



# Evaluation of Local Inhibitor for Waxy Crude Oil in Horizontal Flow line

Solomon Williams<sup>1\*</sup>, Osokogwu Uche<sup>2</sup>

*Department of Petroleum and Gas Engineering, University of Port Harcourt, Rivers State, Nigeria*

## ABSTRACT

One of the most outstanding flow assurance problems is wax deposition. In order to prevent wax deposition in flow lines, wax inhibitors are utilized. This study evaluates local wax inhibitors on waxy crude oil in horizontal flow line by utilizing agricultural waste as materials for production of wax inhibitors. Orange peel and soya bean husk were sourced and prepared and chemical method of extracting solvents' (soxhlet extractor), was used to extract oil from the prepared orange and soya bean husk. The Orange Peel oil (OP) and the Soya Bean Husk oil (SBH) were applied on the waxy crude oil samples A and B obtained from a field in Niger Delta. The effect of OP and SBH on Wax Appearance Temperature (WAT) of the waxy crude oil samples were investigated using viscosity profile curve obtained from viscometer readings. The results of the experiment showed that OP had better results in WAT for waxy crude oil samples A and B. For comparative purpose, toluene was used as waxy inhibitor and, the result revealed that OP and toluene had the best ability to inhibit the waxy crude oil. However OP which performed better than SBH could be a good substitute for chemical wax inhibitor.

**Keywords:** Flow assurance; Wax inhibitors; Agricultural waste; Wax deposition

## INTRODUCTION

The effort to use crude oil to meet the world's enormous and infinite demand for exploiting energy in the bid to enhancing man and general well-being at nominal cost, flow assurance of hydrocarbon serve as base for fiscal sustainability and is a critical goal of the petroleum engineers and industry, which is continuously connected with innovative designs geared towards an effective throughput of hydrocarbon fluids. Thota and Onyeonuna mentioned that the production and transportation of these hydrocarbon fluids have negative implication, such as impairment of production equipment, which is significant and must be addressed include [1]:

- Wax deposition inorganic salts formation and deposition
- Gas hydrates formation
- Scales
- Emulsifying agents and emulsion

As there is progression of production of hydrocarbon fluid, waxy crude starts to expose wax crystal below the cloud point and the fluid begin to exhibit non-Newtonian behaviour. Wax in hydrocarbon is associated with drop in production rate as it recurrently amasses in production tubing strings and surface flow lines, rouse demand for more power to run down whole pumps, increases downtime and operational costs Wei [2].

## Concern for wax deposition

The problem of wax deposition has inundated the petroleum industry for decades, arousing two main concerns which are technical and economic-upon its occurrence. Wax deposition can be mild or it can be severe enough that it is uncontrollable. The earlier the problem is identified in the life of a reservoir or well, the easier it will be to design a preventive or control management plan that will reduce or eliminate some of the technical and economic problem associated with wax deposition.

Technical issues connected with wax deposition include:

- Reduced transmissibility of fluid and damage to pay zone once it happens in the region of the wellbore and its environs.
- Reduced internal length and ultimately blocking the down whole assembly flow path.
- Alteration of the composition of the hydrocarbon cum flow ability owing to separation of phase as wax comes out of solution
- Further tension on installed equipment used for production due to excessive reduction of pressure in flow conduit resulting to rheological alterations as crystallization of wax starts.
- Restricting the managerial competence of operations of the full production system.

**Correspondence to:** Solomon Williams, Department of Petroleum and Gas Engineering, University of Port Harcourt, Rivers State, Nigeria, E-mail: Willele86@yahoo.com

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The crucial role of economics in crude oil production makes wax deposition an important economic concern to the industry due to the following:

I. Capital investment and operating costs are greater when developing paraffinic crude oil fields. This could cause severe financial strain on the operator of such a field or even lead to abandonment when it becomes uneconomical viable due to obstruction of facilities by wax deposits and lost production.

II. Risk element in development, a setback that could jeopardize the development of marginal fields given the current economic situation. The additional cost of controlling and managing wax places a greater risk of abandonment on such fields.

Hence, control of wax deposition is essential. To address the issue of wax deposition, three important phenomena have to be considered: wax precipitation, dynamic wax deposition, and heat transfer from the wellbore. Wax plug, which is obtained from wax deposition, is a gel that contains solid wax crystals and trapped liquid [3]. Wax precipitation is a thermodynamic phenomenon that will lead to deposition of solid wax crystals. Dynamic wax deposition is the phenomenon in which a gel is formed with wax crystals and liquid. Wax precipitation should be described accurately in order to develop the solutions to control wax deposition in wellbores.

