Research Status and Development Trend of Water Cut Detection Methods for Crude Oil

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Abstract. Water cut detection of crude oil plays a very important role in the petroleum and petrochemical industry. At present, the existing crude oil water cut detection methods include capacitance method, conductance method, radio frequency method, Ray method, spectrum method. Firstly, the measuring principle, application conditions, advantages and disadvantages of the existing methods are summarized, and the factors affecting the measuring accuracy of the existing methods are analyzed. Afterwards, the latest development of water cut measurement technology of crude oil is mentioned, such as multi-sensor information fusion technology, tomography technology, neural network technology. With the emergence of new technology and new method, the development trend of crude oil water cut measurement technology is towards full range, high precision, intelligence, multi-parameter fusion, safety, energy saving, environmental protection and so on.

1. Introduction
The water cut of crude oil is one of the important measurement parameters in the petrochemical industry. The high-precision, full-range and high-stability online real-time detection of the water cut of crude oil is the key issue in the process of crude oil production, gathering and transportation, storage and transportation and chemical refining[1-3]. The accurate measurement of the water cut of crude oil can help oilfield managers to timely understand and grasp the production status of each production layer of the oil well. At the same time, it is very important for the production quality control of the oilfield, the detection of the oil well condition, the reduction of energy consumption and the automation of oil production management. In addition, it also plays a vital role in the reference research of water cut in petrochemical production, scientific research and other industries[4-6].

Many oilfield units and scientific research institutions at home and abroad have successively developed a variety of measurement methods, and designed different types of measurement instruments for crude oil water cut. After being applied to actual production, they have not been able to obtain satisfactory results due to the limitations of the process and technology of each measurement instrument, there are many problems in the measurement range, measurement accuracy, measurement stability and other aspects that need to be resolved urgently.
The article summarizes and analyzes detection methods of the existing online crude oil water cut, summarizes the advantages and disadvantages and existing problems of the existing detection methods. In addition, it explains the latest developments of measurement methods in water cut of crude oil, and provides an overview of the development trend of measurement methods for water cut of crude oil in the future.

2. Research on existing detection methods of water cut of crude oil

With the continuous development and improvement of non-electric power measurement technology, the online measurement method for water cut of crude oil has been developed more and more widely [7-10]. At present, the commonly used detection methods of water cut include capacitance method, radio frequency method, infrared spectroscopy, ray method, conductivity method, BP neural network method.

2.1. Capacitance Method

The basic principle of the capacitance method: the relative permittivity of water is about 80, and the relative permittivity of oil is about 2.2 [11-13] under normal temperature and pressure. Taking advantage of the obvious difference in the relative dielectric constant of oil and water, when crude oil with different water content flows through the capacitor, the dielectric constant will change, which will cause the capacitance value of the sensor to change. According to the change in capacitance value, the water content of crude oil can be obtained to achieve the purpose of measuring the water content of crude oil. Fig. 1 is a schematic diagram of the structure of a sensor for measuring the water content of crude oil by the capacitance method.

The capacitance method to measure the water cut of crude oil has the advantages of simple structure, low cost and convenient installation. However, the capacitance method also has its limitations. The capacitance method to measure water content is affected by many factors such as temperature drift, free gas, emulsification degree, etc. which makes its measurement accuracy have a greater impact and poor measurement stability. At the same time, the capacitor sensor is also faced with fouling, waxing, corrosion, etc. Therefore, it needs regular maintenance in the later period. The capacitance method is suitable for measuring the water content of crude oil with a measuring range of 0–40%.

2.2. Radio Frequency Method

The basic principle of the radio frequency method: the relative dielectric constants of oil and water are obviously different, and the impedance characteristics presented are also very obvious. The dielectric loss of the electromagnetic wave signal of different water content crude oil is different. By comparing the energy attenuation of the electromagnetic wave before and after passing through the water-containing crude oil, it can be used to calculate the water content of crude oil. The schematic diagram of the structure diagram is shown in Fig. 2.

The radio frequency method has the advantages to measure the water cut of crude oil for high measurement accuracy, simple principle, short measurement time, and wide measurement range. However, this method has its shortcomings: the developed instrumentation is affected by the
electromagnetic environment, have general stability, and need cleaning and maintenance later regularly. The radio frequency method is suitable for measuring the water cut of crude oil with a measuring range of 0~100%.

2.3. Infrared Spectroscopy

Principle of infrared spectroscopy: infrared spectroscopy is based on Lambert-Beer law for quantitative analysis. When infrared light is irradiated on the surface of a water-bearing crude oil medium and passes through a certain thickness of water-bearing crude oil, part of the light energy of the infrared light is absorbed by the water-bearing crude oil, the intensity of the projected light will be weakened, by measuring the intensity of the infrared light passing through the water-containing crude oil, the water cut of the crude oil can be obtained.

