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Review Article

A State of the Art Review on the Wellbore Blockage of Condensate Gas Wells: Towards Understanding the Blockage Type, Mechanism, and Treatment

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With the development of high-pressure and high-temperature condensate gas wells, the wellbore blockage problems have become increasingly serious. Hence, selecting appropriate treatment technology plays a crucial role in solving the wellbore blockage problems. This study presents a comprehensive literature review on understanding the blockage type, mechanism, and treatment of the high-temperature and high-pressure condensate gas wells. The causes, endangerments, mechanisms, influences, and preventive technologies of the 4 wellbore blockage types are presented. The significant aspects of the treatment technology, such as the principle, type, advantage and disadvantage, adaptability, limitation, and future research direction of the treatment technologies, are thoroughly discussed. The breakthrough solid autogenetic heat treatment technology has been selected to remove hydrate blockage. The present review highlights the current state in the industry, future position, and strategies for the researchers to follow. Finally, the advantages and disadvantages and future research directions of specific treatment technology are presented on the removing effect, cost, and environmental aspects.

1. Introduction

With the industrial activities and scientific and technological advancements worldwide, the energy demand is increasing continuously. It is projected that the energy consumption in non-OECD countries increases almost 70% between 2018 and 2050 in contrast to a 15% increase in OECD countries of which the industrial sector will be the largest consumer, followed by the transportation section. It is also forecasted that dry natural gas, crude oil, and lease condensate will dominate energy production until 2050. Therefore, the exploration and development activities to pursue oil and gas will continue to rise in the coming years. Today's world is observing a depletion stage of oil rate production in oil-producing regions [1, 2]. The petroleum industry faces many challenges in producing oil and gas, and conventional techniques may not fulfill the growing demand for oil and gas resources [3, 4]. Ensuring the growing demand for oil and gas resources will be a major challenge in the forthcoming decades [5–12]. So, developing the condensate oil and gas resource is also an urgent task.

Usually, the occupancy of condensate gas dominates in deep (>4572 m) and ultradeep (>7620 m) reservoirs. The potential production of condensate gas from these deep and ultradeep reservoirs is considerably higher than the shallow pools. So, developing condensate gas resources is necessary to fulfill the energy demand. And the condensate gas reservoirs are mainly located in the deep and the ultradeep layer, with high-temperature and high-pressure conditions. The wellhead pressure of the deep layer condensate gas wells is generally greater than 70 MPa, and the bottom-hole pressure is generally greater than 105 MPa. For ultrahigh-temperature and ultrahigh-pressure condensate gas wells, the wellhead temperature is greater than 150°C, the wellhead pressure is greater than 105 MPa, the bottom-hole pressure is greater than 140 MPa, and the bottom-hole temperature is greater than

175°C. So, there are an increasing number of risks and problems that will happen, which will increase production costs and pose certain risks to staff.

The common wellbore blockage types are sand blockage, scale blockage, hydrate blockage, and wax blockage. This paper mainly reviews the wellbore blockage problems of condensate gas wells under high temperature and high pressure. Start from the blockage type, mechanism, and treatment measures, solving wellbore blockage, restoring gas well productivity, and reducing production costs. And there are 7 best commercial software that can be used to predict the above 4 kinds of blockage problems in the condensate gas wellbores, such as Sandctrl, Sand3D, Scale Chem, Aspen hysys, Pipesim, OLGA, and SPS. Usually, the sand blockage is the rarest problem, and the main reason for it is that the formation sand moves and accumulates in the wellbore. This will result in forced shutdown and maintenance [13–15]. Compared with sand blockage, the wax blockage is more common. Because the condensate gas belongs to the retrograde condensation phenomenon of condensate oil under high-pressure and high-temperature conditions, its essence is similar to conventional crude oil, which contains a large number of hydrocarbon substances [16]. With the reduction of temperature and pressure, wax components will crystallize and precipitate under the action of molecular diffusion and shear dispersion. And accumulate and deposit on the inner wall of the wellbore, which brings difficulties to production operation and hinders the normal production of condensate gas wells. Similarly, the wellbore of condensate gas wells with formation water production will have the risk of scaling and blockage in the wellbore. This is mainly due to the partial pressure of CO_2, which leads to a large number of carbonate ion generation combining with Ca^{2+} and Mg^{2+} in the wellbore, and accumulates and deposits in the inner wall of the wellbore. The hydrate blockage problem usually occurs at the wellhead. Moreover, in the high-pressure and low-temperature environment, if there is throttling or turbulent disturbance, it will be easier to generate hydrate blockage.

These are the four common blockage problems in the wellbore of high-temperature and high-pressure condensate gas wells, but in some cases, these problems are not generated alone. In addition, in the late development of high-temperature and high-pressure condensate gas wells, there will be a decrease in the liquid carrying capacity of the gas phase due to the decrease of the gas pressure, which will lead to the liquid loading phenomenon in the wellbore. The consequent change of the multiphase flow pattern will form such phenomena as slugging flow, annular fog flow, bubble flow, etc., and will also lead to shutoff pressure and shutdown of gas wells. In view of the blockage or slugging problem caused by liquid loading, it is necessary to strengthen the gas pressure or carry out bubble discharge operation in the late development [17–20]. There will be several coexistence situations, which will require special attention.

2. Sand Blockage

2.1. Causes and Endangerments. Based on the analysis from blockage mechanics, shearing and stretching are the main influence factors that can cause the high-pressure and high-temperature condensate gas well sand blockage. Hence, the destructed rock will impel sand to shed and to move. Some blockages from sand blockage gas wellbore are shown in Figure 1.

Figure 1: Blockages from sand blockage condensate gas well.

Two reasons, which cause the sand blockage problem of high-pressure and high-temperature condensate gas wells, are given by the following:

(1) Reservoir geological condition: stress state

(2) Producing factors: cementing quality and shot density

The problem of sand blockage in the wellbore will lead to an increasing number of negative effects such as prolonging operations and affecting the normal mining process. Common hazards caused by sand blockage are given by the following:

(1) Stopping production and decreasing productivity

(2) Landfilling reservoir and influencing recovery ratio

(3) Shortening equipment using time

(4) Causing formation stress change

2.2. Mechanisms and Influences. When shear stress and tensile stress are more than the strength of rock, it will cause the rock crushing and moving by the high-pressure and high-speed fluids, which is the biggest stress to resist the rock breakup. The rock stress mainly consists of compressive strength, tensile strength, and shear strength [21]. The uniaxial compressive strength is also an important parameter determining the sand production in wells. The tensile strength and shear strength are characterized by Young's modulus and shear modulus, which are defined for homogeneous and fully elastic media. But these parameters are still used for nonuniform and nonperfectly elastic geological bodies such as rocks. Next, the calculation formulas of these two parameters will be introduced.

Young's modulus is the ratio of stress to linear strain in tensile (or compressive) direction when rock tensile (or compressive) deformation occurs.

$$E = \frac{F/S}{\Delta L/L}, \quad (1)$$

where F is the external force, N; L is the length, m; ΔL is the length changes account, m; S is the cross-section area, m^2; E is the Young's modulus of rock, N/m^2.

The shear modulus is the sign of rock shear elasticity strength. When the shear angle is small, the formula of shear modulus can be obtained by Hooke's law.

$$\mu = \frac{F_t/S}{\theta}, \quad (2)$$

where F_t is the shear stress, N; S is the surface area affected by shear stress, m^2; μ is the shear modulus, N/m^2; θ is the shear angle, °.

The sand blockage problems of high-pressure and high-temperature condensate gas wells will bring an increasing number of wrong influences, such as decreasing yield and increasing the production cost. So, it is crucial to understand the influence factor of sand blockage. Formation sand production and sand blockage of fracturing are the main reasons. The formation sand production is brought by high-speed fluids from the bottom of wellbores. And four reasons can accelerate sand production, such as formation lithology and stress distribution, mining conditions, physical properties of formation fluids, and drawdown pressure. Generally, the inappropriate operation will also cause sand blockage in the fracturing process.

2.3. Preventive Treatment Technology. Sand production is extremely harmful. The wellbore sand blockage causes gas wells to stop production, and sand production causes serious abrasion and sand sticking of surface and downhole equipment. It will not only increase production cost but also increase the difficulty of gas field management.

Physical sand control technology can be divided into two categories. One is running sand control string to prevent sand production: such as slotted liner, wire wound screen, cemented sand filter, double or multilayer screen, etc. This kind of sand control technology is simple and easy to implement, but the effect is poor and the service life is short. The other type is to run into the sand control string and then fill it with a variety of filling materials. The most commonly used materials are gravel, husks, pits, plastic particles, and glass balls.

Resin bonding is also an effective sand control technology. The technology can be used in the existing construction string of condensate gas wells, without drilling rig or workover rig. It can also be used for abnormal high-pressure wells.

2.4. Unblocking Treatment Technology. To solve sand blockage problems, analyze and summarize unblocking treatment technology. After understanding treatment technology, select the effective solutions, which are suitable for high-pressure and high-temperature condensate gas wells.

A Tapered Outer Diameters Coiled Tubing System (TODCTS) is developed for the deployment of multiple outer diameter coiled tubing sections in a single string, which can maintain sufficient flow capacity for well intervention operations. When operating on the spot without solvents, combining the use of familiar coiled tubing operations and a high-pressure rotary jetting tool can remove the $BaSO_4$ scale. Likewise, continuous tubing can be used to solve sand blockage problems in a sand blockage well of Nigeria, so that the productivity will increase to 300%. Found in long-term practice, research a new high strength coiled tubing grade with good ductility. The continuous tubing technology can also be used in offshore oil and gas fields, the first worldwide subsea application for plastic coiled tubing for sand removal.

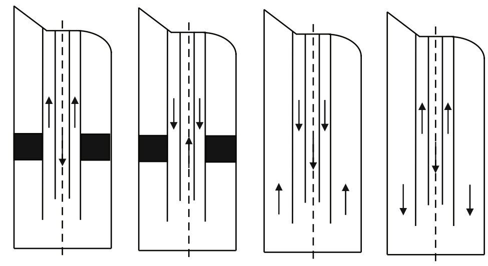


Figure 2: The methods of water blasting technology.

