

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(9): 1152-1159
www.biochemjournal.com
Received: 01-06-2024
Accepted: 06-07-2024

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Advancements in crude wax deposition management: An overview of chemical, physical, and microbial methods

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DOI: <https://doi.org/10.33545/26174693.2024.v8.i9o.2370>

Abstract

Due to increasing demand of crude oil for the essential energy sources in day to day activities, the deposition of crude wax in wells as well as in transporting pipelines is a major concern in the field of crude oil production and transportation industries. Wax deposition leads to blocks pipelines and reduces its inner diameter therefore, the cost of petroleum production increases gradually. This paper summarizes the key technologies used to inhibit or remediate deposited wax in wells. It provides an inclusive review, highlighting the main disadvantages and advantages of each technique. Mechanical removal remains widely used for addressing wax issues in wells, despite its high cost. Heating is another common method, though it can cause damage the pipelines and reservoirs. Biological treatments require additional studies to understand better site conditions. Insulating materials and coating are generally not fully effective and often need supplementary methods. Cold flow has only been tested in pipelines and is not appropriate to wells. Lastly, methods like electric, WIT and magnetic fields, and oscillatory motion are practical applications that have yet to be totally proven. By synthesizing current research and case studies, current review intend to highlight the progress and future directions in crude wax deposition management.

Keywords: Crude wax, microbial treatment, bio-surfactant, paraffin, wax deposition, biosurfactant

Introduction

The wax in crude oil usually contains of a variety of light and intermediary hydrocarbons (Paraffins, aromatics, naphthenes) and extra heavy organic compounds, including resins, asphaltenes, diamonDoids, mercaptans, and organometallics, although these are present in very low concentrations. Crude oil is a multifaceted organic mixture composed mainly of hydrocarbons, with a few non-hydrocarbon components. Its general composition can be categorized into saturates, aromatics, resins, and asphaltenes. Some saturate compounds have high melting points, making them prone to solidification at low temperatures. (Brain and Surya 2004) ^[42]. The deposition of wax in crude oil is observed starting from the reservoir, in well-bore, in tubing, during surface transportation and also in production facilities. The wax deposition reduces the effective flow area of the production tubing, surface flow lines or pipelines and may lead to their complete blockage (Sousa *et al.* 2019) ^[40].

Crude oil is a yellowish-black mineral oil extracted from beneath the Earth's surface. This oil consists of various hydrocarbon compounds, formed from the remains of ancient plants and animals over millions of years. Under normal atmospheric conditions, this mixture of hydrocarbons remains in liquid form, and when distilled, produces several by-products. The type of crude oil can vary based on its origin and relative weight (Binks *et al.* 2015) ^[8].

Brent crude oil is a lighter type with an API gravity of 38-39 units and medium sulfur levels. Waxy crude oils exhibit complex rheological properties. When the temperature is above the wax appearance temperature (WAT), these oils behave like simple Newtonian fluids. However, as the temperature fall below the WAT, their viscosity significantly increases, and they become more sensitive to mechanical forces due to the formation of crystals of paraffin and a gel-like structure. Research has shown that cold flow technology, which involves cooling the oil to ambient temperature, is effective in reducing both wax and hydrate deposition. The review also indicated that a combination of chemical interventions is necessary, with pigging capabilities remaining essential as a backup strategy.

The experimental approach focused on assessing the cold flow technology's effectiveness in reducing wax deposition. (Bruno *et al.* 2008) ^[10].

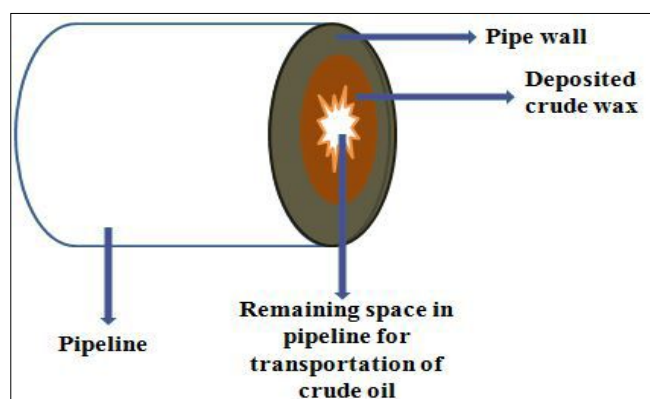


Fig 1: Represents the deposition of crude wax in the wall of pipelines and a narrow region left for the transportation of crude oil

