Sudan University of Science and Technology

College of Petroleum Engineering and Technology

Department of Petroleum Engineering

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Final graduation project

Mitigation of Wax Crude Oil problems in Wellbore

Case Study: AL-RAWAT Oil Field (R-C10 well)

تخفيف مشاكل الخام الشمعي في البئر

تطبيق حقلي: الراواات - البئر (R-C10)

Project submitted to College of Petroleum Engineering and Technology in partial fulfillment of the requirements for the degree of B.Sc in Petroleum Engineering

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October 2018

Research about:

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Date: / / 2018

الإستهلال

يقول الله تعالى :

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Dedication

This study is dedicated to all our Fathers, Mothers, Brothers, Sisters, Friends, Teachers and Every person that support us during our long journey in our education life.
May Allah (Subhanhu Wa Ta’ala) bless you and give you what you want .

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ABSTRACT

Wax deposition in wellbore tubing at shut-in status is one of the major problems in ALRAWAT oil field. The main purpose of this research is to find suitable solution for wax deposition in tubing as one of the major problems in ALRAWAT oil field .One of the main objectives of this study is to optimize wellbore production by select feasible technique based on heating solutions. Production optimization techniques (software) applied to determine optimum location of electrical heater in tubing of (R-C10 well) Al RAWAT. The optimum depth was found to be 5100 ft .The experimental results of this study show that the main reason for wax deposition in tubing at well shut-in status was the wax apparent temperature which was found at high degree of (68^{o}C). Analyzing procedure is applied to get feasible technique to solve the problem of wax in (R-C10) depend on the advantages and disadvantages of these techniques , the study provide a role of this procedure as table.

Keywords: Wax Precipitation, Wax Deposition, Wax Appearance Temperature.

التجــريد

مشكلة الترسبات الشمعية في أنابيب الإنتاج عند إغلاق البئر تعتبر من المشاكل الأساسية في حقل الراوات. الهدف الأساسي من هذا البحث إيجاد الحلول المناسبة لمشكلة الترسبات الشمعية في أنابيب الإنتاج داخل البئر من احدي المشاكل الأساسية في حقل الراوات.

أحد الأهداف الأساسية للبحث إختيار أنسب تقنية من انواع الطرق الحرارية وتحديد أنسب عمق لوضع السخان الكهربائي (Downhole Electrical Heater) في أنبوب الانتاج في البئر (R-C10) ، وجد أن أنسب عمق لوضع السخان الكهربائي عند 5100 قدم .

أجريت مجموعة من التجارب المعملية وجد من خلال نتائجها أن الدرجة التي يبدأ عندها ظهور الشمع (WAT) عالية تصل إلى (68 C) وهذا يعتبر السبب الأساسي لترسب الشمع في أنبوب الإنتاج عند إغلاق البئر.

تم اجراء تحليلات إعتمادا علي التقنيات المطبقة للحصول على جدول يبين انسب الطرق لحل مشكلة الشمع في البئر (R-C10) بناء على محاسن ومساوئ هذه التقنيات.

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NOMENCLATURE

WAT	Wax Appearance Temperature.
SARA	Saturates Aromatics Resins Asphaltenes.
R-C10	ALRAWAT CENTERAL TEN.
GOR	GAS OIL RATIO.
WOR	WATER OIL RATIO.

Chapter 1

Introduction

Wax deposition is one of the mainly problems in oil Industry, highly paraffinic (or waxy) crude oil can cause significant problems in the tubing and pipelines due to wax-oil gel blockage resulting from the precipitation of the wax components. Once blockage of the tube or pipeline occurs and flow ceases, flow cannot be restarted with the original steady state operating pressure but instead requires significantly higher pressures to restart the flow. Due to this, it is important to maintain the oil at a temperature above its natural pour point.

1.1. Wax Composition:

The wax present in petroleum crudes primarily consists of paraffin hydrocarbons (C18 – C36) known as **paraffin wax** and naphthenic hydrocarbons (C30 – C60). These molecules can be either straight or branched hydrocarbon chains, and can contain some cyclic and/or aromatic hydrocarbons. Hydrocarbon components of wax can exist in various phases either gas, liquid or solid depending on their temperature and pressure. When the wax freezes, it forms crystals. The crystals formed of paraffin wax are known as macrocrystalline wax (figure 1) (Mansoori, 2009). Those formed from naphthenes are known as microcrystalline wax (figure 2). A collection of normal paraffin's, with 16 or more carbon atoms ($\geq$C16) that form crystalline solid substances at cloud point, are known as wax. The severity of the wax deposition problems depends on type of oil and the molecular composition of the wax molecules. The waxes in crude oils are often more difficult to control when compared to condensate, because the alkane chains are often longer in the crude oil than in the condensate, which consists of lighter hence shorter hydrocarbons,(Surya at el, 2016).

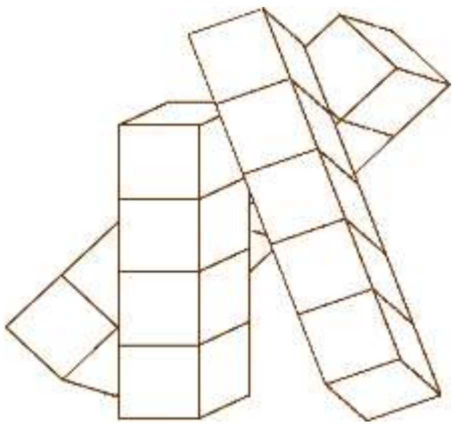

Figure 1.1: Macocrystalline (Mansoori, 2009).

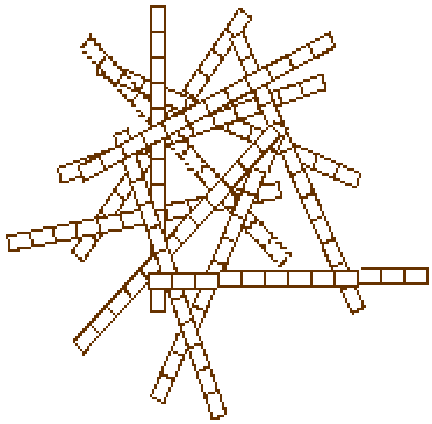

Figure1.2: Microcrystalline (Mansoori, 2009).

1.2 Waxy Crude Oil:

Wax is a component of crude oil that remains in solution until operating conditions are favorable to its precipitation, a condition caused by changes in the temperature–pressure equilibrium of the crude oil. Upon precipitation (crystallization), wax is deposited on the components of the production system by various mechanisms including molecular diffusion, shear dispersion, Brownian diffusion, and gravity settling. Brownian diffusion and gravity settling are not very significant in the dynamic condition obtainable in crude oil production. Wax deposition has been reported in all facets of the production system including the reservoir, wellbore, tubing, flow lines, and surface facilities. Wax deposition causes loss of production, reduced pipe diameter, and increased horsepower requirements, and negatively impacts production economics. The available remedial measures include mechanical, chemical, and thermal techniques. Temperature reduction/heat loss is a dominant factor in wax problems, as wax begins to precipitate from crude when the temperature falls to or below the cloud point (wax appearance temperature [WAT]. However, other factors such as pressure, oil composition, gas-oil ratio, water-oil ratio, flow rate, well completion, and pipe-surface roughness also contribute to the problem of wax deposition. Laboratory experimental work using stock tank oil (STO) under static condition predominated wax deposition research in the past. Recent investigations have centered on the use of live oil at raeservoir temperature and pressure, which is more representative of the reservoir oil in experimental work under dynamic conditions. Thermodynamic modeling of wax deposition and validation with experimental data is gaining wide acceptance. The onset of wax deposition (true cloud point) is yet to be achieved because all the available techniques require some crystals to be formed for detection, thus giving a value that is less than the true cloud point. The improvement of existing techniques or the development of new ones, to detect the onset of wax crystallization is a major challenge to research in this area (Tao Zhu at e, 2008).

1.3 Wax Forming Compounds:

•Waxes consist of branched (ISO), cyclic and straight chain (normal) alkenes having chain lengths in excess of 17 carbon atoms and potentially up to and over C100

•Distribution of waxes depends on the individual crude oil, but generally above C20, the amount of any single carbon number paraffin decreases exponentially

•Normal paraffin's are generally the more abundant species

•ISO and cyclic paraffin's may also be present in significant quantities.

1.4 Process of Paraffin Precipitation:

•Paraffin's remain soluble in oil under reservoir conditions.

•As hydrocarbon fluids are produced from the reservoir, they will inevitably cool and undergo changes in pressure.

•As a consequence of any changes, high molecular weight components of the oil have the potential to precipitate as solids (including paraffin's).

•Paraffin's can crystallize and potentially cause a host of operational problems anywhere throughout the production and export system.

•Waxes can solidify in the bulk oil as discrete particles or crystals and condense onto cooled surfaces such as pipe walls and tubular, Shekhar Khandkar (Schlumberger 2001).

1.5 Concern for Wax Deposition:

The problem of wax deposition has plagued the petroleum industry for decades, arousing two main concerns—technical and economic—upon its occurrence. Wax deposition can be mild, or it can be severe enough that it is unmanageable. The earlier the problem is diagnosed 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 problems associated with wax deposition. Technical issues associated with wax deposition include:

- Permeability reduction and formation damage when it occurs around the wellbore and its vicinity.
- Changes in the reservoir fluid composition and fluid rheology due to phase separation as wax solid precipitates.
- Additional strain on pumping equipment owing to increased pressure drop along flow channel consequent to rheological changes as wax begins to crystallize.
- Limiting influence on the operating capacity of the entire production.
- Reduction in the interior diameter and eventual plugging of production strings and flow channels. Venkatensan et al. (2007).