### Causes of wax deposition

They attributed deposition of wax to the factors that follows [4]:

a) **Difference in temperature:** Deposition of wax has a larger tendency to take place once there is a raise in change in temperature amid the temperature of the solution and the internal surface pipe wall temperature. It is however known when the temperature of the surface is lower than the temperature of the solution and the temperature at which wax appears.

b) **Composition of the crude oil:** it has been known that Crude oil consist of SARA component. Larger quantity of asphaltenes resins and paraffin's give rise to high depositional prospect of wax.

c) **Rate of cooling:** A high rate of cooling brings about the development of larger amount of tiny crystals which are unequally dispersed in the region of the channel line while a little rate of cooling bring about the development of a tiny quantity of little crystals which are comparatively better collected together

d) **Rate at which the fluid flows:** laminar flow encourages deposition of wax as there is comparatively little shear distribution whereas turbulent flow helps in its reduction as a result of the obvious assistance of shear distribution

e) **Roughness of the walls of the pipe:** Parts of the internal walls of the pipe that are not smooth are known to be nucleation sites that speed up deposition of wax. As a result of this it can be concluded that, when the surface is irregular, there is a high propensity for deposition of wax.

f) **Water in the crude oil:** Ameibibama observed that water in considerable quantity could help to facilitate deposition of wax, because of melted solutes in the water [5]. They mentioned that a sum of dissolved solids in water in the range of 10000-400000 ppm produced problems of paraffin in the fields of North Michigan in Niagara. The solids acted like nucleation sites that stimulate deposition of wax.

### Mechanisms of wax deposition

The mechanisms through which wax crystals precipitate and get adhered to pipe walls. These include:

**Molecular diffusion:** As well temperature falls to cloud point, solid crystals precipitate from solution, with more crystals in the fluid than at the wall. This sets up a concentration gradient at the fluid-wall interface causing a migration of wax molecules from the fluid to the pipe wall, where they are precipitated from solution.

**Brownian diffusion:** Wax crystals in the reservoir fluid get bombarded continually by the oil molecules. These collisions result in Brownian motion, and will direct the movement of wax molecules to the pipe walls if a concentration gradient is set up between the pipe walls and the fluids.

**Shear dispersion:** Particles present in a liquid tend to move in the direction of the liquid system. This is also an associated collision of wax particles, leading to dispersing of particles. Also in this case, with a concentration gradient set up between the liquid and the containing pipe wall, the dispersion is

One of the profits of using pour point depressant is to decrease the force of interaction between the wax molecules [6,7]. However, the precise communication mechanism of the wax molecules and the inhibitors such as polymeric pour point depressants are still under study. Nevertheless, studies by Chi, Yang and Li have shown some of the mechanisms that include nucleation, adsorption, co-crystallization, and solubilisation interactions [8].

For the duration of the nucleation, as wax molecules precipitate below the wax appearance temperature, acrySTALLINE nucleus of a subcritical volume is formed, leading to the development of a big composite wax crystal. Again, the high-molecular-weight polymeric inhibitor precipitates and operates as a crystalline nucleus for the wax crystals [7]. Ultimately, this leads to the development of more subcritical nuclei of micelle like aggregates. Afterwards, this inhibits the crystal development and decreases the super saturation. Thus, ensuing the formation of smaller wax crystals that are stable in the oil phase, this means enhanced flow capacity [9,10]. Once the oil temperature plunges below wax appearance temperature, the precipitated wax molecules are adsorbed on the polymeric inhibitor nuclei with similar chemical structure, through co-crystallization.

This changes the morphology of the wax crystal (from elongated stick-like or large plate-like to minute spherical-like), which impedes the development of new crystals [7,10]. According to Li, the alteration of wax crystals decrease the exact surface area and decrease the surface energy, this makes it difficult to form three-dimensional network structure. Subsequently, as the concentration of the inhibitor increases in crude oil, there will be a continuous development of tiny spherulitic-like crystals in the crude oil system. The crude oil (liquid) and precipitated wax crystals (the solid) behave like disperse and continuous phase along with the system.

Nevertheless, when pour point depressants are not present in the system, the solid-liquid interface between the wax crystal and liquid phase as well as the energy of the system is great, given rise to an unstable system [7,9]. To reduce the energy of the system the solid-liquid interface has to be reduced, by so doing it could cause a unification of the wax crystals, as a consequence, big crystals will be formed and will produce three-dimensional network structure. Hence, the addition of pour point depressants advances the dispersion of small wax crystals Li [7].

Muhammad carried out an experimental study on the effect of inhibitors on wax deposition [11]. They evaluated the performance of some of wax inhibitors to determine their effects on the pour point, wax appearance temperature and the viscosity of the crude oil using the programmable rheometer rig at gradient temperatures (55°C) and shear rate 120 1/s before and after adding 1000 ppm and 2000 ppm of inhibitors to the crude oil.

They utilized three different inhibitors; they added that the inhibitors worked more efficient compared with its original components. They made comparison between the prepared mixtures, where it was noticed that at concentration 1000 ppm that Mix02 was produced better results, compared with Mix01 and Mix03, in pour point and wax appearance temperature 12.5°C and 16.3°C, respectively. They said 2000 ppm Mix 01 produced best results compared with the prepared mixtures and the original inhibitors, where it was the pour point and the wax appearance temperature 11°C and 14.5°C respectively.

However, the use of foreign wax inhibitors still aches and leaves operational costs on the high side and as well not environmentally friendly, hence the option for locally sourced green wax inhibitor which is cheap and environmentally friendly in order to help foster sustainable development in Niger Delta. This work is aimed at evaluating local wax inhibitors in waxy crude oil in horizontal flow line in Niger Delta. The objective of this study is to develop

waxy crude oil inhibitors using locally sourced non-edible orange peel and soya bean husk. Characterize the extracted solvent (oil) and waxy crude oil samples then determine the viscosity at varying temperature of the crude oil sample when doped and undoped to obtain the viscosity curve of the crude oil both doped and undoped and determine the wax appearance temperature using the curve. Compare the results between local wax inhibitor and toluene on waxy crude oil samples.

