

Utilization of Vegetable Oil for Crude Oil Pour Point Reduction in Hydrocarbon Wells and Surface Facilities

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Research Article

Keywords: Vegetable Oil, Pour Point Depressant, Hydrocarbon Wells, Surface Facilities

Posted Date: March 4th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-8599752/v1>

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Additional Declarations: No competing interests reported.

Abstract

The ability of the crude oil to flow with little obstruction is one of the key features that allow us to produce it. Any factor that can impact the flowability of the oil will result in a reduction in oil production and may even result in safety hazards and equipment damage or malfunction. Pour point temperature is the lowest temperature at which the crude oil will remain flowing; if the temperature falls beneath the pour point, the oil will cease to flow. This research investigates the ability of vegetable oil to act as a pour point depressant for crude oil at different concentrations and compares its performance to that of two other pour point depressants including methanol and vinyl acetate monomer. The concentrations tested include 500, 1000, and 2000 ppm and the experimental vessel used was constructed as per the ASTM D97 standards. The results showed that the vegetable oil managed to reduce the pour point of the crude oil and even outperformed the methanol. The performance of the vinyl acetate was higher, however with extreme difference in price and handling and toxicity of the vinyl acetate compared to the vegetable oil, the performance of the vegetable oil has significant advantages. This research emphasizes the need for less costly and less toxic and environmentally damaging chemicals in the oil and gas industry to improve its environmental footprint and overall effectiveness in flow assurance.

1. Introduction

During its production the crude oil flows through the tubing string in the wellbore. When moving upward through the well, the oil exhibits a change in temperature due to the geothermal gradient of the earth. If the oil temperature falls beneath its pour point temperature, the oil will cease to flow. Pour point depressants work by altering the pour point of the crude oil in order to allow it to flow under conditions in which it would normally not be able to flow. This can prevent severe operational issues including cessation of flow, sudden pressure build-up, and multiple health and safety considerations.

Many types of pour point depressants have been tested for effective pour point depressing. One of the main additives used to enhance the properties and performance of pour point depressants include nanoparticles, polymers, and surfactants [1]. The additives used were primarily targeting the alteration of the binding properties of the wax crystal including the usage of bionic nanocomposites, high amphiphilicity polymers, diesel depressants, poly(octadecyl acrylate-methylbutenol), vinyl acetate-octadecyl acrylate polymers, silicon oxide nanocomposites, and alcohol acetoacetate aluminum chelates [1–12]. Although these chemicals and additives have been reported to perform effectively with specific crude oils, little evidence exists on their ability to reduce the pour point of multiple crude oils of specific compositions. This emphasizes the fact that pour point depressants should be used based on its compatibility with the crude oil itself.

Pour point depressants have been used for multiple applications in the oil and gas industry. The three main targets of pour point depressant treatments include near wellbore formation, wellbore itself and downhole equipment, and flowlines/pipelines [13–15]. If the crude oil nears, or falls beneath, its pour point in the formation, the wax crystals will begin to form agglomerates within the pores near the

wellbore. This will result in three main operational issues including pore plugging, flow reduction or cessation, and wettability alteration. In this case, the pour point depressant is injected into the formation near the wellbore, usually a few inches into the formation, to avoid these issues at or near the perforations and the wellbore [13–24]. The most common location for pour point issues is within the wellbore due to the decrease in temperature, especially near the surface. The pour point depressant is usually injected into the wellbore via a capillary tube. This is a continuous injection to ensure that the crude oil remains flowing [24–34]. The pour point depressant needs to be highly soluble in the oil ensure continuation of flow. Finally, if there is risk of temperature drop or falling beneath the pour point in pipelines or flowlines, the pour point depressant can be directly injected in the flow stream to avoid flow interruptions [34–38].

It is imperative to investigate the compatibility of different pour point depressants with each specific crude oil before application in the field in order to evaluate the different mechanisms by which the depressant will function and ensure the effectiveness of the pour point depressant. This research investigates the ability of corn vegetable oil to be used as a pour point depressant in a crude oil from the Western Desert of Egypt and compares the performance of the corn oil to that of two other chemical agents, methanol and VAM. The research also determines the mechanism by which the corn oil operates to reduce the pour point of the crude oil based on the composition of the crude oil used in this study.

2. Pour Point Depressant

A pour point depressant is a chemical or material that can be used to alter the pour point of the crude oil to allow the oil to flow at conditions under which it would normally not be able to flow. The exact mechanism of how the pour point depressant operates is illustrated in Fig. 1. There are fundamentally three methods by which pour point depressants work:

a) Co-Crystallization: During co-crystallization, the pour point depressant forms a network that mimics the structure of long-chain paraffins. This prevents the wax from creating long and thick crystals that result in the problematic cessation of flow. Instead, due to the pour point depressant, the wax is forced to form short and thin crystals that do not impact the flow of the oil severely and can be easily broken during flow of oil, especially at higher rates. This is shown in Fig. 1.

b) Modification: The pour point depressant adsorbs to the surface of the wax crystals. This prevents the wax from any further growth and prevents any crystal interlocking that can result in the formation of flocculation or agglomerations.

c) Dispersion: The pour point depressant acts as a surfactant that aids in the dispersion of the wax crystals. The wax particles remain small and suspended in the crude oil, hence preventing the wax from flocculating into larger particles that can result in flow issues.