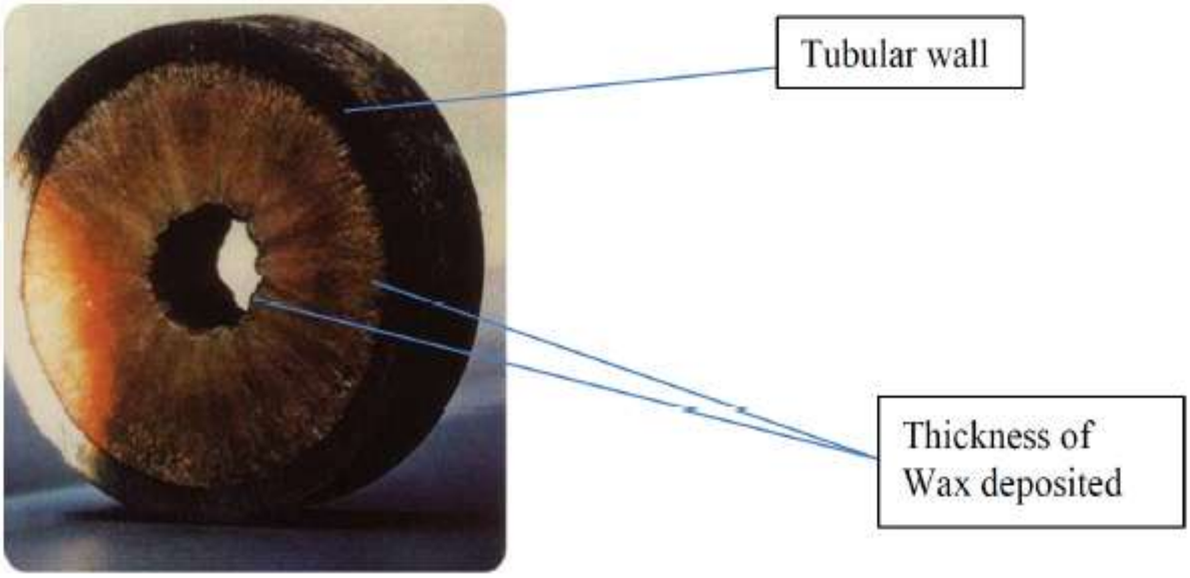

Figure 1.3: Wax deposit reducing the effective diameter in tube (Elizabith at el,2016).

The critical role of economics in crude oil production makes wax deposition a significant economic concern to the industry due to the following:

- Capital investment and operating costs are increased when developing paraffinic crude oil fields. This could cause serious financial strain on the operator of such a field or even lead to abandonment when it becomes uneconomical due to blockage of facilities by wax deposits.
- Lost production.
- Risk element in development, a problem that could jeopardize the development of marginal fields given the prevailing economic situation. The additional cost of controlling and managing wax puts a greater risk of abandonment on such fields.

1.6. Background about ALRAWAT oil field:

ALRAWAT oil field located in Block 25D, 450 Km South West of Khartoum. Its include Rawat Central and Wateesh.

The Oil Reservoirs is Galhak Sandstone Formation, the tested oil wells on Seven (7) wells, exist the medium Crude Oil with API (27°- 32°).

Most critical issues of this crude related to flow assurance, where Wax Content > 33%, Pour Point >48°C and wax appearance temperature (WAT)> 60°C. Eng. Aisha Mohammed Musa (2018) RPOC.

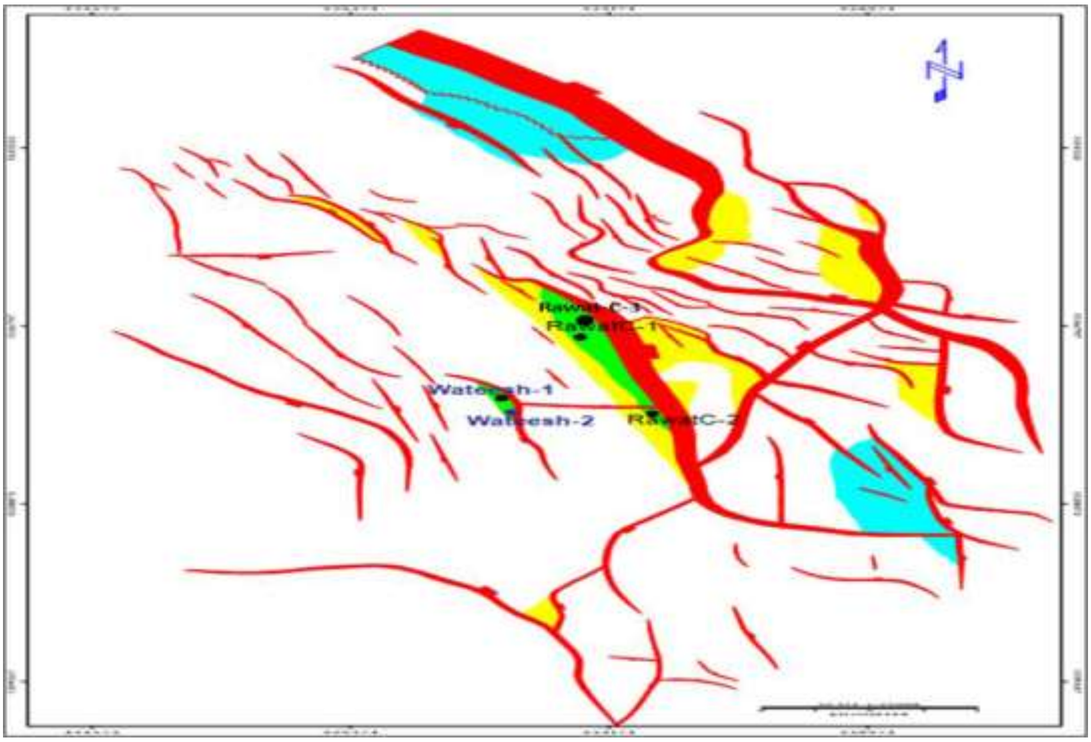

Figure1. 6: Regional Structure Map of AL-RAWAT Oil Field.

1.4. The objectives of research:

- The main objective is to study different technologies would suitable to solve ALRAWAT wax crude oil problem.

- Sub-objectives:

1. Analyze rheological properties for feasible method to solve the wax problem

2. Determine wax rheological properties experimentally (Pour point°(C), Dynamic Viscosity to select the optimum technical method .
3. Answer optimal location of the electrical downhole heater by using PIPESIM software.

Chapter 2

Literature review and theoretical background

2.1. Literature review

There are different methods for removal and prevention of wax formation such as mechanical methods like scraping and pigging, thermal methods like hot-oiling, chemical inhibition methods and also more sophisticated methods such as ultra-sonic removal, electro-magnetic treatment and microbial inhibition.

Nelson O.Rocha and Carlos Khalil at el. (2003) study wax damage removal by the injection of an emulsion formed by an aqueous solution containing nitrogenated salts, an organic non-polar solvent and a viscoelastic polymer. When the mixture is placed in the annulus, a strongly exothermic chemical reaction occurs, generating a high quality stable foam. The penetration radius of the foam into the porous media is enough to assure sufficient wax removal.

Atle Lenes | Jens Kristian Lervik at el(2015) The direct electrical heating system (DEHS) has been developed and qualified for heating of flowlines and is the only system for heating that has been installed on subsea flowlines in the North Sea. Especially for deep-water fields electrical heating of pipelines is attractive for achieving reliable operation of transport flowlines.

Norhadhirah Halim and Sapih Ali at el. (2011) discuss using wax inhibitor to reduce the pour point by **CRODDA-A** from the hydrophobically modified polybetaines (zwitterionic) family for treating waxy crude A located in Peninsular Malaysia. The synthesized wax inhibitor had been evaluated as flow improver, crystal modifier and pour point depressant.

R.Hallot at el (2018) The purpose of this paper is to present an overview of the local heating technology under qualification by Saipem. The heat is provided using induction. This solution is thus able to provide a very high power density leading to a very compact solution. The internal diameter of the line in the heating station remains unchanged from the main production line, which makes the solution fully compatible with preservation by flushing and allows to pig the system in case of deposits. The temperature is monitored throughout the heating module by means of a network of optical fibers.

Jens Kristian (2017) A develop program founded by the Norwegian Research Council for further increase the competitiveness of the direct electrical heating (DEH) technology was initiated in 2016 and will finish at the end of 2018. The partners in this project have long experience in development, manufacturing, installation of DEH systems and expertise inside all research areas inside DEH.

Elizabeth I.Obode and Juwon Ifalade (2016) study prevent wax production by utilization Nano fluid the methodology involves sending a mixture of nano (10-9) sized metallic particles through the oil column to keep the oil in thermal equilibrium with itself.

Peter L. Perez, A.Kate Gurnon at el.(2016) In this paper, they explore the correlations between the effectiveness of several wax inhibitors and physico-chemical properties of crude oils.

Brian Francis Towler (U. of Wyoming),Ashok Chejara (U. of Wyoming) at el.(2007) in this paper present invention is a method for mitigating the wax deposition during crude oil flow in a well-bore or pipeline. The method comprises positioning one ultrasonic frequency generating device adjacent to the production tubing walls and producing one ultrasonic frequency thereby disintegrating the wax and inhibiting the wax from attaching to the production tubing walls. Experiments were done to measure the effect of ultrasonic waves at a frequency of 120 kHz on wax deposition during crude oil flow in a pipeline. In this paper, all the experimental results are described. Some reduction in wax deposition was also achieved due to the ultrasonic waves. Further work is required to identify the optimum frequencies.

S.J. Paitakhti Oskouei and R.Roostaazed (2005) study Mesophilic bacterial specie to decrease PH from 7 to 5.5, the initial surface tension of 65 toas low as 55 dyne/cm and wax asphaltene content as much as 27% and 10% respectively . These effects are expected to have a positive effect on the cloud and pour points, deposition tendency of the crude and/or emulsification of deposited wax in a sweeping medium such as injected water.

