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Research Article

Synergistic Control of Wax Deposition and Rheology in Niger Delta Crude Oil Using EVA Copolymer and Magnesium Oxide Nanofluid

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Abstract

Wax precipitation and deposition remain critical flow assurance challenges in offshore and onshore production systems. This study evaluates the effects of ethylene–vinyl acetate (EVA) copolymer, magnesium oxide (MgO) nanofluid, and their blend on the rheology of crude oil from field X in the Niger Delta. Baseline characterization (API gravity, pour point and cloud point) confirmed a heavy, high-viscosity crude prone to gelation at low temperature. Using ASTM-based protocols for density/API and pour/cloud points and a rotational viscometer, viscosity was measured across 5–25°C at multiple shear rates. Gas chromatography fingerprinting indicated reduced n-paraffins (C14–C18) with concentration of heavy ends. Relative to the blank sample, EVA alone produced a marked viscosity reduction; MgO nanofluid alone was also effective, but the EVA+MgO blend delivered the largest reduction across temperatures and shear rates. The blend lowered apparent viscosity by an order of magnitude at 300 rpm and improved low-temperature flow, with an observed pour-point reduction from −5°C to ≈ −12°C. These results support a synergistic mechanism in which EVA modifies wax crystallization while MgO-based nanodispersion aids dispersion and disrupts agglomeration, together mitigating gelation and deposition risk. Operational implications include lower restart pressures and extended pigging intervals for pipelines transporting waxy crude.

Keywords

Wax Deposition, Wax Appearance Temperature, Pour-Point Depressant, Eva Copolymer, Magnesium Oxide Nanofluid, Rheology, Niger Delta Crude

1. Introduction

Niger Delta crude oils are known for their high paraffin content and pronounced wax appearance temperatures (WAT), making them particularly susceptible to flow-assurance challenges.

As conventional oil reserves continue to decline, there has been a growing shift toward the exploitation of unconventional resources, including heavy crude and waxy oils. Waxy crude is estimated to account for roughly one-fifth of global oil reserves, while heavy crude represents a significant proportion of recoverable resources [10]. A major challenge associated with these types of crude oils is their high paraffin

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wax content. When the temperature of the flowing crude drops below a critical threshold known as the wax appearance temperature (WAT), wax crystals begin to form and deposit along pipeline surfaces. This deposition can restrict flow and create serious operational challenges, making it one of the most persistent flow assurance issues in the petroleum industry. Wax-related problems can occur throughout the entire production chain, from the reservoir to processing facilities. Therefore, accurately determining the temperature at which wax begins to precipitate or the crude begins to gel is essential for predicting and managing wax formation [7].

During subsea transportation, crude oil is often exposed to very low ambient temperatures, sometimes approaching 5°C near the seabed. Under such conditions, waxy crude in the liquid state can undergo multiple phase transitions [5]. Variations in operating conditions, particularly temperature and pressure, promote the aggregation of wax particles into larger structures or clusters [6]. As these clusters grow beyond a critical size, wax begins to separate from the oil phase and precipitate. Continued accumulation of these deposits leads to the formation of a gel-like wax layer on pipeline surfaces. Over time, this layer thickens through successive deposition, potentially restricting flow and, in severe cases, causing complete blockage of the pipeline system. Consequently, controlling wax precipitation and deposition remains a critical flow assurance challenge in oil and gas production.

Several technologies have been employed for stoppage of wax deposition in petroleum industry. The Wax Inhibiting Tool (WIT), a device made of alloys is designed to prevent or reduce wax precipitation inside the tubing string [15]. Bosh and Eastlund [4] discussed the utilization of downhole electrical impedance heating techniques for the mitigation of paraffin wax deposition in oil wells. Mechanical pigs have been used to periodically scrape off deposited wax from the internal pipe walls [17] and hot oils, or heating have also been used in wax control [3].

Chemical control is the commonly used method of wax control. This involves the use of solvents, wax crystal modifiers and dispersants. Paraffin removal using solvents typically involves blends of organic compounds, with common examples including terpenes, benzene, toluene, and carbon disulfide. These solvents can be applied either through continuous injection or periodic batch treatments to break down and dissolve accumulated wax deposits.

Paraffin dispersants function by interacting with asphaltenes, which act as binding agents, thereby weakening their tendency to adhere to surfaces. These chemicals help break larger wax deposits into finer particles, allowing them to remain suspended in the fluid rather than accumulating. For optimal performance, the presence of water is typically required. Dispersants are commonly introduced either by mixing them with produced water or by injecting them directly into the aqueous phase in downhole environments, flowlines, or storage facilities. Most paraffin dispersants are surfactants composed of two key functional groups: a hydrophilic (water-soluble, polar) component and a hydrophobic (oil-soluble, non-polar) component.