2.4.1. Coiled Tubing Treatment Technology. The coiled tubing treatment technology [22] drives the coiled tubing and tools to the goal position and uses the high-speed drill to remove the blockage efficiently. At last, sand and debris are brought out wellbore by liquid circulation. In addition to the coiled tubing treatment technology, the common removing technologies of sand blockage are mechanical sand fishing and water blasting. Mechanical sand fishing technology can be divided into two parts, which are wire rope conveying sand fishing and oil pipe conveying sand fishing. But it is usually abandoned at present. The principle of water blasting technology is utilizing high-speed fluids to remove the sand blockage and utilizing up-flow fluids to bring sand to the wellhead. The water blasting technology also can be divided into four parts as follows: forward, back, doubly forward, and forward and back, which are presented in Figure 2.

Compared to the other two sand blockage removing technologies, the coiled tubing technology can fully utilize the continuous and reliable seal characters of tubing and operate in a negative pressure environment. With a closed-cycle system, it could solve sand blockage reliably and safely. The demerits of unblocking treatment technology are mentioned in Table 1.

After understanding the principle, advantages, and disadvantages of the coiled tubing technology, the applicability and attention of coiled tubing treatment technology can be summarized approximately which are given by the following:

(1) With wide applicability and good sand blockage removal effect, the coiled tubing technology can be utilized in high-temperature and high-pressure condensate gas wells

(2) Average operating depth can reach more than 6000 m, wellbore operating temperature can reach 150°C~170°C, and the acceptable pressure of wellbore can reach 90 MPa

(3) In the process of removing the sand blockage, it should pay attention to the pressure of the wellhead to avoid sand overflow and the high-pressure jet jurying staff

Table 1: The sand blockage removal treatment technology.

Technology type	Technology advantages	Technology disadvantages
Forward water blasting	Remove sand blockage easily	Weak sand carrying capacity, card drilling easily
Back water blasting	Strong sand carrying capacity, card drilling uneasily	Weak impact force
Forward and back water blasting	Combining the advantages of forward and back water blasting	Low operating safety
Coiled tubing	Continuous and reliable seal, operate in negative pressure availably	High operating cost

(4) The coiled tubing treatment technology, with less actual operations and higher operating costs, is the most effective measure to remove the sand blockage in high-temperature and high-pressure condensate gas wells

2.4.2. Other Treatment Technology. Recently, there are 3 kinds of unblocking treatment technologies, coiled tubing treatment technology, acidification unblocking technology, and overhaul. Selecting unblocking treatment technology should pay attention to safety, economic effectiveness, completeness, and rationality and consider the blockage type and degree of the wellbore blockage.

When scale content is more than sand content in the blockage, considering economic cost and rationality selects acidification unblocking technology. Besides technology being mature and safety controllable, it also has the characteristics of a short construction period, low cost, and high-cost performance. To solve the tubing string broken problems of condensate gas wells, when coiled tubing treatment technology and acidification unblocking technology cannot be utilized, the overhaul treatment technology could be applied to the recovery of the normal production of condensate gas wells.

2.5. Limitations and Future Research Directions. Through literature review on the sand blockage removal technologies to solve the sand blockage problem of condensate gas wells under high-temperature and high-pressure, the coiled tubing technology is considered to be the best blockage treatment technology. The limitations of the coiled tubing technology are given by the following:

(1) The cost of the coiled tubing technology is so high

(2) The strength of coiled tubing and wire rope string is a problem when operating at high temperature and high pressure

After specifically understanding the limitation of the coiled tubing technology, further research directions will be introduced. It will make it easier to select the optimized treatment technology. And the future research directions are given by the following:

(1) *Strengthening Pressure Strength of Tools.* Because coiled tubing technology will remove the sand blockages in the higher depth layer, the tools will be operated under extremely high pressure. It is necessary to strengthen the pressure strength of tools

(2) *Reinforcing Toughness and Strength of Tubing or Cable.* When the coiled tubing technology is used to remove the sand blockage at a deeper depth, it is necessary to use the tubing to drive in series. Reinforcing the toughness and strength of tubing or cable can prevent from tools falling or tubes or cables fracturing

(3) *Optimization of Coiled Tubing Rotary Nozzle.* To effective and rapid blockage removal, the coiled tubing rotary nozzle should be further optimized and improved and strive for high efficiency, high speed, safety, and low cost to meet condensate gas wellbore rapid blockage removal

3. Scale Blockage

High salinity formation water and acidic components of H_2S and CO_2 will cause scaling, corrosion, and blockage in different degrees in the production process of high-temperature and high-pressure condensate gas wells. The scale blockage will increase friction and pressure drop and influence gas well percentage recovery.

3.1. Causes and Endangerments. When formation fluids flow from wellbore to wellhead, the temperature, pressure, oil-gas-water balanced state, and the ion concentration of Ca^{2+}, Mg^{2+}, Ba^{2+}, CO_3^{2-}, SO_4^{2-}, and Cl^- will be changed. In the process, salt scales, corrosion scales, and deposition scales will generate rapidly, which is insoluble, less soluble, or slightly soluble materials. Salt scaling is composed of carbonate and sulfate, such as $CaCO_3$, $CaSO_4$, $BaSO_4$, and $SrSO_4$. Due to fluids containing organic matter, sulfate-reducing bacteria, iron bacteria, CO_2, H_2S, and so on, it corrodes wellbore and generates scale corrosion products such as $FeCO_3$ and FeS. Moreover, there are also existing many impurities such as microbial excreta and solid particles and less sand in the condensate oil and gas. Through the analysis of the mechanism of salt water scaling, it has been proved that scaling phenomenon is not only simply directly related to temperature and pressure but also affected by the interface and its flow [7, 11, 12]. Scaling is a complex process, as shown in Figure 3, generally divided into four steps.

(1) Salt molecules with low solubility are generated, such as $CaCO_3$, $CaSO_4$, $BaSO_4$, and $SrSO_4$

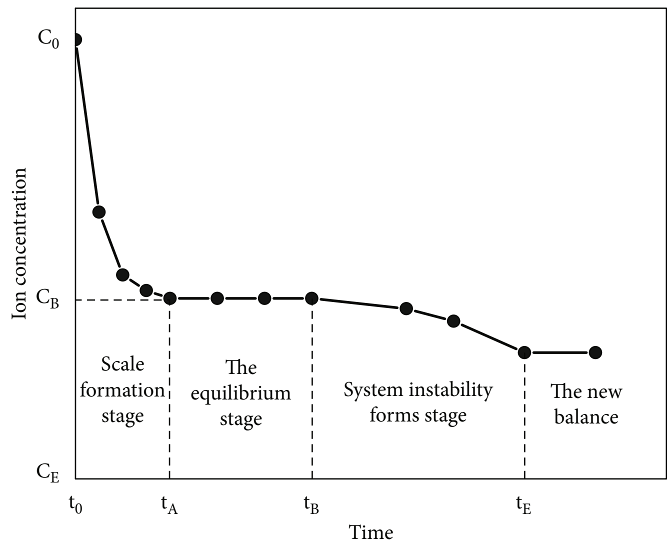


FIGURE 3: Formation process of scale in system.

(2) Under crystallization, molecules combine, microcrystal formation of arrangement and produce grains

(3) An increasing number of crystals grow up and generate scales

(4) Due to different conditions, generate scale blockage with different occurrences

Due to the existing a large number of high salinity formation water and acidic components such as H_2S and CO_2, it will form a corrosion-prone scaling environment to cause scaling and wellbore blockage. After appearing scale blockage in the high-temperature and high-pressure condensate gas wells, this will cause a series of problems, which are given by the following:

(1) Increase friction coefficient and condensate oil casing pressure

(2) Reduce wellbore diameter and drifting tools are unable to enter a predetermined well section

(3) Instability or decline in gas or liquid production and control production difficulty

(4) The flow of wellbore scale into the ground will result in increased pressure on the ground equipment

3.2. Mechanisms and Influences. Scales of the wellbore are composed of $CaCO_3$, $CaSO_4$, and iron-containing compounds mainly. When fluids flow from layer to ground, the pressure of CO_2 drops, and the change of formation water composition will bring a large number of CO_3^{2-}. So many scales will be generated in the suitable wellbore temperature and pressure environments. The high-temperature and high-pressure condensate gas wellbore scaling phenomenon is shown in Figure 4.

FIGURE 4: Scale blockage in the wellbore.

The mechanism of scale blockage mainly includes incompatibility theory, thermodynamic condition change theory, and adsorption theory [7, 11, 12]. The incompatibility theory, two chemical incompatible liquids (formation water and ground water and formation water containing incompatible ions in different reservoirs) are mixed, because different ions or different concentrations of ions will produce unstable material and precipitate solids easily. In the thermodynamic condition change theory, in the process of condensate gas well production, when the temperature rises, pressure drops, or flow rate changes, high salinity water will generate scale. The last one is the adsorption theory. Scaling can be divided into three stages: scale precipitation, scale growth, and scale deposition. The surface of equipment is uneven, and it is a micro rough surface. The scale ions will be adsorbed on the wall and taken as the crystal center, growing up and becoming a solid and dense scale.

In the high-temperature and high-pressure condensate gas wells, the common scales are mainly $CaCO_3$, $CaSO_4$, $MgCO_3$, $MgSO_4$, etc. They are insoluble, less soluble, or slightly soluble materials. The following is the chemical formula of the above scale.

$$\begin{aligned} Ca^{2+} + CO_3^{2-} &= CaCO_3\downarrow \\ Ca^{2+} + SO_4^{2-} &= CaSO_4\downarrow \\ Mg^{2+} + CO_3^{2-} &= MgCO_3\downarrow \\ Mg^{2+} + SO_4^{2-} &= MgSO_4\downarrow \\ Ca^{2+} + 2HCO_3^{-} &= CaCO_3\downarrow + CO_2\uparrow + H_2O \\ Mg^{2+} + 2HCO_3^{-} &= MgCO_3\downarrow + CO_2\uparrow + H_2O \end{aligned} \quad (3)$$

Table 2: Scaling influence factor.