Muhammad Ali Theyab Pedro Diaz (2016) the objective of this study is using spiral flow to mitigate wax deposition. An experimental flow loop system was built in the lab to study the variation of wax deposition thickness under the single phase transport. A series of experiments were carried out at different flow rates (2.7 and 4.8 L/min) to study wax deposition process and measure the wax thickness. The effects of factors on wax formation, such as spiral flow, inlet coolant temperature, temperature drop, flow rates and experimental time have been examined.

2.2 Factors Affecting Wax deposition:

2.2.1. Crude Oil Composition:

Crude oil is composed of saturates, aromatics, resins, and asphaltenes (SARA), Therefore, knowledge of the oil composition (SARA) gives a fair idea of the wax deposit potential of the crude and, hence, the oil stability. Oil stability has been reported to depend on its solids content and the balance between aromatics and saturates. By SARA analysis, the distribution by weight percent of saturates, aromatics, resins, and asphaltene components, for stable and unstable crude oils, is as follows:

Unstable crude: Saturates > Aromatics > Resins > Asphaltenes.

Stable crude: Aromatics > Saturates > Resins > Asphaltenes.

2.2.2. Pressure:

Pressure, as an important parameter in the exploitation of reservoir fluids, plays a significant role in wax precipitation and deposition. The pressure profile during oil production is such that the reservoir pressure declines with production, and the pressure of the flow stream drops all the way from the reservoir to the surface. The lighter components of the reservoir fluid tend to be the first to leave the reservoir as pressure depletes. This causes an increase in the solute solvent ratio, since the light ends serve as solvent to the wax components. Hence, the solubility of wax is reduced with the loss of these light ends.

Brown et al.(1994) studied the effect of pressure on the cloud point of dead oil as well as live oil by measuring cloud point at atmospheric pressure and higher pressures. The wax appearance temperature increases with increase in pressure above the bubble point, at constant composition. This phenomenon implies that increase in pressure in the one-phase liquid region (above bubblepoint pressure) will favor wax deposition. The situation is different below the bubblepoint where there is two-phase existence. Here wax appearance

2.2.3. Temperature:

Temperature seems to be the predominant and most critical factor in wax precipitation and deposition due to its direct relationship with the solubility of paraffin. Sadeghazad et al. (1998) reported that temperature and the amount of light constituent are the two most important factors affecting wax precipitation and deposition. Paraffin solubility increases with increasing temperature and decreases with decreasing temperature.

2.2.4. Water-oil ratio:

•The primary effect of water-oil ratio is related to changes in the rate of fluid production with changes in water cut.

•Increased fluid production rates involve higher wellhead temperature and less wax deposition; whereas, decreased fluid production would have the opposite effect.

•Water tends to increase the water wettability of metal surfaces, thereby reducing the likelihood of wax and crude contact with the metal surface.

•Water being a conductor of heat will reduce the deposition

2.2.5. Other Contributing Factors:

Though temperature, composition, and pressure of oil play the most significant role in wax deposition, other factors that have been identified as contributing to wax deposition include flow rate, gas-oil ratio, and pipe/tubing wall roughness. Laboratory investigations have revealed that wax deposition is influenced more by laminar flow than when flow is in the turbulent regime. Increasing flow rate from laminar to turbulent reduces maximum deposition rate and at the same time lowers the temperature at which maximum deposition rate occurs. Low flow rates offer the moving oil stream longer residence time in the flow channel. This increased residence time allows more heat loss to the surroundings, leading to a higher chance of the bulk oil temperature falling below the WAT and enough time for wax precipitation and final deposition. Jessen and Howell (1958) believed that when flow is in the laminar regime, wax deposition increases with increase in flow rate. Increase in flow rate in the laminar regime makes more fluid available for wax deposition. However, wax deposition decreases as flow moves to the turbulent regime. Turbulent flow stream exerts a kind of viscous force, which tends to drag or slough the wax deposits from the pipe wall. When this viscous drag exceeds the resistance to shear in the deposits, the wax then sloughs and is lodged back into the liquid.

Gas/oil ratio influences wax deposition in a manner that depends on the pressure regime. Above the bubble point, where all gases remain in solution, solution gas helps to keep wax in solution.

Pressure of the oil system depletes a situation that can aggravate the wax deposition problem. In a study to reduce wax-appearance temperature by injection of diluents lift gas, Singh et al. (2004) noted that good results were not obtained in high GOR wells.

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Chapter 3

Methodology

3.1. Lab Experiments:

3.1.1. Sample Preparation:

Rheologically, crude oil can be described as a low viscosity Newtonian fluid at high temperature, but it exhibits non-Newtonian behavior due to the crystallization of wax as the crude oil cools to low temperatures. The oil samples used in this research work were supplied from AL-RAWAT oil field –well name central (10). The oil samples have been kept at different ambient temperatures. Crude oil composition as well as wax precipitation is sensitive to changes in temperature and pressure. Laboratory testing with crude oil requires some preliminary preparation of the oil sample to ensure that a representative sample is used. This preparation produces a homogeneous oil sample used for testing. Different tests may require different techniques depending on the expected result, test standard procedure, and sensitivity of equipment. Generally, most crude oil tests would require that the oil be heated to a high temperature and rocked/stirred during the heating period to produce a homogenous fluid. The method of preparation for all the tests carried out in this work is similar. The wax appearance temperature (WAT) test requires that all paraffin's remain in solution prior to commencement of testing. Using the water bath involved a simple procedure outlined as follows:

• Power-on the heating bath and set to a temperature of about 60°C (140°F) to 80°C (176°F).

• Immerse the sample container in the heating bath for several hours (about 10 to 20 hours), depending on the gravity of the oil sample. The crude oils with low density are heated to 60°C, thus for less time than crudes having high density. This minimizes the loss of light ends from the crude oil sample.

• Occasionally agitate the oil sample manually with a stirrer during the heating process.

• Remove the sample container from the heating bath at the end of the heating period and stir.

• Draw sample for test.

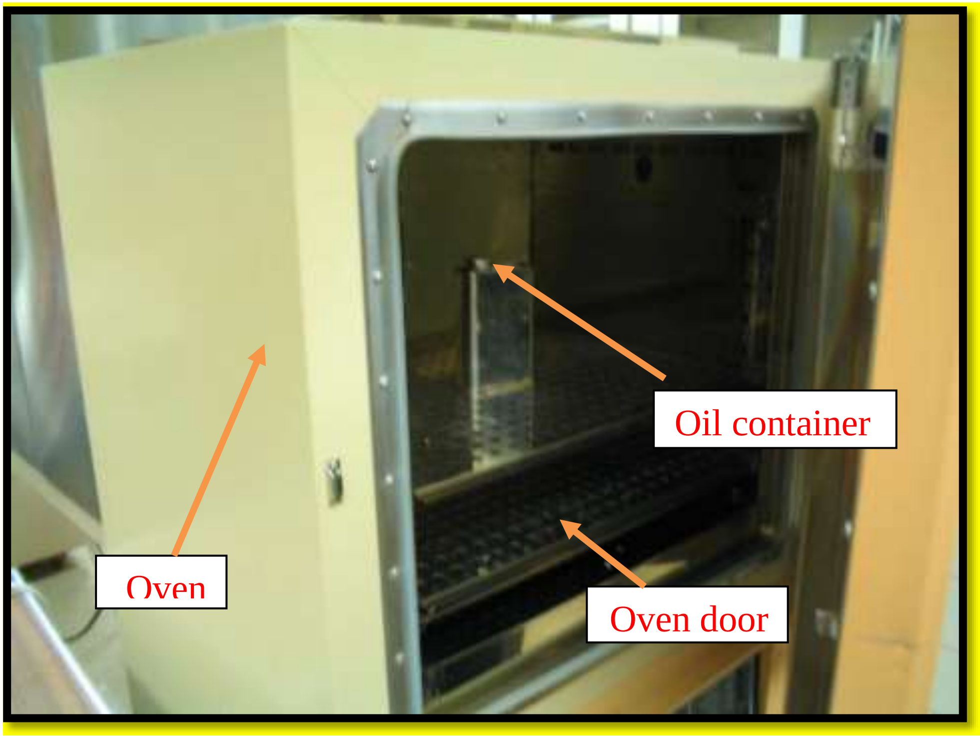


Figure 3.1: Oil sample in the oven ready for heating (Tao Zhu, 2008).

3.1.2. Measurement of Viscosity:

The experimental setup is the Brookfield Viscometer model LVDV-II+, The model consists basically of a small sample adapter which holds the sample, a spindle which is immersed in the sample in the holder. The spindle rotates by the action of a synchronous motor through a calibrated spring. Also part of the setup are a heating/refrigerating circulating bath for temperature control through the jacket of the sample adapter, and the interfacing computers which contain the software for gathering the viscosity data (WinGather) and controlling the temperature (EasyTemp)(Labes-

Carrier et .,al 2002). The viscometer measures the torque required to rotate the immersed spindle. The spindle size and rotational speed are combined in such a manner as to produce a torque that lies between 10% and 100%. The accuracy improves as the torque approaches 100%. A slower speed and/or a smaller spindle is used for high viscous oils, while a higher speed and/or a larger spindle is used for light oils with low viscosities. The viscosity values are digitally displayed in centipoises.

