

## Analysis of Oilfield Wastewater Treatment Effect

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### Abstract

**In order to study the effect of different low temperature plasma treatment technology on the oil field's abolishment, the influence of low temperature plasma discharge frequency, scale inhibitor and the combined application of low temperature plasma and scale inhibitor on the quality of heavy oil wastewater and distilled water was analyzed. When the discharge frequency of low temperature plasma was  $900\text{s}^{-1}$ , the decrease of oil content was 50.56%. The scale inhibitor also reduced the oil content of the heavy oil wastewater and the distilled water. However, the combined use of low temperature plasma and scale inhibitor would increase the content of oil and the content of metal ions in distilled water. The increase of oil content was 56%. The results showed that the low temperature plasma had obvious effect on reducing the oil content and  $\text{SiO}_2$  content in distilled water. Therefore, this study confirms the influence and mechanism of low-temperature plasma treatment on the quality of oil field wastewater.**

### Keywords

**Oilfield wastewater; low temperature plasma; evaporation; pretreatment; scaling.**

### 1. Introduction

The evaporation, concentration and recovery of oilfield wastewater as boiler feedwater is a key link to mitigate heavy oil wastewater's environmental pollution to the water body and realize resource recycling [1-3]. In the process of evaporating and concentrating oil field wastewater, particles such as  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{SiO}_2$  in the solution will form dirt and adhere to the evaporator tube wall. The longer the time, the thicker the deposition. The fouling reduces the heat transfer performance of the evaporator and affects the production safety [4]. The increase of the  $\text{Cl}^-$  concentration in the wastewater will also accelerate the corrosion of equipment and pipelines and even affect the quality of the condensate [5]. With the existence of these problems, the technology of evaporating, concentrating, recycling, and utilizing oil field wastewater faces great challenges [6]. Once the key technologies for the oilfield thermal recovery process are solved, the energy consumption and costs in the operation of the oilfield can be reduced, which will contribute to the sustainable development of the oilfield [7].

At present, there are many studies on the application of low-temperature plasma treatment of organic wastewater [8-10]. Low-temperature plasma water treatment technology has unique advantages and high pollutant removal efficiency. It has a good application prospect. However, the application of low-temperature plasma in the pretreatment of evaporative thickening of heavy oil wastewater has been rarely reported in terms of promoting the effect and the quality of heavy oil wastewater and distilled water [11]. There are many types of plasma discharges. It can be divided into electron beam, glow discharge, corona discharge, dielectric barrier discharge, sliding arc discharge, high voltage pulse discharge and so on. Physical water treatment technology is an environmentally friendly method for degrading organic materials that are difficult to decompose [12]. Low temperature plasma technology is one of them. In this study, high-voltage pulsed discharges were used to generate low-temperature plasma. Then, it was used to treat heavy oil wastewater, and the effects of discharge frequency, scale inhibitors. The combined use of low temperature plasma and scale inhibitors on the quality of heavy oil wastewater and distilled water were analyzed to verify the effect of low temperature plasma on water quality.

## 2. Experimental Program

At present, the mechanism of action of low-temperature plasma and wastewater includes various free radicals, electric fields, strong ultraviolet radiation, high-pressure shock waves, ozone, and high-energy electrons bombarding substances in solution [13]. It can be divided into four basic processes: primary process, secondary process, regeneration process and subsidiary process. In this study, the functions of ionization, radiation, oxidation, degradation, cavitation, and pyrolysis of low-temperature plasmas were used to decompose some of the organics in heavy oil wastewater to achieve the purpose of reducing oil content in heavy oil wastewater [14]. At the same time, the oil content, SiO<sub>2</sub> content, and metal ion content of distilled water are reduced. The conductivity of distilled water is reduced. The pH of distilled water is adjusted. The quality of distilled water was increased to meet the standards for heavy oil thermal recovery boiler feed water [15].

The process of treating oilfield wastewater with low temperature plasma and falling film evaporation is shown in Figure 1. The generating device adopts a plurality of sets of line-tube-type electrode annular devices, and the falling film evaporator adopts an evaporation system composed of a plurality of heat exchange tubes. The steam generated by the electric boiler is used as a heat source. The waste water is lifted by the circulation pump to the upper part of the falling film evaporation pipe and distributed to the evaporation pipe through a film applicator to circulate and evaporate. After the steam is defoamed, it enters the condenser to recover the condensate. The experimental indicators are PH value, conductivity, SiO<sub>2</sub> content, oil content, metal ion content and so on. The UV-1700 infrared spectrophotometer was used to measure the SiO<sub>2</sub> content. The ET1200 infrared spectrophotometer was used to determine the oil content, and the ICP-MS7700 inductively coupled plasma mass spectrometer was used to determine the metal ion content.