The main factor that caused a pour point depressant to outperform another is based on compatibility with the paraffin molecule existing within the crude oil. The main factors that impact the performance of

the pour point depressant and their impact are presented in Table 1.

Table 1
Main Factors Impacting Pour Point Depressants' Performance

Factor	Impact
Compatibility with Wax Carbon Number Distribution	Crude oil with a high C20-C36 concentration requires a highly compatible pour point depressant to function properly
Pour Point Depressant Molecular Structure	Depending on the mechanism of the pour point depressant, its structure will impact its ability to interact with the oil
Molecular Branches and Side Chains	A large number and structural chains will result in an improved pour point reduction behavior
Pour Point Depressant Molecular Weight	An intermediate molecular weight pour point depressant relative to the molecular weight of the oil is preferred. An extremely low molecular weight will result in ineffective interaction, and an extremely high molecular weight will result in severe gelation or flow reduction behavior
Solubility in Oil Phase	The pour point depressant must be highly soluble in the crude oil especially above the wax appearance temperature to prevent the formation of paraffinic agglomerates
Compatibility with the Specific Chemistry of the Oil	The selection of the pour point depressant must be done in coordination with the testing of the crude oil to ensure compatibility and avoid secondary interactions

3. Experimental Description

The experimental material, setup and procedure followed to conduct all the experiments are explained. All the procedures and setup used were based on ASTM D97 guidelines to ensure accuracy and repeatability of the results.

3.1. Experimental Material

The material used to conduct the experiments are as follows:

- Crude Oil: crude oil samples from the Western Desert Region of Egypt were used to conduct the experiments. The oil samples were dead oil with a high asphaltene and wax concentration.
- Methanol: Methanol was used as one of the chemicals tested as an effective pour point depressant for the oil. It was provided as a transparent liquid with a purity of 99.99%.
- Vinyl Acetate Monomer: This was used as one of the main chemicals for pour point depression for crude oil. This is one of the most commonly used chemicals and is integrated into the formulation of many pour point depressants.

- **Corn Oil:** This was used as the main chemical to test its effect as a pour point depressant. This was purchased as a golden yellow liquid.
- **Thermometer:** A thermometer was used to measure the temperature of the crude oil during each step of the experiment. It was also used to measure the pour point temperature.
- **Water Bath:** A water bath was used to regulate the temperature of the experimental vessel during each step of the experiment, as per the ASTM D97 procedure.
- **Pour Point Vessel:** The pour point vessel was used to house the crude oil sample while also allowing for the thermometer to pass through its cap. It was made of transparent glass to better visualization of the oil during each step of the experiment.
- **Ice Bath:** An ice bath was used to cool down the temperature to below zero, which is an important step in the pour point measurement, as per ASTM D97.

3.2. Experimental Setup

The experimental setup used to conduct the experiments is presented in Fig. 2. The setup used was based on the ASTM D97 procedure for pour point measurement. The setup is composed of the actual pour point testing vessel which houses the crude oil. The vessel is made of transparent glass to allow visualization of the crude oil to determine its flowability. A rubber stopper is present on the top of the vessel to act as a cap. It has a hole in it to allow for the thermometer to pass through and record the temperature of the crude oil. A water bath, that can also act as a cooling bath with a temperature reaching down to -20 C, was used to cool the setup when needed. Finally, a stopwatch was used to record the time for each step when necessary.

3.3. Experimental Procedure

The experimental procedure followed to measure the pour point of the crude oil sample for each experiment was based on ASTM D97. The procedure is as follows:

- a. The crude oil sample is mixed with any additive thoroughly, placed in the experimental vessel and heated to at least 9 °C above the expected pour point temperature.
- b. The volume of the crude oil should be 3 cm below the top of the vessel. This is to ensure that the thermometer can be placed in the vessel to the bottom without overflowing the oil from the experimental vessel. It is also to ensure that the vessel has sufficient oil to undergo a representative experiment. For this research, for each experiment, 100 ml of crude oil was used to conduct the experiments.
- c. The vessel is checked every 3 °C or every 3 minutes, depending on the design of the experiment. For this research, the vessel was checked every 3 °C. The vessel is tilted horizontally for 3 seconds, and the crude oil sample is monitored. If the sample is still moving, then the temperature is further reduced.

- d. The pour point temperature is the lowest temperature at which the oil still moves. When a the temperature at which the oil does not flow is reached, the pour point temperature is recorded as that temperature plus 3 °C. The pour point is recorded as the nearest 3 °C increment, as is explained in the procedure.

4. Results and Analysis

The results for pour point depressing capabilities of methanol, VAM, and corn oil using different concentrations are presented and explained.

4.1. Pour Point Measurement of Original Oil

Initially the pour point of the crude oil was measured to determine its value without any additives. The crude oil was heated to 56 °C. Following this, the temperature was decreased with 3 °C steps and the flowability of the oil was investigated at each step. Based on the experiment, the pour point of the crude oil was determined to be 41 °C. This is classified as a high temperature crude oil and thus is expected to fall beneath the pour point during production, which was the actual case based on the feedback received from the operating company.

