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# Removal of colloidal precipitation plugging with high-power ultrasound

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ABSTRACT

Petroleum is a continuous and dynamically stable colloidal system. In the process of oil extraction, transportation, and post-treatment, the stability of the petroleum sol system is easily destroyed, resulting in asphaltenes precipitation that can make pore throat, oil wells, and pipelines blocked, thereby damaging the reservoir and reducing oil recovery. In this paper, removing near-well plugging caused by asphaltene deposition with high-power ultrasound is investigated. Six PZT transducers with different parameters were used to carry out the experimental study. Results show that ultrasonic frequency is one important factor for removing colloidal precipitation plugging in cores, it could not be too high nor too low. The optimum ultrasonic frequency is 25 kHz; Selecting transducers with a higher power is an effective way to improve the removal efficiency. The optimum ultrasonic power is 1000 W. With the increase of ultrasonic treatment time, the recovery rate reaches the maximum and tends to be stable. ultrasonic processing time should be controlled within 120 min. Besides, three methods — ultrasonic treatment alone, chemical injection alone, and ultrasound-chemical method — for removing colloidal precipitation plugging are compared. Results indicate that the ultrasound-assisted chemical method is better than chemical injection alone or ultrasonic treatment alone to remove colloidal sediment in the core. Finally, the mechanism of the ultrasonic deplugging technique is analyzed from three aspects: cavitation effect, the thermal effect, and mechanical vibration.

## 1. Introduction

Ultrasonic oil recovery is a kind of physical oil recovery technology. As early as the 1950s, the United States and the former Soviet Union began to study the technology and applied it to actual production. By the 1970s, with the rapid development of ultrasonic technique and the further understanding of ultrasonic characteristics, ultrasound-enhanced oil recovery technique has attracted more and more attention in oil production. In the early 1990s, this technique was widely applied in the former Soviet Union and the United States, it can increase oil production by 40–60% and oil recovery by more than 10% [1–5].

Poesio et al. [6] studied ultrasonic plugging removal in porous media through experiments, establish a microscopic theoretical model to calculate the ultrasonic force on the particles, and analyze and calculate the shedding conditions of the deposited particles on the pore wall [7]; Em. Roberts et al. [8] carried out the experimental study on the removal of paraffin deposition and polymer plugging in sandstone core by ultrasonic method. The results show that the ultrasonic wave has an obvious effect on paraffin deposition, but a poor effect on polymer contamination. They believe that it is not feasible to use ultrasound alone to remove polymer plugging; Adinathan Venkitaraman et al. [9] used ultrasonic waves to remove core pollution caused by drilling fluid and particle migration. The results show that the effects of ultrasonic waves on the two kinds of plugging are affected by ultrasonic power, processing time, and displacement flow; U.k.gollapudi et al. [10] carried out an experimental study on asphaltene deposition removal in core by ultrasonic treatment. The main mechanism is that ultrasonic cavitation and heat action reduce the viscosity of crude oil, enhance the flow capacity of crude oil, and the release of asphaltene deposition increases the fluid flow; Brian Champion et al. [11] confirmed the feasibility of near-well plugging removal by ultrasonic treatment through field tests and theoretical studies. The results show that ultrasonic treatment can remove various formation pollution near the well zone, and the improved method of the ultrasonic transducer is

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put forward; Tom W. Bakker et al. [12] studied the phenomenon of downhole ultrasonic cavitation, and the factors influencing ultrasonic near-wellbore removal were given; Sau Wai Wong et al. [13] studied the effect of ultrasonic irradiation on the near-well zone, compared the ultrasonic near-well treatment with traditional stimulation measures, discussed the mechanism of ultrasonic stimulation, and put forward the key issues to be improved in ultrasonic recovery technology; Jose Gil Cidoncha reviewed the development history of ultrasonic oil recovery technology, studied the mechanism of ultrasonic oil recovery, and listed some field application examples [14]; Fairbanks and Chen studied the effect of heat generated by ultrasonic waves on fluid flow in porous media [15]. The results show that ultrasonic irradiation can increase the fluid seepage velocity, but its mechanism still needs further study.