Infrared spectroscopy to measure the water cut of crude oil has the advantages of fast reaction speed, high sensitivity, and high precision. At the same time, the method for measuring water cut of crude oil also has its limitations, the measurement equipment is expensive, the method of application is complicated, the later maintenance is difficult, the measurement range is small, and it is suitable for occasions with low water content[14-17].

2.4. Ray Method

Principle of the ray method: the ray method measures the water cut of crude oil by using the interaction between low-energy rays and substances. When the radiation passes through the water-containing crude oil, the carbon element is concentrated in the oil and the oxygen element is concentrated in water due to the difference in the absorption of the ray by carbon and oxygen, the water cut of crude oil can be calculated by measuring the carbon and oxygen elements in the water-containing crude oil, the principle structure diagram is shown in Fig. 3.

![Figure 3](image1.png)

**Figure 3** Schematic diagram of ray method measurement(left)

![Figure 4](image2.png)

**Figure 4** Double-coil electromagnetic conductivity water content sensor(right)

The ray method to measure the water cut of crude oil has a wide measurement range, good measurement stability, and the measurement device is not easily affected by external environmental factors. However, using this method to measure water content has certain drawbacks, the cost of this method is high, and the later maintenance is difficult. At the same time, there is also the safety problem of radiation. The ray method is suitable for measuring the water cut of crude oil from 0 to 100%.

2.5. Conductivity Method

Principle of conductance method: with double coil electromagnetic conductivity moisture content sensor as an example, as shown in Fig. 4, the sensor is composed of two symmetric metal coil, the launch of the sensor coil, with low-frequency high-power current forming eddy current electromagnetic field in oil-water mixture, and then make the receive coil on the second induction electromotive force, by measuring the secondary induced electromotive force on the receiving coil, the resistivity of the oil-water mixture can be obtained, and then the electrical conductivity of the mixture can be obtained, and the water cut of crude oil can be calculated.

The conductivity method to measure water content has the advantages of simple structure, low cost, fast response speed and wide application. However, the conductivity method to measure the water cut of crude oil is easily affected by temperature and salinity, the measurement results are unstable, and the
measurement range is small. The conductivity method is suitable for a small range of water content measurement.

2.6. BP Neural Network Method

Principle of BP neural network method: the water cut of crude oil is a complex random nonlinear system, the precise measurement of water content is affected by many factors, in order to reduce the influence of various factors on the measurement accuracy, the BP neural network method is used to achieve the nonlinear correction of the system, with the help of sample data to realize the highly nonlinear mapping of input data to output data, which can avoid the influence of influencing factors on the measurement results, thus, the measurement accuracy can be improved\cite{18-20}, Fig. 5 shows the prediction block diagram of BP neural network method.

![Figure 5 Block diagram of BP neural network prediction](image)

The BP neural network method is widely used in the measurement for water cut of crude oil, this method can combine a variety of measurement methods for water cut of crude oil to process the data measured by various methods, so as to improve the measurement accuracy and realize the development of the measurement of crude oil moisture content in an all-round and full range. At the same time, the BP neural network method also has a very obvious drawback, that is, the method may become an open-loop system, once the fitting is wrong, the measurement results will deviate from the actual results, resulting in major measurement errors.

3. The main influencing factors of crude oil water cut detection

The water cut of crude oil is a complex non-linear system, the system is affected by multiple factors, so its accurate measurement is also affected by multiple factors. The main influencing factors are as follows:

1) The influence of the composition of water-bearing crude oil. There are differences in the composition of crude oil in different regions, different production layers, and different links. Factors such as gas content, salinity, and fluid phase transformation will have different effects on the measurement results. Most measurement equipment does not have measurement compensation for the influence of such factors, so the accuracy of the measurement results will be greatly reduced. In addition, the moisture content in some areas is high, and some measurement methods cannot meet the requirements of measurement or even cannot be measured due to their own characteristics.

2) The influence of the measurement environment. Whether it is the measurement of downhole reservoirs or the measurement of water cut of crude oil on surface pipelines, it will be affected by various environmental factors. There are external environments such as temperature, pressure, electromagnetic interference, corrosion, fouling and other influences on the measurement equipment at the detection site. Even if some of the measurement methods have adopted anti-interference measures, the effect of countermeasures will be weakened with the change of the environment, resulting in the decrease of measurement accuracy and accuracy.