4.2. Pour Point Reduction: Methanol

Methanol is classified as a highly polar, low molecular weight alcohol. It is considered a very poor pour point reduction agent. It can impact the waxes in the crude oil via five mechanisms. Firstly, due to its high polarity and relatively low molecular weight, methanol has very little impact on wax solubilization. That being said, it can still weakly solubilize very small wax chains, which makes it capable of reducing pour point in crude oils with very low concentration of wax. Secondly, due to its high polarity, methanol will preferentially associate with highly polar compounds. This makes it a strong agent in weakening the bridging effect of asphaltenes and resins, which can work to stabilize the wax within the crude oil. Hence, it can have a strong impact on wax stability in crude oils with a high concentration of asphaltene and resin, however it does not have any recorded impact on the wax appearance temperature. Thirdly, methanol can act as a weak polar interfacial agent causing the wax crystals to slip past each other, especially at high shear rates. Fourthly, it can inhibit hydrate formation in some crudes with high water content during production which improves flowability, however this has no impact on the wax itself. Finally, it can dilute the crude oil due to its low viscosity, which can improve flowability, however this is very short lived due to the volatile nature of methanol.

Figure 3 shows the pour point reduction potential of methanol using concentrations of 500, 1000, and 2000 ppm and compares the pour point of the oil to that of the original crude oil with no additives. Based on the results, methanol had almost no impact on pour point reduction for the crude oil, even when the concentration of methanol increased. This is in par with the aforementioned mechanisms of methanol and how weak each mechanism is in terms of affecting the pour point of oil. Based on this, methanol is not recommended as a pour point depressant, especially for crude oil with high wax content due to its short carbon chain which limits its wax interaction, its low miscibility with crude oil due to its high

polarity, its volatility which results in a short-lived interaction, and the absence of a polymeric backbone which limits its ability to control the wax crystal growth, hence resulting in large wax aggregations.

4.3. Pour Point Reduction: VAM

Vinyl acetate is short chain monomer with a polar acetate group and no long hydrocarbon backbone. It is a transparent liquid with a pungent odor. Conventionally, VAM is considered a poor pour point reduction agent and hence is usually used as the functional comonomer in ethylene–vinyl acetate (EVA), which is considered an extremely effective pour point depressant. Recently however, VAM has been shown to be a competent pour point depressant via different mechanisms compared to those of EVA. VAM has four main mechanisms by which it can reduce the pour point of crude oil. Firstly, VAM can cause a disruption of wax-resin and wax-asphaltene bridged. In many crude oils, wax crystals alone do not cause gelation. Gel strength comes from polar components acting as bridges; these include resins, asphaltenes, and some polar aromatics. The acetate group in VAM has a dipolar characteristic that allows it to preferentially associate with resins, asphaltenes, and polar aromatics. This can result in breaks in the resin/asphaltene bridges between the wax crystals, hence reducing crystal connectivity. This in turn reduces the gel strength thus impacting the pour point of the crude oil. Although this mechanism impacts pour point, it has little impact on the wax appearance temperature. Secondly, due to its small molecular size and highly polar nature, VAM can also adsorb on the surface of the wax crystals. This lowers the surface energy of the wax crystals and creates a lubricating layer that caused the wax crystals to slide instead of interlock, hence reducing wax crystal growth. Thirdly, VAM has low molecular stiffness and excellent mobility at low temperatures. This allows it to penetrate into inter-crystalline regions, hence acting as a plasticizer which softens the wax aggregates. This can reduce the rigidity of the wax network causing it to collapse. Finally, VAM can locally solubilize C18-C22 paraffins, hence delaying secondary crystallization. This is specific for crude with a high concentration of these specific paraffins.

Figure 4 shows the pour point reduction potential of VAM using concentrations of 500, 1000, and 2000 ppm and compares the pour point of the oil to that of the original crude oil with no additives. Based on the results, the VAM managed to reduce the pour point of the crude oil significantly even at concentrations as low as 500 ppm. The increase in concentration showed little improvement in VAM behavior, indicating that the maximum pour point reduction potential using a reasonable concentration has been reached. To determine the exact mechanism for pour point reduction, the crude oil used was analyzed for asphaltene and C18-C22 paraffins. Based on the results it was observed that the crude oil had an asphaltene concentration exceeding 11% and a C18-C22 fraction of approximately 18%. This indicates that the VAM did indeed result in breaks in the resin/asphaltene bridges between the wax crystals and solubilized the C18-C22 paraffins which resulted in a reduction in the pour point. VAM reduced the crude oil pour point by disrupting wax–resin–asphaltene network formation and weakening interfacial cohesion between wax crystals, thereby lowering gel strength without significantly altering wax crystallization temperature.