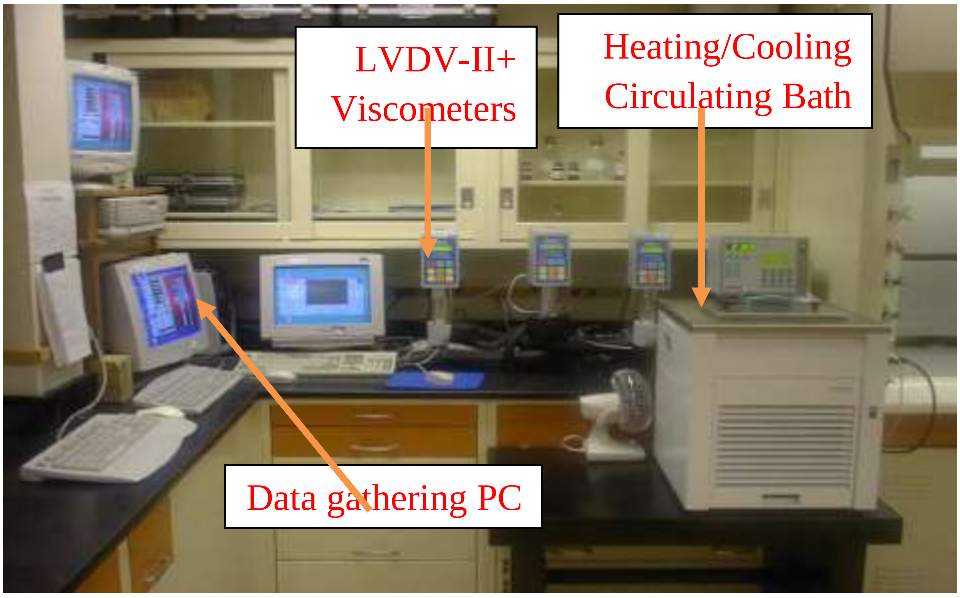


Figure 3.2: Viscosity measurement apparatus (Tao Zhu, 2008).

3.1.3. Viscosity Measurement Procedure:

A satisfactory and accurate viscosity measurement requires the following standard procedure:

- The interfacing computers for LVDV-II+ data collection and for temperature control of the heating/refrigerating circulating bath are turned on.
- The Brookfield LVDV-II+ Viscometer is powered on, and it auto zeros itself through a set of displayed instructions.

- The Julabo heating/refrigerating circulating bath is turned on and set at the desired temperature using the EasyTemp software program in the interfacing computer.
- The WinGather software is opened, and communication between the viscometer and the interfacing computer is ensured.
- The sample Adapter is removed from the jacket, a small sample (about 8 mL), enough to cover the spindle up.
- The viscometer motor is started by pressing the "Motor On/Off" button, and the speed (rpm) is selected, depending on the expected viscosity range, by using the "Set Speed" button. The rpm is chosen in such a manner that a good torque (>10%) is achieved, and the whole profile traversed before a torque of 100% is reached. This is because the torque increases as temperature decreases during ramping.
- The ramping profile is set up using the EasyTemp software by clicking on "Edit Profile" and then "Use Profile" to enable the computer to implement the given profile.

The "Start Profile" button is selected to start the ramping profile.

The "Start Gather" button, indicated by an icon showing a viscometer connected to a computer, is selected on the WinGather program, the "Time Stop" is selected, and appropriate values are input in the "Number of Readings" and "Time Interval" windows.

- Click on "Ok" to commence data gathering when the profile is started.
- The run is complete when the profile is exhausted or the torque displayed on the viscometer has reached 100%, the maximum potential.

The data is saved by selecting “Lotus file*wks,” which allows the data to be easily stored in Microsoft Excel.

- The saved data is analyzed by computing the natural log of viscosity and the inverse of absolute temperature. A plot of the natural log of viscosity (LN Viscosity) versus inverse of absolute temperature (1/K) gives the WAT at the point of deviation from a linear trend.
- The sample adapter and spindle are cleaned up with toluene and acetone following correct procedures, and the process is repeated for another run.

3.1.4 Measurement of Pour Point:

Pour point is defined as the temperature at which the crude oil sample will no longer flow when held at a horizontal position in a test jar for about 5 seconds, due to formation of a wax gel network. Pour point is an indicator of the gelling potential of the crude sample. Its measurement is believed to be affected by factors such as wax content (Albondwarej et al,2006) , wax crystal size and number, pressure, and solution gas, as well as the thermal history of the crude oil. Fast cooling rates tend to raise the pour point, while slow cooling rates yield lower pour point values.

The pour point equipment used in this work is basically a 3-bath bench model 334 from Lawler Manufacturing Corporation (Figure 3.3). The equipment has been designed for performing manual cloud point and pour point tests in conformance with ASTM D2500 and ASTM D97 standard test methods.

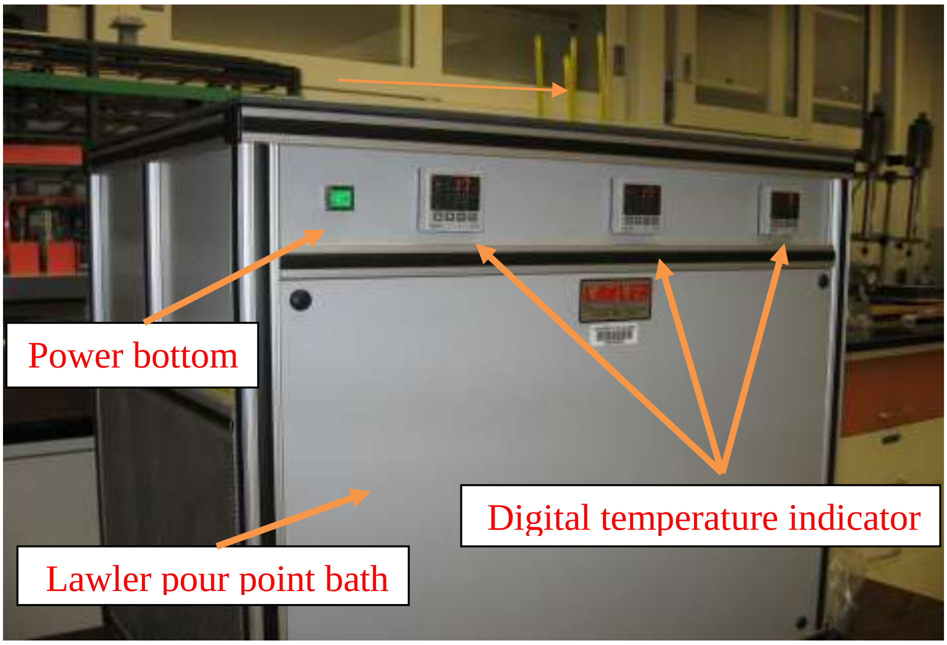


Figure 3.3: Pour point measurement apparatus (Tao Zhu, 2008).

3.2. Pour Point Measurement Procedure:

The three baths are utilized during the test as the test jar is moved around, starting from the highest preset temperature bath. The test jar is placed first in the 0°C (32°F) bath, and the test thermometer in the test jar is monitored. If the oil still flows when the test thermometer reads 9°C (48.2°F), it is transferred to the -18°C (-0.4°F) bath.

- Prepare the oil sample following ASTM D97 test procedure guidelines. This requires that oil samples of unknown thermal history, or samples that have been heated to temperatures higher than 45°C (113°F), be kept at room temperature for about 24 hours before testing.
- Fill the glass test jar with the oil sample up to the marked fill line and cover the test jar with a cork stopper. Insert a 5C ASTM standard ring on the test jar.
- Power on the equipment by pushing the power button, and watch the bath preset temperatures displayed. Each bath then stabilizes at the

preset temperature. Bath temperatures should be allowed to stabilize before using the equipment.

- Place the test jar from Step 2 into the copper jacket immersed in the bath medium.
- Insert a 5C ASTM thermometer into the bath medium through the hole provided for it. This thermometer serves as a check to the bath temperature display on Lawler 334 pour point equipment.
- Start observing the sample for no flow at about 9°C (48.2°F) above the expected pour point of the oil sample. Remove the test jar, and tilt it to observe movement of the sample. If there is movement, return the test jar to the copper jacket. Do all these steps in no more than 3 seconds. Repeat the checking process after every 3°C drop in temperature until no movement is observed. Then hold the test jar in a horizontal position for 5 seconds and observe the flow.
- Record the observed reading of the test thermometer at the point when no flow is observed in the oil as the test jar is being held in a horizontal position for 5 seconds.
- Add 3°C to the recorded temperature, and report that temperature as the pour point of the oil sample by the ASTM D97 standard.

3.2. Electrical Downhole Heater:

Downhole stationary electric heater Is designed to warm up the bottom hole zone of the well and borehole fluid passing through the internal hydraulic channel of the heater for connecting to screwing on the bottom of the oil well tubing .it is possible to install on oil well tubing to other dimension size through an adapter .to attach filters and other protective devices, the bottom of the heater has an oil well tubing thread .other dimensions can be installed in by an adapter.

There are numerous reasons to consider electrical heating in downhole applications and various configurations of electrical heaters have been installed in the past

3.2.1. Infrastructure:

In order to implement a heater cable, the following infrastructures may be required in any typical project.

- Transformer:

A transformer is used to control the surface voltage in order to achieve the desired thermal effect. Typically, the maximum output of the heater cable is approximately 100 watts per foot of deployment.

- Control panel:

Allows the operator to easily and safely increase or decrease the desired power output. Power must be controlled so the formation temperature is kept below the boiling point of water. Otherwise, the water will vaporize and el electrical continuity will be lost.

- Electric cable:

Used to deliver the electric power to the heater cable.

4.Heater Cable:

Special type of cable which transform the electric current to heat energy. There is may types of cables used in downhole applications.

- Cable Guard:

In order to maintain efficient heat transfer, heater cable must be in intimate contact with the production tubing. Hence, to prevent cable "bowing" away from the production tubing, metal cable guards are employed as a physical binding. Cable guards also protect the heater cable from physical damage during installation.

- Cable Termination Block:

The principle of heater cable requires a three phase electrical short down hole. The principle purpose of the cable termination block is to provide this connection.

- Electrical Switch Gear:

Electrical switch gear is necessary to engage or disengage the system. In the simplest form, the switch gear only consists of a single three phase disconnect.

