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Research progress of aging oil dehydration treatment process

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ABSTRACT

This paper summarizes the research progress of aging oil treatment processes and treatment devices in recent years. The treatment processes are mainly based on electrochemistry, heat deposition, centrifugal separation, and other technologies. The emerging treatment processes mainly include ultrasonic treatment technology, distillation dehydration technology, biological treatment technology. Negative pressure dehydration technology, catalytic cracking technology, microwave radiation treatment technology, etc. The advantages and disadvantages of each treatment technology were compared and analyzed. Finally, suggestions were put forward on the research direction of aging oil. The recommendations pointed out that one is to combine each treatment method to develop a practical, efficient, and environmentally friendly treatment process; the other is relevant scientific research units should strengthen scientific research and R&D efforts to tackle the problem in the direction of highly efficient and environmentally friendly pharmaceuticals.

Keywords: Aging oil; Treatment process; Treatment device; Distillation dehydration

1. Introduction

Aging oil, also known as aging waste oil and oilfield flocculation mixture, often refers to crude oil that is difficult to be treated by the existing technology [1–3], which mainly comes from the crude oil storage tank, oil-water settling tank, oil removal tank, flotation tank, etc. to form a considerable amount of waste oil, oily sludge, complex oil in water, or oil in water emulsion [4–9]. The emulsification system of aging oil is very stable because of its complex components, wide sources, less light components, high content of asphaltene gum, and high concentration of inorganic salt. Aging oil occupies the effective volume of the storage tank, reduces the utilization rate of the equipment, and increases the maintenance cost, which has an important impact on the safe operation of crude oil electric dehydrator [10,11].

At present, the treatment methods of aging oil include electric dehydration, thermal sedimentation, centrifugal separation, ultrasonic treatment, back mixing treatment, microbial treatment, and swirl treatment [12]. The aging oil is usually collected in a unified way, added with demulsifier, flocculant, and other methods for pretreatment, fully separating emulsified water and free water, then settling to separate oil, water, and solid three phases, and finally phase by phase advanced treatment to make aging oil resource, sewage, and solid harmless [13], as shown in Fig. 1 is the commonly used aging oil treatment process diagram.

In the past 5 y, the treatment technology of waste oil and aging oil has been developed rapidly. This paper summarizes the research progress of treatment technology and treatment device of complex oil products such as waste oil and aging oil. At present, the treatment technology has developed into a comprehensive treatment process combining multiple methods, which is more environmentally friendly, efficient, and energy-saving.

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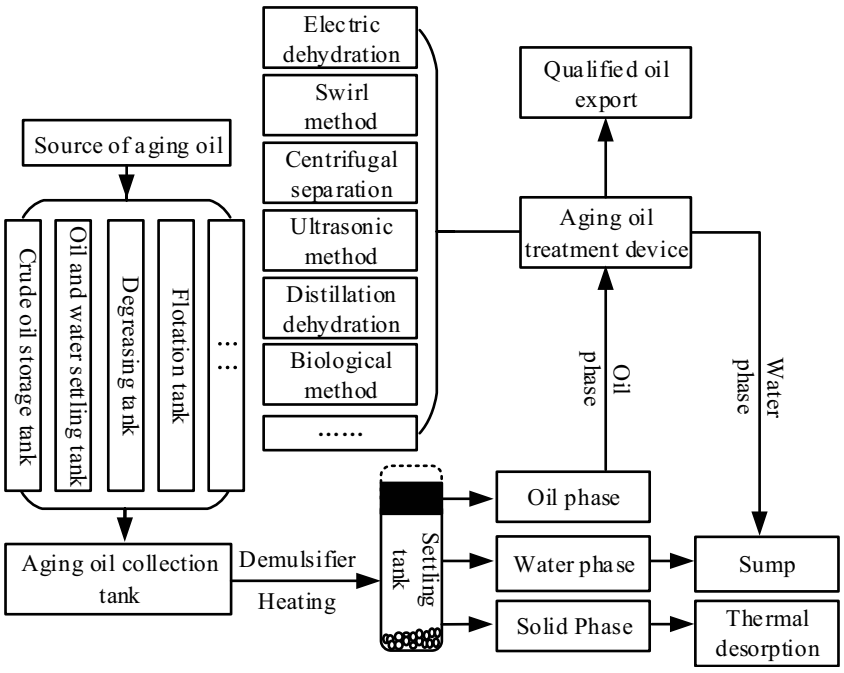

Fig. 1. Schematic diagram of the aging oil treatment process.