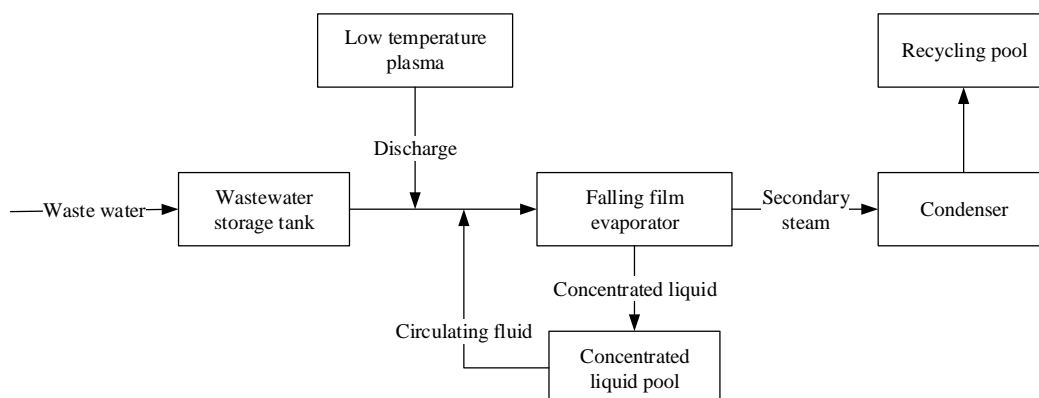


Figure 1. Flow diagram of experiment for viscous oil waste water treatment by non-thermal plasma

## 3. Results and Discussion

Oilfield wastewater undergoes preliminary treatment. The main components and parameters are shown in Table 1.

Table 1. Water quality parameters of viscous oil waste water

Component	$\rho$ /(mg/L)
Na <sup>+</sup>	37.33
K <sup>+</sup>	152.2
Mg <sup>2+</sup>	13.99
Fe <sup>2+</sup>	0.51
Cu <sup>2+</sup>	0.17
Ca <sup>2+</sup>	109.9
Oil	25.18

### 3.1 Effect of Low-temperature Plasma Discharge Frequency on Wastewater Oil Content

Table 2 shows the oil content of waste water samples after low-temperature plasma treatment at different discharge frequencies. From Table 2, it can be seen that as the frequency of low-temperature plasma discharge increases, the oil content tends to decrease. As the discharge frequency increases, the number of active particles increases. Oil-based organic matter is degraded into small non-oil molecules. Therefore, the oil content in the water decreases, but the energy consumption of the low-temperature plasma also increases.

Table 2. Oil content of viscous oil wastewater after different low temperature plasma discharge frequency treatment

Discharge frequency of non-thermal plasma/s <sup>-1</sup>	$\rho(\text{Oil})/(\text{mg/L})$	Oil retortion rate/%
Untreated	25.18	
300	16.15	35.86
500	15.32	39.16
900	12.45	50.56

### 3.2 Effect of Scale Inhibitor on Waste Water Oil Content

Table 3 shows the oil content of heavy oil wastewater after treatment under different experimental conditions. From table 3, the scale inhibitor can not only inhibit the fouling, but also reduce the oil content in the wastewater. The scale inhibitor also has the effect of strong adhesion, complexation and solubilization. The petroleum substance in the waste water is dissolved in the solution, and even is converted into non-oil organic matter, which leads to the decrease of the oil content in the wastewater. However, when the low-temperature plasma is used in combination with a scale inhibitor, degradation of the low-temperature plasma may cause the scale inhibitor to partially decompose and fail. At the same time, the energy of the plasma is also consumed, so that the waste oil content is higher than when a certain process alone acts.