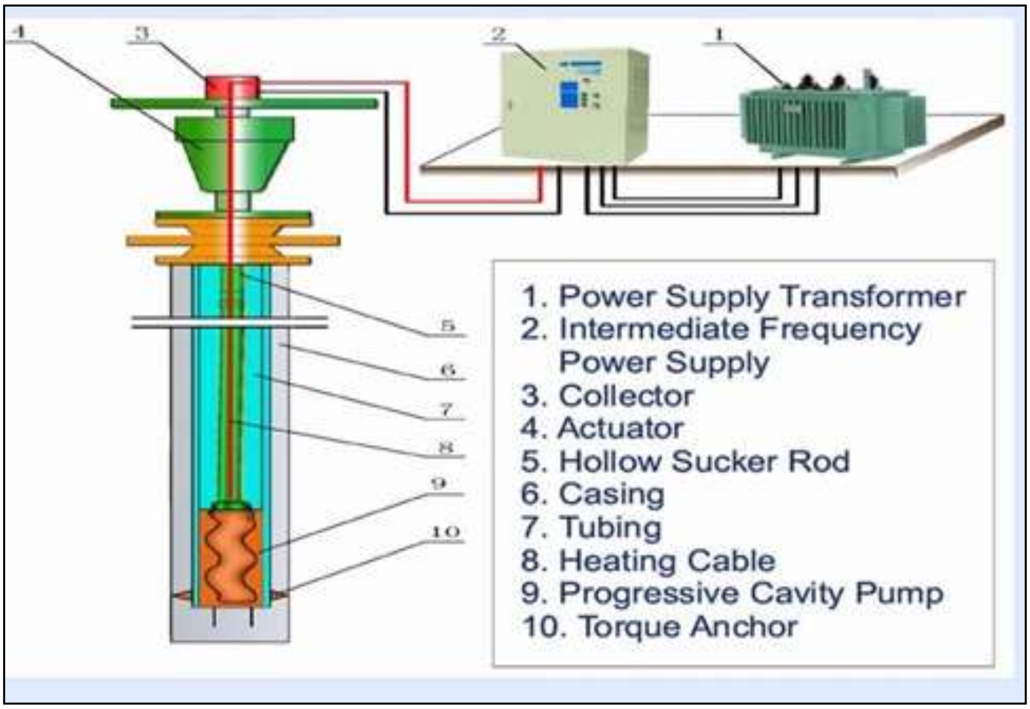


Figure 3.4: Downhole Electrical Heater with progressive Cavity Pump (www.Andmir.com).

3.3. PIPESIM:

PIPESIM is a steady-state; multiphase flow simulator used for the design and analysis of oil and gas production systems. With its rigorous simulation algorithms, PIPESIM helps you optimize your production and injection operations.

PIPESIM is most often used by reservoir, production or facilities engineers as an engineering user type to model well performance, conduct nodal (systems) analysis, design artificial lift systems, model pipeline networks and facilities, and analyze field development plans and optimize production. The PIPESIM graphical user interface (GUI) allows you to easily construct well and network models within a single environment (PIPESIM USER GUIDE, Schulumberger, 2015).

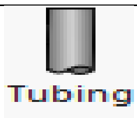
3.3.1. Applications:

1. Accurate flow modeling over the complete lifecycle of system.
2. Operating oil and gas gathering system while honoring multiple system constrains.
3. Determine the optimal locations for pumps and compressors.
4. Designing and operating water or gas injection network.
5. Calculation filed full deliverability to ensure contractual delivery rates are met.
6. Analyzing hundreds of variables such as pressure, temperature and flow assurance parameters through complex flow paths.

3.3.2. Model Building by PIPESIM:

3.3.2.1. Physical component of the model:

Table (3. 2) Physical Component Of The Model (PIPESIM USER GUIDE, Schulumberger).

Button	Function
	A well where fluids exists (production well) or enters (Injection well) the network.
	Placing the tubing object in the allow modeling of vertical or near vertical flow (production or injection) in the wellbore.
	A pipe to stabilize the wellbore.
	Pumping unit that uses a rotor and stator to pump reservoir fluids to the surface.
	An object that can be used to enter engine keywords directly.

3.3.2.2. **Collection of inserted Data**:

The first step in the design process is to gather information for the application of interest; fluid properties, reservoir parameters and production data from testing reports for example

Table (3.2) Example of Inserted Data in PIPESIM

Parameter	**Well data**
Casing (ID) (in)	7
Casing depth (ft)	5679
Tubing(ID) (in)	3.5
Tubing Depth (ft)	5220
Initial Reservoir Pressure (psi)	2134.7
Reservoir temperature (˚F)	194
Oil gravity (API)	24
Ambient temperature (□F)	95
Perforation Depth (ft)	5220
Pump Depth (ft)	5183
Pump speed (rpm)	250

Table (3.3): PVT DATA, (R-C10) Well:

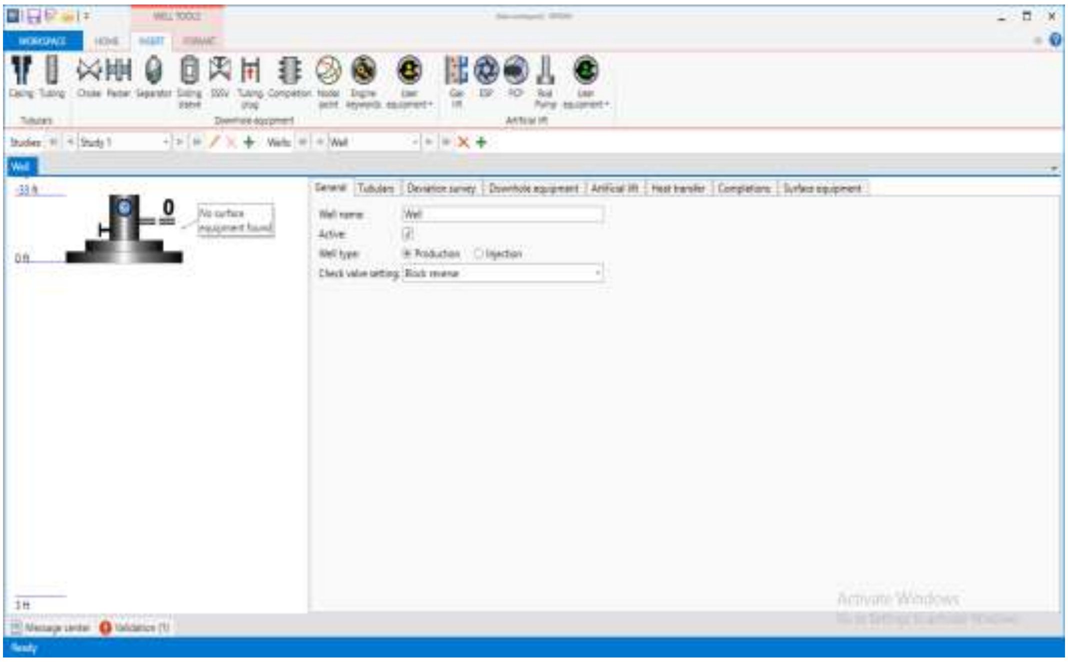
Compositional Analysis of Flashed Gas, Stock Tank Oil and Well Stream in Mole %					
No.	**Component**	**MW**	**Flashed Gas**	**Stock Tank Oil**	**Well Stream**
1	Hydrogen sulphide	34.080	0.000	0.000	0.000
2	Carbon dioxide	44.010	1.290	0.000	0.019
3	Nitrogen	28.013	0.760	0.000	0.011
4	Methane	16.043	36.051	0.000	0.532
5	Ethane	30.070	3.960	0.010	0.068
6	Propane	44.097	15.672	0.183	0.412
7	I-Butane	58.123	11.300	0.471	0.631
8	n-Butane	58.123	17.020	0.866	1.104
9	neo-Pentane	72.150	0.000	0.000	0.000
10	I-Pentane	72.150	10.371	1.106	1.243
11	n-Pentane	72.150	0.272	0.053	0.056
12	Hexanes	86.180	2.476	2.819	2.814
13	Me-Cyclo-Pentane	84.160	0.146	0.314	0.311
14	Benzene	78.110	0.095	0.050	0.051
15	Cyclo-Hexane	84.160	0.247	0.616	0.611
16	Heptanes	100.200	0.152	3.383	3.335
17	Me-Cyclo-Hexane	98.190	0.142	0.033	0.035
18	Toluene	92.140	0.000	1.355	1.335
19	Octanes	114.230	0.014	5.686	5.602
20	Ethyle-Benzene	106.170	0.000	1.781	1.755
21	Meta/Para-Xylene	106.170	0.001	0.392	0.386
22	Ortho-Xylene	106.170	0.001	1.188	1.170
23	Nonanes	128.260	0.000	8.862	8.731
24	Tri-Me-Benzene	120.190	0.011	1.728	1.703
25	Decanes	142.285	0.004	8.365	8.242
26	Undecanes	147.000	0.012	10.095	9.946
27	Dodecanes	161.000	0.001	7.486	7.376
28	Tridecanes	175.000	0.003	7.079	6.974
29	Tetradecanes	190.000	0.000	7.034	6.930
30	Pentadecanes	206.000	0.000	6.458	6.362
31	Hexadecanes	222.000	0.000	7.762	7.647
32	Heptadecanes	237.000	0.000	5.160	5.084

