

Modeling of Wax Deposition in Crude Oil Pipeline Using Simulation

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ABSTRACT

One of the biggest sectors providing energy demands is the petroleum industry. Offshore oil and gas fields make up a large amount of the world's remaining oil and gas resources, and their exploitation necessitates the use of cutting-edge production and transportation technology. Flow assurance is required to ensure a constant fuel delivery. Wax deposition is the most significant issue that impairs flow assurance or reduces the efficiency of conveying crude oil. Because the cost of repairing and troubleshooting in the petroleum industry is so expensive, it's critical to solve flow assurance concerns.

This study looks into the various causes of wax precipitation and deposition in crude oil pipelines during transit, as well as solutions for reducing, cleaning, and monitoring wax buildup. Wax dissolved in the crude oil crystallizes when the bulk temperature of the crude oil falls below the wax appearance temperature, causing buildup over the pipe walls.

Models of wax deposition were analyzed and compared. The review's goal is to provide a trustworthy knowledge input into wax deposition modeling in oil and gas flow systems by offering accurate prediction analysis of wax appearance temperature and wax disappearance temperature.

KEYWORDS: crude oil, flow assurance, paraffinic wax, pipeline, wax appearance temperatures, wax deposition, wax precipitation.

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I. INTRODUCTION

Crude oil is a natural resource that is an energy source that is recovered from the subsurface of the earth through a drilling process. When this crude oil is extracted from a subterranean reservoir at a high temperature and pressure, it is usually transported through a pipeline. The crude oil being carried to the processing facility is a multi-component, multi-phase fluid that comprises numerous hydrocarbon fractions, including paraffinic wax. At reservoir temperatures of (70-150⁰C) and pressures of (50-100 MPa), wax molecules remain soluble in crude oil. However, as the crude oil flows through a subsea pipeline that is lying on the ocean floor at a temperature of 4⁰C, the temperature of oil eventually decreases below its cloud point temperature (or wax appearance temperature, WAT) as a result of the heat losses to the surroundings. As the temperature drops, the solubility of wax in crude oil decreases dramatically, resulting in the precipitation of wax from the crude oil.

High molecular weight paraffins with carbon numbers more than 20 are found in the waxy components of crude oil. These elements are dissolved and soluble in crude oil under reservoir conditions; but, when the crude oil flows closer to the processing facilities and becomes colder, the solubility of the paraffin molecules decreases.

According to Kelechukwu et al., the crude oil flow rate had a significant impact on wax generation, deposition duration, and thickness of the wax layer in the crude oil pipeline (2010). According to Oyekunle and Adeyanju, the operating pressure and amount of various components have an impact on the wax deposition in crude oil pipelines (2011). Wax Appearance Temperature (WAT) affects wax deposition in pipes. Wax that was previously soluble in crude oil begins to precipitate as the oil temperature falls below the WAT (Taiwo et al., 2012).

The wax concentration of crude oil is a factor of the crude's composition, according to study by Ariya et al., 2014 and Thota et al., 2016. When the temperature of the fluid drops below the Wax Appearance Temperature (WAT), the waxy components precipitate out of the liquid phase, crystallize, and deposit on the pipe walls, obstructing flow.

II. FLOW ASSURANCE

It is a self-explanatory term that simply implies delivering and ensuring the transit of well-stream fluid (hydrocarbons) from the reservoir to the processing facilities. Flow assurance is intended to identify, quantify, and eradicate flow difficulties such as hydrate formation, scale deposit, and solid depositions in order to avoid well stream flow constraint or, in the worst-case scenario, blockage of the flow lines, which would result in production suspension.

2.1 Wax

Wax can be characterized as a mixture of n-alkanes with homologous chain lengths, according to chemical research. They are hydrocarbon classes with a composition and physical qualities similar to beeswax from a natural beehive, which deforms above near-ambient temperatures. They are insoluble in water but soluble in organic, non-polar solvents.