It has many advantages, such as low cost, simple process, strong penetration, large radius of treatment, no pollution, and wide application [18–20]. Although some preliminary research works have been carried out on the mechanism and basic laws of ultrasonic production increase and injection. However, it is still at the level of qualitative interpretation, it is impossible to select the best way and optimize the technical parameters according to the specific conditions of the reservoir and oil-water well. Therefore, field application is almost based on experience [16–22]. In this paper, research on removing colloidal precipitation plugging with high-power ultrasound is investigated. The main factors and laws that influence the effect of ultrasonic plugging removal are studied to provide a reliable basis for the optimization design of the process parameters of ultrasonic near-well treatment.

## 2. Experimental condition

Research on removing colloidal precipitation plugging in cores by high-power ultrasound for enhanced oil recovery in investigated using a self-developed oil recovery dynamic simulation system. The structure of the simulation system is shown in Fig. 1. The ultrasonic system is its core component. Six PZT transducers with different parameters are used to carry out experimental study: transducer #1 (18 kHz, 1000 W), transducer #2 (22 kHz, 1000 W), transducer #3 (25 kHz, 1000 W), transducer #4 (30 kHz, 1000 W), transducer #5 (40 kHz, 100 W), transducer # 6 (50 kHz, 200 W). Besides, the oil–water displacement system (ring pressure is 0–50 MPa), constant-flux Pump, balance, core evacuation-saturating device, and water purifier are also used in the experiment.

The ultrasonic deplugging system is mainly composed of an ultrasonic transducer, a core holder, and a core sample (Fig. 2).

Fig. 3 shows three types of artificial core samples. Gas logging permeabilities of the three core samples are 30 × $10^{-3}$ μm$^2$, 80 × $10^{-3}$ μm$^2$and 150 × $10^{-3}$ μm$^2$ respectively. Diameter and length) of the three core samples are all 2.5 cm and 7 cm respectively. The composition of the sample is quartz (54%), feldspar (39%), carbonate (2%), and clay (5%). Besides, two chemical agents — hydrochloric acid solution and slurry acid — are used for investigating the experiment. Volume fractions of them are 10% and 5% respectively.

## 3. Influence of different factors on experimental results

### 3.1. Ultrasonic frequency

The effect of ultrasonic frequency on the removal of core colloidal precipitation with different initial gas permeability is studied. The influence of ultrasonic frequency on the removal rate is shown in Figs. 4–6.

As shown in Figs. 4–6, compared with the other five transducers, transducer #3 has the best removal effect on colloidal precipitation in three core samples with different initial permeability. After treatment with transducer # 3, the permeability recovery rates of the three samples are 31.0%, 27.6%, and 23.5% respectively. Therefore, it can be seen that lower ultrasonic frequency is beneficial to the removal of colloidal sediment in the cores.

Due to the loss of sound energy is proportional to frequency, the energy loss of transducer # 3 is greater than transducer # 1 and transducer # 2 when the three transducers have the same power. But why transducer # 3 is better than transducer #1 or transducer # 2 for removing colloid precipitation plug? The only explanation is that temperature has a greater impact on removing the plug caused by colloid precipitation: more heat energy converted to form the loss of transducer # 3 promotes removing colloidal precipitation plugging in cores. The result indicates that ultrasonic frequency is one important factor for removing the plugging in cores, it should not be too high nor too low.

### 3.2. Power

It indicated from Figs. 4–6 that transducer #1~#3 are better than transducer #4 ~ #6 in removing colloidal precipitation from cores. In addition, after treatment with transducer # 6, the permeability recoveries of the three cores are higher than that treated with transducer # 4 or transducer # 5. It can be seen from Section 2 that the ultrasonic power of transducer # 1~ # 3 are higher than that of transducer # 4~# 6. Therefore, it can be inferred from the experimental results and Section 2 that ultrasonic power cannot be ignored in removing colloidal precipitation from the core, selecting transducers with a higher power is an effective way to improve the removal efficiency. The optimum ultrasonic power is 1000 W.

