

# Research Progress on the Treatment of High - pour - point Oil by Microwave Radiation

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## ABSTRACT

This paper focuses on the all-round research progress of microwave radiation in the field of condensate oil treatment. This paper systematically and deeply analyzes its remarkable results in viscosity reduction and condensation reduction, and explores how to reshape the viscosity characteristics of hypercoagulable oil. Interpret the unique advantages in the dehydration process in detail, and reveal the micro and macro mechanisms of water removal; Comprehensively sort out the internal logic of chemical composition and structural changes, and explore the transformation laws at the molecular level. Present the actual situation of engineering application in detail, and analyze the key points of technology implementation. Through an in-depth analysis of the strengths and weaknesses of existing research and a forward-looking perspective, it aims to lay a solid theoretical foundation for the continuous cultivation of this field, provide guidance with great practical value, help microwave radiation technology achieve breakthrough development in the field of high condensate oil treatment, and promote the petroleum industry to a new level.

## KEYWORDS

Microwave Radiation; Treatment of High Pour - Point Oil; Research Progress.

## 1. INTRODUCTION

In the process of continuous exploitation and deep utilization of global petroleum resources, the effective treatment of high condensate oil has become a key problem to be overcome in the petroleum industry. The high viscosity and high freezing point characteristics of high condensate oil are like heavy shackles, making it difficult for it to flow smoothly from the formation to the wellhead in the mining process, which greatly increases the difficulty and cost of exploitation. In the transportation stage, the poor fluidity of high condensate oil can easily cause problems such as pipeline blockage, which seriously interferes with the continuity and stability of transportation. In the processing process, its special properties also make it difficult for conventional processes to operate efficiently, which in turn seriously restricts production efficiency and greatly reduces economic benefits. Traditional treatment methods, such as heating viscosity reduction, dilution and viscosity reduction, have been applied to a certain extent, but they generally have the disadvantages of high energy consumption and extremely low efficiency, and are easy to cause environmental pollution in the implementation process, which brings potential threats to the ecological balance.

As an emerging treatment method in recent years, microwave radiation technology has gradually emerged in the key field of hypercondensate oil treatment, attracting the attention of many researchers. The unique thermal and non-thermal effects of microwave make it have the ability to deeply intervene in the physical and chemical properties of hypercondensate oil at the microscopic level. In terms of thermal effect, microwave can quickly make the molecules inside the hypercoagulable oil gain energy, trigger the intensification of molecular motion, and then change its key properties such as viscosity

and freezing point. The non-thermal effect can be used to finely control the structure and properties of the hypercoagulable oil by affecting the chemical bonding energy and intermolecular forces of the molecule without significantly increasing the temperature.

It is of great significance to explore the mechanism and treatment effect of microwave radiation on high condensate oil for the technological innovation of the petroleum industry. On the one hand, this will help to develop a more efficient, environmentally friendly and low-cost new process for high-condensate oil treatment, and enhance the core competitiveness of oil exploration and processing enterprises. On the other hand, it can further expand the development and utilization of high condensate resources, increase recoverable reserves and utilization efficiency, and ensure the stability and sustainability of energy supply. In this paper, we will comprehensively and systematically sort out the research context and latest progress of microwave radiation in the field of hypercondensate oil treatment, and summarize and analyze the existing relevant research results in depth, aiming to build a solid and solid theoretical foundation and practical guidance framework for subsequent in-depth research and wide application, and help the petroleum industry to achieve leapfrog development in the field of hypercondensate oil treatment technology and move towards a new stage of development.