2. Research progress of aging oil treatment process and equipment

The traditional methods of heat settlement, centrifugation, and back mixing have some disadvantages, such as long time, large energy consumption, strong drug dependence, and so on.

2.1. Ultrasonic treatment process

Ultrasonic treatment mainly uses its mechanical vibration and thermal effect. Mechanical vibration can accelerate the collision and aggregation of solid particles, molecular particles, and suspended solids. The thermal action can reduce the strength of the boundary film and the viscosity of oil [14–19]. Ultrasonic treatment is mainly used for pre-treatment of aging oil to preliminarily separate the free water and emulsified water in aging oil, which often fails to meet the export requirements. Other treatment processes are often connected at the end of treatment, and the process route is shown in Fig. 2.

Many scholars have studied the effect time, power strength, frequency, and other factors of ultrasonic treatment. The research shows that the larger the ultrasonic power is, the shorter the treatment time is required, and the more obvious the effect of viscosity reduction and dehydration is [20–22]. Zheng [23] discussed the treatment process of aging oil by ultrasonic electrodeposition, and pointed out that this process can effectively reduce the dosage of chemicals, which is beneficial to the whole gathering and transportation system. Sun et al. [24] invented a kind of ultrasonic centrifugal treatment aging oil process and treatment device. The material was pretreated by means of steam jet, air flotation, ultrasonic, centrifugation, etc., and

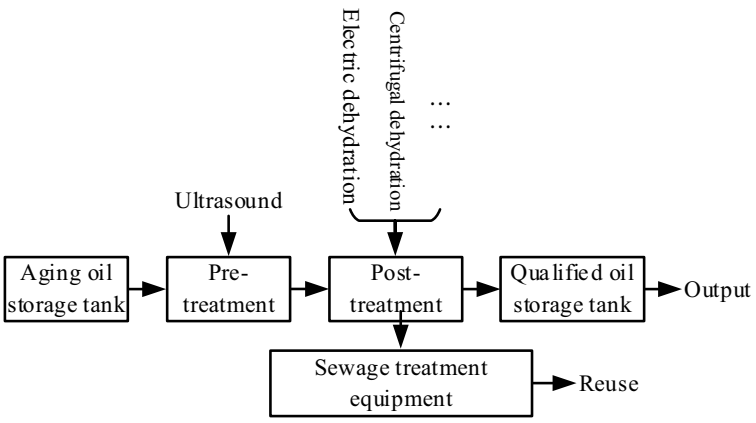

Fig. 2. Ultrasonic process of aging oil.

then the three-phase separator was used to separate oil, water, and mechanical impurities, without adding demulsifier, flocculant, and other chemicals. The treated waste oil was free of sulfide components. The treatment process flow is shown in Fig. 3.

Ultrasonic treatment can effectively reduce viscosity and demulsification. The practice shows that the sound intensity is greater than 1.732 w/cm^2, the frequency is 10–40 Hz, the action time is 2–5 min, the temperature is 50°C–70°C, and the moisture content of aging oil after treatment is less than 5% [25–29]. There are also deficiencies in ultrasonic treatment. In the process of application, due to the excessive sound intensity and long-acting time, it is easy to cause the secondary emulsification of aging oil. Therefore, in practical application, the sound intensity and irradiation acting time should be adjusted according to the physical properties of aging oil [30–33].

2.2. Electric dehydration process

Under the action of electric field, electric dehydration can improve the movement rate of droplets, increase the probability of collision, coalescence, and combination between dispersed droplets, and then realize the purpose of demulsification and dehydration. The technology is mature and the demulsification efficiency is high, but the efficiency of high water content emulsion is low and the energy consumption is high. At present, thermochemical dehydration and electro-chemical dehydration are mostly used in the oil field. The electric demulsification technology is regarded as the final link of crude oil dehydration [34–39], and the treatment process is shown in Fig. 4.