Influence factor	Influence principle	Influence incidence
pH value	Conversion of HCO_3^- to CO_3^{2-} under alkaline condition, CO_3^{2-} combined with Ca^{2+} to form $CaCO_3$	Form salt scale, soluble in acid solution.
Mechanical impurity	Rough cylinder walls and other impurities have strong catalytic crystallization and sedimentation effect on the crystallization process, resulting in precipitation of fluid at low saturation.	Induce scaling in the wellbore as a catalyst.
Temperature condition	The solubility of the $CaSO_4$ scale decreased sharply with the increase of temperature, and $CaCO_3$ did not increase with the increase of temperature, showing a unidirectional trend.	Different salt scales have different sensitivity to temperature.
Pressure condition	When the pressure is reduced, the partial pressure of CO_2 will be reduced, resulting in $CaCO_3$ precipitation.	Scaling easily in the wellbores with decreasing pressure.
Hydrodynamic factor	With the increase of flow velocity, the stirring degree of liquid flow increases, and the precipitation crystal agglomeration intensifies, which promotes the rapid formation of the crystal nucleus.	With the flow velocity increasing, the turbulent flow will greatly promote scaling.

Influence of various factors on wellbore scaling, quick scaling speed of inner wall of the wellbore, and the important factors affecting wellbore scaling are shown in Table 2 [23–28].

3.3. Preventive Treatment Technology. When there is scale blockage gathering in the wellbore of the high-temperature and high-pressure condensate gas wells, the effective flow area in the wellbore will be decreased, and the pressure of the wellbores will be increased. It is common to add corrosion inhibitors or scale inhibitors to the wellbores, and corrosion-resistant materials can be used in the early completion stage.

The principle of chemical antiscale agents is to change the scale-prone environment in the wellbores, because the alkaline environment will be more prone to the formation of scale. So, the chemical antiscale agents are used to make acidic environment to inhibit scaling. Corrosion inhibitor refers to a chemical substance or compound that exists in the environment in an appropriate form and concentration and can effectively alleviate or prevent the corrosion of materials. Therefore, adding corrosion inhibitors can prevent wellbore scaling and reduce the degree of corrosion to the wellbore.

3.4. Unblocking Treatment Technology. To solve the troublesome issue of scale blockage in the wellbore of high-temperature and high-pressure condensate gas wells, the blockage causes, factors, degrees, and unblocking treatment technology should be considered. And combine the technical application of scale blockage prevention and control with unblocking treatment technology of scale blockage in high-pressure and high-temperature condensate gas wells.

PetroChina Changqing Oilfield Company selects out ZH-2 and ZG-558 scale inhibitors, with excellent effect. Yangtze University (China) finds the SIB scale inhibitor with excellent effect by scale prevention experiment. And ascorbic acid is an easily biodegradable natural product, with an excellent environmental profile. In a high-temperature environment, ascorbic acid could be deployed as an excellent green chemical to prevent $CaCO_3$ scale [29]. Not just a single agent can inhibit scaling blockage, polymer inhibitors also can be utilized to inhibit scaling. Northeast Petroleum University (China) generates MA-AA scale inhibitors and MA-AA-SSS-AMPS scale inhibitors, with excellent effect and good high-temperature resistance. Furthermore, the high-frequency electromagnetic field can be used to inhibit scaling, and its inhibitory effect is great. Ultrasonic can also be used as a new and efficient technology in high-temperature and high-pressure condensate gas wells to remove inorganic scale near the well area [30, 31].

3.4.1. Chemical Treatment Technology. The principle of chemical treatment technology is that physical and chemical reactions between chemical agents and scale blockages occur, which makes the scales soften, peel, and dissolve to remove scale blockage. It should also be noted that scale blockages are not homogeneous but a mixture. Three common scale blockage removal technologies are presented in Table 3.

Comparing three common unblocking treatment technology, the application of chemical treatment technology is universal. It is necessary to understand the adaptability of the chemical treatment technology in order to make it easier to be selected.

(1) Chemical treatment technology has the advantages of high removing efficiency, large action space, and wide application range. It is a better technology to remove wellbore scale blockage

(2) Chemical treatment technology is affected by temperature and pressure environment. An increasing number of chemical agents accelerate the removing rate with the increase of temperature and pressure

(3) The harm to wellbore, formation, and environment should be noted in the removing scale blockage process

Table 3: Comparison of common scale removing technology.

Technology type	Technology advantage	Technology disadvantage
Chemical treatment technology	Simple process, short construction period, safety, economy, high efficiency	Some chemical agents have strong corrosivity and are easy to corrode wellbore.
Physical treatment technology	The operation is convenient, the degree of automation is high, and there is no environmental pollution.	The complex mechanism and poor universality, especially in the application of gas fields, need further study.
Mechanical treatment technology	For wellbore scales, it is better that is not suitable for such as $BaSO_4$ for gas wells that are not suitable for pickling.	Descaling is complex, high cost, low efficiency, and high risk of underground operation safety.

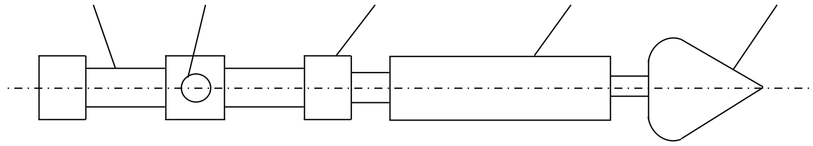


Figure 5: Structure diagram of the mechanical treatment tool.

3.4.2. Other Treatment Technology. Besides chemical treatment technology, the mechanical descaling technology, the downhole jet descaling technology, and the ultrasonic cleaning and antiscaling technology also can be used to remove scale blockage. Next, the principle will be introduced, and the advantages and disadvantages will be compared to select out the optimal treatment technology in the removing scale blockage process.

Mechanical descaling technology, utilizing dynamic drilling tools to remove the gathering scale blockage in the wellbore, is applied early. The technology can be used in the condensate gas wells that cannot be acid washed, with excellent effect to remove $BaSO_4$ and another hard scale. The mechanical treatment tool is shown in Figure 5.

For downhole jet descaling technology, it is potential to apply multiple jet holes or an indexing nozzle to remove wellbore scale blockage. A pure water jet is effective to remove soft scales, but it is not suitable to remove hard scales. However, when pure water jet is only used to remove scale, it will remove harmful scales in large areas and its effect is remarkable [32].

Ultrasonic removing and antiscaling technologies have extensive advantages, such as online continuous work, a high degree of automation, and reliable working performance. The practice has proved that ultrasonic removing and antiscaling technology can not only prevent the formation of scales but also destroy the existing scales. It has an obvious scale prevention effect and strong advantages in environmental protection and energy-saving [13–15].

The adaptability analysis of the above three treatment technologies is as follows:

(1) Removing tools such as milling cutters involved in mechanical descaling technology will damage the integrity of the wellbore string and limit its size during operation

(2) There are many security risks in mechanical descaling technology, which is only suitable for special working conditions

(3) Mechanical descaling technology is suitable for acid-sensitive condensate gas wells, but there is a certain risk in the construction under a high-pressure environment. When the scale blockage is deep, the tool needs to be slowly dropped to prevent the tools from falling

(4) Downhole jet descaling technology needs to pay attention to the design of the jet nozzle, jet nozzle uniform dispersion, and strive to quickly remove scale blockage in the high-temperature and high-pressure condensate gas wellbore

(5) Ultrasonic removing and antiscaling technologies are suitable for removing the scale blockage problems near the well and when the demand for scale blockage removal technology is urgent because it causes high cost and high price

3.5. Limitations and Future Research Directions. The applicability, advantages, and disadvantages of the common unblocking treatment technology in high-pressure and high-temperature condensate gas wellbore have been clarified. The main limitation is that the treatment technologies or unblocking tools are not applicable in condensate gas wellbores. Therefore, the future research direction of scale blockage removal technology will be roughly given to provide help in selecting treatment technology for high-temperature and high-pressure condensate gas wells. The limitations of scale blockage treatment technology will be introduced.

(1) Chemical scale removers are generally toxic and corrosive, which the stability at the high-temperature and high-pressure environment is weak

(2) Mechanical scale removal technology is difficult to construct in high-temperature and high-pressure condensate gas wells, which is easy to cause secondary damage and bring a security threat to staff

(3) Microbial wax removal technology has fewer species of bacteria and higher price requirements

(4) Ultrasonic removing and antiscaling technology is difficult to construct in deeper layers

After a preliminary understanding of the limitations of the scale blockage treatment technology, the following several points mainly focus on its follow-up research direction, so as to better select the scale blockage removal technology and optimize the scale blockage removing scheme. The future research directions are given by the following:

(1) Improve mechanical removing tools in mechanical descaling technology. To remove acid-insoluble hard scales in the deep wellbore of high-pressure and high-temperature condensate gas wells, if the strength and range of mechanical removing tools are not enough to completely remove it, the risk of tool string falling into the reservoir will be induced, which causes secondary damage

(2) Optimize the nozzle and pipeline of the downhole jet tool. In the use of downhole jet tools for downhole jet, the descaling degree of the downhole jet rotating nozzle should be noticed. The delay and cost loss of high-pressure and high-temperature condensate gas wells producing period caused by repeated descaling operation

(3) Optimize ultrasonic cleaning technology and reduce cost. Although ultrasonic has a high removing degree, its application scope is narrow. Hence, it is necessary to strengthen the adaptability of ultrasonic cleaning and antiscaling technology at high-temperature, high-pressure, and deeper strata. Reduce costs and improve economic benefits

4. Hydrate Blockage

With the energy changing, the pressure and temperature of fluids also are changed in the formation fluid flowing process. When arriving at a certain temperature, hydrate will generate and gather in the inner wall of wellbore. The hydrate blockage will damage downhole tools and influence normal production.