4.4. Pour Point Reduction: Corn Oil

Different vegetable oils have different properties depending on their composition and molecular structure. This emphasized the fact that it is imperative that the pour point depressant must be tested for compatibility with the crude oil before being applied. Vegetable oils have five main mechanisms by which they can reduce the pour point of crude oil. Firstly, vegetable oils contain long-chain fatty acids and triglycerides that interact with the waxes in the crude oil. Vegetable oil molecules co-crystallize or adsorb onto growing paraffin wax crystals which disrupts the growth of the crystals. The wax network that normally traps oil and causes gelation does not form, so the crude remains flowable at lower temperatures. Secondly, even if the wax crystals begin growing, the vegetable oil can inhibit further growth by reducing van der Waals attraction between wax platelets hence preventing crystal bridging or crystal growth. Thirdly, it improves wax solubility in the crude oil via the polar ester functional groups. Also, the vegetable oil can help reduce the viscosity of the crude oil especially at lower temperatures via its high solubility. Finally, vegetable oils contain polar ester groups that preferentially adsorb to the wax crystals hence reducing wax cohesion and enforcing repulsion between the wax molecules.

The effectiveness of the vegetable oil in reducing the pour point of the crude oil is impacted by many factors. These include:

- **Vegetable Oil Fatty Acid Chain Length:** Paraffin wax in crude oil is typically C18-C36 normal alkanes. Vegetable oils are mainly triglycerides made of C16-C22 fatty acids. When the fatty acid chain is the same length as the wax, the two chains align with each other. This allows the fatty acid to invade the wax crystal lattice and disrupt its growth. It is therefore imperative for the fatty acids in the vegetable oil selected to have lengths similar to, or close to, those of the wax present in the crude oil.
- **Degree of Unsaturation:** A saturated molecular is a molecule where the carbon atom is fully saturated or is bonded to four other atoms. In a saturated molecule, only single bonds exist, therefore the carbon is saturated or is bonded to its full potential. Degree of unsaturation refers to the existence of double or triple bonds with the carbon. The existence of double bonds creates irregularities in the molecule, which in turn prevent tight packing of the wax crystals and creates strains on the wax molecule. This prevents the formation of long wax crystals, hence reducing the pour point of the oil. The higher the degree of unsaturation of the vegetable oil, the more potent the impact.
- **Triglyceride Molecular Architecture:** Vegetable oils are composed primarily of triglycerides. They are also considered bulky molecules which causes the triglyceride backbones to prevent wax crystals from stacking. This creates steric hinderance at the crystal structures where the bulky triglycerides block crystal growth by obstructing the path of the wax chains. Vegetable Oils with more asymmetric fatty acid distribution are considered more effective compared to those with symmetrical distribution.

- **Polarity and Functional Groups:** In crude oils with high asphaltene and resin concentration, the gel strength of the wax chains depends highly on the bridging effect created by the asphaltene and resin, both of which are highly polar. The ester groups in the vegetable oil interact with these polar crude components hence reducing the resin and asphaltene mediated bridges and weakening the gel network. Although all vegetable oils have ester groups, but effectiveness increases with better crude oil compatibility and higher aromatic component solubility.
- **Solubility and Compatibility with Crude Oil:** Good solubility of the vegetable oil with the crude oil ensures no separation between them which can compromise effectiveness in pour point reduction. Generally, vegetable oils with moderate polarity and unsaturation dissolve best in crude oil.
- **Melting Point of the Vegetable Oil:** The vegetable oil must remain liquid below the crude oil pour point or else it will not flow.
- **Resistance to Self-Crystallization:** Highly saturated vegetable oils crystallize themselves, worsening flow. Examples of poor vegetable oils that crystallize quickly include palm oil and coconut oil.

Based on the factors mentioned, a comparison between three high performance types of vegetable oils in terms of these factors illustrates the optimum oils to be used, shown in Table 2.

Table 2
Comparison between Soybean, Sunflower, and Corn Oil in Terms of Pour Point Depressing Capability

Criterion	Soybean Oil	Sunflower Oil	Corn Oil
Fatty Acid Chain Length	Excellent	Excellent	Excellent
Degree of Unsaturation	Around 88%	Around 88%	Around 86%
Triglyceride Steric Hindrance	Very Strong	Strong	Strong
Polarity and Functional Groups	Moderate	Moderate	High
Solubility/Compatibility with Crude Oil	Excellent	Very Good	Very Good
Melting point	Around – 10°C	Around – 16°C	Around – 10°C
Resistance to Self-Crystallization	Excellent	Excellent	Excellent

Figure 5 shows the pour point reduction potential of corn oil using concentrations of 500, 1000, and 2000 ppm and compares the pour point of the oil to that of the original crude oil with no additives. Based on the results, the corn oil managed to reduce the pour point of the crude oil considerably, with the increase in concentration resulting in a slight increase in performance. It should be noted that VAM had a better performance overall, however its cost is more than ten times that of the corn oil with a slightly higher improvement. Increasing the concentration of the corn oil may have improved the overall performance of the pour point reduction, however this was not tested in order to compare the results to those of the other chemical agents.