Chen et al. [40–45] have been committed to the research of demulsification of aging oil by electric field, investigated the influence of the strength, waveform, frequency, and other parameters of high frequency/high voltage pulse AC electric field on the dehydration effect, and carried out the basic research of static/dynamic demulsification characteristics, systematically studied the effects of electric field, peak voltage, pulse frequency, duty cycle, and water content on the static demulsification of O/W emulsion For the influence of water characteristics, the electrostatic coalescence experimental device is shown in Fig. 5.

In production and application, Wang et al. [46] introduced an electrochemical demulsification method. The electrostatic dehydration is carried out under the pulse frequency of 2 KHz and the electric field strength between the electrode plates is 2,000 V/cm. The water content in the oil treated by this method is not more than 0.3%, and the oil content in the water is not more than 500 mg/L, which conforms to the industry standard. The electric dehydration process of aging oil is shown in Fig. 6.

Electric dehydration is widely used, but there are also shortcomings. In the process of water droplet accumulation, conductive substances are prone to form electric field instability, cross electric field, tripping, and other phenomena. In particular, the aging oil formed by polymer flooding makes water droplets "gather but not collect", which is easy to cause electric field damage.

2.3. Cyclone treatment process

The cyclone separation technology uses the density difference between two or more phases to realize phase separation under the action of centrifugal force. The aging oil enters along the tangent direction of the device, and the fast rotation makes the liquid produce strong centrifugal force, and the substances with different density are thrown to different positions, so as to realize the three-phase separation of oil, water, and mechanical impurities [47–52]. Although the structure of hydrocyclone is simple, there are many factors affecting the oil–water separation effect of aging oil, such as cone angle, structure size, feed inlet mode, treatment capacity, split ratio, feed pressure, feed density difference, etc. [53–65].

In practical application, thermochemical demulsification + multi-stage swirl treatment scheme is often adopted. The dehydration device of heavy oil aging oil invented by Fu and Zhang [66] applies this idea. The aging oil is fully stirred in the mixing tank, and the first normal phase

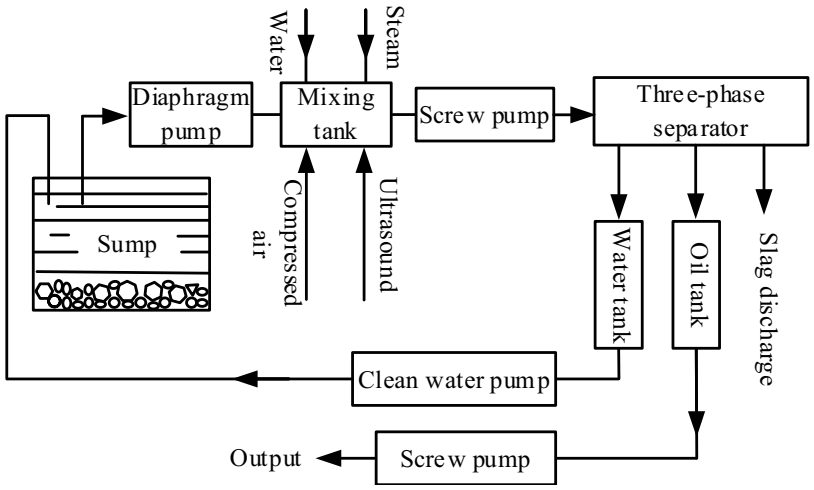

Fig. 3. Process flow chart of aging oil treatment.

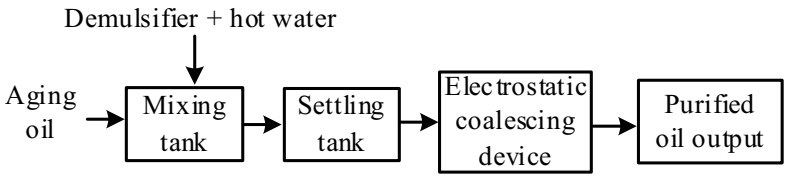

Fig. 4. Process flow chart of aging oil electrical de-treatment.