Paraffin crystal modifiers are chemicals designed to inhibit the formation and growth of wax crystals in crude oil. They operate at the molecular level by interfering with the ability of wax molecules to align and form structured networks within the fluid. By altering crystal development, these additives reduce the likelihood of wax deposition on surfaces. In addition, they can influence key rheological properties of the crude, including viscosity and pour point. Typically, crystal modifiers consist of high–molecular weight compounds, which often results in relatively high pour points and may limit their effectiveness in very cold environments. Their performance is most effective when introduced before the onset of wax crystallization. These chemicals function either by modifying crystal structure as it forms or by integrating into the growing wax crystals to disrupt their arrangement. Application methods include both continuous injection and periodic batch treatment.

Lucas [11], demonstrated that EVA performance depends strongly on vinyl acetate content and molecular weight, showing that optimal compositions (≈35% VA) can significantly reduce pour point and viscosity by altering wax crystallization pathways. Such structural modification limits wax agglomeration and decreases the tendency for deposition under flow.

Wang [16], using molecular dynamics simulations, found that EVA's polar vinyl acetate groups interrupt ordered wax crystallization by preferentially interacting with water molecules and remaining in curly configurations, thus inhibiting the solidification rate of wax clusters. Additionally, EVA was shown to co-crystallize with wax molecules, forming eutectic structures that further modify wax network formation. These findings reinforce the polymer's dual functional role in interrupting wax lattice formation and mitigating hydrate-wax interactions in multiphase systems—an important consideration for deep-sea environments but also relevant to Niger Delta conditions.

Ghobashy et al. [8] introduced gamma-irradiated grafted EVA copolymers to enhance pour-point performance. Their grafted EVA variants achieved dramatic pour-point reductions (from 24°C to as low as −18°C), outperforming unmodified EVA (−9°C). The improved performance was attributed to the nucleating behavior of the grafted chains, which inhibited wax-crystal growth more effectively than standard EVA. This supports the concept that molecular modifications can significantly amplify EVA–wax interactions.

Over the past decade, research has increasingly shifted toward combining polymeric inhibitors with nanoparticles to create synergistic systems. A systematic review by Aji et al. [1] highlighted polymer nanocomposites as an environmentally favorable alternative to conventional wax inhibitors. The review emphasized that nanoparticles when embedded within polymer matrices modify wax crystallization by providing heterogeneous nucleation sites, improving steric hindrance,

and altering aggregation mechanisms. This framework provides the scientific basis for studying EVA- nanoparticle synergistic systems.

Ridzuan et al. [14] provided one of the most relevant insights by investigating the synergy between EVA and sodium-cloisite nanoparticles through molecular dynamics simulations. Their results showed that the presence of nanoparticles shifts critical wax–wax intermolecular interactions (e.g., H59–H60 distances) from 2.75 Å to 3.25 Å, indicating weakened wax aggregation. Cold-finger tests validated that EVA–nanoparticle blends minimized wax deposition more effectively than EVA alone. These findings strongly support the argument that nanoparticles enhance EVA's performance by modifying wax molecular interactions at the nanoscale.

A related study on EVA–MMT (montmorillonite) nanocomposites by Alves et al. [2] demonstrated that nanoparticle intercalation within EVA matrices leads to enhanced pour-point-depression efficiency through improved steric hindrance and better morphology alteration of precipitating waxes. The nanocomposites produced lower pour points and improved flow characteristics in both model systems and wax-doped crude oil. While this research did not involve magnesium oxide (MgO) specifically, the mechanisms described—intercalation, steric interference, and nanoparticle-polymer synergy are transferable to MgO nanofluid systems.

Metal-oxide nanoparticles, including MgO, have been widely recognized for their thermal conductivity enhancement, surface energy properties, and ability to alter crystallization behavior in other petroleum and chemical systems. Aji et al. [1], confirms that metal-oxide nanoparticles act as nucleation inhibitors or promoters, depending on surface chemistry and dispersion. This is achieved through the mechanism of *Surface adsorption* of paraffins (reducing free wax concentration), *Modification of wax-crystal morphology* (through nanoparticle–wax surface interactions) t*hermal conductivity improvement* (reducing local cold-spots and further deposition) and *Enhanced dispersion stability* especially when combined with amphiphilic polymers like EVA.