4.5. Advantages of Vegetable Oil

Based on the aforementioned results, it is apparent that vegetable oil has some major advantages over the conventional pour point depressants. These include:

- **Non-toxic:** many of the conventional chemicals used as pour point depressants contain additives, or are in themselves, toxic. Vegetable oils are nontoxic and therefore are easy to use and will not harm wildlife to the same extent if leakages occur compared to other highly toxic chemicals.
- **Handling:** Since vegetable oil is non-toxic, it does not require any special or excessive handling or storage methods. This reduces the overall cost of utilizing it.
- **Injection:** Due to its relatively low viscosity, even at low temperatures, the injection of the vegetable oil is extremely easy. Additionally, since no solid particles are included in the vegetable oil, there is no risk of flow issues, separation, or precipitation.
- **Separation:** Vegetable oil can be easily separated from crude oil through a conventional distillation column. Depending on the type of vegetable oil used, it will separate at a different temperature. This can be easily determined through analysis of the oil properties.
- **Availability:** Vegetable oil is readily available at many locations. The only challenge is the ability to supply it in bulk.

4.6. Limitations of Vegetable Oil

Although the vegetable oil was effective in reducing the pour point of the crude oil, it still suffers from some main limitations compared to the other conventional chemicals. These include:

- **Viscosity:** Vegetable oil has a relatively low viscosity especially at low temperatures, however many conventional pour point depressants may have an overall lower viscosity value which improves its mobility and injectivity.
- **Solubility in Crude Oil:** Solubility of vegetable oil in the crude oil is strongly dependent on compatibility with the crude oil. It is therefore imperative that this parameter be measured before applying the treatment.
- **Cost of Separation:** Due to its relatively high solubility in crude oil, separation of the vegetable oil, although common practice, may be slightly costly, especially if the vegetable oil has a high boiling point, which is the case with many different vegetable oils.
- **Interactions with Formation Fluids:** Vegetable oil may occasionally interact with some formation fluids, most notably formation water. This can create emulsions that are extremely difficult to break and will cause severe production issues.
- **Compatibility with different Waxes:** Testing the vegetable oil compatibility with the crude oil and the waxes present in an integral part of the success of the treatment.

5. Conclusions

This research tested the ability of corn oil to be used as an effective point depressant for crude oil to improve its flowability and production. The research compared the impact of corn oil to those of conventional pour point depressant chemicals including methanol and vinyl acetate monomer. The main findings of this research are as follows:

- Vegetable oil can function as a strong pour point depressant for some types of crude oils. The compatibility of the crude oil with the vegetable oil should be tested before undergoing the treatment to avoid under performance or complications.
- Different types of vegetable oils will perform differently. This is primarily due to the molecular buildup of the vegetable oil and its overall composition.
- Vinyl Acetate monomer is not observed as an effective pour point depressant on its own, however, it can still be used with specific types of crude oil as was proven in this research.
- Methanol is a weak pour point depressant and should not be used on its own. This is due to its volatility, ineffectiveness in inhibiting the wax crystals and inability to solubilize wax when present in high concentrations.

Declarations

Author Contributions

Conceptualization: Sherif Fakher; Methodology: Sherif Fakher; Software: Sherif Fakher; Validation: Sherif Fakher; Marwan Kabil; Formal Analysis: Sherif Fakher, Marwan Kabil; Writing – Original Draft: Sherif Fakher; Supervision: Sherif Fakher; Project Administration: Sherif Fakher; Funding Acquisition: Sherif Fakher

Funding

Funding for publishing this research was provided by The American University in Cairo through the Faculty Support Grant

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgements

The authors would like to thank AUC for assisting in publishing this research through their Faculty Support Grant.