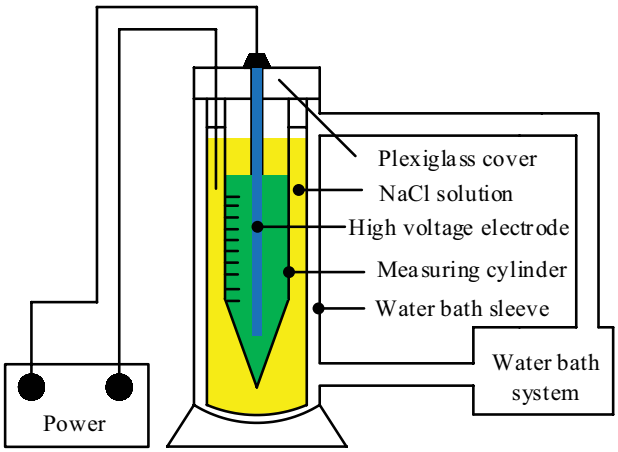

Fig. 5. Schematic diagram of the experimental device for electrostatic coalescence.

demulsifier is added to the mixing tank. The fully stirred aging oil is delivered to the first stage cyclone by pipeline pump, and the water bearing oil from its top is delivered to the third stage. In the second stage hydrocyclone, the oily sewage from its bottom enters the second stage hydrocyclone. A second normal phase demulsifier is added to the third stage hydrocyclone, and a reverse phase demulsifier is added to the second stage hydrocyclone. The purified oil from the top of the two- and three-stage hydrocyclones is discharged in a pipeline, and the sewage from the bottom of the two- and three-stage hydrocyclones is discharged in a pipeline. The structure diagram of the device is shown in Fig. 7.

Because the structure of hydrocyclone is compact and the design parameters are strict, the adaptability of the device is not strong, and the same device is not suitable for multiple working conditions. Therefore, reasonable structure parameters and working parameters should be designed according to the actual working conditions.

2.4. Distillation process

The treatment of aging oil by distillation is mainly based on the boiling point of oil and water, which destroys the structure of oil and water interfacial film by heating and vaporizes water molecules from the structure of oil in water emulsion. This method is mainly proposed by the team of Liang and Chen, and the key technologies of distillation and dehydration, the mechanism of boiling, and the measures of anti-riot are thoroughly studied. It is concluded that the old oil fields in Jilin are old. The initial boiling point of the chemical oil is 102°C, the final boiling point is 115°C, adding zeolite with diameter of 0.5 cm and establishing temperature control mathematical model to accurately control the temperature effectively to prevent boiling [67–71].

In 2014, Liang developed the first skid-mounted high water content distillation dehydration unit, which is mainly composed of two shell and tube dehydration heat exchangers, condensers, buffer boxes, etc. the treatment process is shown in Fig. 8a. The water content of aging oil can be reduced to about 1% by the primary dehydrator and 0.05% by the fine dehydrator; then a new generation of skid-mounted dehydration unit was developed. It combines the primary dehydrator and the fine dehydrator together. It also adopts the shell and tube heat exchanger structure. The same shell is divided into the primary dehydrating chamber and the fine dehydrating chamber. The temperature is accurately controlled to make the dehydration safe and stable. The moisture content of the final treated aged oil is less than 0.5%. The process flow is as shown in Fig. 8b; the previous two process flows are extensive treatment, and its process flow is not considered. As for the problem of

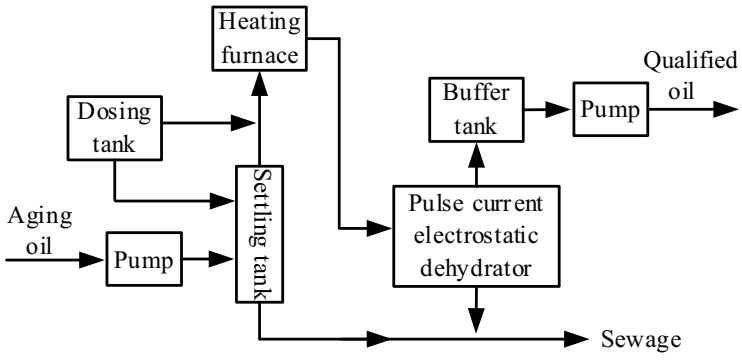

Fig. 6. Process flow chart for dehydration of aged oil.