In their study, Pedersen, K.S. et al. (2007) discovered that high molecular weight alkanes with a higher degree of branching have a lower tendency for wax to precipitate. When wax freezes, it forms crystals; paraffin wax crystals are called macrocrystalline wax (figure 2.1), while naphthenes crystals are called microcrystalline wax (Mansoori, 2009) (Figure 2.2). The intensity of the wax deposition issues is determined by the oil type and the wax molecules' molecular makeup. Crude oil waxes are more difficult to regulate than condensate waxes because the alkane chains in crude oil are generally longer than in condensate.

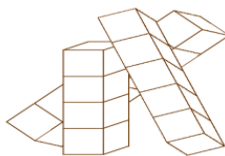


Figure 2.1: Macro crystalline structure (Mansoori, 2009)

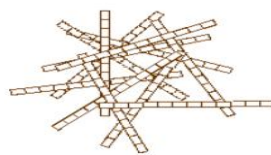


Figure 2.2: Micro crystalline structure (Mansoori, 2009).

2.2 WAX APPEARANCE TEMPERATURE (WAT)

The wax appearance temperature is described as the temperature at which wax crystals begin to precipitate out of hydrocarbon fluids as visible under particular microscopic examinations, as previously mentioned as a temperature threshold. The wax appearance temperature is an important parameter for describing and assessing wax deposition behavior in the oil and gas industry. The terms wax precipitation temperature, wax appearance point, and wax formation temperature is all used interchangeably in several literatures.

2.3 WAX POROSITY

Wax porosity is a metric of the trapped percentage of oil present in depositing wax during wax deposition. It is a crucial indicator in the control of wax deposition since it has a direct impact on the pace of wax deposition. It is said to be affected by the flow regime, flow turbulence, and oil type.

2.4 WAX DEPOSITION

Wax deposition and wax precipitation are often used interchangeably in the literature, although this is incorrect because they are two distinct concepts. Wax precipitation occurs before wax deposition. Wax deposition is defined as the creation of a layer of separated solid phase on a pipeline in contact with crude oil, and the subsequent growth of this layer.

Wax deposition can be created from a previously precipitated solid phase (wax) by mechanisms of shear dispersion, gravity settling, and Brownian motion, or from dissolved wax molecules through a molecular diffusion mechanism, as discussed in the preceding chapter. When crude oil is subjected to low temperatures, it can create thick deposits of wax-oil gels.

High molecular weight paraffins (waxes) are one of the hydrocarbon groups responsible for some of the challenges faced during crude oil transportation and processing. At normal temperature, high molecular weight paraffins have low solubility in most aromatic, naphthenic, and other organic solvents.

At temperatures of 70-150⁰C and pressures of 8,000-15,000 psi, crude oil behaves like a Newtonian fluid with low viscosity in offshore reservoirs due to the aforementioned conditions. Because of the cooler climate, the temperature of crude oil drops as it exits the reservoir and travels through tubing and undersea pipelines. Reservoir temperatures range from 70 to 150 degrees Celsius, while deepwater temperatures near the seafloor hover about 4 degrees Celsius (Huang et al., 2011b). As the oil flows through the pipe walls, heat is lost to the water. As the oil cools, the solubility of the denser oil components drops, causing wax to precipitate out of the crude oil stream (Stubsjoen, 2012). The majority of commercial oil wells is far from coast, in deep oceans or the Arctic, and so suffers from wax deposition (Galta, 2014).

Flow assurance is currently a critical technical and economic concern for the oil and gas sector due to the ongoing drive towards deep sea oil production (Coutinho et al., 2006). The process of wax deposition is divided into two stages:

1. Wax gel formation
2. Aging

The second step of wax deposition is aging (hardening), which is the process of diffusion and counter-diffusion that causes the gel deposit to harden, the size of the solid deposit to increase, and the amount of wax in the gel deposit to increase. Crude oil, water, gums, resins, sand, and asphaltenes are all entrained throughout the crystallization and deposition process and are fully dependent on the nature and composition of the crude oil. The crucial carbon number of the oil regulates this process, causing wax molecules to diffuse into the gel deposit while oil molecules counter-diffusion out of the gel deposit (Burger, E. D., Perkins, T. K., and Striegler, J. H., 1981).

When crude oil from an oil reservoir reaches a temperature above the cloud point and comes into contact with a cold subsea pipe wall, a gel coating forms. The gel pores that open at the gel interface connect the contained oil in the blossoming gel deposit to the bulk oil. When compared to bulk oil, confined oil lacks several heavier hydrocarbons due to the creation of the solid phase.