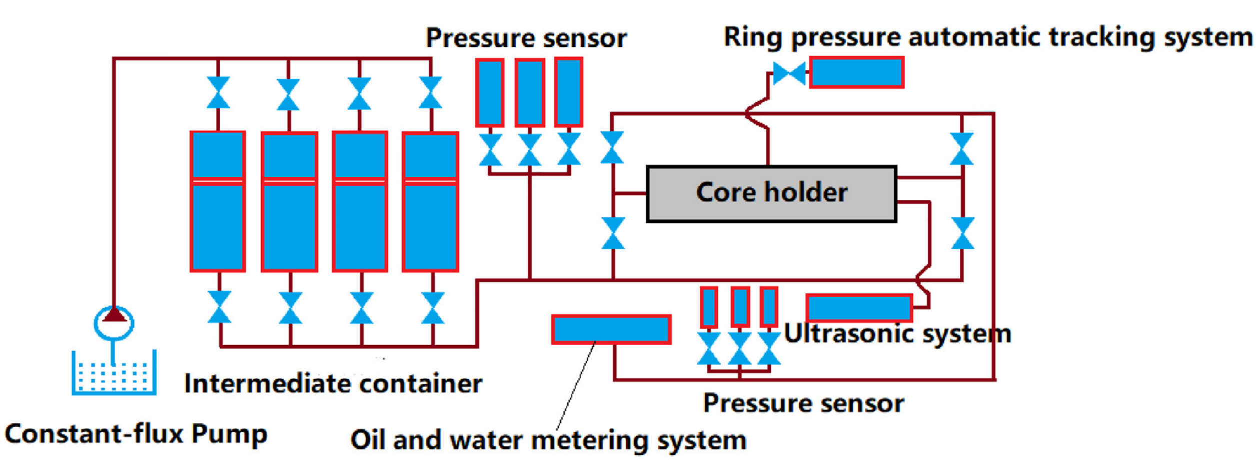


**Fig. 1.** The self-developed oil recovery dynamic simulation system.

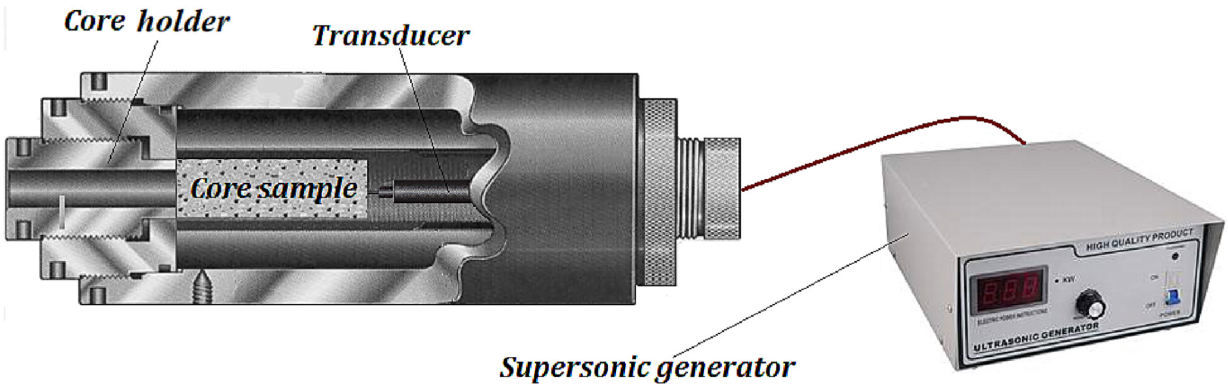


**Fig. 2.** The experimental flow diagram of ultrasonic plug removal.

**Fig. 3.** Core samples.

### 3.3. Initial gas permeability of the core

How does the initial gas permeability of core affect the removal efficiency of colloidal precipitation in the core? The experiment result is shown in Fig. 7.

It indicates from Fig. 7 that the removal efficiency of colloidal precipitation in the cores after ultrasonic treatment gets worse with the increase of initial gas permeability. The physical state of colloid after ultrasonic treatment is fluid. The core diameter increases with the increase of core initial permeability. The flow rate of colloid decreases with the increase of core pore diameter after ultrasonic treatment. When the flow rate decreases, the plug caused by colloidal precipitation plugging is easy to occur. The result provides an important basis for the on-site operation of near-well ultrasonic treatment technology.

### 3.4. Ultrasonic treatment time

According to the experimental results in Section 5, transducer #3 is more effective for removing colloidal precipitation from the core than the other five transducers. Therefore, Therefore, transducer #3 is selected for this experimental study. Experimental results are shown in Fig. 8.

It indicates from Fig. 8 that the maximum permeability recovery rates of three cores are 32.9%, 28.5%, and 26.8% respectively after treatment by transducer # 3. Ultrasound has a better effect for removing colloidal precipitation plugging in cores within 0–60 min, however, with the increase of ultrasonic treatment time, the recovery rate reaches the maximum and tends to be stable. Therefore, the ultrasonic treatment time should be controlled within 120 min.

