands and bitumen, and then the interaction force between sands and bitumen was low.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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