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Figures

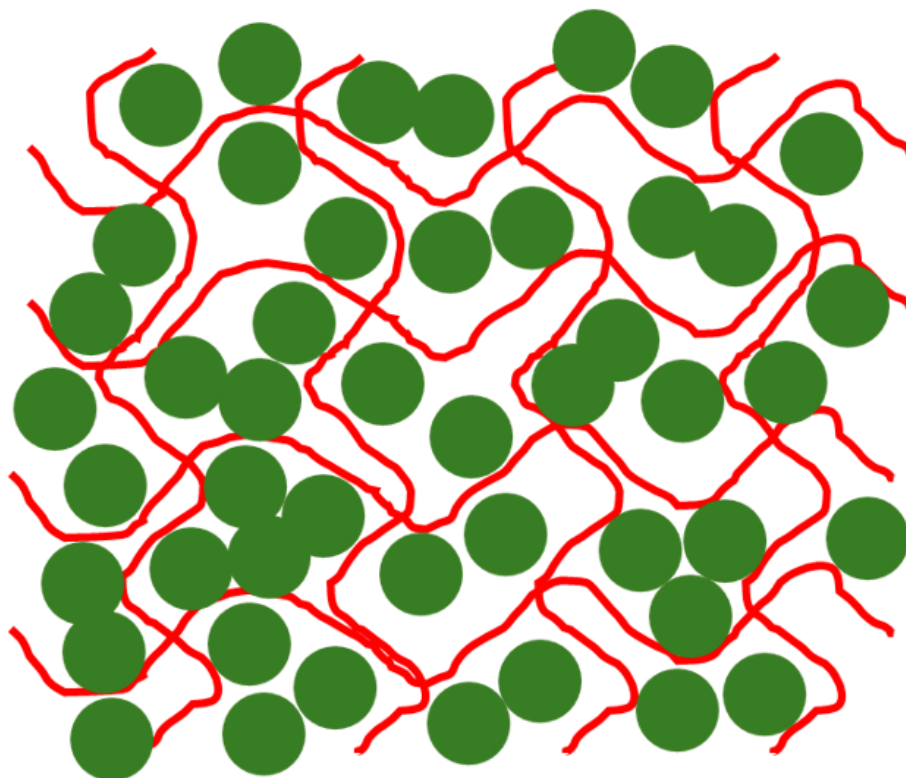


Figure 1

Pour Point Depressant Co-Crystallization Mechanism

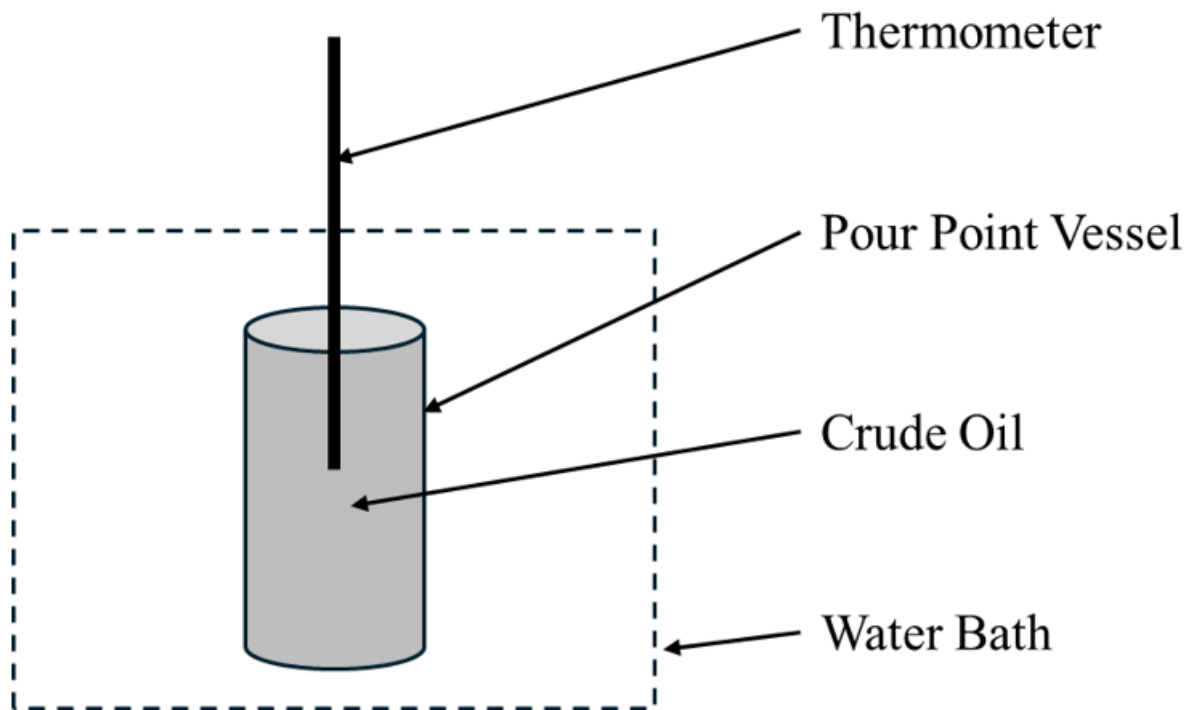