## **2. DOMESTIC RELATED RESEARCH**

### **2.1. Effect of Microwave on the Rheology of Hypercondensate Oil**

#### **2.1.1. Reduction of Viscosity and Freezing Point**

The research of Dai Jingjun et al.<sup>[1]</sup> found that after microwave action, the wax crystal particles of high condensate oil coalesced, not only the particles become larger, but also the structure becomes loose. At the same time, the key indicators such as wax separation point were reduced, which strongly confirmed the non-thermal effect of microwave in the treatment of high condensate oil, and its effect on the improvement of low temperature rheology of high condensate oil was significant<sup>[2]</sup>. Zhang Yinan's research also showed that microwave can significantly improve the rheology of hypercoagulable oil, not only reducing the freezing point, but also making this change irreversible<sup>[3]</sup>. Jiang Huayi<sup>[4]</sup> has proved through research that microwave can significantly reduce the viscosity and freezing point of high-viscosity and high-condensate crude oil, mainly because microwave promotes the thermal cracking of colloidal asphaltenes and long-chain alkanes, thereby changing the internal structure and properties of crude oil<sup>[5]</sup>.

#### **2.1.2. Effect of Microwave Parameters**

After in-depth research, Zhang Yinan pointed out that the rheology of hypercoagulable oil will be improved with the increase of microwave power and the increase of action time. However, when the microwave power reaches a certain level, the improvement effect on the rheology of the hypercondensate oil is no longer significant, which indicates that there are optimal parameters in the process of microwave treatment of the hypercondensate oil. Li Xuemeng<sup>[6]</sup> found through molecular dynamics simulation and experimental research that the viscosity of the model system will decrease first and then increase with the increase of the applied electric field strength at the same electric field frequency. At the same electric field strength, when the electric field frequency increases, the viscosity of the simulated system also decreases first and then increases. In addition, there are better parameters for the effect of different microwave power or electromagnetic field distribution on the viscosity of high condensate oil, and these research results provide an important theoretical basis for the more efficient use of microwave treatment of high condensate oil<sup>[7]</sup>.

## 2.2. Effect of Microwave on the Chemical Composition of Hypercoagulable Oil

### 2.2.1. Change the Content of the Components

Zhang Yinan's experiments show that the asphaltene content in the hypercondensate oil decreases after microwave action, and the amount of aromatic hydrocarbons and saturated hydrocarbons increases to varying degrees, which changes the dispersion state of the dispersion system, makes the micelle dispersion more uniform, weakens the intermolecular force, and decreases the viscosity of crude oil<sup>[8]</sup>. Li Xuemeng's research also found that the microwave effect would reduce the relative content of long-chain n-alkanes and increase the number of short-chain n-alkanes in the high-condensate oil simulation system, and the non-thermal effect of microwave radiation played a role in improving the rheology process and reducing the activation energy of molecular chain breakage<sup>[9]</sup>.

### 2.2.2. Affects Functional Groups and Molecular Structure

Zhang Yinan found that after microwave analysis, the fused cycloaromatic hydrocarbons in the crude oil decreased, the small molecule aromatic hydrocarbons increased, the aromatics/saturated hydrocarbons increased, the dispersion of the dispersion system became better, and the viscosity decreased<sup>[10]</sup>. In the infrared spectroscopy analysis of wax, it was also found that the microwave effect reduced the content of long molecules in wax, decreased the content, and increased the content, indicating that microwave had a non-thermal effect on wax, which reduced the activation energy of wax molecules and broke some long-chain wax molecules.  $C_{7+} - CH_2 - CH_3$ .

## 2.3. Effect of Microwave on Dehydration of Hypercoagulable Oil

### 2.3.1. Increase the Dehydration Rate

Liu Mengfei and other scholars have carried out in-depth exploration on the application of microwave heating in crude oil dehydration. The study shows that microwave heating has obvious advantages in crude oil dehydration compared with traditional water bath heating<sup>[11]</sup>. Microwave heating can significantly improve the dehydration rate of crude oil, the dehydration speed is faster, the dehydration volume is larger, and the oil content of the water is very low, which effectively avoids the problem of rehydration of oily sewage and greatly improves the efficiency and quality of crude oil dehydration. Yang Shiyong also further confirmed the effectiveness of microwave radiation in the demulsification and dehydration of crude oil through experiments<sup>[12]</sup>. The experimental results show that the dehydration rate of crude oil increases with the increase of microwave power and the extension of action time, and the dehydration effect of microwave radiation is more prominent when dealing with low moisture content emulsions. These research results provide new ideas and directions for the optimization and upgrading of crude oil dehydration process<sup>[13]</sup>.