4.1. Causes and Endangerments. Hydrate is a crystalline solid, which is combined between hydrocarbon molecules in condensate gas and free water under a certain degree of pressure and temperature. Generally, the main conditions of hydrate formation include the following: existing extensive free water, low temperature environment, the temperature of condensate gas is less than dew point temperature, and high-pressure environment. Auxiliary conditions include that high-velocity flowing, pressure fluctuation, and the presence of acidic components such as H_2S and CO_2. If there were an environment of pressure fluctuation, temperature drop, closure, or sudden change of airflow direction, the hydrate blockage would be more likely to occur. A schematic diagram of hydrate blockage is shown in Figure 6.

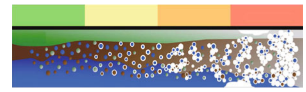


Figure 6: A schematic diagram of hydrate blockage [33].

There are a series of harmful effects caused by hydrate blockage, which will seriously threaten the normal production process of high-temperature and high-pressure condensate gas wells and the safety of staff. Common hydrate blockage hazards in high-temperature and high-pressure condensate gas wells are as follows:

(1) Cause wellbore pressure hold and reduce wellbore circulation area

(2) Decrease gas well production efficiency and cause unsafe accidents

(3) In winter, hydrate freeze blockage problems can be found in the gas recovery tree

4.2. Mechanisms and Influences. Hernandez [34] has built the solid-liquid flow mechanism model of the pipeline system, which is used to predict the pressure drop of the pipeline system, and the deposition process of hydrate particles and the corresponding change of solid-liquid flow pattern are divided into four stages which are shown in Figure 7. These are (a) uniform suspended flow, (b) nonuniform suspended flow, (c) mobile bed flow, and (d) fixed bed laminar flow.

Englezos et al. [35] proposed a kinetic model to describe the growth of pure methane, pure ethane, and mixed gas hydrates on the basis of crystallization theory and dual-mode theory:

$$\left(\frac{dn}{dt}\right)_p = K^* A_p \left(f - f_{\mathrm{eq}}\right), \quad \frac{1}{K^*} = \frac{1}{k_\gamma} + \frac{1}{k_d}, \tag{4}$$

where A_p is the surface area of hydrate particle shell, m^2; f is the gas fugacity, MPa; f_{eq} is the gas fugacity in three phase equilibrium, MPa; k_γ is the reaction rate constant, mol/(m^2·MPa·s); k_d is the mass transfer coefficient, mol/(m^2·MPa·s); K^* is the total rate constant, mol/(m^2·MPa·s); n is the molar number of gas consumed by hydrate growth, mol; t is the time, s.

The main factors affecting hydrate formation include formation water ion concentration, acid gas content, gas composition, and pressure and temperature. Several main factors can be analyzed. Gas composition influences hydrate blockage generation. Under constant pressure conditions,

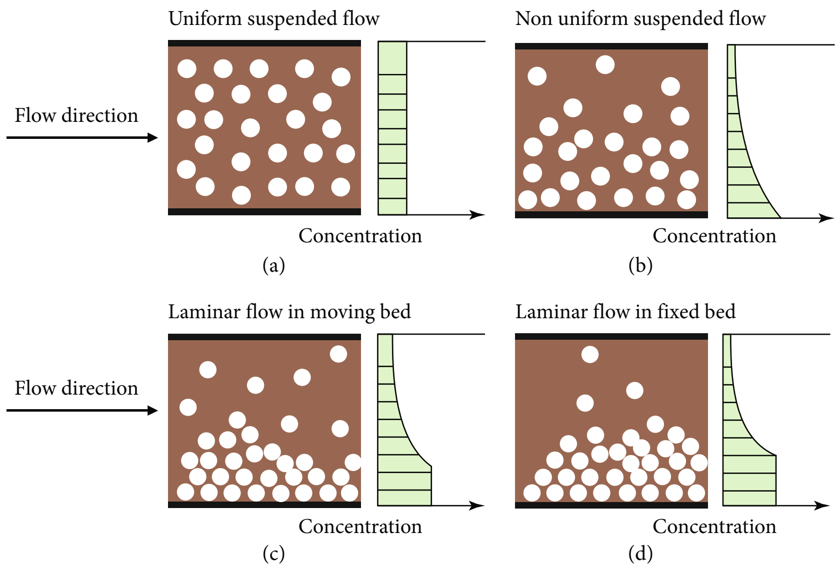


Figure 7: Deposition process of hydrate particles and solid-liquid flow pattern [35].

the higher the content of CH_4, the lower the temperature of hydrate formation, so the higher the content of CH_4 in the gas component, the less easily the hydrate formation. Pressure and temperature influences hydrate blockage generation. The formation temperature of hydrate is almost exponentially correlated with gas environmental pressure. Under a low-pressure environment, the influence of pressure is greater than temperature. Under the high-pressure environment, temperature influence is greater than pressure. Formation water ion concentration influences hydrate blockage generation. Under the same pressure environment, with the formation water ion concentration increasing, the generation temperature of hydrate decreases. So high salinity formation water has a certain inhibitory effect on hydrate formation. Acid gas content influences hydrate blockage generation. Under constant pressure conditions, increasing acid gas content will lead to hydrate formation temperature increasement. The higher acid gas content is more likely to generate hydrate blockage.

To sum up, hydrate formation temperature is almost positively correlated with the pressure. The higher the pressure, the higher the hydrate formation temperature. High salinity formation water has a certain inhibitory effect on hydrate formation, and acid gas content has a certain role in promoting hydrate formation [36].

4.3. Preventive Treatment Technology. To dissolve the problem of wellbore hydrate blockage in high-temperature and high-pressure condensate gas wells, the prevention measures of hydrates in the early stage should be paid attention. Several hydrate blockage preventive technologies will be mainly introduced.

The principle of chemical preventive technology is utilizing inhibitors to change the environment of hydrate generation. Hydrate inhibitors contained in the chemical reaction products can also prevent hydrate formation again, achieving safe and effective removing hydrate blockage [37].

The heating to prevent hydrate technology is that heating condensate gas in the wellbore and making the temperature of condensate gas more than the production temperature of hydrate. Currently, the common heating technologies include steam injection heating, water jacket furnace heating, and cable heating.

4.4. Unblocking Treatment Technology. To solve the hydrate blockage problems in the high-temperature and high-pressure condensate gas wellbores, the blockage causes, degrees, harm, and treatment technology should be considered. The important solution will be introduced as follows:

Since the end of the 20th century, the methanol has begun as a kind of hydrate inhibitor. A semibatch stirring reactor with constant temperature and pressure is designed to characterize kinetic inhibitors. The anticoagulant is found that can be an inhibitor to prevent hydrate generation [38]. Meanwhile, QAB inhibitor is found in the first experiments at the molecular level [39]. The ice structure protein (ISPs) also can be utilized to inhibit hydrate generation. It is not only the Chitosan and Guar agum as biodegradable hydrate formation kinetic inhibitors with good application prospects [40]. The China University of Petroleum found out that downhole throttling technology can decrease the risk of producing hydrate. To solve the toxicity of methanol, a nontoxic new hydrate inhibitor named Z-6 is developed and has an excellent removal effect.

4.4.1. Chemically Autogenetic Heat Technology. The blockage removal process of hydrate is the endothermic decomposition process of hydrate in the wellbores. When the temperature and pressure of the system deviate from the phase equilibrium condition, the hydrate begins to decompose. Hydrate is dissolved by the heat released by the chemical reaction of the blockage agent in the wellbores, and the hydrate inhibitor contained in the chemical reaction product can also prevent the formation of hydrate again, so as to

Table 4: Comparison of common hydrate removing technology.

Technology type	Technology advantage	Technology disadvantage
Chemically autogenetic heat technology	Good blocking effect can quickly remove hydrate blockage in a short time, low process cost, and easy operation.	Unblocking too quickly, high-pressure air jets can cause danger.
Chemical hydrate inhibitors technology	It has good preventive effect, high safety, and strong universality.	The hydrate removing effect in the wellbore is poor, and the main focus is on the early prevention and control.
Mechanical treatment technology	Easy to operate, general unblocking effect, hydrate removal is more complete.	The cost is high, the energy loss is large, and the blockage depth is limited.

achieve the purpose of safely and effectively removing hydrate blockage [41, 42].

The general composition of the autogenetic heat blocking remover formulation is chemical reaction main agent +reaction control agent+corrosion inhibitor+iron ion stabilizer. The comparison of common hydrate removing technology is listed in Table 4.

After understanding the principle of chemical control treatment technology, the adaptability analysis is essential in selecting hydrate blockage treatment technology. Next, the adaptability analysis of chemical treatment technology for hydrate blockage in high-temperature and high-pressure condensate gas wells will be mainly introduced.

(1) Chemical treatment technology is an effective control measure for hydrate blockage, which can make up for the problems of operation in mechanical removing technology

(2) Chemical treatment technology is not affected by the depth of the hydrate blockage but is greatly affected by temperature and pressure

(3) The chemical inhibitors should be no toxicity and no harm to the wellbore environment

(4) To solve dense hydrate blockage, the combination of chemical and mechanical treatment technology can be used to solve the hydrate blockage problem

4.4.2. Other Treatment Technology. Besides chemical treatment technology, there are also 3 kinds of hydrate blockage treatment technologies, such as dewatering to control hydrate, pressure drop control hydrate, heating to prevent hydrate, and downhole throttling technology. Next, they will also be introduced.

The principle of dewatering [43] to inhibit hydrate is removing free water in the produced fluids to inhibit hydrate generation. The pressure drop treatment technology is reducing system pressure to inhibit hydrate generation. In practice, it is better to make the pressure drop process between isothermal and adiabatic conditions. The principle of heating to prevent hydrate is heating condensate gas in the wellbore and making the temperature of condensate gas more than the production temperature of hydrate. Currently, the common heating technologies include steam injection heating, water jacket furnace heating, and cable heating. The principle of downhole throttling technology is utilizing an air nozzle to achieve reducing pressure, which is installed in the wellbore. Through downhole throttling and formation heating condensate gas, the wellbore pressure on the upper part of the throttling nozzle can be reduced. When condensate gas flows to the wellhead, the wellhead pressure decreases. Hence, reduce hydrate generation temperature and increase the temperature of condensate gas to achieve inhibit hydrate formation.