### Statement of theory

The presence of wax is an impediment to crude oil production and flow line transportation in the Petroleum industry, whose presence if not rightfully controlled could lead to high operational cost, downtime or system abandonment. In addition, the use of foreign wax inhibitors still aches and leaves operational costs on the high side and as well not environmentally friendly, hence the option for locally sourced green wax inhibitor which is cheap and environmentally friendly in order to help foster sustainable development in Niger Delta.

## MATERIALS AND METHODS

Summary of Materials used for the experimental research work (Tables 1a-1c) (Tables 2-4).

**Table 1a:** Crude oil samples used for the study.

Material	Sample	Source
Crude Oil	X	Niger Delta
Crude Oil	Y	Niger Delta

**Table 1b:** Materials used as wax inhibitors.

Material	Code	Source
Soya bean husk oil	SBH	Soya bean husk
Orange peel oil	OP	Orange peel
Toluene	TO	Vendor

**Table 1c:** IUPAC name, molecular formula and molecular weight of materials used.

Inhibitor	IUPAC name	Molecular formula	Molecular weight(g/mol)
Orange peel oil	(2-methyl(phenyl) diazenyl)naphthalen-2-ol	C <sub>17</sub> NH <sub>14</sub> N <sub>2</sub> O	262.3
Soya bean husk oil	2-aminhoacetic acid	C <sub>2</sub> H <sub>5</sub> NO <sub>2</sub>	75.07
Toluene	methylbenzene	C <sub>7</sub> H <sub>8</sub>	92.14

**Table 2:** Components of soxhlet extractor and equipment used for oil extraction.

S/N	Equipment	Remark
1	Aspirator	Water container that transfer water to the inlet pipe
2	Condenser	cools and condenses the solvent
3	Extraction chamber	Accommodate samples
4	Round bottom flask	Contains solvent and anti-bumping
5	Inlet pipe	Receives water from aspirator and transport to condenser
6	Outlet pipe	Receives water from condenser transport to containment can
7	Retort stand	grips the soxhlet extractor set-up
8	Measuring cylinder	Used to measure the solvent (N-Hexane)
9	Filter paper	holds ground samples in the extraction chambers
10	Beaker	holds extracted oil
11	N-hexane	solvent used for extraction
12	Anti-bumping	make the N-Hexane to boil faster
13	Funnel	For transferring the N-Hexane into the soxhlet extractor

**Table 3:** Components of rotary evaporator.

S/N	Component	Remark
1	Evaporation flask	used to evaporate samples
2	Rotary motor	drive the evaporating flask at constant speed to obtain large evaporation area and evaporation efficiency
3	Heating bath	It used for heating of samples and regulate temperature
4	Vacuum system	It is used to decrease pressure in the rotary evaporating system to attain low boiling point of the sample at reduced pressure
5	Condensate pipe	It is Used to condense the evaporated system
6	Evaporation pipe	It is used to guard the sample during rotation and enables the vacuum system to suck out samples
7	Receiving flask	It is used to recover the sample after condensation

**Table 4:** Apparatus for experiment and their uncertainties.

S/N	Equipment	Remark	Uncertainty
1	Cannon fenske Viscometer	Used to obtain the kinematic viscosity of the waxy crude oil	± 0.16%
2	Density bottle	Used to obtain the density of crude oil	
3	Electric weighing Balance	Used for weighing density bottle	± 1%
4	Stop watch	Used for timing	± 0.01%
5	Cylinder	Used for measuring the waxy crude oil samples	± 0.1µl
6	Thermometer	Used for measuring temperature	± 0.5 OX
7	Soxhlet extractor	Used for extraction of liquid from sample	± 0.1µl
8	Rotary evaporator	Used for efficient and gentle removal of solvent from sample by evaporation	± 1%
9	Volumetric flask	Used to hold extracted oil and waxy crude oil samples	± 0.05ml
10	Pipette	Used to measure the concentration of the inhibitor to be added to the waxy crude oil sample	± 0.006 µl

### Extraction of orange peel oil and soya bean husk

800 kg of Orange peel and the soya bean husk were sourced from a city called Port Harcourt in Rivers State, Nigeria and was dried in the sun. It took 7 days to properly dry the samples. After which, the samples were ground using a grinding machine. 80 g of the ground orange peel and soya bean husk were enfolded in a filter paper and put into the extraction chamber of the sox let respectively, for effective and efficient extraction of the oil from the ground orange peel and soya bean husk oil, the n-hexane (400 ml) was added through the top of the condenser with the aid of a funnel, the solvent passed through the condenser to the extraction chamber and lastly resolves at the round bottom flask with the anti-bumping. Next the set-up was inspected and then the heating mantle (water bath) was put on, and the mantle was set to n-hexanes boiling point. As the n-hexane begins to boil, there is evaporation of the n-hexane from the round bottom flask through the extraction chamber which contains the sample and lastly the condenser containing the water that cools the system traps the n-hexane and condenses it and it drops as liquid back into the extraction chamber and as the liquid n-hexane increases in volume in the extraction chambers it reaches the siphon point and then siphon back into the round bottom flask, this process continues until the n-hexane in the extraction chamber becomes colorless, which is an indication that the oil in the sample has been extracted and the separated oil was put into the rotary evaporator to gently and efficiently remove the solvent from the sample by evaporation at reduced pressure. This process was repeated until the required volume of the essential oil was obtained from the extraction process.