Wax deposition leads to blocks pipelines and reduces its inner diameter (Figure 1) therefore; the cost of petroleum production increases gradually (Patowary *et al.* 2016) ^[33]. Wax is mainly composed of long straight chain of hydrocarbons called poly-hydrocarbons that are aromatic organic compounds consists of carbons and hydrogen and multiple aromatic rings. Several types of crude oil all over the world rapid deposition property because of it has high viscosity and it also contain paraffin wax content up to 32.5% (Rehan *et al.* 2016) ^[36]. According various investigations it has been observed that the basic reasons behind wax deposition in the pipelines are change in temperature, higher viscosity and presence of higher percentage of wax content (Lonje *et al.* 2022) ^[28]. Since long, several researchers have done lots of work on preventing the prevention of crude wax deposition in the pipelines. This includes several physical, chemical and mechanical processes but these approaches are not cost effective, moreover, leads to secondary pollution (Hamida and Babadagli 2007) ^[19]. Therefore, use of viable and cost effective technique may result in solving this problem. This technique is based on exploitation of microbe's activity on petro-hydrocarbons, it has been found that microorganisms degrade this heavy organic compound and utilize it as a carbon and energy sources for its growth. Due to production of extra cellular enzymes and metabolic activities of microorganisms they can digest this heavy oil by enzymatic mechanisms (Sousa *et al.* 2019) ^[40]. Various types of microbial enzymes are responsible for the degradation of paraffin wax, which will be discussed afterwards in the article. Number of methods are used for detection and identifying the crude wax deposition inside the wells like low production and slow transfer process. Consideration of this problem, there is needed to propose an appropriate and cost effective technique for the removal of crude wax from the wells. Microbial technique is a proved in previous research, is appropriate and effective alternative method in contrast of conventional methods for the prevention and elimination of the wax deposition (Adlan *et al.* 2020) ^[2]. The idea about basic characteristics of the paraffin wax degrading bacteria is they must be facultative anaerobic (Working in the presence or absence of oxygen), environmentally safe, no slime forming and not genetically

altered and non-pathogenic (Sadeghazad *et al.* 2003; Kiyangi *et al.* 2022) ^[37, 26].

Before the discussion about removal and preventive phenomenon, firstly thrash out what are different reasons behind the deposition of waxy crude oil in well-bore, reservoir and pipelines. There are some basic few sources behind crude wax deposition are given below:

Sources of crude wax deposition

- Alteration occurring in the temperature, pressure and gas content during the process.
- High viscosity characteristic. Therefore, high molecular weight heavy hydrocarbon loss their solubility in the system and gets precipitated out of the mixture. Crude oil has one of the demerit, it can immediate changes its physical and chemical properties according to changes in the temperature and pressure of the system (Kiyangi *et al.* 2022) ^[26].

Types of crude wax

Crude oil waxes are basically classified into two groups; paraffin wax and microcrystalline wax. They are present in petroleum residue and distillates containing straight chain of hydrocarbons (Kiyangi *et al.* 2022) ^[26].

Paraffin wax

It consists of a complex mixture of hydrocarbons with the general properties like non-reactive, colourless, non-toxic, good water barrier and burning fuel. Paraffin waxes have clearly defined crystal structure and tendency to be brittle and hard. The melting point of paraffin wax is between 120°-160° F (Tiwari *et al.* 2014) ^[41].

Microcrystalline wax

It is produced from the combination of distillates and residues of oil. Microcrystalline waxes have less-defined crystalline structure, higher viscosity and dark in colour. Sometime also called micro wax, they are soft and tacky to being hard and brittle according to their compositional balance (Kiyangi *et al.* 2022) ^[26].

Problem caused by the wax deposition

In transportation pipelines, deposited wax build-up and causes higher pressure drops and decreases transfer capacity. In storage tanks, these deposits reduce storage capacity. In upstream operations, wax formation around the wellbore decreases permeability, negatively affecting well performance. In most cases, acidizing hasn't proven effective under typical operating conditions. Other conventional methods, including chemical, thermal, and mechanical approaches, also have limitations, similar to methanol-based treatments (Alnaimat *et al.* 2019) ^[4]. Additionally, the low purity of crude oil during distillation often leaves behind impurities like clay and sea waste from the drilling process, which contributes to wax formation during transportation. Here are some few problems caused by wax deposition in the pipelines and reservoirs in brief given below.