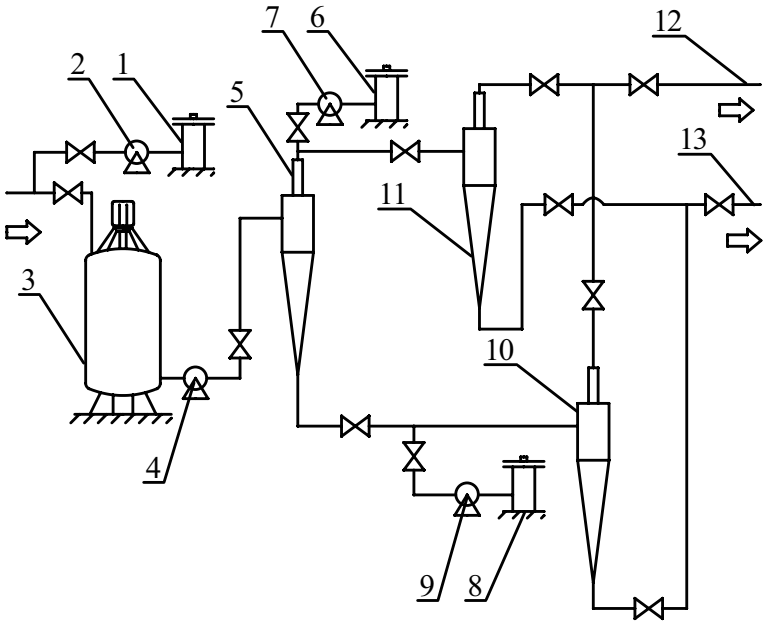

Fig. 7. Sketch map of the dehydration treatment device for heavy oil aging oil: (1) first normal phase demulsifier dosing tank; (2) first dosing pump; (3) stirred mixer; (4) one pump; (5) stage cyclone; (6) second normal phase demulsifier dosing tank; (7) second dosing pump; (8) reverse demulsifier dosing tank; (9) third dosing pump; (10) one- and two-stage cyclone; (11) three-stage cyclone; (12) purified oil pipeline; and (13) drain line.

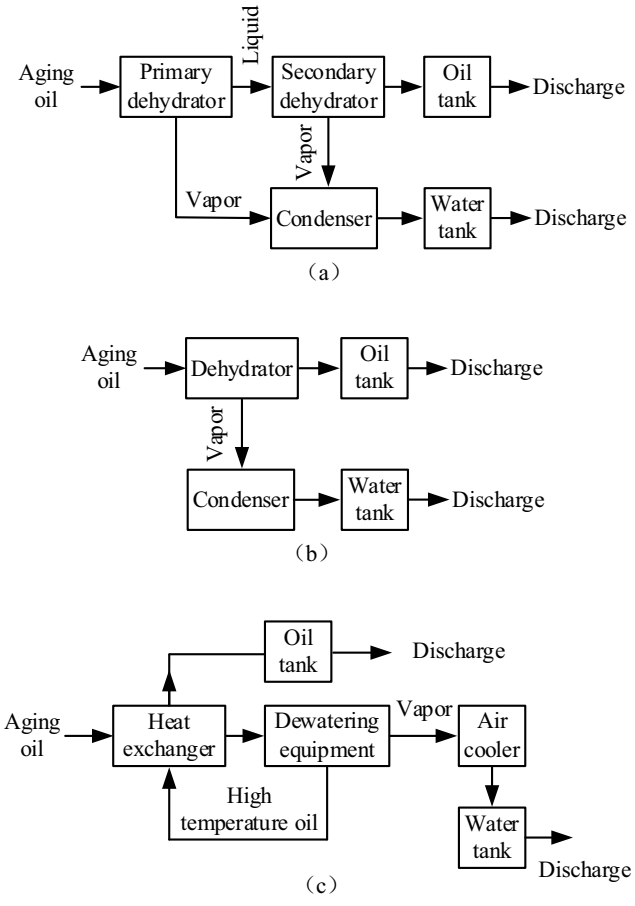

Fig. 8. (a–c) Distillation and dehydration process.

energy, a large amount of energy is lost. Therefore, a more efficient, energy-saving, and environmentally friendly treatment process is developed according to local conditions. In 2018, the treatment of heavy oil aging oil was realized in Tuha oilfield. The process flow is shown in Fig. 8c. It is to exchange heat between the high-temperature oil from the dehydrator and the aging oil, so that most of the heat can be reused. The local water resources are precious, and the steam can be converted to air-cooled. The condenser condenses [72–74], while the steam in process (a) and (b) is condensed by circulating cold water.

