A Simulation Study of the Abo-Alttifel Field Terminal Crude Oil Pipeline

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ABSTRACT

Wax deposition is one of the main flow assurance problems in the oil industry. It can result in the restriction of crude oil flow in the pipeline, creating pressure abnormalities and causing an artificial blockage leading to a reduction or interruption in the production. Wax can precipitate as a solid phase on the pipe wall when its temperature (inlet coolant temperature) drops below the Wax Appearance Temperature (WAT).In situations where sudden temperature drops occur, a crystalline network can be formed, generating flow difficulties in production, transfer and offloading lines. Heating, diluting such oils with other crude oils, or transporting them by trucks or rails are costly. Different methodology for remediating wax deposits both in offshore and deep water is presented; focusing on chemical treatment techniques, mechanical treatment techniques, thermal treatment techniques, thermo-chemical and biological methods.

The current study introduces two scenarios to simulate aground crude oil pipeline (30 inches) diameter and 132 km length. This pipeline is transporting a waxy crude oil with pour point of 39°C. The simulation is split in two parts; the first part investigates changing the crude oil flow rate down to the minimum flow rate that the pipeline may operates, where the arrival temperature should be higher than the pour point. The second part considers inlet temperature as a fixed and then calculate the outlet temperature. The results show that the minimum flow allowed to be 36060 BBLPD at inlet temperature 155 °F (68.3 ^{o} C).

Keywords: Crude, Wax, Pour Point, Thermal, pipeline, Flow, Temperature.

1. Introduction:

Abu-Attifel field is one of the major oil fields in Libya. All crude oils which produced from the reservoir wells are characterized by high wax contents and high pour point. Abu-Attifel crude oil is transported in an insulated (30") pipeline to 103 fields and then through (40") pipeline to Zwitena terminal. The crude oil is heated so that outlet oil temperature does not fall below the pour point.

In the reservoir, crude oil behaves as a Newtonian fluid, since the waxes with high molar mass are in solution, causing the oil to act as a monophasic liquid, i.e., in laminar flow, in which the viscosity is only a function of temperature, independent of the shear rate [1]. As soon as the oil leaves the reservoir and flows through the line at a lower temperature, the temperature gradient between the cold wall of the pipe and the hot oil causes the waxes to precipitate. When the temperature of a crude oil containing high quantities of waxes drops suddenly, a crystalline network forms, impeding its flow in production, transfer or offloading lines. The precipitated waxes, when aggregating, can alter the flow, resulting in non-Newtonian behavior of the oil. The presence of wax crystals can also lead to an increase in viscosity, requiring application of a much higher pressure to assure continued flow [2]. Other components present in petroleum, such as polar compounds, resins and asphaltenes, can co-precipitate with the wax crystals, generating sludges that are hard to remove [3]. In general, organic compounds can be used to prevent wax deposition.

The determination of several parameters, such as the wax appearance temperature (WAT), crystallization enthalpy (using microcalorimetry), pour point and yield stress, can help the evaluation of the crystallization and deposition of waxes in crude oil.

There are many factors that influence the design of a pipeline which is used to handle waxy crudes. The restarting pressure to break the gel and restart the flow may exceed, sometimes, the bursting pressure of the pipeline. This consideration must be taken into account while simulating the pipeline. The use of improvers to reduce the viscosity, gel strength and pour point of the crude oil should also be evaluated. The use of flow improvers is generally effective near the pour point because the waxes do not cause problems until that time [4].

2. Experimental Methodology:

2.1. Characterization of crude oil:

The crude oil that has been used in this study is one of the oil fields reservoirs with waxing problems in Abu-Attifel crude oil. All the crude oil characterization was carried out in the lab following the standards analytical methods as shown in Table 1.