2.4 FACTORS THAT LEADS TO WAX PRECIPITATION AND DEPOSITION

- i. **Temperature:** Because of its direct relationship with paraffin solubility, temperature appears to be the most significant and relevant factor in wax precipitation and deposition. When the temperature drops, the solubility of paraffin wax in crude oil reduces, and vice versa. When the operating temperature is at or below the WAT, wax precipitation from crude oil occurs. Because of the obvious temperature difference between the colder pipe wall and the bulk oil, the ambient temperature outside the pipe is usually lower than the oil temperature inside the pipe. When the pipe wall temperature goes below the cloud point, this temperature differential causes wax deposition. The rate of wax deposition is proportional to the temperature differential between the bulk oil and the pipe wall while the bulk oil temperature remains constant (4).
- ii. **Crude oil composition:** Saturates, Aromatics, Resins, and Asphaltenes make up crude oil (SARA). SARA has an impact on the ability of crude oil to deposit wax solids and, as a result, its stability. Saturates are naturally flexible; paraffins, for example, have the most flexibility because they are straight-chain compounds that cluster and crystallize more easily. Iso-paraffins are similar to paraffins in terms of flexibility, but they generate a wax that is less stable. Because of their cyclic character, cyclo-paraffins (naphthenes) are the least flexible and contribute little to wax deposition. At their original reservoir conditions, these components were in thermodynamic equilibrium. Aromatics have been shown to act as solvents for high molecular weight saturates, which generate paraffin waxes in crude oil, whereas polar components, particularly asphaltenes, encourage wax nucleation. The light saturates also aid in the retention of the heavy saturates with large molecular weight in solution. Because they are the first to leave the reservoir when manufacturing begins, these brilliant ends are lost. It changes the natural makeup of the oil system, making paraffin waxes less soluble. Due to the lack of solubility, wax precipitation and deposition may occur (4).
- iii. **Gas/oil ratio:** This has an effect on wax deposition that is influenced by the pressure regime. Solution gas helps keep the wax in solution above the bubble point, where all gases remain in solution. Gas lift injection in a closed annulet decreases wax deposition by inducing a drop in WAT as a function of pressure when WAT is high and GOR (Gas-Oil ratio) is low. High GOR would result in additional expansion and subsequent cooling when the oil system's pressure is reduced, perhaps speeding up the wax deposition problem. In a study to lower WAT by injecting diluents into gas lift wells, it was discovered that good results were not achieved in wells with high GOR (4).
- iv. **Flow rate:** Dynamic forces are in control in turbulent flow regime and the motion is parallel to the pipe axis with mixing occurring between the different layers. Viscous forces are in control in laminar flow regime and there is no room for mixing in between the layers.
- v. **Pressure:** Pressure, being a key factor in the extraction of reservoir fluids, has a considerable impact on wax precipitation and deposition, though not as much as temperature. During oil production, the reservoir

pressure decreases as production increases, and the pressure of the flow stream decreases all the way from the reservoir to the surface. As the pressure in the reservoir decreases, the light end components of the reservoir fluid are the first to leave. The solute solvent ratio rises as a result of the light ends acting as a solvent for the wax components. As a result, the loss of these light ends reduces the solubility of wax. At constant composition of the crude oil in consideration, the wax appearance temperature rises as pressure rises over the bubble-point (Seteram). Increased pressure in the one-phase liquid region (above bubble-point pressure) favors wax deposition, according to this phenomenon.

2.5 CONTROL OF WAX DEPOSITION

A wax deposit is usually porous with oil entrained within its contents (Aiyejina et al., 2011). Figure 2.1 depicts an example of severe wax deposition in a section of pipeline.