After preliminarily recognizing the principles of the mentioned technologies, the adaptability of the technologies will be mainly introduced to make the subsequent selection easier. The adaptability will be introduced as follows:

(1) Heating to prevent hydrate technology is suitable for condensate gas wells with weak hydrate blockage, and this method is accompanied by the high cost

(2) The downhole throttling technology needs a simple downhole throttling nozzle and producing scheme designed for different production conditions

(3) The downhole throttling technology is less affected by temperature and pressure but needs some throttling devices with high temperature and high pressure. Likewise, it is vulnerable to corrosion

(4) When the downhole throttling device is installed, the installation position should be noted and it should be installed firmly to prevent accidents

4.5. Limitations and Future Research Directions. After summarizing and understanding the treatment technologies mentioned above for the hydrate blockage in high-temperature and high-pressure condensate gas wells, comparing their advantages and disadvantages, applicability, limitations, and future research directions of hydrate blockage removal technology will be analyzed. The limitations of the treatment technology for hydrate blockage are listed below.

(1) Most hydrate autogenetic heat agents are toxic and corrosive, which will corrode the wellbore and damage the reservoir

(2) The performance stability of hydrate autogenetic heat agents under high-temperature and high-pressure environments is uncertain, so it is necessary to conduct stability research

(3) The hydrate preventive technology will be heat loss in the operation of heating, with the high cost and low economic benefit

(4) The strength requirements of downhole tools for downhole throttling technology are not enough, and tools will fall or be carried to the wellhead by high-pressure and high-speed airflow

After a brief understanding of the limitations of the above-mentioned treatment technology for wellbore hydrate blockage in high-temperature and high-pressure condensate gas wells, the following research will be conducted around the subsequent use to successfully solve hydrate blockage problem in the direction of high-temperature and high-pressure. Moreover, reduce economic costs and improve recovery.

(1) Hydrate autogenetic heat agents will be studied in the direction of nontoxic and noncorrosive and reduce the cost of chemical agents

(2) About heating to prevent hydrate technology, reduce heating cost, improve heating technology, and reduce energy loss

(3) The stability of hydrate autogenetic heat agents at high temperature and high pressure should be improved, and the inhibition research should be studied in the composite direction

(4) Strengthen the strength of downhole throttling technology tools, optimize the structural design, and improve stability

5. Wax Blockage

When the temperature and pressure decrease to a certain degree in the producing process, the wax molecule in condensate gas will continuously crystallize and precipitate. After wax deposition in high-temperature and high-pressure condensate gas wells, the inner diameter of the wellbore gradually will be decreased, the condensate oil flow resistance will be increased, and the condensate gas well productivity will be reduced.

5.1. Causes and Endangerments. Condensate gas, a multi-component organic mixture, is composited by hydrocarbon compounds and nonhydrocarbon compounds. The wax blockage is caused by the precipitation of wax molecules from condensate gas [44] and the aggregation and deposition of wax molecules with heavy colloids, asphaltenes, or other impurities on the inner wall of the wellbores [45]. The wax blockage problems will reduce the flow area and increase friction. The schematic diagram of wax blockage formation is shown in Figure 8.

The well of light wax blockage will not have a great impact on production. But with the production time prolonging, the well of serious wax blockage will shorten the production cycle, reduce condensate gas well production, and lead to shut down production possibly. The hazards of wax blockage in the wellbore of high-temperature and high-pressure condensate gas wells are as follows:

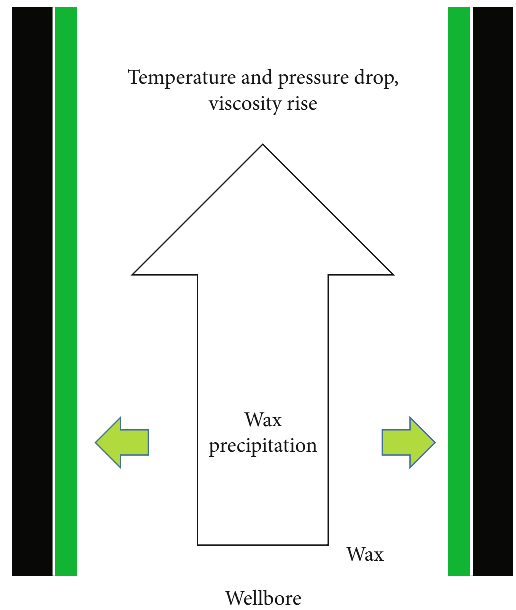


Figure 8: The diagram of wellbore wax blockage [46].

(1) Severe wax blockage in the annulus of the oil jacket will cause hot washing failure

(2) Under the action of formation pressure, the strong lifting string will cause external spraying, resulting in serious environmental pollution

(3) Downhole tools will be not easy to fall into, such as wax scrapers, drift diameter gauge, and perforating guns

(4) Underground and ground wax removing work is difficult to begin, and the construction period is prolonged resulting in materials and cost waste

5.2. Mechanisms and Influences. At present, the understanding of the internal causes of wax deposition blockage has not been unified, and extensive scholars have various explanatory theories on its mechanism [47]. The mechanism of wax blockage can be divided into three parts, such as phase equilibrium theory, solubility theory, and crystallization theory. The schematic diagram of wax blockage formation is shown in Figure 9.

The wax deposition can be regarded as a reversible thermodynamic process [48]. Because the change of condensate oil and gas composition or temperature and pressure, the thermodynamic equilibrium conditions are changed, so that the solubility of wax will be reduced, resulting in wax crystallization, deposition, and blockage. This can be attributed to phase equilibrium theory.

According to the thermodynamic solubility theory, wax soluble in condensate oil and gas under stable conditions can be regarded as a true solution, in which wax is a solute and light components are regarded as solvents. The temperature reduction will decrease the solubility of the wax

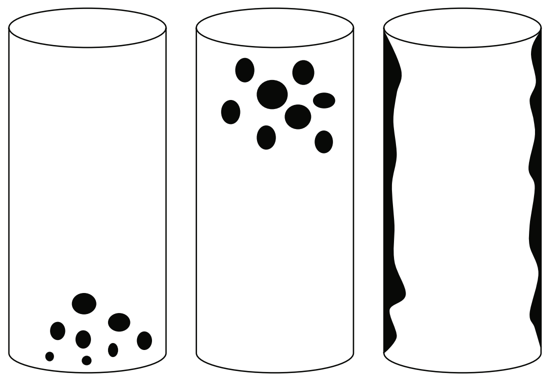


Figure 9: Schematic diagram of wax blockage formation [41, 42].

composition, which leads to the wax crystallization, deposition, and blockage in the condensate gas wells.

In 1988, Weingarten and Euchner [49] proposed the wax dissolution model by fitting the experimental data, according to the ideal melting theory:

$$\ln X_{pt} = \frac{-\triangle h_f}{R}\left(\frac{1}{T_f} - \frac{1}{T_m}\right), \tag{5}$$

where X_{pt} is the molar fraction of saturated wax in liquid phase; R is the ideal gas constant, 8.314 kJ/(kg·mol·K)$^{-1}$; h is the dissolution latent heat of wax, kJ/(kg·mol·K)$^{-1}$.

According to Equation (5), the molar fraction of saturated wax is a function of temperature that can be confirmed, which is the solubility of wax increases with the increase of system temperature and decreases with the decrease of temperature.

The crystallization process is the process of ordering solid structures from the disordered phase [50]. When the condensate oil and gas temperature reduce to the cloud point temperature, the precipitation process of dissolved wax molecules from the liquid phase is generally divided into two stages such as nucleation stage and crystal growth stage.

Combining the above three wax blockage mechanisms, two models were established, which are the molecular diffusion model and the shear dispersion model. The temperature difference between the oil and gas flow and the tube wall causes the concentration gradient of dissolved wax molecules and wax grains, which will make the wax molecules and grains move to the solid surface under the mechanism of molecular diffusion and shear dispersion.

The deposition rate caused by molecular diffusion can be calculated by the Fick diffusion equation:

$$\begin{aligned} W_L &= \frac{dG}{dT} = \rho_L D_M \frac{dw}{dr}, \\ \frac{dw}{dr} &= \frac{dw}{dT} \cdot \frac{dT}{dr}, \\ W_L &= \rho_L D_M \frac{dw}{dT} \cdot \frac{dT}{dr}, \end{aligned} \tag{6}$$

where W_L is the wax molecular mass per unit area diffused in unit time, kg·(s·m^2)$^{-1}$; ρ_L is the wax density, kg/m^3; d is the concentration gradient of dissolved wax related to distance at the wall, m^{-1}; dw/dT is the concentration gradient of dissolved wax related to temperature, °C^{-1}; dT/dr is the radial temperature gradient at wellbore wall, °C·m^{-1}; D_M is the molecular diffusion coefficient of dissolved wax, m^3/s^{-1}, which can be calculated by the following formula:

$$D_M = \frac{B_0}{\mu_0}, \tag{7}$$

where B_0 is the condensate oil constant; μ_0 is the dynamic viscosity of condensate oil, Pa·s.

The shear dispersion, which the wax crystals flowing with condensate oil in the wellbore, and the crystallization near the wellbore wall will radially move under the shear effect of condensate oil flow [51, 52]. Likewise, considering the gradual precipitation of wax grains in the condensate oil flow, the original rough protrusion of the wellbore wall will not be regarded as the crystallization core. The wax deposition and blockage generation by shear dispersion account for a small proportion, which can be ignored in the actual calculation.