### Wax content

The standard acetone method (UOP 46-64 method) was used to take out the wax from the crude oil sample. A sample of the crude

oil was measured and weighed into a 100 ml beaker. Then 25 ml of toluene was added to the sample and stirred for 5 minutes. Again 5 g of fuller's earth (aluminium silicate) was weighed and added to the mixture to make the sample clear of all polar materials in the oil. Subsequently, the toluene was removed from the sample by evaporation in the oven at 45°C. Then, the deposit was dissolved in ether-acetone mixture in a ratio of 3:1 and was put into a freezer at -17°C for two hours. Then, the solution was filtered through a filter paper which was already weighed. The filtrate (precipitated wax) on the filter paper was dried in an oven at 45°C. The wax content was determined using the formula:

$$\text{Wax content} = \frac{(\text{weight of filter paper} + \text{precipitated wax}) - (\text{weight of empty filter paper})}{\text{weight of oil measured}}$$

### Viscosity/temperature profile

A Cannon Fenske Viscometer was used to measure the kinematic viscosity of the crude oil with and without inhibitors at a cooling range from 60°C down to 30°C. For each occasion, the value of the kinematic viscosity was determined after the crude oil with or without inhibitors flowed from the top of the graduated red line to the bottom of the graduated red line. The density of the crude oil with and without inhibitors was determined by the aid of a density bottle and an electronic weighing balance at varying temperature of the crude oil with and without inhibitors and the dynamic viscosity was computed by multiplying the kinematic viscosity with a cannon Fenske viscometer constant with the density of the crude oil with and without inhibitors at various temperature ranges considered. The data for the crude oil samples with inhibitors should then be compared to the crude oil without inhibitors (blank) results, and the inhibitor that maintains the flattest, smoothest trace for the longest time is considered the most effective wax inhibitor Theyab [12].



### Wax Appearance Temperature (WAT)

WAT is the temperature at which the first wax crystals start to form and precipitate, from crude oil, on the cold surface of the pipe. The Cannon Fenske viscometer was used to measure the viscosity of the crude oil with and without inhibitor at different temperatures. In viscosimetry, the viscosity is determined at different temperatures. The cloud point of the crude oil is estimated by plotting viscosity values versus reciprocal temperature. Typically the cloud point is taken as the temperature where the data begin to deviate from linearity. However, this technique can provide values for WAT that are lower than the real ones. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased [13].

### Performance evaluation of soya bean husk oil and orange peel oil as wax inhibitors on waxy crude oil

10 ml of the crude oil sample was poured into 27 different sample bottles, which was then dosed with individual and combined pour-point depressants using micro-syringe at different dosage concentrations 700 ppm, 1400 ppm, 2100 ppm and 2800 ppm. The effect of the inhibitor on the sample of crude-oil pour-point and viscosity was evaluated.

## RESULTS AND DISCUSSION

Figure 1 below showed the plot of dynamic viscosity and temperature of the waxy crude oil sample X without wax inhibitor. The WAT was determined from the converted point on the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased and this point is at 135°F (Tables 5-14).

Figure 2 below showed the plot of dynamic viscosity and temperature

of the waxy crude oil sample Y without wax inhibitor. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased and this point is at 135°F.

Figure 3 below shows the plot of dynamic viscosity and temperature of the waxy crude oil sample X plus SBH. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased and this point is at 131°F.

Figure 4 showed a plot of dynamic viscosity and temperature of the waxy crude oil sample Y plus SBH. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased and this point is at 130°F.

Figure 5 below showed the plot of dynamic viscosity and temperature of the waxy crude oil sample X doped with OP. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased and this point is at 122°F.

Figure 6 below showed the plot of dynamic viscosity and temperature of the waxy crude oil sample Y doped with OO. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased and this point is at 122°F.

Figure 7 below shows the plot of dynamic viscosity and temperature of the waxy crude oil sample Y doped with Toluene. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased and this point is at 113°F.

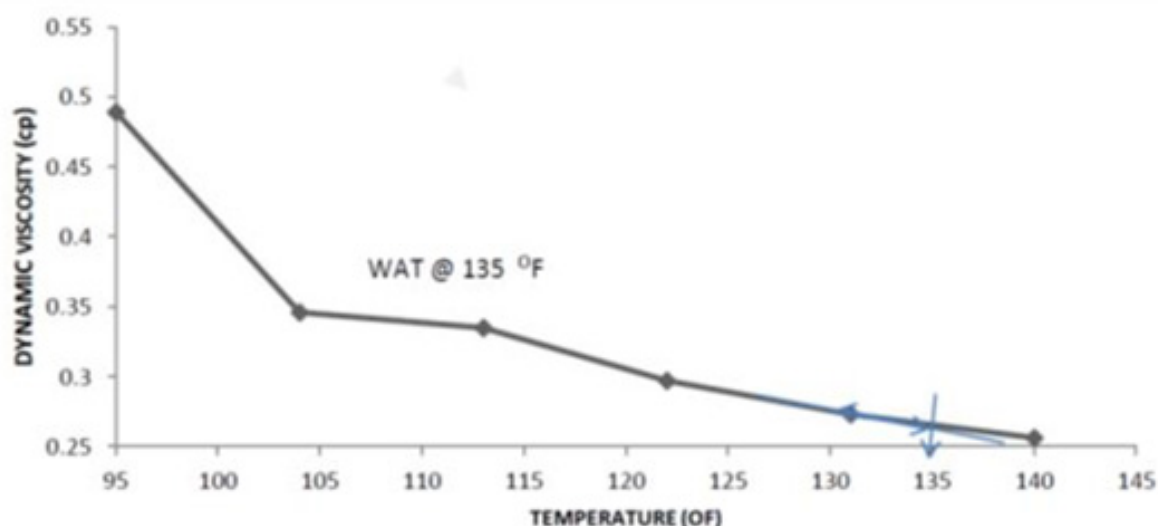


Figure 1: A Plot of dynamic viscosity (cp) vs. temperature (°F) for crude oil sample X without wax inhibitor.