Odutola and Allaputa [12] investigated the influence of aluminum oxide nanoparticles on the rheological behavior of Niger Delta waxy crude oil across a range of temperatures. Their findings showed that crude oil viscosity decreased with increasing temperature, and this reduction was further enhanced by the introduction of aluminum oxide nanoparticles. At lower temperatures of 10°C and 15°C, an optimal nanoparticle concentration of 4 wt% was identified, resulting in a viscosity decrease from 72.5 mPa·s to 55 mPa·s.

In a related study, Odutola and Idemili [13] examined the combined effect of poly(ethylene-butene) (PEB) and nano-aluminum oxide on Nigerian crude oil. The results indicated that the hybrid system achieved a greater degree of viscosity reduction compared to the use of either PEB or aluminum oxide nanoparticles individually, suggesting a synergistic interaction between the polymer and nanoparticle components.

Furthermore, Isiakepre and Odutola [9] extended this line of research by evaluating zinc oxide nanoparticles as wax inhibitors. Their work also considered the performance of polyethylene vinyl acetate (PEVA), magnesium oxide (MgO) nanofluids, and a combined PEVA–MgO system. The study demonstrated the effects of these treatments on both viscosity and pour point of Niger Delta crude oil, highlighting the potential of hybrid nanofluid–polymer systems for enhanced flow assurance performance.

2. Methodology

The study investigates the synergistic effect of a blend of PEVA and MgO nanoparticle on the rheology of a Niger Delta crude oil sample at varying temperature. The resources used in the experiment are crude oil sample from field X, polyethylene vinyl acetate, magnesium oxide nanoparticle and xylene as solvent. Four different concentrations of polyethylene vinyl acetate (PEVA) 5000ppm, 4000ppm, 3000ppm, 2000ppm and 1000ppm were prepared by initial dissolving 50ml of the polymer into 1000ml of xylene (Stock solution)

The dilution principle (equation (1)) was used in preparing subsequent concentrations of PEVA (4000ppm, 3000ppm, 2000ppm and 1000ppm)

$$C_1V_1 = C_2\ V_2 \tag{1}$$

The nano particle of similar concentration is prepared by dissolving 5g of magnesium oxide into 1000ml xylene (Stock solution) subsequent concentration were prepared using the dilution principle in equation (1). The prepared solutions were continuously stirred in a mixer for 30min prior to being added to 300mml of the crude oil sample. The crude oil sample was stabilized at various temperature using a cold-water bath/chiller before being blended with the prepared solution of nano particle and polymer. The viscosity of the blends crude oil (without inhibitor) and the viscosity of the crude oil mixed with polymer and nano particle blend at different temperature were obtained using viscosity. The API, pour point, cloud point and chromatograph of the crude were also carryout using the American Society for Testing and Materials (ASTM) methods.

3. Results and Discussion

The physiochemical properties of the blank crude oil sample is shown in Table 1. The API value (Table 1) indicates the sample is a medium crude implying that the crude will not flow easily. Viscosity is a property that determines flowability of crude oil and it's influence by wax precipitation and deposition rate. The chromatogram shows that the sample has a lot of fractions with carbon chain of 18 and above. The chromatograph, Figure 1 $C_{14} - C_{18}$ indicates low Aromatic content, the n-paraffin have been degraded and consistently lowered the residual heavy component such as asphaltenes is gradually

concentrated accounting for the low API.

Table 1. Physiochemical properties of the crude oil sample.

Property	Value
API @72C	17.0
API @60/60	16.4
Specific Gravity	0.9567
Cloud Point (°C)	0
Pour Point (°C)	-5
Density (kg/m3)	956.7