Wax deposits are usually removed by the following methods:

- i. **Mechanical method:** As shown in Figure 2.2, the pigging operation (mechanical removal of wax deposits in the pipeline using pig) is carried out using an instrument called a pig. The amount of wax present and its thickness, however, limit the applicability of this procedure (Eskin et al., 2014).
- ii. **Thermal methods:** It necessitates insulation and active periodic heating, both of which are costly (Deo et al., 2007).
- iii. **Chemical injection method:** It is another strategy that can be employed, but its usefulness is typically limited (Deo et al., 2007). Exothermic reactions inside the pipeline are used to generate heat or gas using chemical additives (Deo et al., 2007).
- iv. **Cold-flow method:** This method of controlling wax deposition in subsea pipelines is a novel and intriguing approach. The crude oil is seeded and then cooled in this manner. This method reduces the radial heat gradient and increases the surface area available for wax formation within the bulk oil rather than on the pipe wall (Deo et al., 2007). When the solid content of oil reaches around 4–5%, it can gel, causing the oil's rheological properties to change and it to become a shear-thinning suspension (Ramirez-Jaramillo et al., 2004). Internal coatings, biodegradation, and sonic techniques are examples of less prevalent wax deposition prevention strategies (Deo et al., 2007). Wax control strategies can also be combined with one another, such as pigging and thermal insulation.



Figure 2.1: Wax deposit (Siljuberg, 2012)

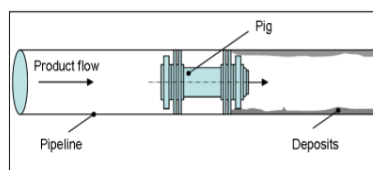


Figure 2.2: Diagram of pig removing deposits (Devaux)

TYPES OF CHEMICAL INHIBITORS USED IN CHEMICAL INJECTION METHOD

- **Pour Point Depressant (PPD):** Vander Waals forces cause PPDs to co-crystallize into the paraffin structure. This allows the detachable polar end tail to cause steric interference with the alignment of fresh wax molecules. PPDs lower the pour point temperatures of crude oil, lowering the solid structure of the wax deposition and making it easier to remove by shear force. It is important to highlight that a drop in crude oil PPD does not imply a decrease in crude oil WAT, because PPDs hinder the formation of wax crystals rather than crystallization [3]. PPD differs from wax dispersant in that the latter adsorbs into the wax crystal and prevents the wax molecules from sticking together further. PPD includes olefin-maleic anhydride copolymer (MAC), diethanolamine (DEA), methyl methacrylate (MMA), and polyethylene vinyl acetate (EVA) [3].
- **Wax Crystal Modifier:** Wax crystal modifier, which alters the development and surface features of wax crystals during the nucleation process, can induce them to reassemble into micelle-like aggregates. As a result, more subcritical nuclei are generated, lowering the super saturated qualities of crude oil. Smaller wax

crystals form as a result and remain stable in the oil phase [3]. Wax crystal modifiers reduce the ability of wax crystals to form a three-dimensional network, which helps to lower the pour point and viscosity of the oil.

- **Wax Dispersants:** They are a type of surfactant that adsorbs on pipe wall surfaces and lowers wall adhesion by altering the wettability of the pipe wall or forming a thin layer that allows wax crystals to easily shear off. Adsorption of a wax dispersion onto crude oil wax crystals results in the formation of a wax crystal lattice structure. Later, the wax crystal structure decreases the morphology of the forming crystals, delaying the formation of a three-dimensional crystal. This spherical-like crystal, which evolved from a huge plate-like crystal, is expected to improve crude oil flow properties [3].

III. METHODOLOGY

Wax deposition modeling is a difficult task that necessitates a thorough understanding of several disciplines, including chemistry, fluid mechanics, and thermodynamics. The recommended technique for this project combines two dependable simulation tools, ASPEN HYSYS and PVTp, to meet the project's goals.

3.1 ASPEN HYSYS Simulation

ASPEN HYSYS is a chemical process simulator that can mathematically represent everything from unit activities to entire chemical plants and refineries. For steady state and dynamic simulation, process design, performance modeling, and optimization, HYSYS is widely used in the chemical and petroleum engineering industry and academia.

Wax deposition models are included in ASPEN HYSYS' pipe module. However, n-alkanes with a molecular weight greater than C_{30} are not supported by HYSYS' standard chemical elements package. Alkanes up to C_{70} can be found in most crudes including wax, as can be observed in this case. The hypothetical components function of HYSYS is used to accommodate components with alkane values greater than C_{30} . The crude oil's light end components were added first. Then, utilizing the aforementioned hypothetical component feature, the higher n-alkanes that HYSYS does not support were added. The thermodynamic properties of the hypothetical components that were added to the simulator were entered.