### 2.3.2. Dehydration Mechanism

In the research scope of hypercondensate oil treatment, Dai Jingjun made an in-depth analysis of the mechanism of microwave radiation in it. She believes that when microwave radiation acts on the hypercondensate oil, the dielectric loss of the emulsified water in the hypercoagulate oil will increase significantly, resulting in an uneven internal electric field and temperature<sup>[14]</sup>. In this case, the water molecules swell, and the interfacial membrane that encloses the water droplets ruptures. At the same time, the heat conduction promotes the gradual dissolution of wax crystals and colloidal asphaltene, creating conditions for the transition from small droplets to large droplets, and finally allowing the water to be free. Coincidentally, Fu Dafang's research also shows that microwave has the property of selectively heating water droplets, and through this selective heating, the oil-water interface film will rupture, so as to achieve effective separation of oil and water. Their research results reveal the important role of microwave in the oil-water separation process of hypercondensate oil from different perspectives, and provide a solid theoretical foundation for the development of related technologies.

## **2.4. Simulation and Analysis of the Interaction between Microwave Electromagnetic Field and High Condensate**

### **2.4.1. Molecular Dynamics Simulations**

Li Xuemeng used molecular dynamics simulation software to investigate the effects of applied electric field strength and frequency on the viscosity, dipole moment, intermolecular radial distribution function, mean square displacement and diffusion coefficient of paraffin molecules in the hypercondensate oil simulation system, and found that the appropriate electric field strength and frequency could inhibit the aggregation of paraffin molecules and reduce the viscosity of the system, which was consistent with the influence trend of microwave power on the viscosity of hypercondensate oil in the experimental results<sup>[15]</sup>.

### **2.4.2. Electromagnetic Field Distribution Simulation**

Xuemeng Li used the COMSOL Multiphysics software to simulate the electromagnetic field distribution in a single-cavity microwave device, and found that the waveguide length has a great influence on the electromagnetic field distribution, port reflection coefficient, and power loss density of oil samples, and the microwave treatment effect on high condensate oil under different electromagnetic field distributions

## **3. RELEVANT RESEARCH ABROAD**

### **3.1. Hot Heavy Oil Recovery**

Bientinesi M, Petarca L, et al.<sup>[16]</sup> Cerutti A proposed RF/RF based on a novel compact shell concept design Microwave heating methods are a cause for concern. The researchers explored the method in depth through carefully designed experiments. Experimental results show that shells made of low-loss materials play a key role in this process, significantly reducing well temperatures and avoiding local overheating, thereby optimizing the heating environment. At the same time, this tight shell design can also achieve better distribution of radiant energy in the oil layer, which greatly improves the energy utilization efficiency and helps to realize the recovery of hot heavy oil more effectively. The research results provide new ideas and directions for the development of hot and heavy oil recovery technology, and have potential application value and research significance in the future oil exploitation industry, which is worthy of further exploration and improvement.

### **3.2. Effect of Microwave Heating Time on the Properties of Heavy Oil**

Chalcogens - Sulfur<sup>[17]</sup> focuses on the effect of microwave heating time on the properties of heavy oils. It was found that with the change of microwave heating time, the properties of heavy oil showed significant changes. Among them, the light carbon component has a significant increasing trend, which is of positive significance for improving the quality of oil products<sup>[18]</sup>. The C1–C20 composition also changed accordingly, further affecting the chemical composition and properties of the oil. At the same time, the reduction of sulfur content makes oil products more advantageous in terms of environmental protection. These research results fully show that microwave heating technology shows a broad application prospect in heavy oil upgrading. It is expected to become an efficient and environmentally friendly means of heavy oil treatment, providing new technical support and development path for the sustainable development of the petroleum industry, and further in-depth research is still needed to realize its industrial application<sup>[19]</sup>.

## 4. LACK OF EXISTING RESEARCH AND FUTURE DIRECTIONS

### 4.1. Deficiencies in Existing Research

At present, there are many shortcomings in the research on microwave radiation treatment of hypercoagulable oil. In the optimization of microwave parameters, although it has a significant impact on the processing effect, there is no unified standard so far. The optimal microwave power, action time, frequency and other parameters of different studies are uneven, which makes it difficult to determine the actual operating conditions, which greatly hinders the popularization of the technology<sup>[20]</sup>.