By analyzing the wax blockage samples of different wellbore positions, the gas mass and oil sample characteristics are studied. Common influence factors of wax blockage in condensate gas wells are as follows:

(1) *Properties of Condensate Oil* [53]. For different condensate oil, the higher the wax content, the more serious the wax blockage problem

(2) *Oil Temperature and Temperature Difference between Condensate Oil and the Wellbore Wall* [54]. When the oil temperature is between wax precipitation point and freezing point, there will be wax deposition peak area

(3) *Pressure*. When the pressure is lower than the bubble point pressure, the pure oil phase will be transformed into a gas-liquid two-phase. And the precipitation of light hydrocarbon molecules reduces the solubility of condensate oil to wax, which increases the wax precipitation point

(4) *Water Content* [50, 55]. With water content increasing, the wax deposition rate first decreases slowly and then decreases rapidly

(5) *Mechanical Impurities* [56, 57]. Mechanical impurities can be used as a crystallization center to promote wax deposition

5.3. Preventive Treatment Technology. The problem of wellbore wax blockage has become a crucial problem in the production process of condensate gas wells. In order to solve the problem of wellbore wax blockage in high-temperature and high-pressure condensate gas wells, chemical wax inhibitors can be periodically added to prevent wellbore wax

Table 5: Chemical wax removers.

Wax remover type	Wax remover introduce	Wax remover disadvantage
Oil-based wax removers	The mainstream direction of wax removers	Toxic, flammable, and unsafe
Water-based wax removers	Emulsifying oil-based wax removers in water, releasing demulsification in the wellbore, safety, and environmental protection	Weak wax removal effect.
Emulsion wax removers	Combining the advantages of oil-based wax removers and water-based wax removers can effectively prevent wax while removing wax.	High requirements for stability

generation, and electric heating wax preventive technology can also be used to prevent wellbore wax blockage.

The wax blockage is generally divided into three stages, such as the wax precipitation, the wax crystal growth, and the deposition blockage. The wax inhibitors can inhibit the wax deposition process at any stage to achieve the purpose of preventing wax.

Electric heating wax removal technology utilizes thermal cable or downhole electric heater to heat oil flow to achieve the aim to dissolve wax blockage of the inner wall of the wellbore.

5.4. Unblocking Treatment Technology. To remove the wax blockage in the high-temperature and high-pressure condensate gas wellbore, consider the causes, level, and unblocking treatment technologies of wax blockage. Combining worldwide treatment technologies, summarize the effective wax blockage removal solutions.

Northeast Petroleum University (China) developed a kind of O/W emulsion wax removers, which utilize the thermal effect of the heating agent to achieve wax removal effect [58]. M.S. Voss found a formulation originally developed for removing ink from printing presses turns out to be a successful dispersant for wax. And continuously adding copolymers can be used to inhibit the wax blockages, such as polyacrylates, polymethacrylates, or poly (ethylene-co-vinyl acetate) (EVA) [59]. Southwest Petroleum University (China) utilized an an-ionic surfactant to develop middle-phase microemulsion. Likewise, researchers compound a dispersing PPD with high activity and excellent effect. PetroChina Changqing Oilfield Company developed a microemulsion efficient wax remover to solve the problems of the oil-based wax removers are toxic and flammable and has low density, and the water-based wax removers have low wax dissolving efficiency. And there are new additives that present better results than the commercially available polymer-based inhibitors in all tested samples, even when applied at smaller concentrations, compared to many other polymer-based inhibitors reported in the literature [60]. China National Offshore Oil Corporation selected the mechanical removing wax of steel wire as the main wax removal method, and the conventional wax removal tool was modified.

5.4.1. Chemical Treatment Technology. The principle of chemical removing wax blockage technology is utilizing a chemical agent to dissolve and disperse the wax blockage in the wellbore. Chemical agent addition can be divided into two ways, such as oil sleeve annular dosing and oil pipeline dosing. The former is be commonly used. The chemical wax removers also can be divided into three kinds, such as oil-based wax removers, water-based wax removers, and emulsion wax removers.

The principle of oil-based wax removers is utilizing organic solvent to dissolve wax and remove it from the inner wall of the wellbore, with excellent solubility and carrying capacity. The common oil-based wax removers are summarized as follows, such as petrol, kerosene, diesel, heavy naphtha, and carbon tetrachloride. The water-based wax removers make water as a dispersion medium and add a certain number of surfactants, mutual solvents, and bases. It utilizes the wetting reversal effect of surfactants to make the inner wall of the wellbore change from lipophilic to hydrophilic and remove the wax blockage from the wellbore. The emulsion wax removers combine the advantages of oil-based removers and water-based wax removers, which can not only improve the flashpoint of wax remover but also play a role in wax prevention. It is composed of aromatic or mixed aromatic solvents and nonionic surfactants [13–15, 61]. A comparison of the advantages and disadvantages of the chemical wax removers is introduced in Table 5.

Next, the applicability of chemical wax removers will be analyzed and listed below to better select wax removal technology.

(1) Solvent wax removers are convenient in construction, with widely used and strong applicability

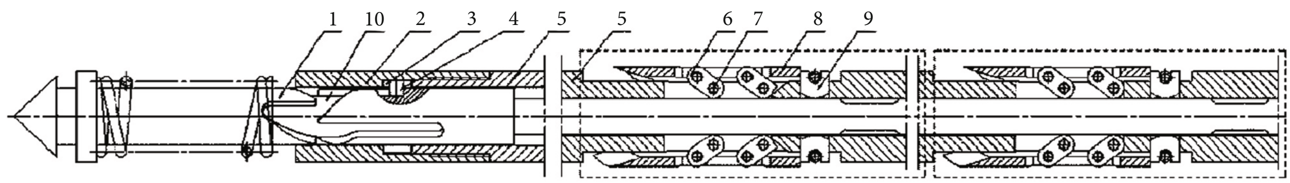
(2) Required dosing facilities

(3) Chemical wax remover is susceptible to surface factors such as wellhead, and its product selectivity is strong. It needs to be selected and optimized

(4) When the wellbore wax blockage is dense, it is necessary to combine chemical and mechanical wax removal technology

(5) Some of the wax remover agents are toxic and harmful to staff, but they have high safety and low fire risk in overall application, such as water-based wax cleaning agents

5.4.2. Mechanical Treatment Technology. For acid-sensitive gas wells, utilizing acid agents will harm condensate gas wells, so it should utilize mechanical treatment technology. The mechanical removing wax technology is a traditional and common technology, which uses a scraper to remove the wax blockage of the wellbore wall. Mechanical wax removal technology is easy to manage and simple to operate,



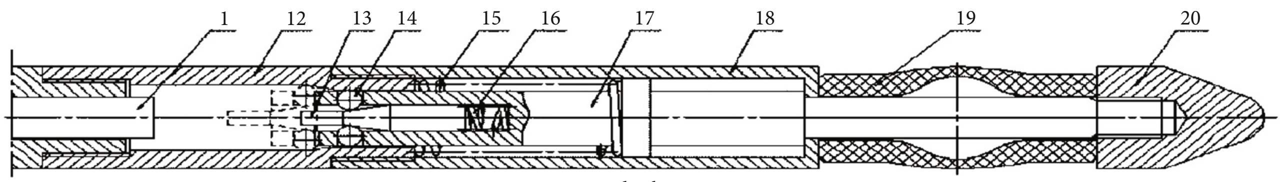


FIGURE 10: Mechanical wax removing device. 1: wax scraping central rod, 2: upper joint, 3: slip ring, 4: slip ring pin, 5: outer sleeve, 6: pin shaft, 7: connecting rod, 8: scraper, 9: limiting block, 10: chute, 12: cone casing, 13: locking rod, 14: locking block, 15: large spring, 16: small spring, 17: locking sleeve, 18: lower joint, 19: rubber sleeve, and 20: base.

has no harm to the reservoir, and effectively reduces labor intensity, as shown in Figure 10.

After understanding the principle of mechanical wax removal technology, the adaptability analysis of mechanical wax removal technology will mainly be introduced.

(1) The technology with low cost and simple operation is generally suitable for condensate gas wells with low wax deposition and small deviation

(2) Mechanical wax removal technology will be of high risk when utilized in high-pressure condensate gas wells

(3) Poor safety tools are easy to be damaged, and there is a risk of string fall of wire tools

(4) But the equipment investment is low, and the overall economy is feasible

5.4.3. Other Treatment Technology. Besides chemical wax removing technology and mechanical wax removing technology, there are 4 kinds of treatment technologies such as microbial wax removal technology, ultrasonic wax removal technology, electric heating wax removal technology, and coiled tubing wax removal technology.

The microbial wax removal technology is a relatively new removing technology, which utilizes some specific bacteria metabolism to achieve removing wax. Such microbes can reduce the molecular weight of saturated wax and long-chain hydrocarbons or degrade them into unsaturated hydrocarbons. The ultrasonic wax removal technology utilizes the cavitation and mechanical and thermal effects of acoustic waves to get the aim to remove wax [62]. Using ultrasonic wax remove technology can optimize management costs, reduce operating procedures, and reduce labor intensity [13–15]. Electric heating wax removal technology utilizes thermal cable or downhole electric heater to heat oil flow to achieve the aim to dissolve wax blockage of the inner wall of the wellbore. It can avoid formation pollution caused by chemical agents, but it has low efficiency, high cost, and poor reliability. The coiled tubing wax removal technology mainly uses the heat energy of heated oil, water, and wax removers to melt and dissolve the wax blockage [13–15, 63–66]. Using coiled tubing technology can solve wax blockage problems that cannot be solved by conventional wax removal technology. The advantages and disadvantages of the mentioned wax removal technologies are listed in Table 6.

5.5. Limitations and Future Research Directions. After preliminarily understanding the causes, hazards, influencing factors, and treatment measures of wax blockage, the limitations and future research directions of common wax blockage treatment technologies are mainly introduced. After understanding the limitations and future research directions of treatment technologies, it is helpful to compare and select technology in solving the wax blockage problems of high-temperature and high-pressure condensate gas wells. The limitations of wax blockage treatment technology will be introduced.

(1) Chemical wax removers are generally toxic and corrosive, which the stability at the high-pressure and high-temperature environment is weak

(2) Mechanical wax removal technology is difficult to construct in high-temperature and high-pressure condensate gas wells, which is easy to cause secondary damage and bring a security threat to staff

(3) Microbial wax removal technology has fewer species of bacteria and higher price requirements

(4) The heat energy loss of electric heating is large, and the construction cost is high

(5) Ultrasonic wax removal technology is difficult to construct in deeper layers

Table 6: Other wax removal technologies.