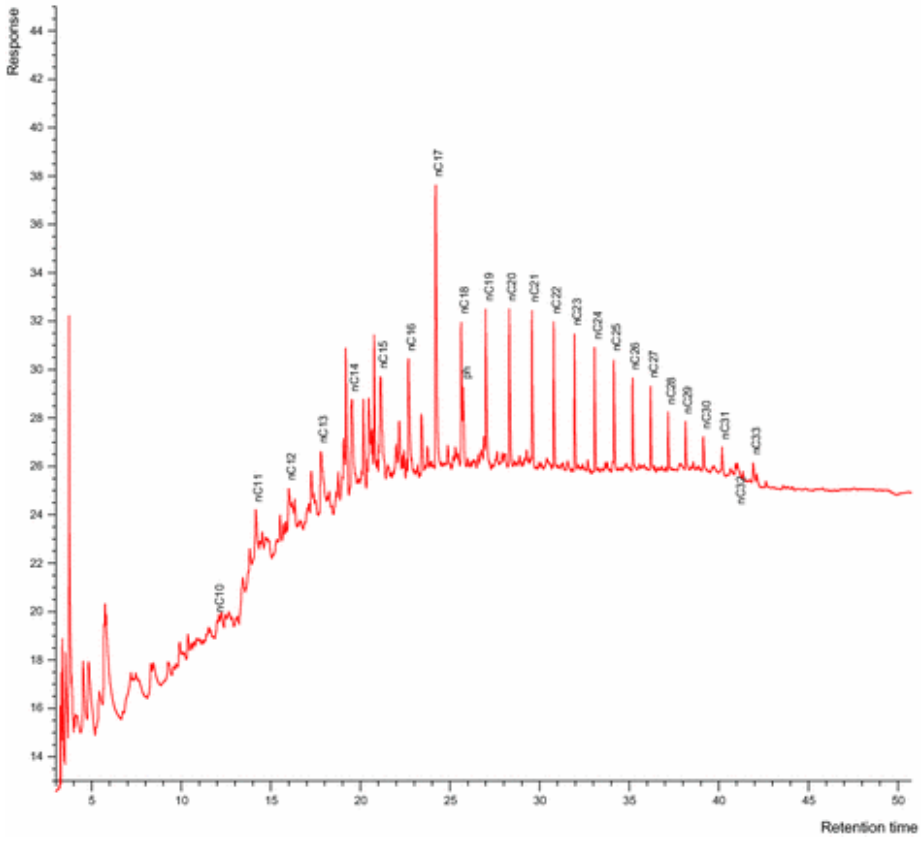

Figure 1. Chromatogram of Blank Crude Sample.

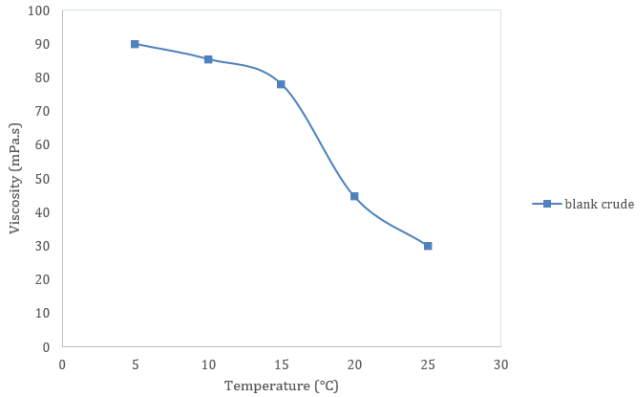

Figure 2. Plot of the viscosity against temperature for the blank crude.

Figure 2 shows the plot of the viscosity against temperature for the blank crude. Notice that the viscosity of the crude was the lowest at the highest temperature considered in this study (25°C). As the crude temperature reduced, the crude viscosity increased. A rapid increase is noticed as the crude is cooled from 20°C to 15°C. This signifies rapid precipitation and agglomeration of wax particles, causing gelation. Notice that as the crude oil was cooled from 15°C to 5°C, the wax crystals rate of viscosity increase had reduced as most of the wax crystals had precipitated and wax gelation was taking place. It is imperative to prevent wax precipitation in this crude sample because the increase of viscosity may be challenging when processing the crude oil.

3.1. Temperature and Shear Effects on Baseline Viscosity

Baseline viscosity increased sharply with decreasing temperature (25 → 5°C) and with higher shear rates, consistent with shear-thickening behavior for this crude under the tested conditions (Figure 3). This underscores the risk of gelation and high restart pressures in unconditioned lines at low seabed temperatures.

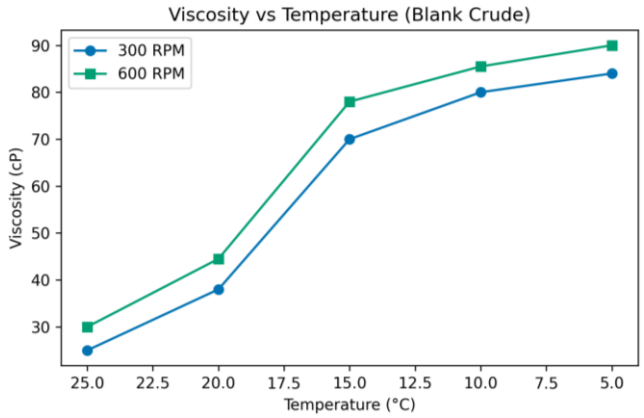

Figure 3. *Viscosity vs temperature for blank crude at 300 and 600 rpm.*

3.2. Effect of EVA, MgO Nanofluid, and Blends

At 300 rpm, both EVA (5,000 ppm in xylene) and MgO nanofluid (5,000 ppm) reduced apparent viscosity across 5–25°C relative to the blank (Figure 4). The combined EVA+MgO blend delivered the strongest viscosity depression, indicative of a synergistic action—EVA acting as a crystal modifier/PPD and MgO facilitating dispersion and disrupting wax–wax interactions.