In terms of microscopic mechanism, although microwave can change the chemical composition and molecular structure of condensate oil, there is a lack of in-depth theoretical explanation of how it can accurately affect molecular chain breakage, functional group transformation and intermolecular force change, which seriously restricts technological improvement and innovation<sup>[21]</sup>.

Engineering application research also has limitations, mostly limited to laboratories or small installations, and does not explore key issues such as equipment stability, energy efficiency, and cost-effectiveness in large-scale industrial applications. Moreover, the actual reservoir conditions are complex, and the existing research has shortcomings in simulating the real working conditions, which makes it difficult for the technology to move from laboratory to industrial application.

### 4.2. Future Development Direction

First of all, a systematic study on the synergy of multiple factors can be carried out, and a general microwave parameter optimization model can be established by comprehensively considering the properties of high condensate oil, the characteristics of microwave equipment and other factors. Through a large number of experimental data and theoretical analysis, the optimal microwave parameter range of different types of high-condensate oil under various treatment targets is determined, which provides a reliable operation guide for actual production.

Secondly, with the help of advanced analysis and testing techniques, such as high-resolution spectral analysis and quantum chemical calculation, the interaction mechanism between microwave and hypercondensate oil can be deeply analyzed from the atomic and molecular levels. The study of the dynamic behavior, reaction path and energy transfer process of molecules under microwave radiation provides solid support for the improvement of the theoretical system, and then guides the improvement of technology and the development of new methods.

Finally, we can increase the investment in the research and development of industrial-scale microwave processing equipment, optimize the equipment design, and improve the energy conversion efficiency and equipment stability. Carry out field and pilot studies to simulate different reservoir conditions and production scenarios, and comprehensively evaluate the feasibility, reliability and economic benefits of the technology. At the same time, it pays attention to the combination with traditional petroleum treatment technology, explores the best entry point of microwave technology in the existing process, and realizes the seamless integration and efficient application of technology.

## 5. SUMMARY

In this paper, the research progress of microwave radiation treatment of hypercoagulable oil is reviewed. The domestic research results are fruitful: in terms of rheology, Dai Jingjun et al. found that microwave can make the wax crystal particles of high condensate oil loosen and reduce the wax separation point, Jiang Huayi proved that it can reduce the viscosity point of high viscosity and high condensate crude oil, Zhang Yinan pointed out that the microwave parameters have the optimal value,

and Li Xuemeng revealed the relationship between the relevant parameters and viscosity changes; In terms of chemical composition, Zhang Yinan's experiments showed that microwave could change the proportion of condensate oil components, and Li Xuemeng found that it could adjust the hydrocarbon structure and have non-thermal effects, and also changed the molecular structure of wax. During the dehydration of crude oil, the research of Liu Mengfei et al. and Yang Shiyong showed that the microwave dehydration rate was high, the speed was fast, the water oil content was low, and the effect on the emulsion with low water content was good, and the dehydration mechanism was to increase the dielectric loss of the emulsion and promote the coalescence of water droplets. The new microwave heating method and the influence of microwave heating time on the properties of heavy oil in foreign countries have also achieved remarkable results, which can optimize the heating and energy distribution and increase the light carbon content.

However, there are shortcomings in the existing research. There is a lack of unified standards for microwave parameter optimization, and the conclusions of different studies vary greatly. The microscopic mechanism of action lacks depth; Engineering application research is limited to laboratories or small installations, and the key issues of industrialization are not explored enough, and the simulation of actual working conditions is defective. The direction of future research is clear. It is necessary to construct a general microwave parameter optimization model based on multiple factors to provide guidance for production. With the help of advanced technology, the interaction mechanism between microwave and hypercoagulable oil was analyzed and the theory was improved. Increase investment in the research and development of industrial equipment, carry out field tests, combine traditional processes, promote the industrial application of microwave technology in high-condensate oil treatment, and help the development of the petroleum industry.

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