Table 5: Characteristic property of waxy crude oil sample.

Waxy crude oil sample	Wax content (%)
X	14.4
Y	15

Note: The table above shows the characteristic property of the waxy crude oil samples used for this experimental study.

**Table 6:** Viscosity (cp)/Temperature (°F) for crude oil sample X without wax inhibitor.

Temp (°F)	Kinematic Viscosity (mm <sup>2</sup> /s) of crude oil sample	Cannon fenske viscosity constants	Density (kg/m <sup>3</sup> )	Dynamic viscosity (cp)
140	7.11	0.03633703	991	0.256
131	7.58	0.03634959	991	0.273
122	8.25	0.03636216	991	0.297000
113	9.3	0.03637472	991	0.335
104	9.58	0.03638728	992	0.346000
95	13.59	0.03639985	992	0.489

**Table 7:** Viscosity (cp)/Temperature (°F) for crude oil sample Y without wax inhibitor.

Temp (°F)	Kinematic viscosity (mm <sup>2</sup> /s) of crude oil sample	Cannon fenske viscosity constants	Density (kg/m <sup>3</sup> )	Dynamic viscosity (cp)
140	7.08	0.036337031	991	0.255
131	7.38	0.036349594	991	0.266
122	8.05	0.03636157	991	0.29
113	9.1	0.03637472	991	0.328
104	9.38	0.036387283	992	0.339
95	13.39	0.036399846	992	0.483

**Table 8:** Viscosity (cp)/Temperature (°F) for soya bean husk oil (2100ppm) oil plus crude oil sample X.

Temp (°F)	Kinematic Viscosity (mm <sup>2</sup> /s) of crude oil sample	Cannon fenske viscosity constants	Density (kg/m <sup>3</sup> )	Dynamic viscosity (cp)
140	6.55	0.036337	993	0.237
131	7.4	0.0363496	993	0.267
122	8.2	0.0363622	994	0.296
113	9.1	0.0363747	994	0.329
102	9.45	0.0363873	994	0.342
95	13.44	0.0363999	994	0.486

**Table 9:** Viscosity (cp)/temperature (°F) for soya bean husk (2100ppm) oil plus crude oil sample Y.

Temp (°F)	Kinematic viscosity (mm <sup>2</sup> /s) of crude oil sample	Cannon fenske Viscosity constants	Density (kg/m <sup>3</sup> )	Dynamic viscosity (cp)
140	7.05	0.036337	993	0.254
131	7.14	0.03635	993	0.257
122	8.12	0.036362	994	0.293
113	9.21	0.036375	994	0.333
107	9.55	0.036387	994	0.345
95	13.54	0.0364	994	0.49

**Table 10:** Viscosity (cp)/temperature (°F) for orange peel oil (2100ppm) plus crude oil sample X.

Temp (°F)	Kinematic Viscosity (mm <sup>2</sup> /s) of crude oil sample	Cannon fenske Viscosity constants	Density (kg/m <sup>3</sup> )	Dynamic viscosity (cp)
140	6.45	0.03633703	992	0.232
131	7.25	0.03634959	992	0.261
122	7.5	0.03636216	992	0.271
113	8.14	0.03637472	992	0.294
107	8.47	0.03638728	992	0.306
95	11.02	0.03639985	992	0.398

**Table 11:** Viscosity (cp)/temperature (°F) for orange peel oil (2100ppm) plus crude oil sample Y.

Temperature (°F)	Kinematic viscosity (mm <sup>2</sup> /s) of crude oil sample	Cannon fenske Viscosity constants	Density (kg/m <sup>3</sup> )	Dynamic viscosity (cp)
140	6.25	0.03633703	992	0.225
131	7.05	0.03634959	992	0.254
122	7.3	0.03636216	992	0.263
113	7.58	0.03637472	992	0.273
107	8.27	0.03638728	992	0.299
95	10.45	0.03639985	992	0.377