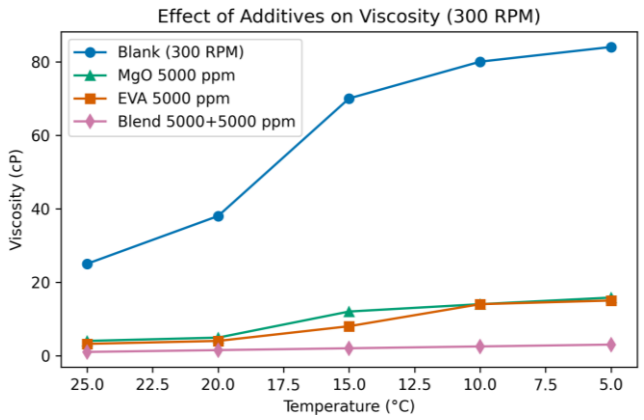

Figure 4. *Additive strategies at 300 rpm: blank vs MgO 5000 ppm, EVA 5000 ppm, and equal-parts blend (5000+5000 ppm).*

3.3. Dose–Response in EVA+MgO Blends

Increasing the nominal ppm of EVA and MgO in equal-proportion blends further lowered viscosity at all temperatures, with the 5,000+5,000 ppm blend showing the largest effect (Figure 5). These reductions translate to lower pressure drop, improved flowability, and diminished propensity for shear-induced deposition.

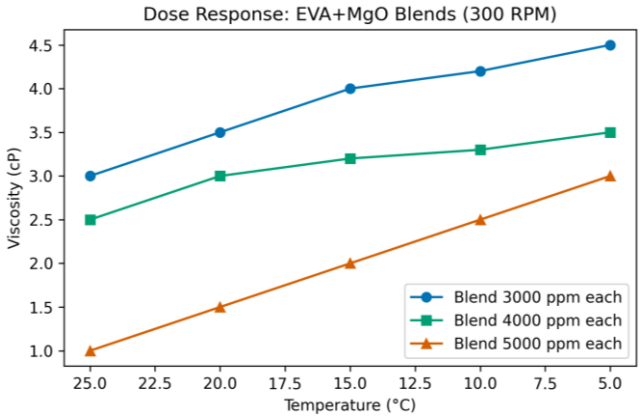

Figure 5. *Dose response of EVA+MgO blends (equal ppm each) at 300 rpm.*

3.4. Pour Point, Cloud Point, and GC Fingerprinting

The native pour point (−5°C) and cloud point (0°C) indicate susceptibility to low-temperature wax crystallization. With EVA+MgO treatment, the pour point was observed to drop to approximately −12°C, aligning with viscosity depression trends.

4. Conclusion

Wax deposition has long been recognized as a persistent challenge in the oil and gas industry, attracting significant research attention due to its impact on production efficiency. Key parameters governing this phenomenon include the cloud point and pour point, which define the temperatures at which wax crystals begin to form and the crude oil progressively loses its ability to flow.

This study provided a preliminary assessment of wax deposition behavior and potential mitigation strategies using crude oil samples obtained from a waxy field in the Niger Delta. The accumulation of wax on the internal surfaces of pipelines and production equipment presents serious operational difficulties, making the physicochemical characterization of crude oil essential for effective flow assurance management. In this work, the performance of an ethylene–vinyl acetate (EVA) inhibitor and magnesium oxide (MgO) nanoparticles was evaluated through viscosity measurements obtained using a viscometer.

The results indicate that MgO nanoparticles independently contributed to a reduction in crude oil viscosity. However, a more pronounced improvement was observed when EVA was combined with the nanoparticles, particularly under low-temperature conditions. Overall, temperature was found to be a dominant factor influencing crude oil rheology, with the fluid exhibiting non-Newtonian behavior at lower temperatures. Additionally, the pour point showed a strong dependence on wax content. The application of chemical treatments, such as PEVA and MgO nanofluid blends at varying concentrations, not only acted as wax inhibitors and pour point depressants but also altered wax crystal morphology, thereby enhancing flow characteristics and reducing viscosity.

Abbreviations

PEVA	Polyethylene Vinyl Acetate
MgO	Magnesium Oxide
PEB	Polyethylene Butene
EVA	Ethylene–Vinyl Acetate

Author Contributions

Nwaobi Henry Christopher: Data curation, Funding acquisition, Methodology, Resources, Writing – original draft

Odutola Toyin Olabisi: Conceptualization, Methodology, Supervision

Odutola Ibukunoluwa Abdulaziz: Resources, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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