33	Octadecanes	251.000	0.000	3.391	3.341
34	Nondecanes	263.000	0.000	1.555	1.532
35	Eicosanes	275.000	0.000	1.274	1.255
36	Heneicosanes	291.000	0.000	0.835	0.823
37	Docosanes	305.000	0.000	0.720	0.710
38	Tricosanes	318.000	0.000	0.414	0.407
39	Tetracosanes	331.000	0.000	0.336	0.331
40	Pentcosanes	345.000	0.000	0.234	0.230
41	Hexacosanes	359.000	0.000	0.189	0.186
42	Heptacosanes	374.000	0.000	0.095	0.093
43	Octacosanes	388.000	0.000	0.246	0.242
44	Nonacosanes	402.000	0.000	0.132	0.130
45	Triacosanes	416.000	0.000	0.011	0.011
46	Hentriacosanes	430.000	0.000	0.004	0.004
47	Dotriacosanes	444.000	0.000	0.231	0.227
48	Tritriacosanes	458.000	0.000	0.000	0.000
49	Tetratriacosanes	472.000	0.000	0.000	0.000
50	Pentatriacosanes	486.000	0.000	0.000	0.000
51	Hexatriacosanes Plus	506.987	0.000	0.000	0.000
	Total=		100.0	100.0	100

3.3.2.3. Define the physical component of the model by the following steps:

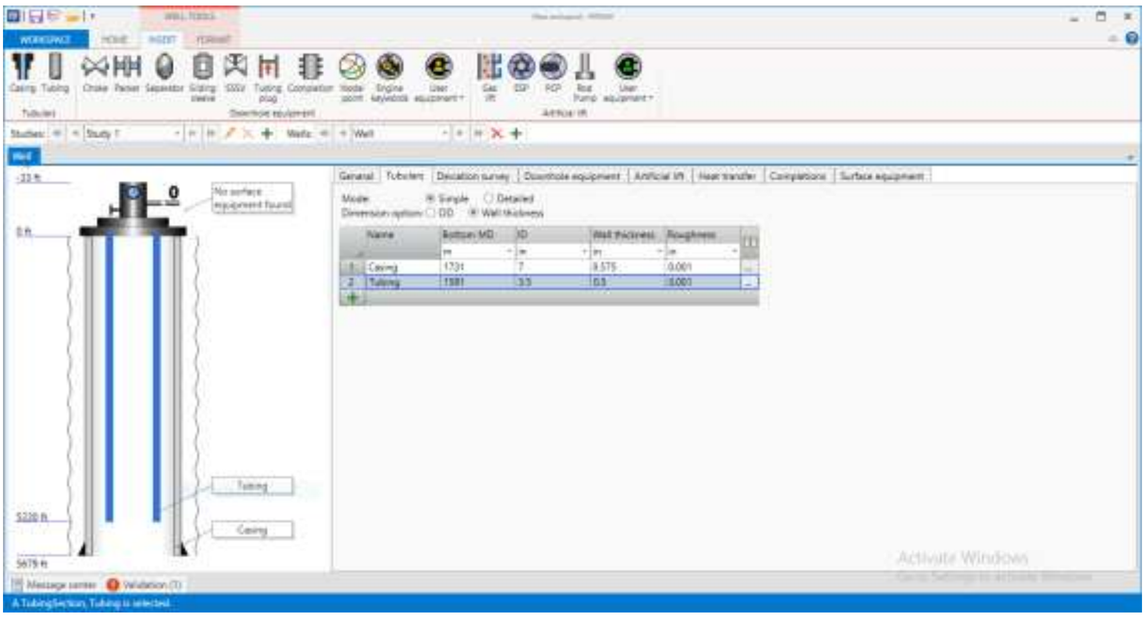
Step 1: **General data:**

From the workspace screen of PIPESIM select the option create new network and select well type (production or injection) and well name.



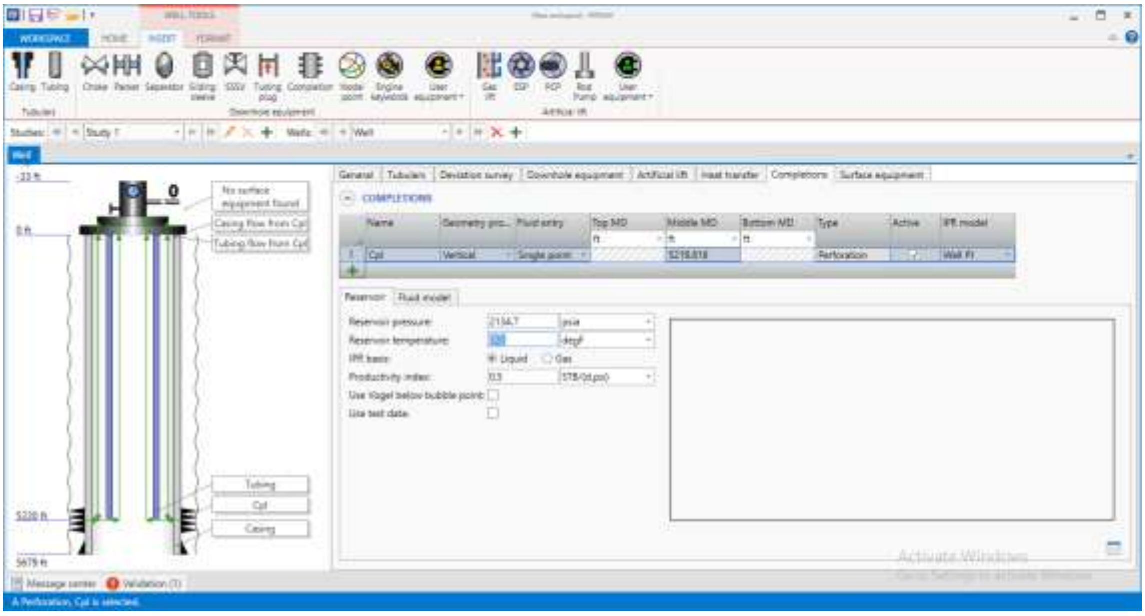
Step 2: **Tubular data**:

Choose the well description mode (simple or detailed), insert the measured depth and the inside diameter of casing and tubing.

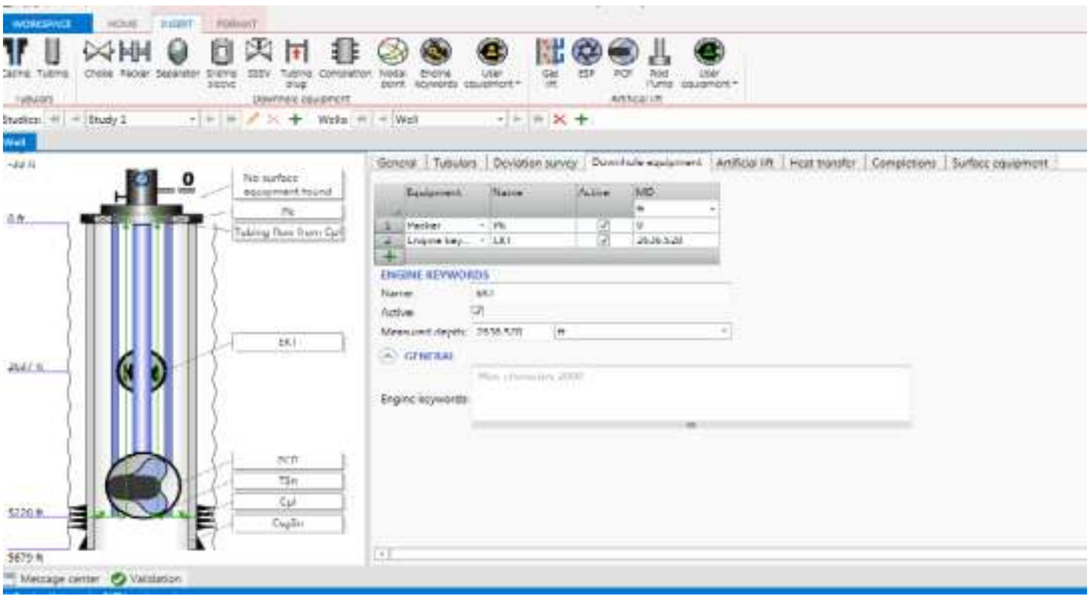


Step 3: **Completion data**:

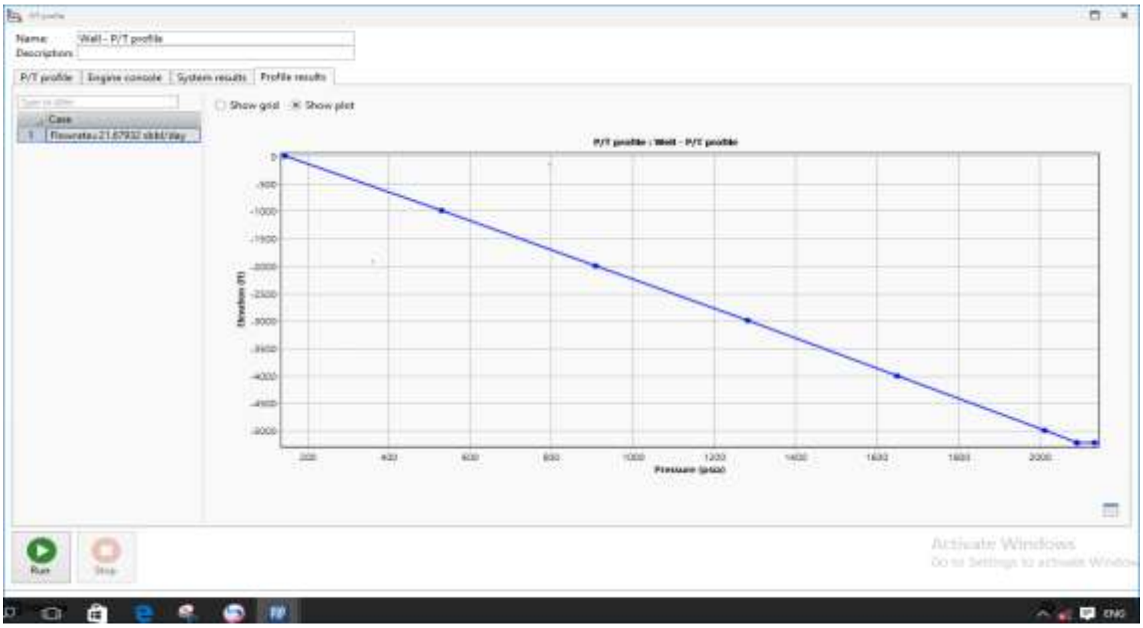
Select the perforation depth and choose the inflow performance relationship model (well PI) and insert its data (reservoir pressure and temperature, IPR basis (liquid or gas).