Low flow rate: In transportation pipe lines, waxy crude oil deposition in the wells develops greater drops and smaller transfer capacities. Low flow rate means a huge loss in the production of crude oil. Wax appears thicker and thicker makes the flow area smaller with time going by persuade the

transportation capacity and operation safety of the pipelines. It is because it can increase the pressure; blocking area and can cause leakage.

Losses storage capacity: In storage tanks, crude wax deposited on to the walls and bottom, resulting into the occupation of storage tanks area which leads to the loss of tank storage capacities (Alnaimat *et al.* 2019) ^[4].

Methods for crude wax control are as follows

There are numerous conventional methods used for the prevention and control of wax deposition.

Thermal methods

Earlier, hot oiling methods were used for dissolving waxy crude oil. In this method hot oil was pumped between casing and tubing, where it returns to the tubing with dissolved wax. Nowadays, several electrical heating methods are used like heat tracing, steam tracing, insulation Parman *et al.* 2013) ^[32] and many more methods that have given below:

Electric downhole heaters: Use of electrical heating for wax prevention purposes is done in two different ways: insertion of electrical cable through flexible line and use of internal steel layer on electricity conductor. Thermo electric cables are installed on the inner side of the well and the paraffin sediment is melted through electro thermal function or it is never formed. The effect of this method is very prominent but it is not formally used because of its high cost.

ii) Heat tracing: It consists of pipeline with insulation and active heating inserted inside wells. There are two types of active heating methods one is electric and other one is circulation of hot fluid.

iii) Steam tracing: It is done to maintain higher temperature to reduce product viscosity (Oskouei *et al.* 2005) ^[31].

Mechanical Methods

Numerous mechanical methods are implemented in few past years for the crude wax management; few of them are as follows:

Wire line scrapping

This is a relatively new tool to remove paraffin's from tubing of flowing wells. The weight of scraper varies from 1lb to 5 lb and is of a diameter slightly less than that of tubing into which it runs. These are placed in the wells by means of a lubricator and allowed to fall in the bottom of the tubing or to a stop or pinned collar placed just above normal paraffin zone. When the well is opened, the scrapper is propelled to the top of hole then it enters the lubricator and remains there until the well is shut in. Either a gate or spring latch is provided for retention of the scraper on the surface (Sausa *et al.* 2019) ^[40].

Automatic tube scrapping

This is a relatively new tool to remove paraffin's from tubing of flowing wells. The weight of scraper varies from 1lb to 5 lb and is of a diameter slightly less than that of tubing into which it runs. These are placed in the wells by means of a lubricator and allowed to fall in the bottom of the tubing or to a stop or pinned collar placed just above normal

paraffin zone. When the well is opened, the scrapper is propelled to the top of hole then it enters the lubricator and remains there until the well is shut in. Either a gate or spring latch is provided for retention of the scraper on the surface (Tiwarei *et al.* 2014) ^[41].

Pigging

Pipe pigging technology has been in existence for many years because of its low cost in comparison to replacement of pipelines. Pigging is also considered to be the most convenient method to assess the internal condition of an operating pipeline (Shamari *et al.* 2012) ^[38]. Soon after placing in service, the flow efficiency of pipelines decreases. It is easily noticeable by lower flow rates, increased operating pressure, higher fuel bills, undesirable product and pig wear.

Chemical methods

Chemical injection along with system design can increase the production capacity of the system. Factors considered while using a chemical method includes its suitability in terms of risk to personnel, material compatibility, environment profile, availability, cost and impact on process facilities (Gentili 2005) ^[17]. Maximum value can be achieved in minimum capital expenditure by using proper chemical injection techniques and procedures (Willmon *et al.* 2006) ^[44]. Chemical methods include surfactants, dispersants, solvents and wax crystal modifiers. Solvent dissolve only a fixed amount of paraffin.