The natural boiling point, molecular weight, and liquid densities were the only thermodynamic parameters that HYSYS required as input, with the rest of the properties needed to run being approximated by HYSYS.

FLUID SIMULATION IN PVTp

A hypothetical fluid from a typical production oil field with subsea production flow line for subsea oil transport was created for simulation of wax. The hydrocarbon composition was keyed into the GUI of PVTp for characterization; where the molar concentration of the characterized hydrocarbon fluid was obtained. The table below shows the composition of the described hydrocarbon fluid from the PVTp simulator.

Table 3.1: Properties of higher alkanes (source: Mortern K. Siljberg)

Alkanes	Natural boiling point (^o F)	Molecular weight	Liquid Density (g/cm ³)
n-C ₃₁	365.45	436.9	808
n-C ₃₂	380.93	450.9	810
n-C ₃₃	394.79	464.9	810
n-C ₃₄	408.65	478.9	812
n-C ₃₅	422.15	493.0	813
n-C ₃₆	435.11	507.0	814
n-C ₃₇	447.71	521.0	814
n-C ₃₈	459.95	535.0	815
n-C ₃₉	471.83	549.1	816
n-C ₄₀	483.35	563.1	817
n-C ₄₁	494.51	577.1	818
n-C ₄₂	505.31	591.1	818
n-C ₄₃	515.75	605.2	819
n-C ₄₄	526.01	619.2	820
n-C ₄₅	535.91	633.2	820

IV. RESULTS AND DISCUSSIONS

4.0 RESULTS OF THE ANALYSIS ON ASPEN HYSYS

Under specific physical conditions and pipe qualities that could lead to wax deposition, ASPEN HYSYS was utilized to characterize the fluid (hydrocarbon) and plan the flow through various pipe segments. The estimated and analyzed properties include; pipe roughness, pipe wall conductivity, pipe nominal diameter, mole fraction, calculated wax deposition thickness (mm), deposition volume (m³), deposition rate (kg/s-m²), film coefficient (KJ/h-m²-C), deposition temperature (°C), fluid temperature (°C) and critical deposition temperature (°C).

The values of certain properties and components were keyed into the simulator while the other unknown properties were estimated by the simulator ASPEN HYSYS. The results obtained were products of different wax deposition models/correlations such as Chung, Pederson, and Conoco and Pederson and they can be seen in the tables below.

4.2 SENSITIVITY ANALYSIS

The study of how the uncertainty in a mathematical model's or system's output may be separated and ascribed to various sources of uncertainty in its inputs, according to Wikipedia.

In this project, sensitivity analysis is used to check the validity of a model's conclusions in the face of uncertainty by recalculating the results under different assumptions to see how a variable affects the outcome.

The "One -At-a -Time" (OAT) sensitivity analysis method was applied in this study.

It comprises altering one thing at a time to observe how it affects the outcome.

Typically, OAT entails:

- i. Changing one input variable while leaving the rest constant is an example of this.

To that effect a sensitivity analysis was conducted on the results gotten from the simulator PVTp while also comparing the results gotten from different wax deposition models.

Table 4.1: Results obtained for the wax deposition temperature from the different wax model used using mild steel as the pipe material

Cumulative pipe length (m)	Calculated wax deposition thickness (mm)	Conoco wax model deposition temperature (°C)	Chung wax model deposition temperature (°C)	AEA wax model deposition temperature (°C)	Pederson wax model deposition temperature (°C)
200.00	0.000	48.912	48.912	48.912	48.912
400.00	0.050	48.958	48.958	48.958	48.958
600.00	0.100	49.004	49.004	49.004	49.004
800.00	0.150	49.050	49.050	49.050	49.050
1000.00	0.200	49.096	49.096	49.096	49.096
1200.00	0.250	49.143	49.143	49.143	49.143
1400.00	0.300	49.189	49.189	49.189	49.189
1600.00	0.350	49.235	49.235	49.235	49.235
1800.00	0.400	49.282	49.282	49.282	49.282
2000.00	0.450	49.328	49.328	49.328	49.328