Table 1: *characteristics of Abu-Attifel crude oil*

Characteristics	Unit	Value
Density	g/ml (60 ^{0}F)	0.8246
Sp-Gravity	60/60 ^{0}F	0.8251
API Gravity	60 ^{0}F	40.0
Wax content	% wt.	36
Pour point	°F	102.2
Asphaltenes	% wt.	0.09

3. Waxy Crude Handling:

There are many factors that influence the design of a pipeline which is to handle waxy crude oils. The designer must evaluate these factors and determine which will provide the most economic transportation system. The use of improvers to reduce the viscosity, gel strength and pour point of the crude oil should also be evaluated. The use of flow improvers is generally effective near the pour point because the waxes really have not start to cause problems until that time. Transporting waxy hydrocarbons poses serious handling problems that historically have been very expensive to overcome. Heating, diluting with low pour point oils, or transporting by truck or rail have been costly means of handling such crude oils.

Handling problems are better defined by viscosity of the crude oil at its pipeline temperature. The basic task is to determine the lowest temperature which oil can be pumped satisfactorily. From the rheological point of view, heavy crude oils (waxy or asphaltentic) behaves as a non-Newtonian fluid. For crude oil having such behavior, it is necessary to evaluate the change of the rheological characteristics caused by temperature gradients at conditions as close as possible to actual operating conditions [5].

4. Technologies of Transportation of Waxy Crude:

In addition to analyses and laboratory tests of the fluid to be transported, it is also important to characterize its exact rheological behavior by means of a full scale test loop. Once the exact characteristics of the fluid have been determined, several methods are available to solve pipeline transportation problems.

These technologies consist primarily of making the crude fluid enough or at least, suitable for pumping and transporting. These techniques are listed below:

1- Transporting at temperature exceeding the pour point by insulating the pipeline and by heating the fluid at intermediate stations.
2- Mixing to various degrees with low pour point crude oils.
3- Treating for wax removal.
4- Addition of chemicals which reduces crude oils pour point.

The choice of suitable methods depends on several factors and must be influenced by these circumstances. In general, however methods 1 and 3 are the most effective but also the most expensive, as they involve substantial modifications of the transport system. Mixing of heavy crude oil with light oil or product of different specifications (method 2) is not always possible due to the obvious difficulty in having the right fluid available in the required quantities and sites.

Doping with flow improvers (method 4) is usually the method which combines economics and simplicity and thus solves the problem in most cases. Also called "cold flow improvers" or "wax crystal modifiers" chemical additives are long chain polymeric materials that crystallize with the precipitating wax, altering both the shape and size of the wax crystal. Hydrocarbons containing the resulting smaller, randomly shaped wax crystal have lower pour point and reduced viscosities at low temperatures than those that contain large regular wax crystals [6].

The flow improvers (additives) available on the market influence in different ways the rheological parameters (viscosity, yield stress, pour point, etc.). Furthermore, it must be pointed out that the percentages of additive dose not influence linearly the rheological parameters [7].

5. The Inlet Data for Computer Program:

Total pipeline length	(km)	= 132.00
Outside diameter for pipeline	(inch)	= 30.375
Inside diameter for pipeline	(inch)	= 30.000
The wall thickness	(inch)	= 0.3750
Depth burial to center line	(ft)	= 3.2808
API gravity		= 40.000
Insulation thickness polyurethane	(inch)	= 2.0000
Pour point of crude	(˚C)	= 39.000
Temperature of soil	(˚F)	= 60.000
Thermal conductivity of oil	(Btu/hr.ft. ^{o} F)	= 0.1000
Thermal conductivity of insulation	(Btu/hr.ft. ^{o} F)	= 0.0150
Thermal conductivity of pipeline	(Btu/hr.ft. ^{o} F)	= 26.200
Thermal conductivity of soil	(Btu/hr.ft. ^{o} F)	= 0.2000
Specific heat of oil	(But/Ib. ^{o} F)	= 0.5000
Specific heat of soil	(But/Ib. ^{o} F)	= 0.1496
Specific heat of insulation	(But/Ib. ^{o} F)	= 1.5900
Acceleration of gravity	(ft/sec ^{2})	= 32.200

6. Computer Program:

This program calculates temperature profiles for pipeline transporting waxy crude oil.