The advantages of distillation dehydration process are not affected by the density, viscosity, and emulsification of oil and water, no need to add demulsifier, strong adaptability and stability, simple and easy operation of the process, and the aged oil after treatment meets the export standard, the disadvantage is that the input cost of the unit is high, and it is highly popularized in terms of efficiency and service life.

2.5. Biological treatment process

The new supersedes the old. The biological treatment process is to select the strain and ferment it into the culture medium, add it to the aging oil, the microbial metabolism, or metabolites form the biosurfactant, destroy the structure of the oil–water interfacial film, and achieve the aging oil demulsification and dehydration [75–79], and the schematic diagram of biological treatment is shown in Fig. 9 [80].

Wen et al. [81–83] isolated from petroleum contaminated soil and identified as *Alcaligenes* sp., by demulsification strain (S-XJ-1). When the cell concentration is 500 mg/L, the demulsification rate of W/O emulsion in 24 h is 81.3%.

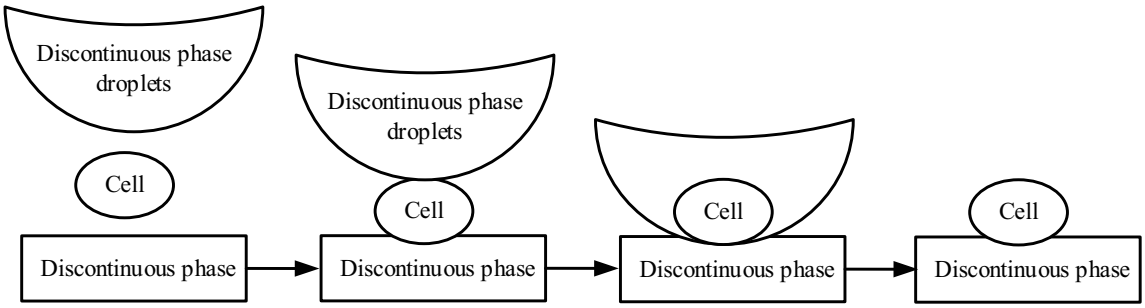

Fig. 9. Schematic diagram of biological treatment of aging oil.

Cai et al. [84] identified a highly efficient demulsifier, Clostridium westermani n3–2a. The cell itself and the biosurfactant formed by its metabolism contribute to demulsification, which is 92.5% in 24 h.

The biological treatment process has the advantages of good treatment effect, low comprehensive cost, and environmental friendliness, but it also has some disadvantages, such as long period of strain screening, long treatment time, and poor broad-spectrum.

2.6. Negative pressure dehydration process

The negative pressure dehydration technology is to use the boiling point difference between oil and water, under the condition of vacuum pumping, the boiling point of water is reduced, and flash evaporation is fast to realize the separation of oil and water [85–88]. The aging oil vacuum dehydration process is shown in Fig. 10.

Li [89] invented a comprehensive treatment process of aging oil combining ultrasonic hot water washing, chemical heat treatment, high gravity separation technology, and MVR negative pressure dehydration technology, which has good treatment effect on aging oil, and has the advantages of simple process, strong adaptability, and low energy consumption. The water content of aging oil after treatment is less than 0.5%, but the process recovery treatment effect is limited, which needs to be improved.

Liu et al. [90] investigated the influence of water content, temperature, vacuum degree, oil injection speed, and other factors on negative pressure evaporation, and compared the energy consumption with atmospheric distillation. The experiment showed that the water content of aging oil with 30% water content could be reduced to within 2% by heating to 65°C–70°C without adding demulsifier.

Compared with atmospheric distillation, the energy consumption of vacuum dehydration is lower, which can be used as a supplement to other treatment processes.

2.7. Microwave radiation processing technology

The technology of microwave radiation is to make use of the internal heating characteristic of microwave and the electromagnetic field generated by high frequency, resulting in decreasing the zeta potential of oil–water interfacial film and promoting the aggregation of dispersed phase particles, thus accelerating the separation process of oil and water and improving the demulsification rate of Tong et al. [31].