Table 4.2: Results obtained for the critical wax deposition temperature for the different wax models

Cumulative pipe length (m)	Calculated wax deposition thickness (mm)	Critical wax deposition temperature for Conoco model (°C)	Critical wax deposition temperature for Chung model (°C)	Critical wax deposition temperature for Pederson model (°C)	Critical wax deposition temperature for AEA model (°C)
200.00	0.000	37.253	36.659	36.868	37.299
400.00	0.050	37.253	36.659	36.868	37.298
600.00	0.100	37.253	36.659	36.868	37.298
800.00	0.150	37.253	36.659	36.868	37.297
1000.00	0.200	37.253	36.659	36.868	37.296
1200.00	0.250	37.253	36.659	36.868	37.295
1400.00	0.300	37.252	36.659	36.868	37.294
1600.00	0.350	37.252	36.659	36.868	37.293
1800.00	0.400	37.252	36.659	36.868	37.292
2000.00	0.450	37.252	36.659	36.868	37.291

According to the results in the tables above, the wax deposition temperature varied with cumulative pipe length in the first table but remained constant for the different wax models. However, as can be shown in table 4.2, the critical wax deposition temperature differed depending on the wax model utilized. Also from the

results obtained in table 4.2, it can be observed that the AEA wax model gave the best result as it gave varying values for the varying cumulative pipe length.

Table4.3: Results obtained from using galvanized iron as the pipe material.

Cumulative pipe length (m)	Calculated wax deposition thickness (mm)	Deposition volume (m ³)	Deposition temperature (°C)	Critical deposition temperature (°C)
200.00	0.000	0.000	48.913	36.868
400.00	0.050	0.013	48.963	36.868
600.00	0.100	0.027	49.013	36.868
800.00	0.150	0.040	49.062	36.868
1000.00	0.200	0.054	49.112	36.868
1200.00	0.250	0.067	49.162	36.868
1400.00	0.300	0.081	49.211	36.868
1600.00	0.350	0.094	49.261	36.868
1800.00	0.400	0.108	49.311	36.868
2000.00	0.450	0.121	49.361	36.868

Table4.4: Results obtained from using cast iron as the pipe material.

Cumulative pipe length (m)	Calculated wax deposition thickness (mm)	Deposition volume (m ³)	Deposition temperature (°C)	Critical deposition temperature (°C)
200.00	0.000	0.000	48.915	37.299
400.00	0.050	0.013	48.968	37.298
600.00	0.100	0.027	49.020	37.297
800.00	0.150	0.040	49.073	37.296
1000.00	0.200	0.054	49.125	37.295
1200.00	0.250	0.067	49.178	37.294
1400.00	0.300	0.081	49.230	37.293
1600.00	0.350	0.094	49.283	37.292
1800.00	0.400	0.108	49.336	37.291
2000.00	0.450	0.121	49.389	37.290

Table4.5: Results obtained from using asphalted iron as the pipe material

Cumulative pipe length (m)	Calculated wax deposition thickness (mm)	Conoco wax model deposition temperature (°C)	Deposition volume (m ³)	Critical deposition temperature (°C)
200.00	0.000	48.913	0.000	36.868
400.00	0.050	48.962	0.013	36.868
600.00	0.100	49.010	0.027	36.868
800.00	0.150	49.059	0.040	36.868
1000.00	0.200	49.108	0.054	36.868
1200.00	0.250	49.155	0.067	36.868
1400.00	0.300	49.202	0.081	36.868
1600.00	0.350	49.248	0.094	36.868
1800.00	0.400	49.294	0.108	36.868
2000.00	0.450	49.341	0.121	36.868

The results obtained from employing different pipe materials in the tables above show that there were slight differences in deposition temperature for the various pipe materials employed, ranging from mild steel to asphalted iron. The wax deposition temperature increased with cumulative pipe length, and mild steel is the best material to utilize in pipeline design among the four pipe materials since wax began to deposit on the pipe wall at the lowest temperature when compared to the others.