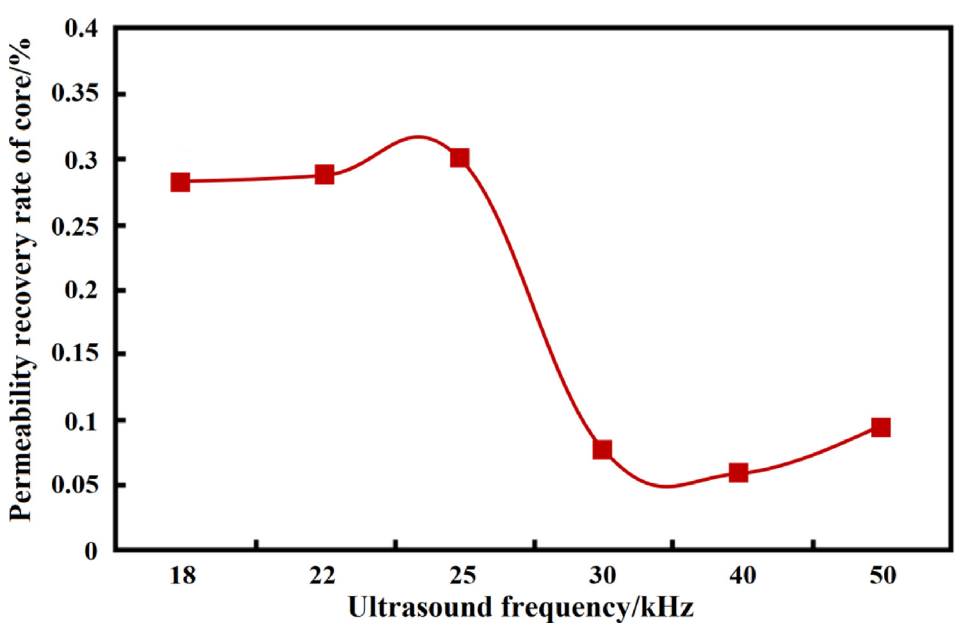


**Fig. 4.** The effect of different frequency on removal rate of core colloidal precipitation (gas logging permeability is 30 × $10^{-3}$ μ$m^2$).

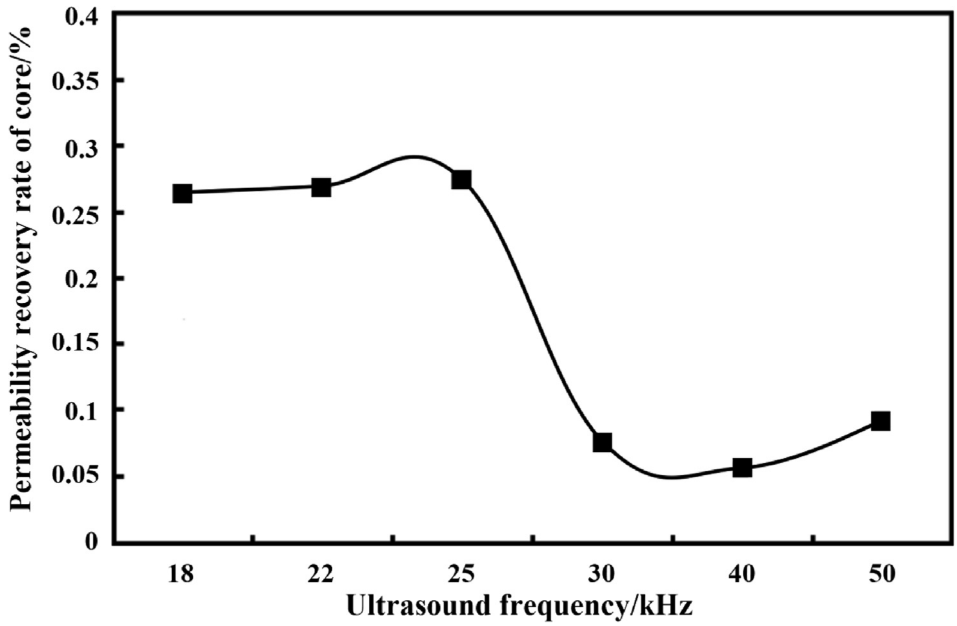


**Fig. 5.** The effect of different frequency on removal rate of core colloidal precipitation (gas logging permeability is $80 \times 10^{-3}$ μm$^2$).