Technology type	Technology advantage	Technology disadvantage
Microbial wax removal technology	The wax cleaning effect is a good and advanced technology.	The strain has a short validity period, weak universality, and may have adverse genetic variation.
Ultrasonic wax removal technology	Optimize management costs, reduce operating procedures, and reduce labor intensity.	Effect of wax removal at different frequencies
Electric heating wax removal technology	Convenient construction, long working life, and can be used repeatedly in many wells	Relatively large power consumption and low efficiency
Coiled tubing wax removal technology	Simple, safe, and reliable, the operation efficiency is improved, and reservoir protection is also beneficial.	High construction cost

After understanding the limitations of the wax blockage treatment technologies mentioned above, the next research direction will mainly focus on the above limitations. Strive to improve production efficiency and reduce work costs.

(1) The concept of environmental protection and safety is introduced into the preparation of chemical wax removers, which strives to be nontoxic and noncorrosive and improves the stability of high pressure and high-temperature environment

(2) Optimize the structure of mechanical wax scrapers, and strengthen the strength and toughness of steel wire

(3) Further research on microbial wax removal technology, and strengthen the exploration of strain groups

(4) Improve wax removal efficiency of electric heating wax removal technology and reduce cost

(5) Improve the working depth of ultrasonic removal technology, and promote it to a deeper layer and high-pressure direction

6. Conclusion

With a significant increase in energy demand, the development of high-temperature and high-pressure condensate gas wells is important for the quest for energy demand. The effective technologies to solve wellbore blockages play a crucial role in safe and effective producing process. The common wellbore blockage problems can be divided into sand blockage, scale blockage, hydrate blockage, and wax blockage. Besides these common blockage types, there are also sand-scale blockage and wax-scale blockage. The special unblocking treatment technologies and preventive technologies can be summarized as follows:

(1) The optimal sand blockage treatment technology is coiled tubing treatment technology, which has an excellent removing effect and high one-time removing effect. But the cost is relatively high. In the future, it is necessary to optimize the downhole nozzle to improve the blockage removal efficiency and reduce the production cost

(2) The optimal scale blockage treatment technology is chemical treatment technology, which has an excellent removing effect and scale inhibition effect after successfully removing blockages, and can prevent secondary scale blockage in a short time. But the corrosion, toxicity, and high-temperature and high-pressure stability of chemical scale removers need further study. Similarly, to remove severe dense scale blockage, a combination of chemical and mechanical removing blockage technology should be adopted

(3) The optimal hydrate blockage treatment technologies are chemically autogenetic heat technology and downhole throttling technology. The chemical hydrate agents have an excellent removing effect and can prevent hydrate speed generation in a short time. But the corrosion, toxicity, and high-temperature and high-pressure stability of chemical scale removers need further study. The downhole throttling technology combined with chemical treatment technology can prevent reformation of hydrate blockage and improve production efficiency

(4) The optimal wax blockage treatment technologies are chemical treatment technology, mechanical treatment technology, and electric heating wax removal technology. The removing and treatment effect of the chemical treatment technology is excellent, which is the most suitable technology. The mechanical treatment technology is suitable for acid-sensitive condensate gas wells, and the removing wax effect is more complete. However, the use of mechanical treatment technology in the high-temperature, high-pressure, and ultradeep environment still has high risk, which needs further research. The electric heating wax removal technology is relatively focused on the prevention of wax generation, but its cost and the heat energy loss are high. Therefore, it is necessary to conduct further research on heating methods and heat energy maintaining methods

(5) To solve the problem of sand-scale blockage, acid-removing blockage technology can be used when the content of sand is less and the content of scale is more, which has a better-removing effect, mature technology, and low cost. When the blockage is mainly composed of sand, coiled tubing blockage removal technology should be adopted, which can better remove the blockage and recover the productivity of condensate gas wells

(6) About the wax-scale blockage problems, the chemical removing technology can be used to develop a dual-effect remover for wax-scale blockage. It can better remove the blockage and convenient operation. But when the blockage is severely dense, the combination of chemical and mechanical blockage removing technology should be adopted

This review mainly summarizes the treatment measures of condensate gas wellbore blockage under the high-temperature and high-pressure environment, in order to provide technical guidance, select technology facilely, improve condensate gas well productivity, and reduce production costs.

Data Availability

All data and models generated or used during the study appear in the submitted article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] J. Hite, S. Avasthi, and P. Bondor, "Planning successful EOR projects," *Journal of Petroleum Technology*, vol. 57, no. 3, pp. 28-29, 2005.

[2] Z. Li, Y. Liang, Q. Liao, B. Zhang, and H. Zhang, "A review of multiproduct pipeline scheduling: from bibliometric analysis to research framework and future research directions," *Journal of Pipeline Science and Engineering*, vol. 1, no. 4, pp. 395–406, 2021.

[3] F. Zhang and H. Emami-Meybodi, "Analysis of early-time production data from multi-fractured shale gas wells by considering multiple transport mechanisms through nanopores," *Journal of Petroleum Science and Engineering*, vol. 197, article 108092, 2021.

[4] F. Zhang and H. Emami-Meybodi, "A type-curve method for two-phase flowback analysis in hydraulically fractured hydrocarbon reservoirs," *Journal of Petroleum Science and Engineering*, vol. 209, article 109912, 2022.

[5] G. Jiang, J. Sun, Y. He et al., "Novel water-based drilling and completion fluid technology to improve wellbore quality during drilling and protect unconventional reservoirs," *Engineering*, 2021.

[6] G. Cui, S. Pei, Z. Rui, B. Dou, F. Ning, and J. Wang, "Whole process analysis of geothermal exploitation and power generation from a depleted high-temperature gas reservoir by recycling CO_2," *Energy*, vol. 217, article 119340, 2021.

[7] Z. Wang, X. Liu, H. Luo et al., "Foaming properties and foam structure of produced liquid in alkali/surfactant/polymer flooding production," *Journal of Energy Resources Technology*, vol. 143, no. 10, pp. 1–25, 2021.

[8] M. Saggaf, "A vision for future upstream technologies," *Journal of Petroleum Technology*, vol. 60, no. 3, pp. 54–98, 2008.

[9] H. Zhong, Y. He, E. Yang, Y. Bi, and T. Yang, "Modeling of microflow during viscoelastic polymer flooding in heterogenous reservoirs of Daqing Oilfield," *Journal of Petroleum Science and Engineering*, vol. 210, article 110091, 2022.

[10] H. Luo, J. Wen, C. Lv, and Z. Wang, "Modeling of viscosity of unstable crude oil-water mixture by characterization of energy consumption and crude oil physical properties," *Journal of Petroleum Science and Engineering*, vol. 212, article 110222, 2022.

[11] Y. Wang, X. Li, and J. Lu, "Experimental study and numerical modeling of boron transport in reservoir and its influence on seawater-breakthrough calculation," *SPE Reservoir Evaluation & Engineering*, vol. 24, no. 2, pp. 292–309, 2021.

[12] H. Wang, Y. Xu, B. Shi, C. Zhu, and Z. Wang, "Optimization and intelligent control for operation parameters of multiphase mixture transportation pipeline in oilfield: a case study," *Journal of Pipeline Science and Engineering*, vol. 1, no. 4, pp. 367–378, 2021.

[13] X. Wang, X. Guo, Q. Liu et al., "Design of method for quantitatively evaluating pollution scale of oil well in unconsolidated sand reservoir," *Unconventional Oil & Gas*, vol. 9, no. 3, pp. 125–130, 2022.

[14] Z. Wang, Y. Xu, Y. Gan, X. Han, W. Liu, and H. Xin, "Micromechanism of partially hydrolyzed polyacrylamide molecule agglomeration morphology and its impact on the stability of crude oil-water interfacial film," *Journal of Petroleum Science and Engineering*, vol. 214, article 110492, 2022.

[15] Z. Wang, X. Liu, H. Zhang et al., "Modeling of kinetic characteristics of alkaline-surfactant-polymer-strengthened foams decay under ultrasonic standing wave," *Petroleum Science*, 2022.

[16] A. Sousa, H. Matos, and L. Guerreiro, "Preventing and removing wax deposition inside vertical wells: a review," *Journal of Petroleum Exploration and Production Technology*, vol. 9, no. 3, pp. 2091–2107, 2019.

[17] M. Tugan, "Deliquification techniques for conventional and unconventional gas wells: review, field cases and lessons learned for mitigation of liquid loading," *Journal of Natural Gas Science and Engineering*, vol. 83, article 103568, 2020.

[18] A. L. Pagou, G. Han, L. Peng et al., "Liquid loading prediction and identification model for vertical and inclined gas wells," *Journal of Natural Gas Science and Engineering*, vol. 84, article 103641, 2020.

[19] A. L. Pagou, X. Wu, Z. Zhu, and L. Peng, "Liquid film model for prediction and identification of liquid loading in vertical and inclined gas wells," *Journal of Petroleum Science and Engineering*, vol. 188, article 106896, 2020.

[20] H. Rodrigues, E. Pereyra, and C. Sarica, "Pressure effects on low-liquid loading oil-gas flow in slightly upward inclined pipes: flow pattern, pressure gradient and liquid holdup," *SPE Journal*, vol. 24, no. 5, pp. 2221–2238, 2018.

[21] M. Hubbert and D. Willis, "Mechanic of hydraulic fracturing," *Transactions of the AIME*, vol. 18, no. 6, pp. 153–163, 1972.

[22] J. Khan, S. Irawan, E. Padmanabhan, H. H. Al-Kayiem, and S. Rai, "Optimization of coiled tubing nozzle for sand removal from wellbore," *Journal of Petroleum Exploration and Production Technology*, vol. 10, no. 4, pp. 1–14, 2019.

[23] M. Khan, M. Budair, and S. Zubair, "A parametric study of $CaCO_3$ scaling in AISI 316 stainless steel tubes," *Heat and Mass Transfer*, vol. 38, no. 1-2, pp. 115–121, 2001.