Table 4.6: Result obtained at varying temperature and pressure at 3500 psig

Temperature (°F)	Pressure (psig)	Number of phases	Solid phase (percent)	Solid weight (percent)	Gas phase (percent)	Liquid phase (percent)
0	3500	2	11.417	15.523	-6.460	95.042
22.5	3500	2	7.983	12.135	-7.948	99.965
45	3500	2	7.731	11.835	-7.120	99.389
67.5	3500	2	6.063	9.810	-5.036	98.973
90	3500	2	4.058	7.054	0	100
112.5	3500	2	1.710	3.250	0	100
135	3500	1	0	0	0	100
157.5	3500	1	0	0	0	100
180	3500	1	0	0	0	100

From the table above, it can be observed that from 135⁰F, the solid weight became zero because heating (liquefaction) makes the complex hydrocarbons to decompose; hence increasing the density and reducing the forces of attraction between each model.

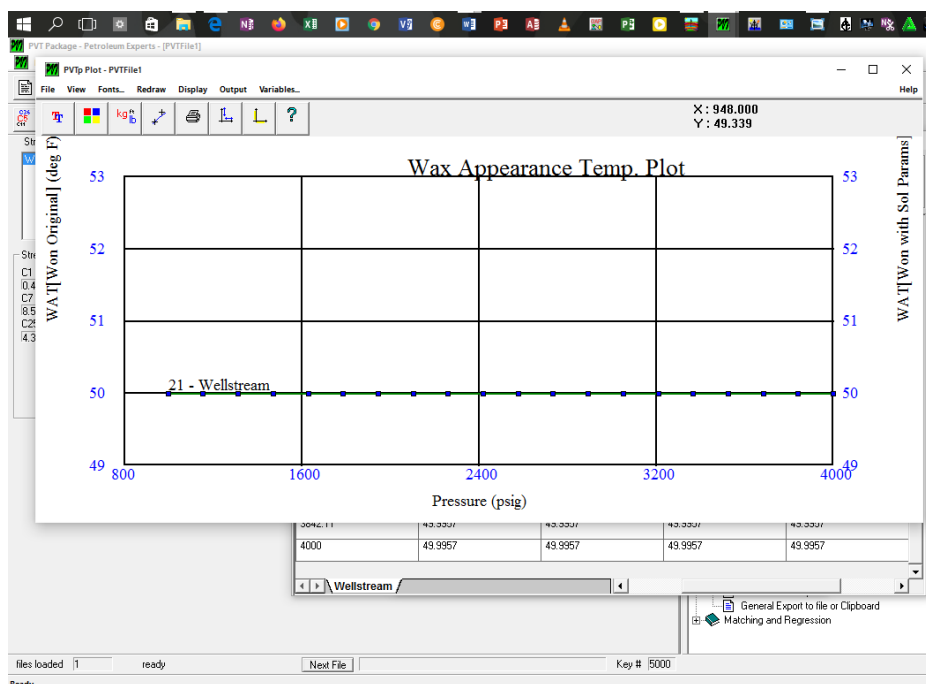


Figure 4.5: Wax appearance temperature plot

This plot shows that pressure has an insignificant effect on wax deposition

V. CONCLUSIONS

When it comes to ensuring the smooth flow of hydrocarbons via a pipeline, a good wax appearance prediction approach is critical.

The capacity to foresee the appearance of wax during fluid flow will assist in pushing fluid transport to the positive side while reducing costs.

The following conclusions were reached after a thorough investigation and modeling of wax deposition as a flow assurance concern:

- An effective flow assurance management hinges on a good prediction of wax deposition and its appearance temperature. The primary cause of wax precipitation and deposition in crude oil pipeline is a significant drop in temperature which in turn leads to the cooling of the crude oil due to gas expansion, evaporation and vaporization of light ends. When present, this light ends serves to keep the wax particles in solution.
- While wax deposition is a function of time, it does not start to develop at the cooled pipeline's immediate entrance.
- Critical deposition temperature remained slightly constant as the cumulative pipe length increased.
- Deposit thickness increased with an increase in pipe cumulative length. It is also worthy of noting that deposition volume increased as the length of pipe was increasing.
- The mass of the wax increases with decrease in temperature and an increase in temperature causes the pseudo components to thin out and converts it to liquid phase and increases the molar weight until it gets to the WDT.

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