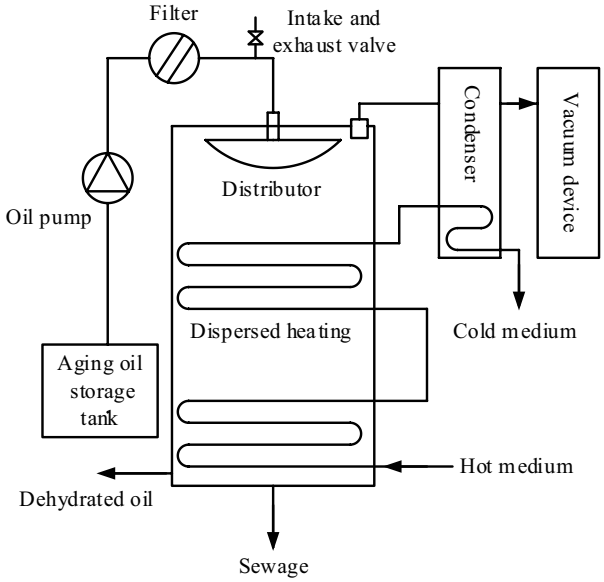

Fig. 10. Pressure dehydration process.

Liu et al. [91] carried out the dehydration experiment of aging oil by microwave radiation, and compared with water bath, the dehydration rate and dehydration rate were significantly improved. Zhang [92] studied the microwave thermochemical dehydration of aging oil, and determined the best dehydration conditions. The highest dehydration rate can reach 94.05% under the conditions of microwave radiation power 406 W, radiation time 4 min, demulsifier dosage 125 mg/L, centrifugal speed 4,000 min^{-1}, and centrifugal time 10 min.

Ma et al. [93] invented a method of microwave treatment of aging oil, and gave the specific operation steps and working parameters. Under the condition of nitrogen replacement and absolute oxygen, the reaction temperature was set as 20°C–100°C, the microwave power was 400–1,000 W, the stirring speed was 500–1,700 rpm, and the microwave radiation was carried out under the microwave treatment time of 1–10 min. After the microwave treatment, the aging oil was poured into the separating funnel, and after settling complete separation of oil and water.

The advantages of microwave radiation treatment are time-saving, high efficiency, clean, and good treatment effect. The disadvantage is that the aging oil with low

water content needs small power and long-time treatment to prevent the water droplets from microminiaturization due to high temperature, and the difficulty of dehydration is increased.

2.8. Extraction process

In the extraction method, the oil in the aged oil is extracted with the oil-friendly extractant based on the similar phase dissolving principle, so that it can be separated from water and solid-phase sediment, and the extractant can be regenerated and reused.

Tong et al. [94] invented the two-stage extraction aging oil treatment process, which combines the heat settlement and centrifugation process. The first stage extraction agent can be recycled. The second stage extraction agent can be used together with the separated oil to prepare fuel oil, and the moisture content of the aging oil after treatment is ≤3%.

The extraction process is green and environmentally friendly, and there are few reports about the treatment of aged oil. Some laws and mechanisms need to be studied, such as the selection and compounding of extractants, the factors related to the treatment capacity, and the regeneration process parameters.

2.9. Catalytic cracking technology

Catalytic cracking usually refers to the decomposition of large molecules in reactants into small hydrocarbon molecules by cracking reaction under the action of catalyst. The domestic catalytic cracking technologies mainly include: deep catalyst cracking process (DCC), catalytic pyrolysis process (CPP), and heavy oil contact cracking process (HCC) [95–103].

Wanning [104] studied and analyzed the performance and composition of the cracking products of aging oil, and applied the cracking products (under optimized catalyst conditions) to tractor engine for verification test. The method can fully recycle the aged oil and has good economic benefits.

Catalytic cracking technology is a new technology for aging oil treatment and an important technological innovation for aging oil resource utilization. Its treatment process is also restricted by aging oil moisture content, oil physical properties, catalyst types, and other factors.