Figure 2

Pour Point Measurement Apparatus

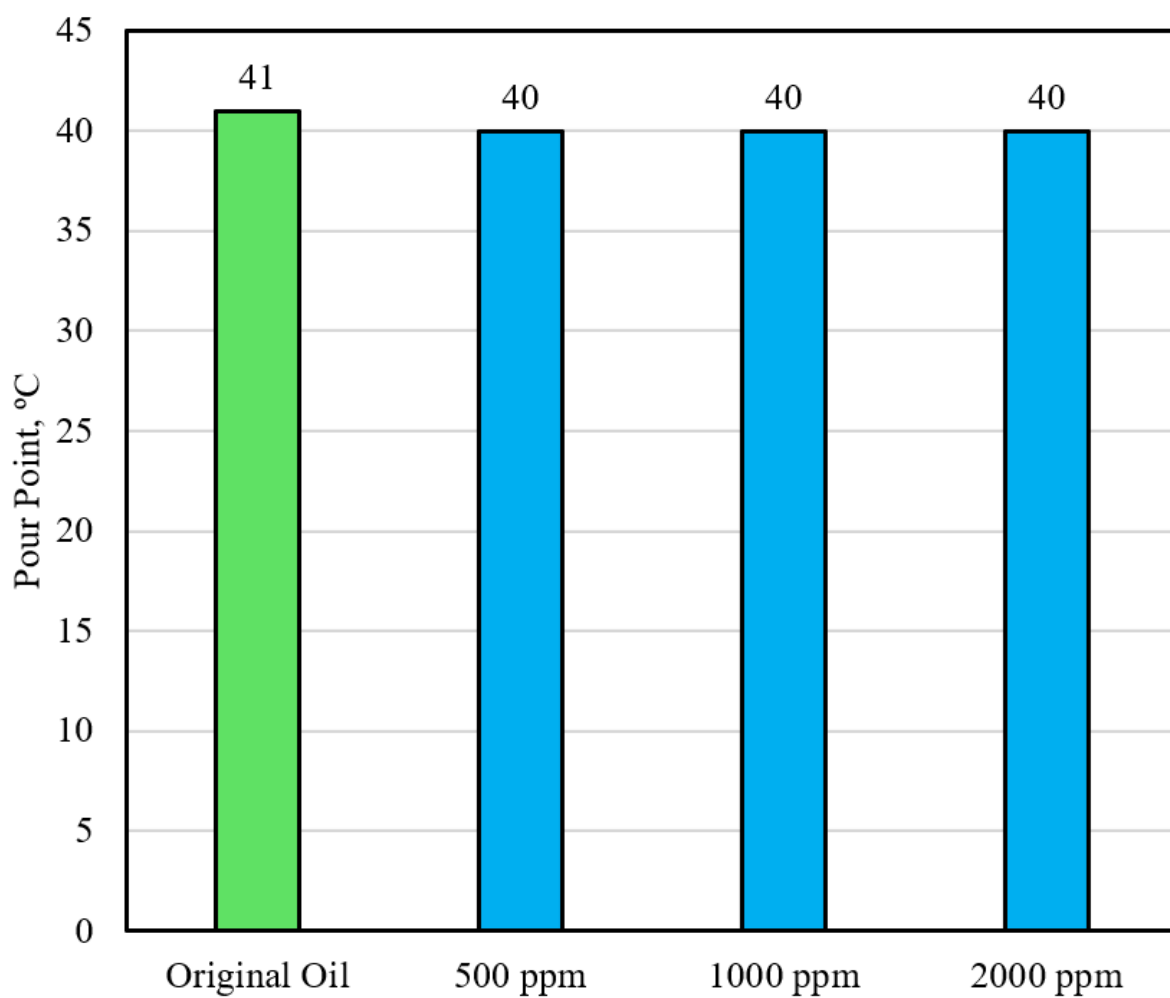


Figure 3

Methanol Pour Point Reduction Compared to Original Oil Pour Point

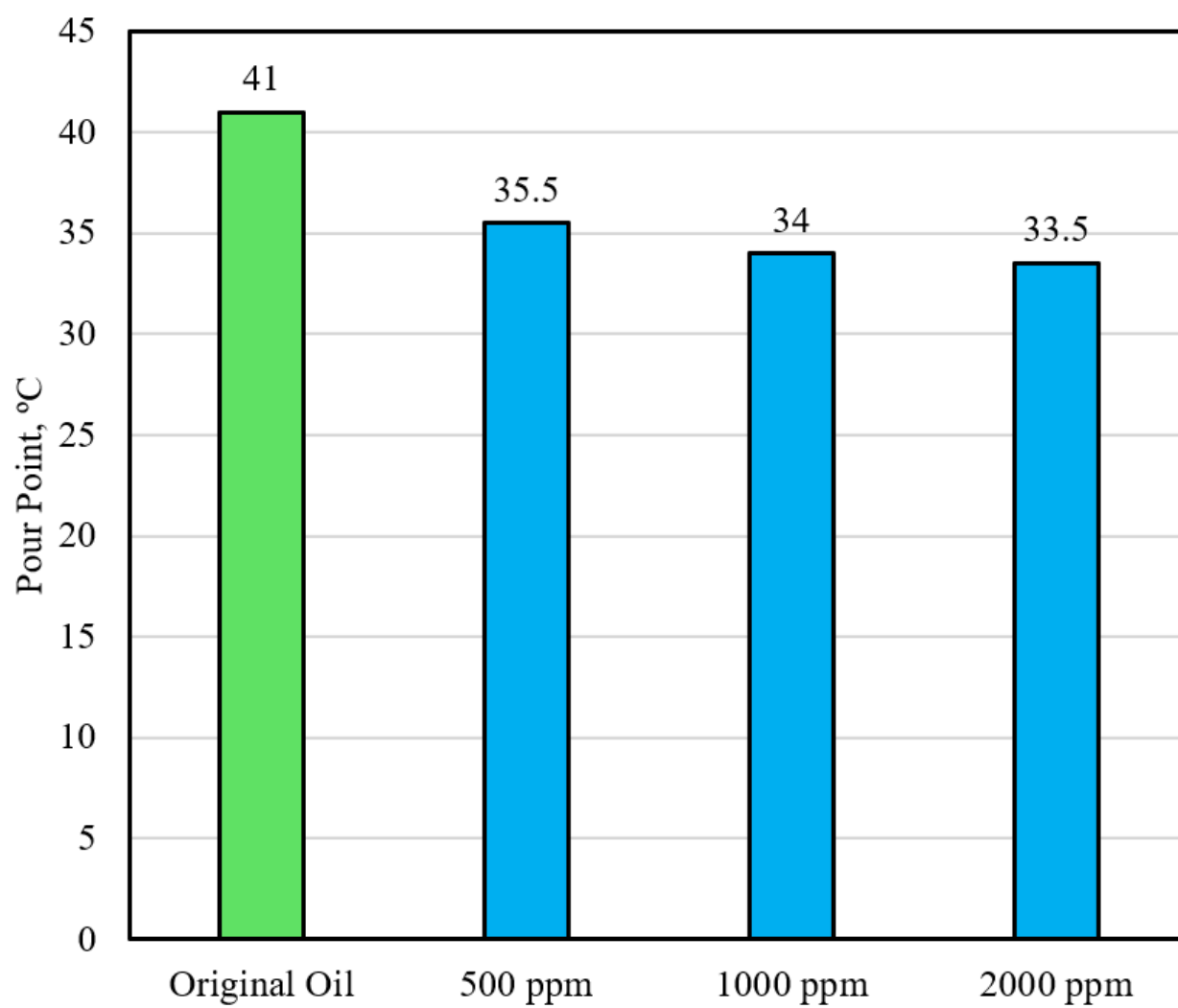