Pour point depressants

Paraffin consists molecular species of linear chains of carbon containing 14 or more carbon atoms. These species, known as waxy substances, can lead to oil pumping issues at low temperatures. The pour point temperature is the lowest temperature at which crude oil can flow when cooled under specific conditions. At lower temperatures, wax tends to form crystals with a lattice-like structure (Boucetta *et al.* 2022) ^[9]. To address this issue, pour point depressants are used. Also known as paraffin inhibitors or flow improvers, these substances are polyesters of fatty acids. Essentially, they are polymers with a paraffinic segment that co-crystallizes with the wax and a polar component that restricts the degree of co-crystallization. These depressants modify the size and shape of the wax crystals, preventing the formation of large crystals. They achieve this by either adsorbing onto the surface of newly formed crystals or co-crystallizing with the precipitating wax. In this way, pour point depressants work by adhering to the surface of growing wax crystals. (Nijjaawan *et al.* 2010) ^[30].

Paraffin Dispersants

These are surfactants which keep the already formed paraffin crystals from agglomerating into a mass with enough weight to fall out of the solution and get deposited. Water soluble Detergents play a crucial role in breaking down asphaltenes and paraffins while also aiding in the separation of oil from water. Additionally, they form a protective layer on the surface of equipment, which helps prevent future deposits. The action of detergents is based on their ability to neutralize the forces that cause paraffin particles to clump together. Dispersants, on the other hand, have a unique structure: one end of the molecule attaches to the paraffin, while the other end dissolves either in oil or

water, depending on the phase where the paraffin needs to be dispersed (Craddock *et al.*, 2007) ^[13]. These dispersants are typically made from substances such as sulfonates, alkyl phenol derivatives, ketones, and terpenes. They are versatile, functioning both in removing existing deposits and in preventing new ones. Their application can vary; they might be used in batches, continuously, or injected directly into the matrix (Dobbs, 1999) ^[15]. Solvent combined with dispersants can prolong the period of re-deposition. They can be used in deep water where pipeline plugging is always problematic.

Winterized Paraffin Crystal Modifier

This method employs a combination of solvated and non-solvated mixtures of various paraffin crystal modifiers, including maleic olefin esters, polymeric acrylate and methacrylate esters, as well as ethylene vinyl acetate polymers and copolymers (Joutey *et al.*, 2013) ^[24]. The objective is to create a stable solid suspension of these active crystal modifiers within a non-solvent liquid matrix (Becker, 2001) ^[7]. Specialized wax dissolvers, when used in tailored treatments, have proven effective in enhancing the removal of wax deposits from pipe walls and preventing future accumulation. The application of wax dissolvers changes the physical properties of pig waxes, facilitating the removal of hydrocarbon deposits. These chemical injection strategies significantly improve the cleaning process, allowing for more accurate data collection during intelligent pigging operations.

Various factors affect the success of using a solvent. Some of these are type of paraffin, quantity of paraffin, solvent used, contact time and temperature (Chen and Zhong 2019) ^[11].

Emulsion Method

It considers addition of surfactants to endorse emulsification which can reduce the tendency for wax deposition. It uses surfactants to form an (Oil in water) emulsion from produced fluids in the well bore and to wet the steel surfaces with water film which does not allow adherence of wax (Karamalidis *et al.* 2010) ^[25]. Emulsion can cause lower interfacial tension and greater shear rate that lead to reduced paraffin deposition (Amin *et al.*, 2007) ^[5]. Emulsification method inhibits the deposition of higher molecular weight paraffin components. They reduce total amount of wax and leave a softer wax (Ahn *et al.*, 2005) ^[3]. This enhances well productivity and operational efficiency while minimizing the need for regular removal of paraffin build-up.

Thermo Chemical Methods

In this technique exothermic reaction between a blend of solvent and other active compound forms chemical which is a concentrated solution of an extremely effective paraffin wax dispersant in a hydrocarbon solvent and act as dispersant that tends to change the morphology of wax from crystalline to amorphous (Ibrahim *et al.*, 2005) ^[22]. The two pack system is injected simultaneously through production tubing into the well bore. Injection of two pack chemicals and post flush is carried out using pumps, tanks, tubing to mix two pack chemicals in production tubing. Minimum soaking period required after chemical injection is 12 hours (Hidayat and Turjaman 2016) ^[20]. Upon mixing, both components will produce heat and reaction product. Reaction product is powerful paraffin dispersant that

prevent re- deposition after temperature returns to normal (Mineki *et al.* 2015) ^[29]. The salts formed act as excellent wax dispersing agents. Heat generated is generally adequate to melt organic deposits. Organic acids used mainly include alkyl substituted analogs of benzene sulphonic acids and naphthalene sulphonic acid (Becker *et al.*, 2001) ^[7].