Table 3. Oil content of heavy oil wastewater treated with different experimental conditions

Process condition		$\rho(\text{Oil})/(\text{mg/L})$	Oil retortion rate/%
Discharge frequency of non-thermal plasma/s <sup>-1</sup>	w (Scale inhibitor)/( $\mu\text{g/g}$ )		
Untreated		25.18	
500	0	15.32	39.16
-	5	13.69	45.63
500	5	17.43	30.78

### 3.3 Effect of Different Treatment Processes on the Quality of Treated Distilled Water

The conductivity, SiO<sub>2</sub> content, and oil content of distilled water for steam injection boilers are the key indicators of their quality. The content of soluble solids in the solution directly determines the conductivity of the solution. The more dissolved solids, the more conductive the solution. The steam injection boiler water supply indicator specifies the PH value within the range of 7.5-11.0. SiO<sub>2</sub> in distilled water is prone to silicon scale formation and is difficult to remove, which affects boiler operation. The heavy oil wastewater treated by various processes is evaporated. After concentration, the lead content of distilled water, the SiO<sub>2</sub> content and the oil content were determined.

Figure 2 shows the change of the conductivity of distilled water obtained by treating various heavy oil wastewaters with concentration. As can be seen from Figure 2, the low-temperature plasma discharge frequency is 500 s<sup>-1</sup>. The conductivity of the distilled water of the heavy oil wastewater is the smallest. It shows that a series of complicated physical and chemical processes are generated in low-temperature plasma and heavy oil wastewater, and part of the organic matter in the water is

eventually mineralized into  $\text{CO}_2$  and  $\text{H}_2\text{O}$ . Low-temperature plasma can promote precipitation of metal ions and  $\text{CO}_3^{2-}$  in the solution, which leads to a significant reduction in the probability of  $\text{CO}_2$  being introduced into distilled water. These effects effectively reduce the impurities in distilled water and reduce the conductivity of distilled water. Low-temperature plasma and scale inhibitors are used in conjunction with the process. Although low-temperature plasma can partially mineralize organic matter into  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , it does not promote the conversion of  $\text{CO}_2$  to  $\text{CO}_3^{2-}$ . Instead, it is carried by steam, which increases the conductivity of distilled water.

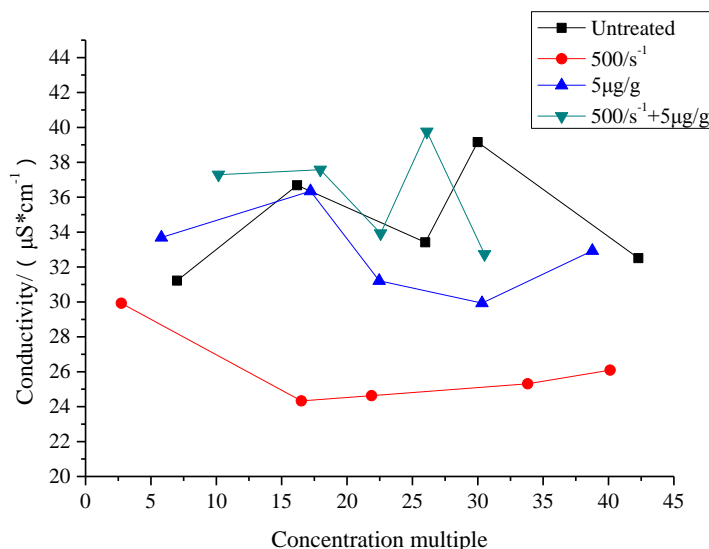


Figure 2. The change of the electrical conductivity of distilled water from the wastewater treatment by various processes with the concentration multiplier

Figure 3 shows the change of the PH value of the distilled water obtained by treating various heavy oil wastewaters with concentration. As can be seen from Figure 3, the pH of distilled water tends to decrease with the increase in the concentration factor.  $\text{Fe}^{2+}$  or  $\text{Mg}^{2+}$  in the solution may be deposited in the form of hydroxides, resulting in a decrease in the pH of the wastewater and a gradual decrease in the pH of the distilled water.  $\text{Fe}^{2+}$  may be oxidized to  $\text{Fe}^{3+}$  so that it is precipitated. As the concentration of  $\text{Mg}^{2+}$  increases, it is also possible to form precipitates with  $\text{OH}^-$ .