Figure 4

VAM Pour Point Reduction Compared to Original Oil Pour Point

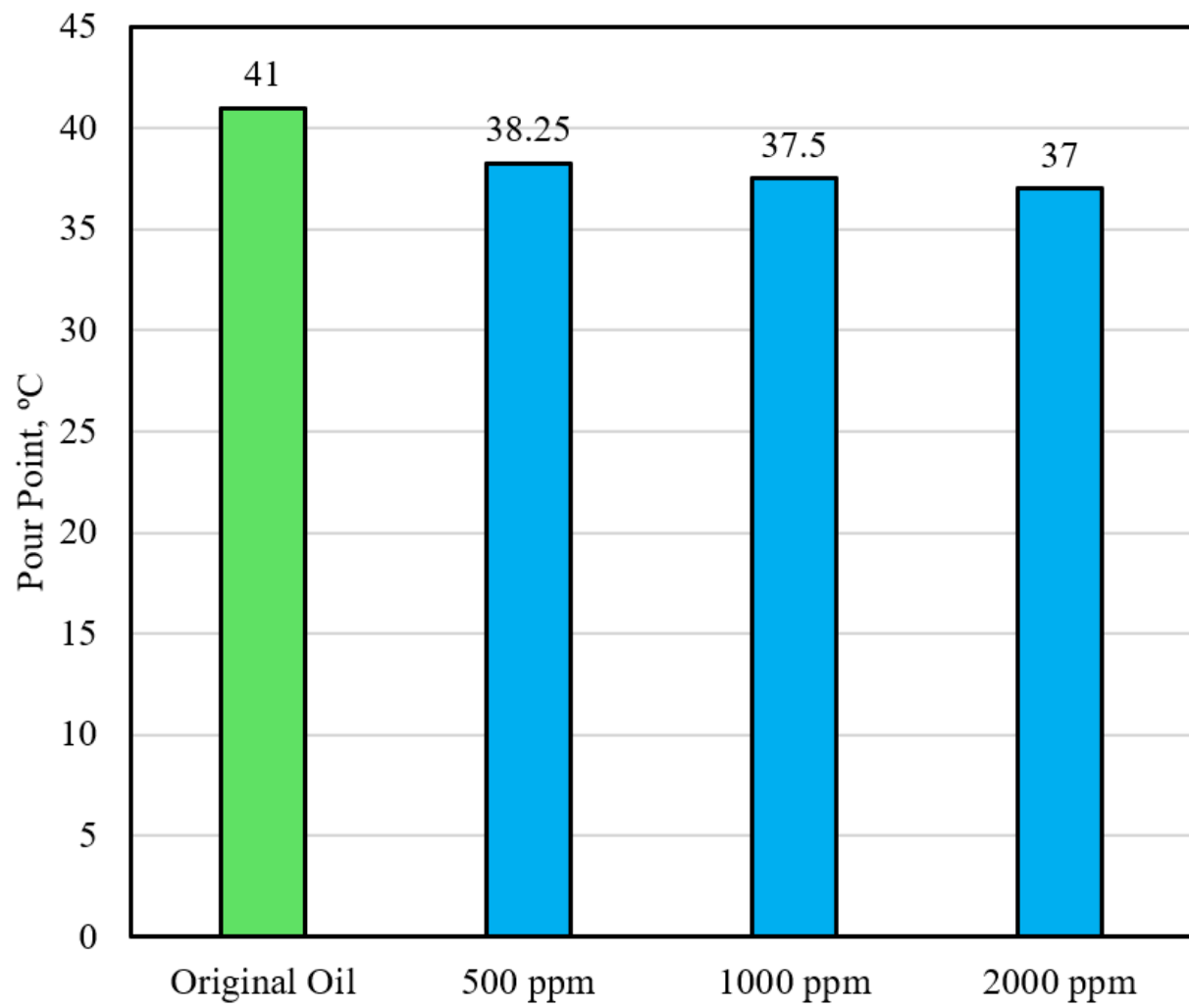


Figure 5

Corn Oil Pour Point Reduction Compared to Original Oil Pour Point