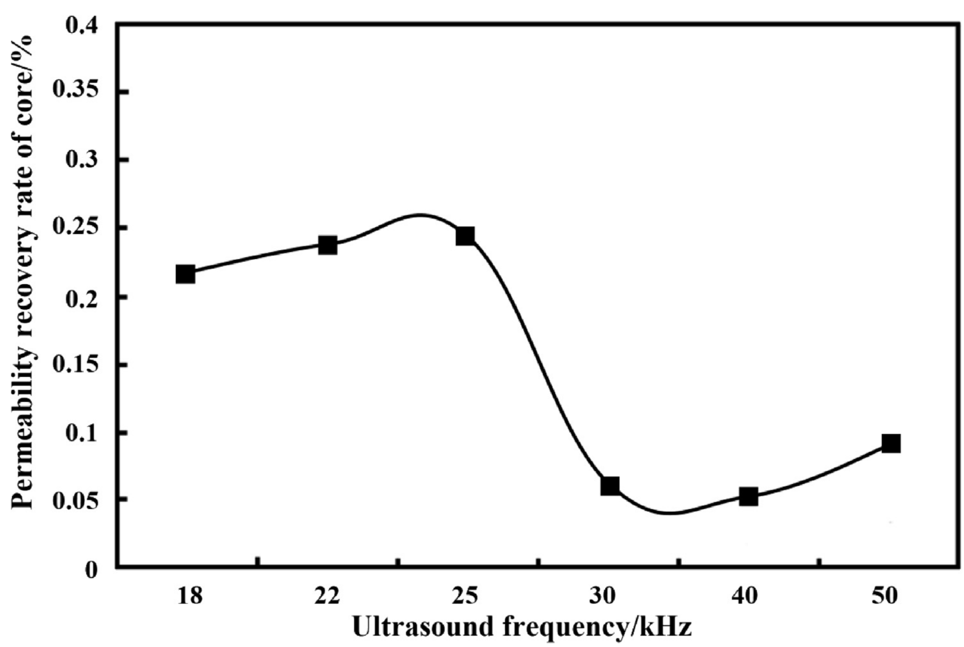


**Fig. 6.** The effect of different frequency on removal rate of core colloidal precipitation (gas logging permeability is $150 \times 10^{-3}$ μm$^2$).

## 4. The comparison of removing colloidal precipitation plugging in cores by ultrasonic treatment, chemical injection, and ultrasound-chemical method

Whether ultrasonic treatment is better than chemical injection in removing colloidal precipitation from the cores? Whether the ultrasound-chemical method is more effective than ultrasonic treatment alone or chemical injection in removing colloidal precipitation from the cores? These two questions will be resolved in this section. As can be seen from Section 5 that transducer #3 is more effective than the other five transducers. Therefore, the comparison of the three methods is carried out using transducer #3 (25 kHz, 1000 W). In addition, a hydrochloric acid solution with a concentration of 10% is used as a chemical agent to remove colloidal precipitation from the cores at an injection multiple of 2 PV. What needs to emphasize that the agent amount added for chemical injection alone is the same as that for the ultrasound-chemical method. The comparison results of the three methods are shown in Fig. 9.

It indicates from Fig. 9 that agent injection has no more effect than ultrasonic treatment for removing colloidal precipitation plugging in cores. However, considering the reduction of production costs and the protection of the oil layer from pollution, it is recommended to use ultrasonic treatment alone instead of chemical injection. Ultrasonic plugging removal technique has many advantages, such as low cost and no pollution to the reservoir. In addition, with the increase of initial gas permeability of the core, the removal effect of colloidal precipitation from cores by chemical agent injection alone or the ultrasound- chemical method gets better. However, with the increase of initial gas permeability of cores, the removal effect by ultrasonic treatment alone becomes worse. The results are as same as those acquired in Section 3.3;