**Table 12:** Viscosity (cp)/temperature (°F) for toluene (2100 ppm) plus crude oil sample X.

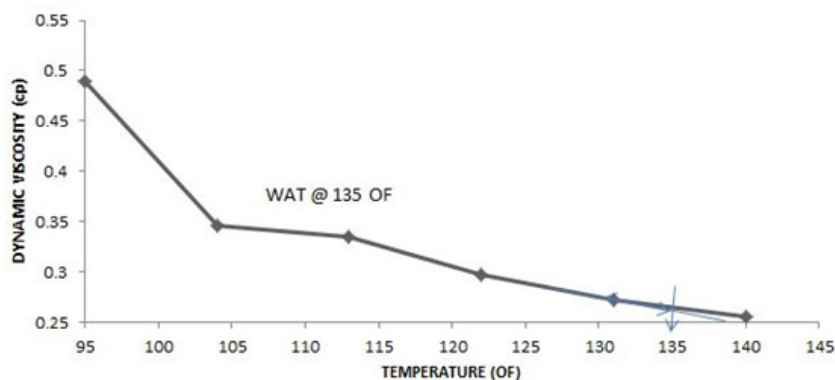
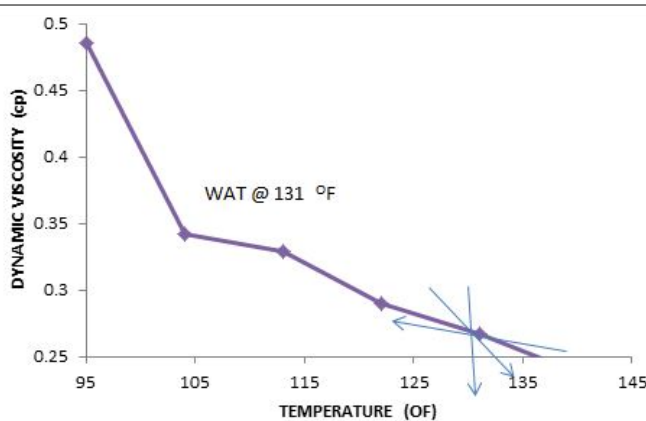
Temp (°F)	Kinematic viscosity (mm <sup>2</sup> /s) of crude oil sample	Cannonfenske viscosity constants	Density (kg/m <sup>3</sup> )	Dynamic viscosity (cp)
60	7.08	0.03633703	995	0.256
55	7.4	0.03634959	995	0.268
50	8.22	0.03636216	995	0.297
45	9.25	0.03637472	995	0.335
40	9.5	0.03638728	995	0.344
35	13.5	0.03639985	995	0.489

**Table 13:** Viscosity (cp)/Temperature (°F) for toluene (2100 ppm) plus crude oil sample Y.

Temp (°F)	Kinematic viscosity (mm <sup>2</sup> /s) of crude oil sample	Cannonfenske viscosity constants	Density (kg/m <sup>3</sup> )	Dynamic viscosity (cp)
140	7	0.03633703	995	0.253
131	7.2	0.03634959	995	0.26
122	8.02	0.03636216	995	0.29
113	9.05	0.03637472	995	0.327
107	9.3	0.03638728	995	0.337
95	13	0.03639985	995	0.471

**Table 14:** Viscosities (cp) of crude oil sample X and Y doped and undoped and corresponding temperatures (°F).

Temp (°F)	Sample X(cp X10 <sup>-3</sup> )	Sample Y(cp X10 <sup>-3</sup> )	Sample Y+"T(cp X10 <sup>-3</sup> )	Sample X+"T(cp X10 <sup>-3</sup> )	Sample Y+OP(cp X10 <sup>-3</sup> )	Sample A +ÖP(cp X10 <sup>-3</sup> )	Sample Y+SBH(cp X10 <sup>-3</sup> )	Sample X +SBH(cp X10 <sup>-3</sup> )
140	256	255	253	256	225	232	254	237
131	273	266	260	268	254	261	257	267
122	297	290	290	297	263	271	293	296
113	335	328	327	335	273	294	333	329
107	346	339	337	344	299	306	345	342
95	489	483	471	489	377	398	490	486

**Figure 2:** Plot of dynamic viscosity (cp) vs. temperature (°F) for crude oil sample Y without wax inhibitor.**Figure 3:** Plot of dynamic viscosity (cp) vs. temperature (°F) for crude oil sample X doped with SBH wax inhibitors.

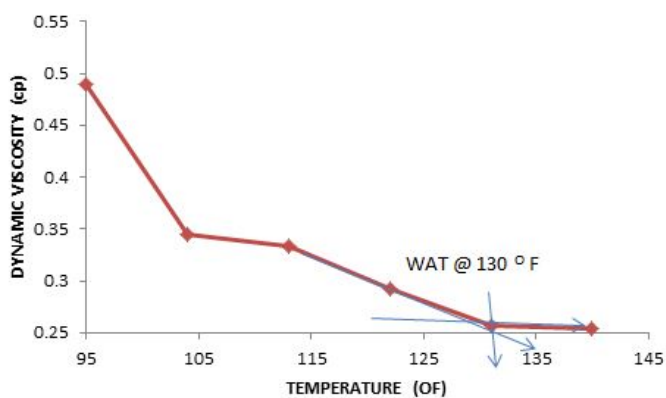


Figure 4: Plot of dynamic viscosity (cp) vs. temperature (°F) for crude oil sample Y doped with SBH wax inhibitor.

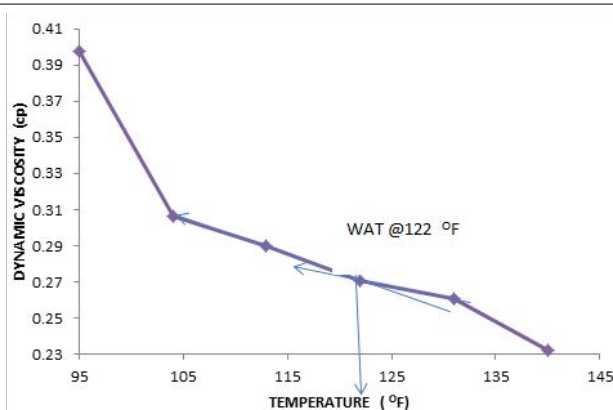


Figure 5: Plot of dynamic viscosity (cp) vs. temperature (°F) for crude oil sample X doped with OP wax inhibitor.