Magnetic Methods

In this method, oil is made to pass through the powerful magnets. Basic mechanism is that when crude oil flows through magnetizer, the wax is set on the action of magnetic field and an electronic circumference is generated in the molecule of wax and a cyclic magnetic field is generated in this electronic circumflex. It disturbs and deteriorates the orientation of the momentary magnetic pole in the wax molecule and weakens the chromatic dispersion to inhibit the growing and coagulation of wax crystals and to prevent the paraffin precipitation in oil wells. The wax molecules get paralyzed and orient them in direction of flow thus inhibiting their ability to migrate to the walls to deposit. The device utilizing magnetic fields are called magnetic fluid conditioners or stabilizers (Ahn *et al.*, 2005) ^[3].

Microbial Treatment

The microbial treatment based on the activity of naturally occurring selected and isolated bacteria has proved to be an effective technique to the conventional chemical methods in preventing and removing wax deposition in oil field facilities and pipelines. These techniques use gas, acid, surfactant and alcohol producing bacteria to remove blocking type hydrocarbons. Micro-organism involved with microbial treatment of crude oil are mostly facultative, live, naturally occurring and are anaerobic, non-pathogenic, contains no sulphate reducing bacteria or slime forming bacteria and are environmentally safe (Willmon *et al.*, 2006) ^[44]. Various bacterial activities were found to have the ability of producing bio surfactant in the form of biological molecules (Oskouei *et al.*, 2005) ^[31]. These bio surfactants possessing higher surface activities were capable of reducing surface and interfacial tension at interface between liquids and solids. It can control paraffin deposition by reducing the length of paraffin molecule and producing by products that acts as surfactant and paraffin solvent (Etoumi, 2007) ^[16]. In this method cultured microbes are injected into a well bore to produce chemicals that inhibit wax precipitation to break down the produced wax. These methods provide continuous wax remedial solution rather than a temporary one. Thus, biological wax removal methods are quite effective, economically viable and warrant further study (Binks *et al.*, 2015) ^[8]. This method has some drawbacks. Microbes are imported from abroad and the price is very high and application in oilfield is inconvenient since the oil well is required to be neatly washed before adding bacterium into it (Guerreiro *et al.* 2012) ^[18]. Microbes require water to survive and cannot tolerate high temperature. So, this method was limited to wells that produce water and have bottom hole temperature below 200°F (Kovrigin and Kukharchuk 2016) ^[27].

Recent developments in microbial methods

Microbes can produce various fermentation products, including carbon dioxide, methane, nitrogen, and biosurfactants. The effectiveness of wax removal is influenced by factors such as the concentration of the

injected bacteria, the size of the bacterial culture plug, incubation time, and the level of residual oil saturation. Biosurfactants, whether added externally or produced in situ, play a key role in emulsifying oil and helping detach it from wax, making them highly promising for microbial wax remediation (See Table 1). These biosurfactants also reduce the viscosity of heavy crude oil, which makes it easier to pump. *Pseudomonas* sp. DG2 has shown a strong ability to degrade paraffin and efficiently remove wax. The lipopeptide biosurfactant produced by this strain has excellent emulsifying properties and can significantly lower the oil-water interfacial tension. Biosurfactant extracted from *Bacillus* sp. G6 is highly stable at high temperature

upto 100 °C so it can be appropriate choice for the elimination of wax deposition (Rawat *et al.* 2024) ^[35].

Pseudomonas aeruginosa (N2), a strain isolated from the formation water in the Bi-304 block of the Henan Oilfield, has been identified as a highly efficient producer of rhamnolipids, a type of biosurfactant. This biosurfactant demonstrates strong surface activity and remains stable across a wide range of pH levels (5-12), temperatures (15-80 °C), and salinity (0-32 g/L NaCl). On the other hand, *Bacillus licheniformis* (KB18), which was isolated from petroleum-contaminated soil, does not have the ability to produce biosurfactants.