3) The influence of the measurement model. The measurement principle of the existing measurement equipment for water content of crude oil is to ideally process the measurement object-water-bearing crude oil, and establish a model of oil-water two-phase flow or oil-gas-water three-phase flow. The measurement equipment is designed according to the established ideal model, and other factors in the water-bearing crude oil are ignored, there are fundamental factors that have not been
resolved, that is, the main influencing factors or all factors have not been considered, so there are fundamental errors in the measurement equipment.

4. New developments in detection methods for water cut of crude oil
In view of the problems of the existing measurement methods for water cut of crude oil, in order to improve the measurement precision and accuracy for water cut of crude oil and overcome or reduce the shortcomings of the existing measurement methods, some new measurement methods have been introduced.

4.1. Multi-Sensor Information Fusion
Multi-sensor information fusion of crude oil moisture content measurement technology is the multiple sensor detection information integration, through a certain algorithm to multi-sensor redundancy in space or time or complementary information according to certain standards for processing, extraction of water cut of crude oil moisture content of the consistency of interpretation and description information, to eliminate the disturbance variable factors on the moisture content of the comprehensive and systematic description of information, multi-sensor information fusion technology has a more complex form, measuring information can be at different levels under the fusion and integration, can adapt to a variety of factors under the influence of the moisture content measurement.

4.2. Mathematical Algorithm Analysis Technology
Mathematical algorithm analysis technology uses some mathematical algorithms combined with existing online measurement technology of water cut of crude oil to evolve new technologies. Aiming at the drawbacks of the existing measurement of water cut of crude oil, the technology uses algorithms in the mathematical model to remove the non essential interference which affects the objective reality as far as possible, and establish the input-output relationship model or output signal algorithm processing model, so as to reduce the measurement error interference and improve the measurement accuracy.

4.3. Direct Downhole Measurement Technology
Direct downhole measurement technology is to select the existing online measurement technology with a full range, high accuracy, small contact area, and non-scaling measurement sensor placed in the downhole for direct measurement. Because the downhole fluid phase changes little or does not change, the measurement results closer to the true value, the underground measurement environment has fewer interference factors than the ground, and the measurement accuracy is high and the precision is high.

4.4. Visualized Real-Time Measurement Technology
Visual real-time measurement technology is a new measurement technology based on the combination of microwave measurement and electromagnetic tomography. The measurement technology is based on the microwave method to measure the water cut of crude oil, and introduces electromagnetic tomography technology in the field of non-destructive testing to identify the flow pattern and gas compensation in the process of oil-gas-water three-phase flow. This technology has the advantages of two measurement technologies: high measurement accuracy, full range, and visualization.

5. Development trend of crude oil water cut measurement methods
With the progress of technology and the improvement of detection methods, the detection of water cut of crude oil will also make progress and development. In order to meet the requirements of digital oilfields, the future detection for water cut of crude oil is bound to develop in the following directions:

5.1. Full Range, High Precision and Strong Stability
In the future, digital oilfields tend to include the detection of all aspects of oilfield production management. Taking into account the different measurement requirements of different regions, different
production zones, and different production links of crude oil water content, the measurement for water cut of crude oil needs to develop towards the full range, high precision and strong stability.

5.2. Multi-Parameter Integration, Functionalization and Intelligence
With the progress and development of technology, higher requirements have been put forward for the intelligence of oil fields. In order to comply with the development trend of smart oil fields, the measurement for water cut of crude oil should be developed in the direction of multi-parameter fusion, and testing instruments should integrate multi-parameter functions to promote the portability, small size and multi-function of the instrument. In addition, with the popularization and application of various artificial intelligence technologies and mathematical algorithms, the measurement for water cut of crude oil will also develop towards intelligence to meet the requirements of intelligent oilfields.

5.3. Safety, Energy Saving and Environmental Protection
Digital oilfields put forward higher requirements for the safety, energy saving, and environmental protection of each link of production management. As an important part of the measurement for water cut of crude oil, new requirements for measurement methods are required. Some measurement methods in measurement for water cut of crude oil, such as the ray method, it has problems with radiation and energy consumption, and it is necessary to improve the safety and energy saving of such methods.

6. Concluding remarks
The water cut of crude oil is an important measurement parameter in the petrochemical industry. The accurate measurement of the water cut of crude oil directly affects all aspects of production in crude oil and it is receiving more and more attention. The article summarizes and includes the principles of various measurement methods from the existing measurement methods for water cut of crude oil. The main influencing factors of the existing online measurement methods for water cut of crude oil are described, the latest measurement methods for water cut of crude oil are summarized, and the future development trend in measurement methods for water cut of crude oil are predicted and analyzed.

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