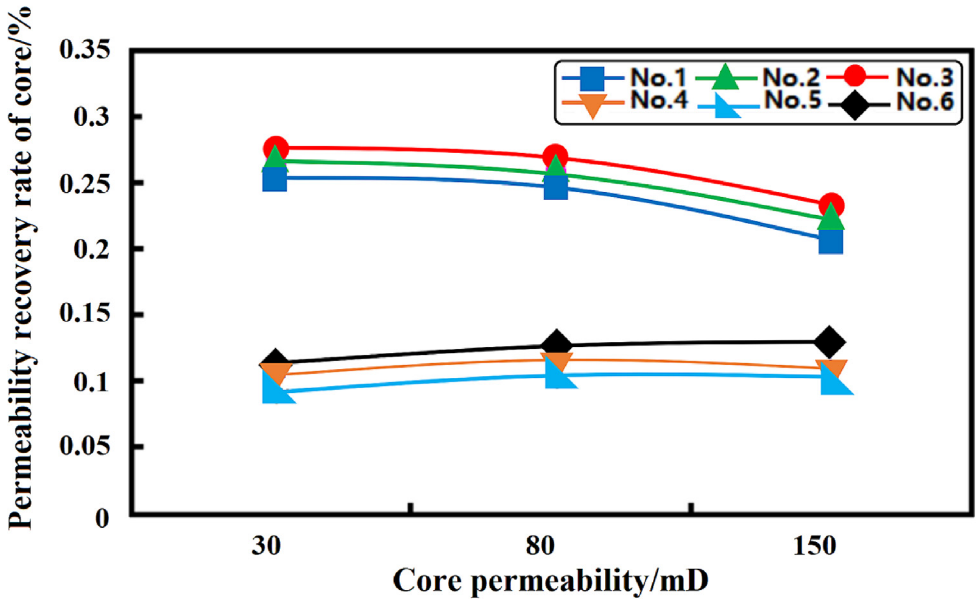


**Fig. 7.** The effect of initial gas permeability the removal efficiency of colloidal precipitation in the cores.

The ultrasound-assisted method is better than chemical injection alone or ultrasonic treatment alone to remove colloidal precipitation in the core. It is proved that the combination of ultrasound and chemistry can not only give full play to the separate functions of ultrasound and chemicals but also promote each other to improve the effect of plug removal. On the one hand, ultrasonic stimulation can improve the activity of chemical agents, accelerate the chemical reaction and promote the degradation of organic macromolecules by chemical agents; on the other hand, chemical agent reaction can change the force state of colloidal precipitation plugging in the channel to clear the channel, thereby promoting the effect of ultrasonic plugging removal.

## 5. Mechanism analysis

The combination of ultrasound and chemistry can not only give full play to the separate functions of ultrasound and chemicals but also promote each other to improve the effect of plug removal. On the one hand, ultrasonic stimulation can improve the activity of chemical agents, accelerate the chemical reaction and promote the degradation of organic macromolecules by chemical agents; on the other hand, the chemical agent reaction can change the force state of colloidal precipitation plugging in the channel to clear the channel, thereby promoting the effect of ultrasonic blocking removal [23–39].

## 6. Conclusion

In this paper, research on removing colloidal precipitation plugging with high-power ultrasound is investigated. Besides, three methods — ultrasonic treatment alone, chemical injection alone, and ultrasound-chemical method — for removing colloidal precipitation plugging are compared. The main factors and laws that influence the effect of ultrasonic plugging removal are studied to provide a reliable basis for the optimization design of the process parameters of near-well treatment with ultrasound. The specific conclusions drawn in this paper are as