[24] N. Andritsos, M. Kontopoulou, A. Karabelas, and P. G. Koutsoukos, "Calcium carbonate deposit formation under isothermal conditions," *The Canadian Journal of Chemical Engineering*, vol. 74, no. 6, pp. 911–919, 2009.

[25] T. Kim, C. Bai, and Y. Cho, "A study of $CaCO_3$ fouling with a microscopic imaging technique," *Journal of Heat and Mass Transfer*, vol. 45, no. 3, pp. 597–607, 2002.

[26] C. Patton, "Injection-water quality," *Journal of Petroleum Technology*, vol. 42, no. 10, pp. 1238–1240, 1990.

[27] J. Macadam and S. Parsons, "Calcium carbonate scale formation and control," *Reviews in Environmental Science and Bio-Technology*, vol. 3, no. 2, pp. 159–169, 2004.

[28] N. Andritsos and A. Karabelas, "The influence of particulates on $CaCO_3$ scale formation," *Journal of Heat Transfer*, vol. 121, no. 1, pp. 225–227, 1999.

[29] S. Kundu, B. Ghosh, S. Balasubramanian, and M. Haroun, "A biodegradable scale inhibitor for oil well application," *Petroleum Science and Technology*, vol. 29, no. 14, pp. 1512–1520, 2011.

[30] Y. Zhao, L. Zhang, X. Zhao, J. Liu, and M. Gao, "Research on descaling characteristics and simulation calculation of a coaxial high-frequency electronic descaling device," *Water*, vol. 13, no. 6, p. 789, 2021.

[31] J. Taheri-Shakib, H. Naderi, Y. Salimidelshad, A. Teymouri, and A. Shekarifard, "Using ultrasonic as a new approach for elimination of inorganic scales (NaCl): an experimental study," *Journal of Petroleum Exploration and Production Technology*, vol. 8, no. 21, pp. 1–12, 2017.

[32] J. Fair, "Development of high-pressure abrasive-jet drilling," *Journal of Petroleum Technology*, vol. 33, no. 8, pp. 1379–1388, 1981.

[33] D. Turner, *Clathrate Hydrate Formation in Water-in-Oil Dispersions*, Golden Colorado School of Mines, 2005.

[34] O. Hernandez, *Investigation of Hydrate Slurry Flow in Horizontal Pipelines*, University of Tulsa, 2006.

[35] P. Englezos, N. Kalogerakis, P. Dholabhai, and P. R. Bishnoi, "Kinetics of formation of methane and ethane gas hydrates," *Chemical Engineering Science*, vol. 42, no. 11, pp. 2647–2658, 1987.

[36] C. Liu, Z. Hao, X. Liu, H. He, S. Wei, and C. Zhou, "Phase equilibrium dynamic model and thermodynamic behavior of tight gas hydrate," *China Petroleum Machinery*, vol. 49, no. 9, pp. 85–91, 2021.

[37] S. Halligudi, C. Sajanikumari, R. N. Kala, S. S. Deshpande, and M. P. Degaonkar, "Liquid phase allylation of phenol using Hβ zeolite," *Journal of Molecular Catalysis A: Chemical*, vol. 175, no. 1-2, pp. 161–167, 2001.

[38] Z. Huo, E. Freer, M. Lamar, B. Sannigrahi, D. M. Knauss, and E. D. Sloan Jr., "Hydrate plug prevention by anti-agglomeration," *Chemical Engineering Science*, vol. 56, no. 17, pp. 4979–4991, 2001.

[39] C. Koh, R. Westacott, W. Zhang, K. Hirachand, J. L. Creek, and A. K. Soper, "Mechanisms of gas hydrate formation and inhibition," *Fluid Phase Equilibria*, vol. 194-197, pp. 143–151, 2002.

[40] S. Sanatgar and K. Peyvandi, "New edible additives as green inhibitors for preventing methane hydrate formation," *Journal of Environmental Chemical Engineering*, vol. 7, no. 3, article 103172, 2019.

[41] J. Yang, Y. Feng, B. Zhang, Y. Tang, and Z. Jiang, "A blockage removal technology for natural gas hydrates in the wellbore of an ultra-high pressure sour gas well," *Natural Gas Industry*, vol. 40, no. 9, pp. 64–69, 2020.

[42] J. Yang, Y. Lu, N. Daraboina, and C. Sarica, "Wax deposition mechanisms: is the current description sufficient?," *Fuel*, vol. 275, article 117937, 2020.

[43] G. Chen, "Formation and prevention of hydrate during process of gas exploitation and transmission," *Natural Gas Industry*, vol. 8, pp. 89–91, 2004.

[44] L. Guo, X. Nie, J. Ji, L. Wang, H. Sun, and G. Ju, "Yield characteristics of the waxy crude water-in-oil emulsions cementitious system," *Acta Petrolei Sinica (Petroleum Processing Section)*, vol. 38, no. 1, pp. 110–118, 2022.

[45] Z. Ye, J. Long, and Z. Dai, "Effects of heteroatom on molecular interactions of asphaltenes: a computational study," *Acta Petrolei Sinica (Petroleum Processing Section)*, vol. 38, no. 1, pp. 75–84, 2022.

[46] C. van der Geest, A. Melchuna, L. Bizarre, A. C. Bannwart, and V. C. B. Guersoni, "Critical review on wax deposition in single-phase flow," *Fuel*, vol. 293, article 120358, 2021.

[47] X. Zhou, F. Thomas, and R. Moore, "Modeling of solid precipitation from reservoir fluid," *Journal of Canadian Petroleum Technology*, vol. 35, no. 10, pp. 37–45, 1996.

[48] P. Singh, R. Venkatesan, H. S. Fogler, and N. R. Nagarajan, "Morphological evolution of thick wax deposits during aging," *AICHE Journal*, vol. 47, no. 1, pp. 6–18, 2001.

[49] J. Weingarten and J. Euchner, "Methods for predicting wax precipitation and deposition," *SPE Production Engineering*, vol. 3, no. 1, pp. 121–126, 1988.

[50] W. Hayduk and B. Minhas, "Correlations for prediction of molecular diffusivities in liquids," *The Canadian Journal of Chemical Engineering*, vol. 60, no. 2, pp. 295–299, 1982.

[51] Z. Wang, Y. Xu, Y. Zhao, Z. Li, Y. Liu, and J. Hong, "Role of shearing dispersion and stripping in wax deposition in crude oil pipelines," *Energies*, vol. 12, no. 22, 2019.

[52] J. Zhao, X. Xi, H. Dong, Z. Wang, and Z. Zhuo, "Rheo-microscopy in situ synchronous measurement of shearing thinning behaviors of waxy crude oil," *Fuel*, vol. 323, article 124427, 2022.

[53] Y. Xu, H. Wang, Z. Wang, Z. Xu, J. Hong, and W. Sun, "Microscopic mechanism of asphaltene and resin behavior to the stability of oil-water interface," *Journal of Northeast Petroleum University*, vol. 45, no. 6, pp. 90–101, 2021.

[54] D. Jennings and K. Weispfennig, "Effects of shear and temperature on wax deposition: coldfinger investigation with a Gulf of Mexico crude oil," *Energy & Fuels*, vol. 19, no. 4, pp. 1376–1386, 2005.

[55] Y. Liu, X. ZhuGe, Z. Wang, and L. Zhang, "Effect of emulsification mechanism on morphology and aggregation behavior

of wax crystals in waxy crude oil," *Oil & Gas Storage and Transportation*, vol. 38, no. 8, pp. 877–884, 2019.

[56] R. Sarmento, G. Ribbe, and L. Azevedo, "Wax blockage removal by inductive heating of subsea pipelines," *Heat Transfer Engineering*, vol. 25, no. 7, pp. 2–12, 2004.

[57] R. Hoffmann, L. Amundsen, and R. Schüller, "Online monitoring of wax deposition in sub-sea pipelines," *Measurement Science and Technology*, vol. 22, no. 7, article 075701, 2011.

[58] H. Chen, Z. Shen, P. Yan, and Z. Mo, "Highly efficient heat-melting wax removal agent," *Journal of Northeast Petroleum University*, vol. 2, pp. 36–41, 1996.

[59] A. Machado, E. Lucas, and G. González, "Poly (ethylene-co-vinyl acetate) (EVA) as wax inhibitor of a Brazilian crude oil: oil viscosity, pour point and phase behavior of organic solutions," *Journal of Petroleum Science & Engineering*, vol. 32, no. 2-4, pp. 159–165, 2001.

[60] B. C. Lemos, V. Gilles, G. R. Gonçalves et al., "Synthesis, structure-activity relationship and evaluation of new non-polymeric chemical additives based on naphthoquinone derivatives as wax precipitation inhibitors and pour point depressants to petroleum," *Fuel*, vol. 220, pp. 200–209, 2018.

[61] M. Li, G. Zhao, G. Zhang, and J. Ge, "Study on the property of oil-base paraffin remover," *Journal of China University of Petroleum (Edition of Natural Science)*, vol. 2, pp. 61–63, 2004.

[62] P. Roberts, A. Venkitaraman, and M. Sharma, "Ultrasonic removal of organic deposits and polymer-induced formation damage," *SPE Drilling & Completion*, vol. 15, no. 1, pp. 19–24, 2000.

[63] E. Bell, Y. Lu, N. Daraboina, and C. Sarica, "Experimental investigation of active heating in removal of wax deposits," *Journal of Petroleum Science and Engineering*, vol. 200, article 108346, 2021.

[64] C. Zhu, X. Liu, Y. Xu et al., "Determination of boundary temperature and intelligent control scheme for heavy oil field gathering and transportation system," *Journal of Pipeline Science and Engineering*, vol. 1, no. 4, pp. 407–418, 2022.

[65] Y. Liu and Z. Rui, "A storage-driven CO_2 EOR for net-zero emission target," *Engineering*, 2022, In Press.

[66] W. Yang, C. Fu, Y. Du et al., "Dynamic contact angle reformulates pore-scale fluid-fluid displacement at ultralow interfacial tension," *SPE Journal*, vol. 26, no. 3, pp. 1278–1289, 2021.