Step 4 : **Insert The PCP Pump and The Heater** :



Step 5: **Run model** in pressure / temperature (P/T profile) to show the natural production of the well.



3.4. Other Methods:

3.4.1. Ultrasonic Waves:

It is invention method for mitigating the wax deposition during crude oil flow in a well-bore or pipeline. The method comprises positioning one ultrasonic frequency generating device adjacent to the production tubing walls and producing one ultrasonic frequency thereby disintegrating the wax and inhibiting the wax from attaching to the production tubing walls. Experiments were done to measure the effect of ultrasonic waves at a frequency of 120 kHz on wax deposition during crude oil flow in a pipeline. In this paper, all the experimental results are described. Some reduction in wax deposition was also achieved due to the ultrasonic waves. Further work is required to identify the optimum frequencies.

Ultrasonic waves are mechanical pressure waves formed by actuating the ultrasonic transducers with high frequency, high voltage current generated by electronic oscillators (power generators). Recent investigations have confirmed that higher frequencies are more effective for the removal of certain contaminants (Brain F.Towler at el, 2007).

3.4.2. THE NANOFLUID:

A nanofluid refers to a mixture of metal particles with diameters less than or equal to 10 and a liquid of choice (usually water). The mixture of the fluid and the nano particles gives a consistent fluid system (homogenous mixture) known a nanofluid.

Nanofluid is a mixture of nano (10^9) sized metallic particles and a base fluid of choice mixed using a two-step method that ensures that the nanofluid is mixed to a good consistency.

As the nanofluid interacts with the reservoir, it is brought into thermal equilibrium with the reservoir. As both nanofluid and oil flow to the surface, the nanofluid keeps the oil in thermal equilibrium with itself.

Heat loss along the conduit is minimal because of heat transfer through radiation from the reservoir to the fluids which further maintains nanofluid at a temperature infinitesimally close to reservoir temperature. The authors advice that compatibility tests should be run with the nano particle of choice to ensure that crude composition is not changed (Elezabith at el, 2016).

Chapter 4

Results and Discussion

4.1. Result and Discussion of viscosity:

Viscosity is the property that determines the flow ability of crude oil. It is influenced by wax precipitation. Crude oil viscosity plays a significant role on the wax deposition rate. When oil viscosity is high, the wax deposition rate tends to be low because high oil viscosity makes diffusion of wax molecules to the walls of the tubing/pipe more difficult. All mechanisms for wax deposition (molecular diffusion, shear dispersion, Brownian diffusion, and gravity settling) seem to be influenced by oil viscosity. The experimental result for oil sample of RC10 well is presented in Table 4.2.5, while all results are shown in Appendix B.

Table (4.1) Viscosity of oil sample of R-C10 as a function of temperature (WAT = 68°C [150°F]).

Temperature C	Viscosity cp
80	45.53
79	45.53
78	47.10
77	47.88
76	49.45
75	51.02
74	54.95
73	57.30
72	62.01
71	70.65
70	79.28
69	91.06

68	104.40
67	131.09
66	153.85
65	180.54
64	223.72
63	254.33
62	303.00
61	337.54
60	392.48
59	451.36
58	494.53
57	563.61
56	611.49
55	689.99
54	749.64
53	814.01

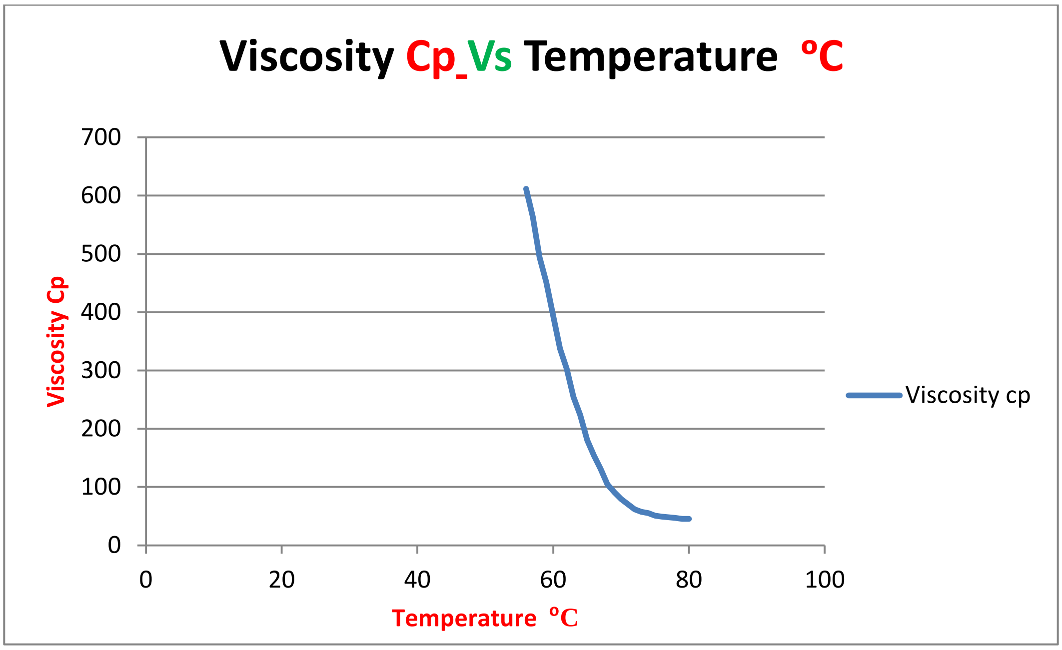


Figure 4.1: Show Temperature ° C Vs Viscosity Cp.

4.2. Results and Discussion of Pour Point:

The R-C (10) oil samples tested have high pour points > 48C. Pour point qualitatively indicates the temperature at which the crude oil gels under static condition. The gelling is a result of buildup of a network of wax crystals. The network buildup depends on the wax content of the oil and the wax particle size and number. The wax particle size and number tend to be influenced by the cooling rate. The large difference between the WAT and pour point could be attributed to low wax content.

4.3. Analysis to used electrical heater by PIPESIM software:

4.3.1. First case:

When put the electrical heater at depth 200 ft observe that the temperature of oil below the wax apparent temperature .this location of electrical heater it is not effective so it necessary change the location of heater.

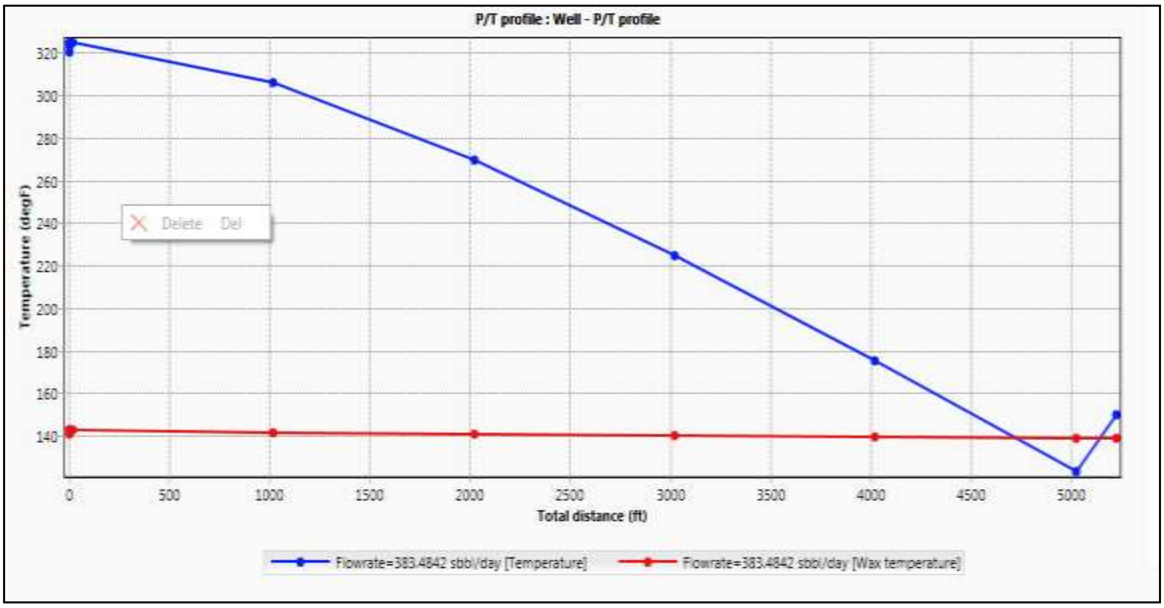


Figure 4.2: Heater located on depth 200 ft.

4.3.2. Second case:

When put the electrical heater at depth 2000 ft observe that the temperature of oil below the wax apparent temperature .this location of electrical not effective it is necessary that change the location of heater.