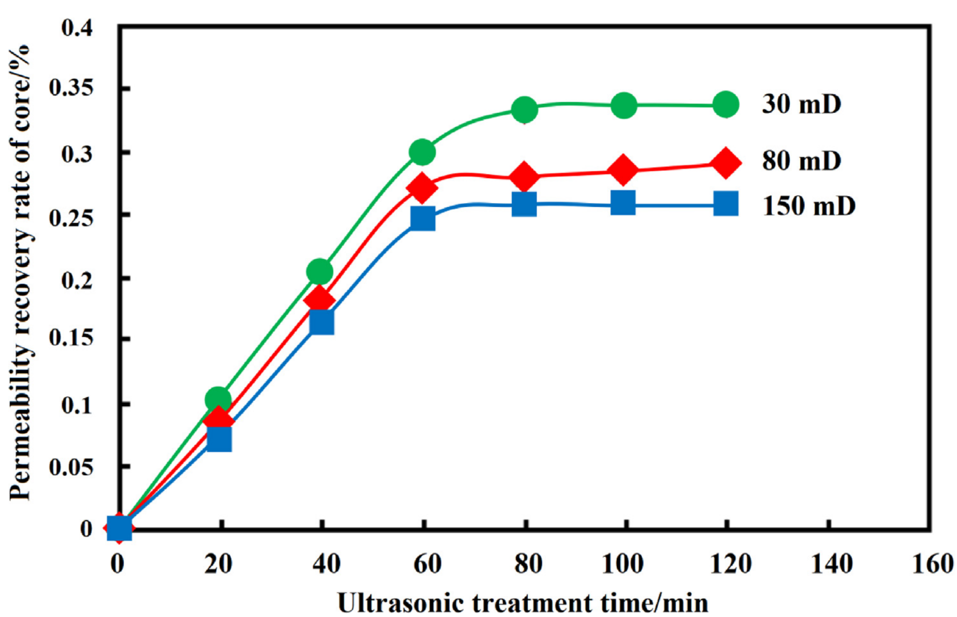


**Fig. 8.** Effect of ultrasonic treatment time on the removal of core colloidal precipitation.

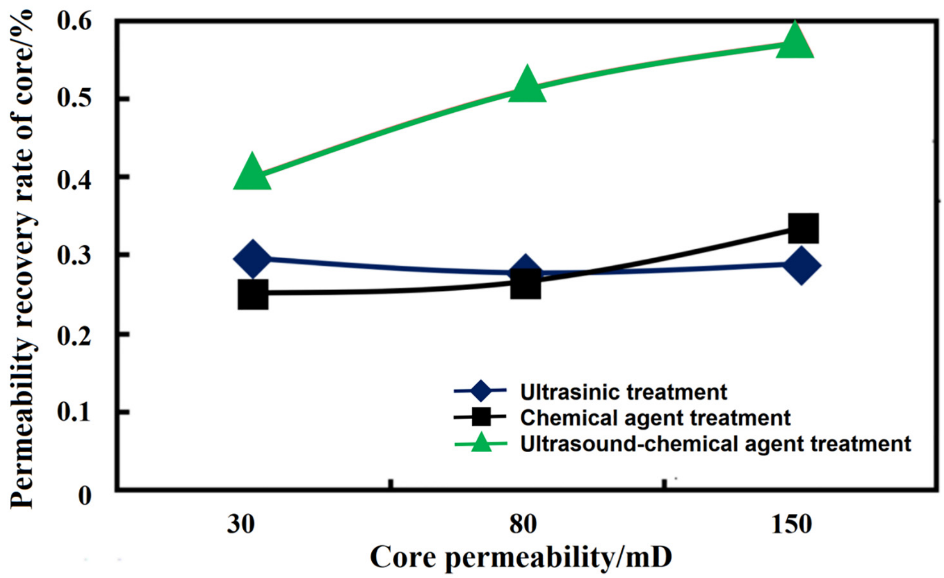


**Fig. 9.** The results of removing colloidal precipitation plugging from cores by ultrasound, chemical agent and ultrasound-chemical method.

follows:

1. The ultrasonic frequency is one important factor for removing colloidal precipitation plugging in the core. The optimum ultrasonic frequency is 25 kHz;
2. Higher ultrasonic power is good for improving the efficiency of removing colloidal precipitation plugging. The optimum ultrasonic power is 1000 W;
3. Ultrasonic processing time is another factor that affects ultrasonic colloidal precipitation plugging removal. Ultrasonic processing time should be controlled within 120 min. The maximum permeability recovery rates of three cores are 32.9%, 28.5%, and 26.8% respectively;
4. Lower core initial permeability is helpful to ultrasonic colloidal precipitation plugging removal;
5. The ultrasound-chemical method is better than chemical injection alone or ultrasonic treatment alone to remove colloidal precipitation in the core.

It is proved that the combination of ultrasound and chemistry can not only give full play to the separate functions of ultrasound and chemicals but also promote each other to improve the effect of plug removal. On the one hand, ultrasonic stimulation can improve the activity of chemical agents, accelerate the chemical reaction and promote the degradation of organic macromolecules by chemical agents; on the other hand, chemical agent reaction can change the force state of colloidal precipitation plugging in the channel to clear the channel, thereby promoting the effect of ultrasonic plugging removal. However, considering the reduction of production costs and the protection of the oil layer from pollution, it is recommended to use ultrasonic treatment alone instead of chemical injection.

## 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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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ultsonch.2020.105259.

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