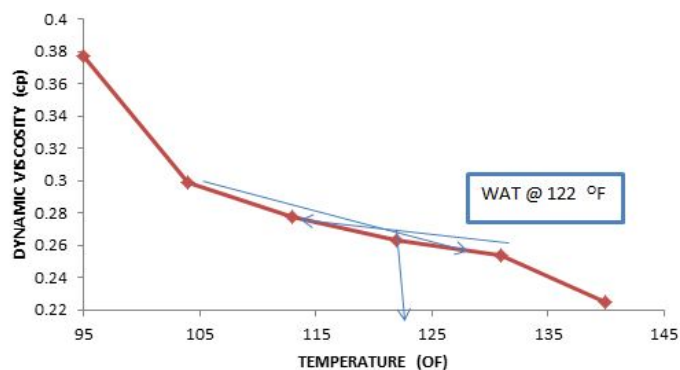


Figure 6: Plot of dynamic viscosity (cp) vs. temperature (°F) for crude oil sample Y doped with OP wax inhibitor.

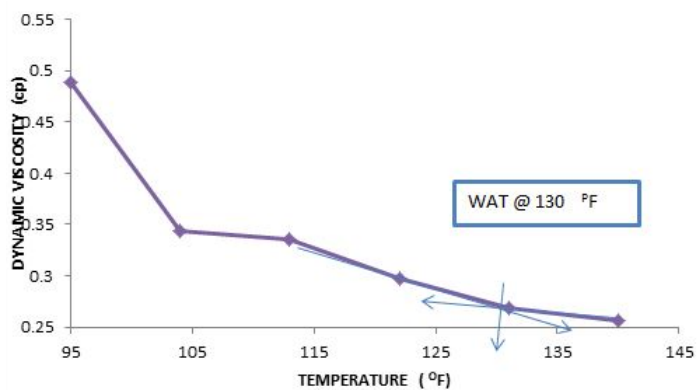


Figure 7: Plot of dynamic viscosity (cp) vs. temperature (°F) for crude oil sample X doped with T wax inhibitor.



Figure 8 below shows the plot of dynamic viscosity and temperature of the waxy crude oil sample Y doped with Toluene. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased and this point is at 130°F. This result provides an insight into the waxy content of these samples. This implies, the higher the wax content of the sample, the easier the wax appearance, and the higher the pour point of crude oil. A similar result was reported by Bai and Zhang.

From the Figure 9 below the viscosities of the crude oil samples X and Y both doped and undoped were closely tied together but samples containing orange peel oil flow fastest as demonstrated by the figure with the least viscosity been sample X and sample Y to their corresponding temperatures.

### Development of kinematic viscosity temperature correlation

The development of generalized correlation was based on the modified form of Eyring's equation (using the kinematic viscosity-temperature data for the two waxy crude oils from a field in Niger delta (Amin and Maddox) carried out extensive research work on a correlative procedure for predicting the viscosity of petroleum fractions [14]. They used several modifications of (Eyring) equation and the one which best correlated viscosity data was found to be of the following forms [15]:

$$\eta = A \text{Exp} (B/T) \quad (2)$$

Where  $\eta$  is the kinematic viscosity (cp), T, the temperature (°F), X and Y is constants. Plot of kinematic viscosity vs. the inverses

of absolute temperature for each of the waxy crude oil and model values is shown in Figure 10. The data followed a linear behaviour and it was concluded, therefore, that the modified Eyring's equation could be used to develop the generalized viscosity-temperature correlation. The constants X and Y in equation were estimated using non-linear least-square fitting of a given set of data.

### Estimation of parameters

In order to formulate a generalized kinematic viscosity-temperature correlation, The validity of equations 10 to produce parameters X and Y respectively for the two waxy crude oil considered can be checked by computing the viscosities for these samples and comparing them with the corresponding experimental values. Table 15 shows the experimental viscosity data and the computed values using the proposed model and the percent error for the values of waxy crude oils. The minimum error is  $\pm 0.00\%$  and the maximum error is  $\pm 3.62\%$  for waxy crude oil sample X and Y. The above result is in line with the result of Mohamed.

$$\text{MODEL: } \eta = 1.84e^{188.33/T} \quad (3)$$

### Kinematic viscosity-temperature behaviour

The wide range of temperature is proposed model was found to fit the data for 6 experimental measurements of kinematic viscosity on two waxy crude oil samples with an overall absolute error of 3.62%. The present investigation was, therefore, initiated in the view to validate the experimental result and to obtain a method of estimation which can be used to predict reliably the variation of kinematic viscosity-temperature behaviour of waxy crude oil over (Figures 11-15) [16,17].