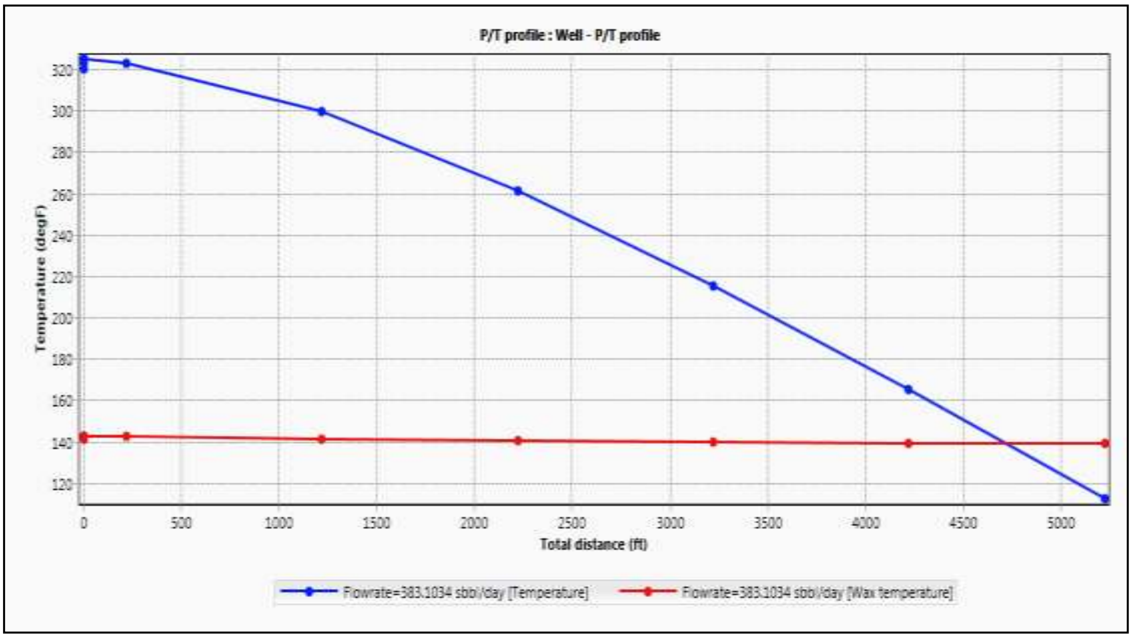


Figure 4.3: Heater located on depth 2000 ft.

4.3.3. Third case:

When put the electrical heater at depth (5100) ft observe that the temperature of oil not exceed the wax apparent temperature .This location of electrical heater is good effective considered as optimum location of heater.

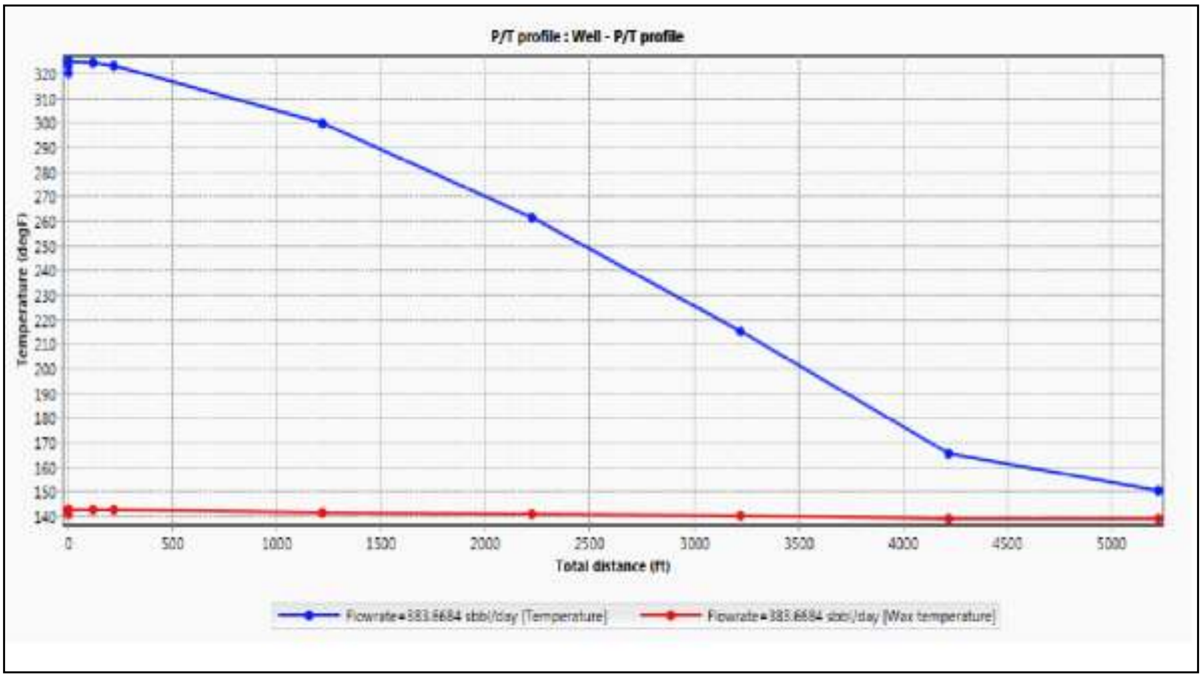


Figure 4.4: Heater located on 5100 ft.

4.3.4. Combination of Three Heater Location Depth:

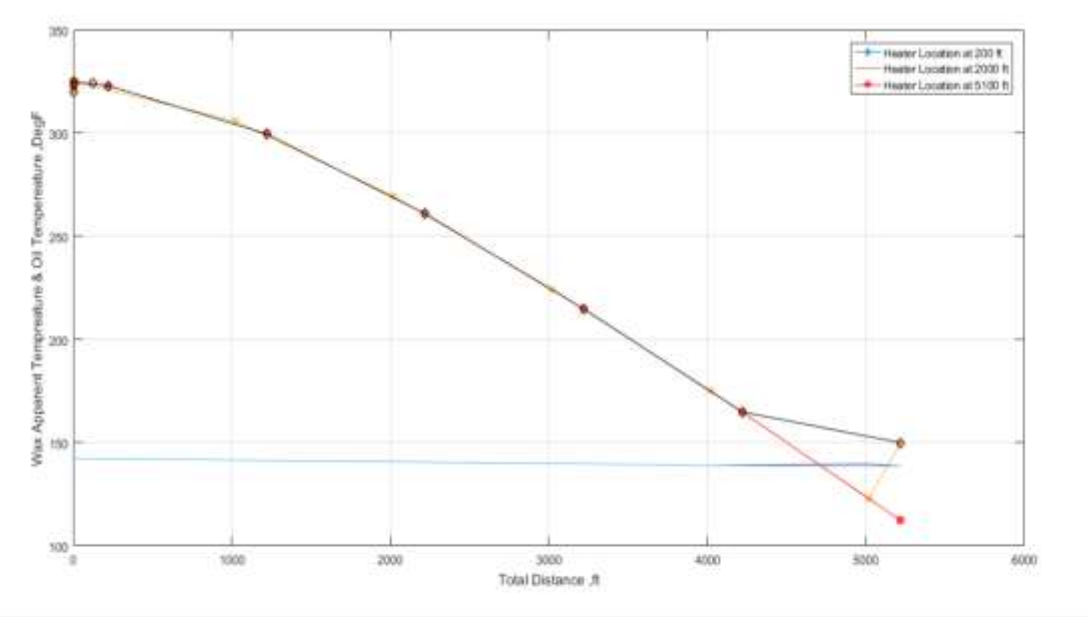


Figure 4.5: comparison between depths (200, 2000, 5100) Vs Wax apparent temperature.

Table (4.2) :Show theoretical comparison of Three techniques :

Method	Advantages	Disadvantages
Ultrasonic Waves.	• breaks wax molecule bonds. • flow rates and productio efficiency.	• have only a mini effect on the wax deposition.
NANOFLUID	• keeps the produced crude in equilibrium with itself. • would be applied to originally highly viscous liquid.	• High Cost.
	• Reduce energy losses in overburden. • One can put heat where you want it • Does not increase water cut	• Electrical heater technology is still immature. • BTU energy equivalent cost

Downhole Electrical Heater	• Controllable high temperature available. • Temperature not dependent on pressure. • No water to react with formation (Carbonate). • Can use renewable energy. • Possible "Demand Response" revenue source.	higher than natural gas. • Significant electrical generation capacity usually not available. • Most Petroleum Engineers not familiar with electrical engineering. • products, designs, and options.

From The comparison table, the suitable technical to mitigate the wax Deposition in well (R-C10) is Downhole Electrical Heater.

Chapter 5

Conclusion and Recommendations

5.1. Conclusion:

Based on result of lab experiences, practical Observations and theoretical studies made from this study, the following conclusions are made:

1. After Doing the Experimental Laboratory the result of dynamic viscosity at 60 ° C equal 392.48 Cp and pour point >48 ° C.
2. By analyzed the rheological properties of AL-RAWAT wax crude oil we found the suitable solve of this problem is the Downhole Electrical Heater.
3. From putting the heater in different depth by Using PIPESIME software we found 5100 ft is farmable Depth to set the heater.

5.2. Recommendations:

Based on the scope of this study the following recommendations are proposed**:**

- Measure the rheological properties than not covered by the study.
- Made Full Experimental Study to Chemical inhibitors and evaluate it with The RAWAT crude oil.

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APPENDICES

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TEST REPORT

Sample Type	Crude Oil
Sample Code	Cr-2095
Sample ID	22662
Customer Name	**student**
Customer Reference	rawat C10
Date /Time Received	14-Aug-18

Report Number
22662
Date /Time Report
3-Sep-18

Test Name	Test Method	Unit	Result
Pour point	ASTM D5853	^0C	>48
Wax Content	UOP 46	Wt%	*
Sulfur Content	ASTM D4294	%m	*
Dynamic Viscosity	BROO FILD	CP	**
WAT	IP389	^0C	*

*Could not be done due to techincal problem
** See attached

MINISTRY OF PETROLEUM
SUDANESE PETROLEUM CORPORATION
PETROLEUM LABORATORIES RESEARCH & STUDIES
(PLRS)
Date: 3-9-2018

• TEST (S) Has Ihave been subcontrcted ,please reter to PLRS for deails	**Reported by:** Dr. Waleed Salih
• No part of this report can be reproduced except full in any form or by any electrnic or mechanical including photocopying and recording without awritten pemission of the issuing laboratry	**Sig.:**

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