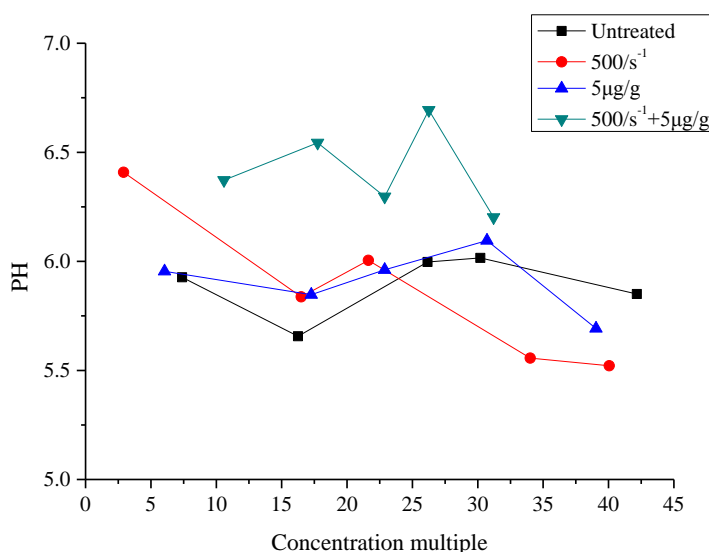


Figure 3. The change of pH value of distilled water from heavy oil wastewater treatment with the concentration multiplier

As can also be seen from Figure 3, the effects of the three processes on the pH of the distilled water obtained are different. The low-temperature plasma contributes to the precipitation of metal ions and  $\text{CO}_3^{2-}$  ions in the solution, which causes the pH of the solution to gradually decrease. As a result, the pH of distilled water is also reduced, and the reduction is large. The other two kinds of pretreatment processes are less effective than the low temperature plasmas, and the decrease in the PH value is less than that of low temperature plasmas.

Table 4 lists the  $\text{SiO}_2$  and oil content of distilled water from various processes for treating heavy oil wastewater. It is clearly shown in the table that low temperature plasma can reduce the content of  $\text{SiO}_2$  in distilled water, while the scale inhibitor is not obvious in reducing the content of  $\text{SiO}_2$  in distilled water. Low temperature plasma can promote the deposition of silicate in the solution and reduce the opportunity for steam to be brought into the distilled water. Therefore, it reduces the content of  $\text{SiO}_2$  in distilled water. If the low temperature plasma is combined with the scale inhibitor, it cannot play the role of low temperature plasma, that is, it cannot play the role of reducing the  $\text{SiO}_2$  content of distilled water.

At the same time, it can be seen that both low temperature plasma and scale inhibitor can effectively reduce the oil content of distilled water, and the reduction rate is 27.42%% and 38.71%, respectively. If a low temperature plasma is combined with a scale inhibitor, the oil content of the distilled water is increased to 56%. The reason is that the low temperature plasma also partially degrades the scale inhibitor. Meanwhile, the decomposition of the scale inhibitor consumes the energy and the active group produced by the low temperature plasma, resulting in the increase of the oil content.

Table 4.  $\text{SiO}_2$  content of distilled water treated with different experimental conditions

Process condition		$\rho(\text{SiO}_2)/(\text{mg/L})$	$\rho(\text{Oil})/(\text{mg/L})$
Discharge frequency of non-thermal plasma/ $\text{s}^{-1}$	w (Scale inhibitor)/( $\mu\text{g/g}$ )		
Untreated		2.23	0.62
500	0	0.67	0.45
-	5	2.23	0.38
500	5	1.89	0.97

#### 4. Conclusion

When the oil field wastewater is reused, poor water quality will cause more steam, salt and other impurities in the steam generated by the boiler, which will directly affect the safe operation of the equipment. Therefore, it is necessary to monitor the quality of distilled water collected from the evaporation of oil field waste water at any time. Low temperature plasma is produced by high voltage pulse discharge point. Then, it is used to treat heavy oil wastewater. The effects of the combined use of discharge frequency, scale inhibitor and low temperature plasma and scale inhibitor on the water quality of heavy oil wastewater and distilled water were analyzed. The results show that low temperature plasma can help to reduce the oil content and  $\text{SiO}_2$  content of heavy oil wastewater and distilled water. The scale inhibitor can reduce the oil content of heavy oil wastewater and distilled water. It has no obvious effect on the content of  $\text{SiO}_2$ . However, when the low temperature plasma and scale inhibitor are combined in the oil field wastewater, the oil content of the distilled water is increased.

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