3. Comparative analysis of aging oil treatment process

The mixing ratio of the traditional back mixing process cannot be greater than 6%, and impurities and water are also mixed into the gathering system, which is very unfavorable to the downstream process. Although it can produce effective benefits, it is no different from drinking poison to quench thirst. Thermochemical sedimentation process is commonly used in the pretreatment of aging oil, which can separate the free water and emulsified water of aging oil, but its long treatment time and large dosage of chemicals also affect the efficiency of aging oil treatment. The centrifugal treatment process can only separate the free water. Because of the complexity and stability of the oil products, the centrifugal process often blocks the equipment and affects the treatment efficiency to a certain extent. Ultrasonic is often combined with chemical heat treatment, high gravity separation technology, mechanical vapor recommendation (MVR) negative pressure dehydration technology, centrifugal separation technology, and thermochemical treatment to reduce the water content to 0.3%–0.5%. The moisture content of the aged oil is less than 0.3% after the combined treatment of electric dehydration and chemical demulsification. The moisture content of aged oil after extraction treatment is less than 3%. The hydrocyclone treatment process can also obtain oil with water content meeting the requirements of export. In the distillation dehydration process, different boiling points of oil, and water are used to precisely control the temperature, and anti-boiling measures are taken. The moisture content of the aged oil after final treatment is less than 0.5%.

The advantages and disadvantages of other treatment processes are summarized in Table 1:

4. Conclusion and prospect

The physical properties of aging oil determine that the treatment process is not a method to achieve the treatment effect, usually one method dominates, and many methods cooperate. This paper summarizes the research progress of aging oil treatment process in recent years. The treatment process is mainly based on the traditional electrochemical, thermal sedimentation, centrifugal separation, and other technologies. In recent years, many new treatment processes have good results and advantages and disadvantages. The author believes that it is urgent to combine various treatment technologies to develop a practical, efficient, and environmental protection treatment process, as shown in Fig. 11. The basic idea of aging oil treatment was put forward.

It can be seen from Fig. 11 that the aging oil treatment process is divided into three stages: pre-treatment, medium treatment, and post-treatment. In the future research of aging oil treatment process, we can connect the treatment

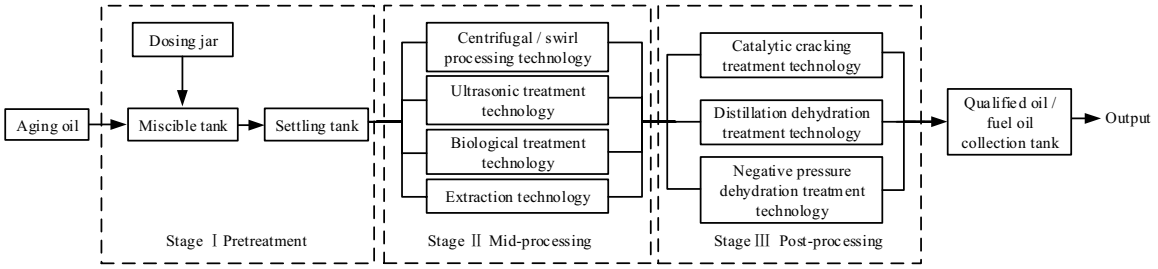

Fig. 11. New ideas for aging oil treatment process.

Table 1
Analysis of advantages and disadvantages of aging oil treatment process

Treatment process	Water content after treatment	Advantage	Disadvantages
Ultrasonic treatment process	1%~5%	Low operating cost, easy equipment operation, low processing temperature, short processing time, and suitable for aging oil treatment that is difficult to be worked by conventional methods	The physical properties of the aging oil are different in different areas, the processing parameters are different, and there is the possibility of secondary emulsification
Extraction treatment technology	≤3%	Extractant can be renewable or recyclable	The selection and compatibility of the extractant are different: the delivery is not fixed
Centrifugal and cyclonic dehydration	0.5%~1%	It occupies a small area and is suitable for areas with strict space requirements	High equipment investment and maintenance costs
Distillation dehydration	≤0.5%	Not affected by oil water density, viscosity, emulsification, no need to add demulsifier, strong adaptability, stability, simple process, and easy operation	High equipment investment costs
Catalytic cracking technology		Resource conversion	Strict requirements on water content and catalyst
Biological treatment process	0.5%~1%	Green environmental protection, high dehydration rate	Long cultivation time and long screening cycle
Microwave radiation treatment technology	2%~3%	Fast processing speed, high efficiency, clean, and good processing effect	When the water content is low, the power needs to be adjusted down, and it takes a long time to process
Negative pressure dehydration technology	≤0.5%	Simple process, strong adaptability, and low energy consumption	Processing capacity is limited and needs improvement

process of each stage, study the relationship between agent dosage, settling residence time, treatment capacity, and energy consumption, and optimize them to maximize the efficiency of each stage of the treatment process and make the whole process more efficient.

Acknowledgments

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