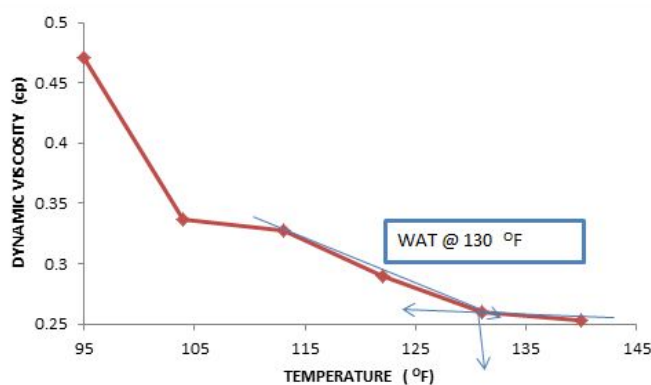


Figure 8: Plot of dynamic viscosity (cp) vs. temperature (°F) for crude oil sample Y doped with T wax inhibitor.

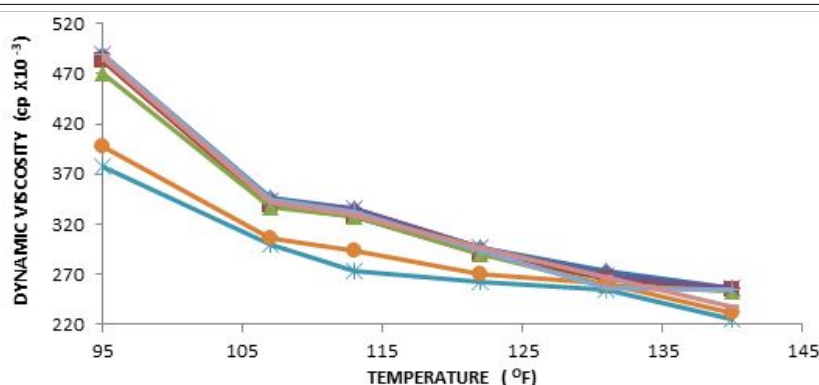


Figure 9: Plot of viscosities of crude oil sample X and Y doped and undoped and corresponding temperatures.

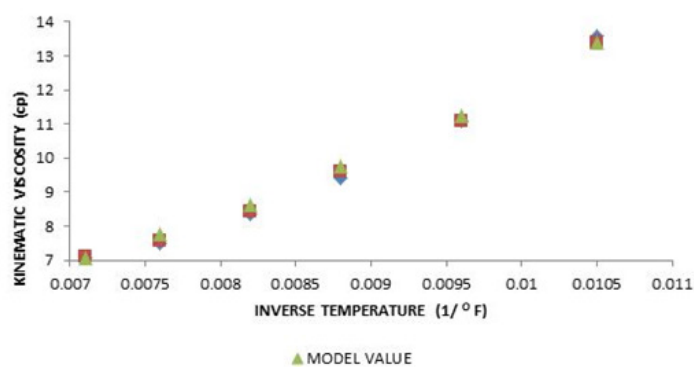


Figure 10: Plot of kinematic viscosity vs. inverse of temperature for sample X and Y with the model values.

Table 15: Temperature (°F), experimental value of samples A and B with model values and its corresponding errors.

T (°F)	1/T (1/°F)	Sample X	Sample Y	Existing model values	Error of sample X with mode (±)%	Error of sample Y with model (±)%
140	0.0071	7.08	7.1	7.06	0.28	0.56
131	0.0076	7.48	7.58	7.75	3.61	2.24
122	0.0082	8.35	8.45	8.61	3.11	1.89
113	0.0088	9.4	9.6	9.74	3.62	1.46
104	0.0096	11.07	11.1	11.25	1.62	1.35
95	0.0105	13.59	13.39	13.39	1.47	0



Figure 11: Fresh and dried orange peel orange peel.



Figure 12: Ground orange peel.



Figure 13: Soya bean husk.



Figure 14: Ground soya bean husk.

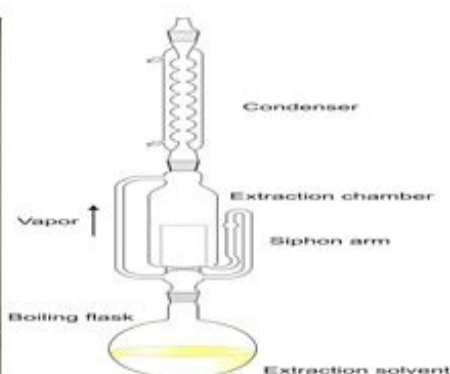


Figure 15: Soya bean husk oil and orange peel orange oil, and schematic of soxhlet extractor.

## CONCLUSION

Waxy crude oil inhibitors was developed using locally sourced non-edible orange peel and soya bean husk. The solvents (oils) were applied on the waxy crude oil samples to determine the wax appearance temperature (WAT) of the waxy crude oil. The WAT was determined from the converted point in the viscosity curve from the straight line to the incline line, at which the viscosity start to increase gradually when the temperature is decreased (Muhammad and Pedro).

The WAT for waxy crude oil without inhibitor, waxy crude oil doped with soya bean oil, waxy crude oil doped with orange peel oil and waxy crude oil doped with Toluene for crude oil sample A were 105°F, 105°F, 122°F and 130°F and for crude oil sample B were 105°F, 130°F, 122°F, and 130°F respectively This result provides an insight into the waxy content of these samples. This implies that the higher the wax contents of the sample, the easier the wax appearance. A similar result was reported by Bai and Zhang. The results between local wax inhibitor and toluene on waxy crude oil samples were compared. It was observed that both SBH and OP could be used as wax inhibitors.

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