Table 1: Microbes involved in removal of crude wax deposition and their mechanism of action

S. No.	Microbes involved	Mechanism of treatment	References
1.	<i>Pseudomonas aeruginosa</i>	Biodegradation of wax components	Smith <i>et al.</i> 2019 ^[39]
2.	<i>Bacillus subtilis</i>	Production of biosurfactants to disperse wax	Johnson <i>et al.</i> 2020 ^[23]
3.	<i>Rhodococcus erythropolis</i>	Wax ester formulation and emulsification	Kiyingi <i>et al.</i> 2022 ^[26]
4.	<i>Acinetobacter calcoaceticus</i>	Enzymatic degradation of long chain alkanes	Lonje and Liu 2022 ^[28]
5.	<i>Alcanvorax borkumensis</i>	Alkane hydroxylase production for wax breakdown	Theyab M A 2021 ^[45]
6.	<i>Candida tropicalis</i>	Yeast mediated wax conversion	Liang <i>et al.</i> 2016 ^[46]
7.	<i>Micrococcus luteus</i>	Surface mediated wax solubilization	Kiyingi <i>et al.</i> 2022 ^[26]
8.	<i>Pseudomonas fluorescence</i>	Produces extracellular polymeric substances	Kiyingi <i>et al.</i> 2022 ^[26]

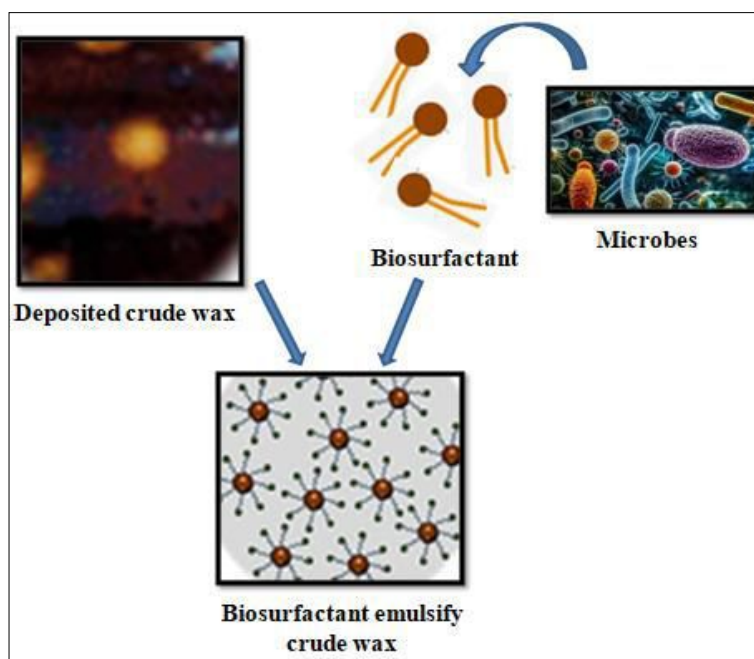


Fig 2: Microbial treatment for emulsifying the deposited crude wax

Bio surfactant from the thermo- and halo tolerant species, *Bacillus licheniformis* isolates and thermo tolerant *Bacillus subtilis* strains have been tested for with various levels of success in reservoirs and in laboratory simulations (Adedeji *et al.* 2022) ^[1].

Pipelines wax deposition is a critical problem in oil pipelines transportation and its severity increases in offshore pipelines. Wax deposition occurs when paraffin components in crude oil precipitate and deposit on the cold pipelines wall, when the inner wall temperature falls below the cloud point temperature or wax appearance temperature. Different wax deposition techniques were reported it includes chemical application, mechanical, thermal method, magnetic method, bacterial method, application of ultrasonic waves, laser technology, piezoelectric method, cold flow technology etc. In the worst cases, when no of such

techniques is feasible to be used, production must be stopped in order to cut and replace the plugged portion of the line (Kiyingi *et al.* 2022) ^[26].

Microbial method has been proposed as an attractive and encouraging technique to tackle the wax deposition problem. Microbes have the ability to absorb wax, are able to remove effectively wax deposits or at least reduce the deposition over a certain time period (Figure 2). Applications of micro-organisms is a popular technique because they are non-pathogenic, non-carcinogenic, and non-combustibles and are environmentally safe (Patowary *et al.* 2016) ^[33].

Kiyingi *et al.* (2022) ^[26] conducted a study to evaluate the ability of three bacterial species-*Pseudomonas aeruginosa*, *Bacillus subtilis*, and *Acinetobacter lwoffii*-isolated from petroleum-contaminated water and soil to break down crude

oil. They tested the effectiveness of these bacteria both individually and in combination as a mixed bacterial consortium, using capillary gas chromatography to measure the biodegradation of crude oil. The results showed that the individual bacterial cultures were less effective in terms of growth and oil degradation compared to the mixed consortium. At a temperature of 22 °C, the mixed consortium achieved the highest degradation rate, breaking down 88.5% of Egyptian crude oil after 28 days of incubation. This was followed by *Pseudomonas aeruginosa* with 77.8% degradation, *Bacillus subtilis* with 76.7%, and *Acinetobacter lwoffii* with 74.3%. These findings indicate that while each bacterial species can degrade oil on its own, their combined use in a consortium significantly enhances the biodegradation process.

In related research, Theyab *et al.* (2021) examined the displacement of weakly compressible waxy crude oil from a pipeline when displaced by an incompressible and less viscous fluid. Their study found that fluid compressibility mainly influences the time it takes for all residual oil to be cleared from the pipeline, without affecting the initial

breakthrough of the new fluid. They also provided analytical estimates for the drainage time under conditions of either fixed pressure drops or a constant displacement rate. When the displacement rate is fixed, the waxy crude initially behaves like a gel but thickens as hydrocarbon molecules are separated from the crude oil. At low temperatures, wax can precipitate and form deposits on the inner walls of the pipeline, particularly if the crude oil temperature falls below the cloud point or solidification temperature, which is around 35 °C. The cloud point is the temperature at which dissolved solids begin to precipitate, giving the fluid a cloudy appearance. Over time, as the temperature continues to drop, more wax forms, gradually narrowing the flow area within the pipeline (Hou *et al.* 2015) [21].

All reported methods for crude wax removal have their own advantages and disadvantage depend on their mechanism of treatment and action. The advantages and disadvantage of different methods including chemical, physical, thermal and biological and their application proven yet or not is represented below in Table 2.

Table 2: Comparison of different existing methods employed for wax removal their advantages and disadvantages and their application proven and not proven yet.

S. No.	Method	Advantage	Disadvantage	Application proven or not yet	References
1.	Chemical inhibitors	Effective only at low concentration	Potential environmental impact	Proven	Craddock <i>et al.</i> 2007 [13]
2.	Chemical dispersant	Reduces the viscosity of wax	Can cause secondary deposits	Proven	Willmon and Edwards 2006 [44]
3.	Thermal treatment	Immediate wax removal	Energy intensive	Proven	Parman <i>et al.</i> 2013 [32]
4.	Mechanical pigging	Effective at removing large deposits	Can damage pipelines	Proven	Wang W, Huang Q (2014) [43]
5.	Biosurfactant	Biodegradable and eco-friendly	High production cost	Not yet	Rawat <i>et al.</i> 2024 [35]
6.	Enzymatic degradation	Specific and effective wax breakdown	Enzyme stability issues	Not yet	Johnson, A., <i>et al.</i> (2020) [23]
7.	Microbial degradation	Sustainable and low cost	Slow process and maintenance required	Not yet	Patowary <i>et al.</i> 2016 [33]
8.	Hot oil circulation	Effect for immediate wax remove	Requires continuous heating	Proven	Bahadori (2014) [6]

Conclusion

In crude oil production and transportation pipelines, wax deposits cause greater pressure drops and reduce transfer capacity. In storage tanks, these deposits lead to a loss of storage space. In upstream operations, deposits can decrease permeability near the wellbore, which negatively impacts well performance. Traditional acidizing methods haven't proven effective in these situations, and other conventional approaches whether chemical, thermal, or mechanical come with significant drawbacks, such as secondary pollution, high costs, pipeline damage, and the risk of re-deposition of crude wax.

In some studies, bio-treatment methods have been explored to address paraffin deposits. Tests have shown that biosurfactant-producing species can alter the wettability of stainless steel, making it water-wet, and reduce the surface tension between water and stainless steel by forming an emulsion. This process is crucial for preventing paraffin buildup. Bacterial treatment has been found to remove up to 79.0% of paraffin deposits.

Conflict of Interest

Authors declare that there is no conflict of interest in this review article.

Contribution: GR

Original draft and conceptualization and design, Review and editing,

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