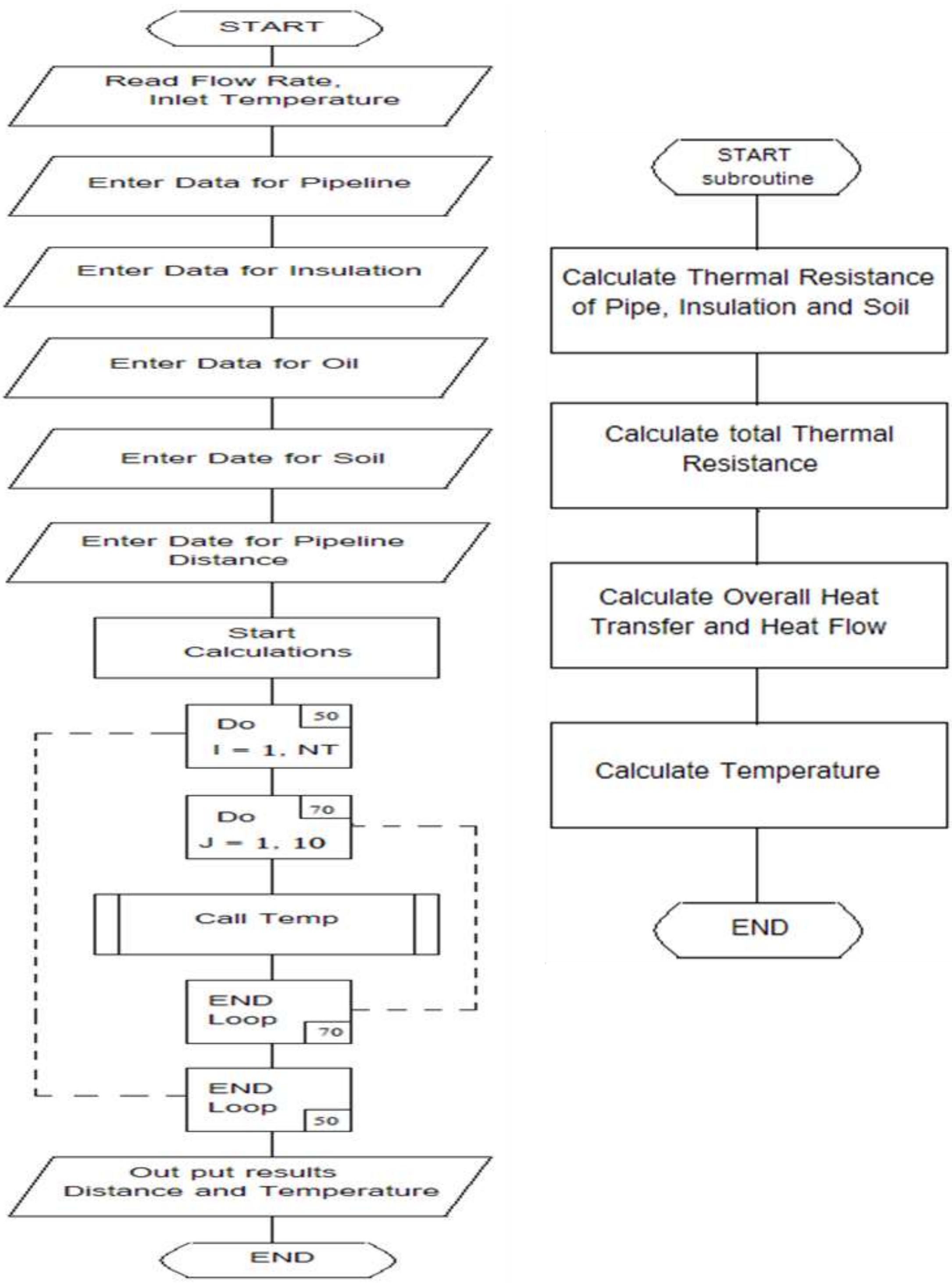

Figure 1: Flow chart of computer program.

7. Equations Used in Computer Program:

The following equations were taken from [8].

1- Specific gravity of crude:

$$S.g = \frac{141.5}{(API + 131.5)}$$

2- Density of oil (lb_m/ft^3):

$$\rho = S.g * 62.4$$

3- Mass flow rate (lb_m/Sec):

$$m = Q * \rho$$

Where: Q= Flow rate of crude oil (ft^3/Sec).

4- Velocity of crude oil (ft/Sec):

$$\upsilon = \frac{Q}{A}$$

Where: A= Area of the pipe.

5- Thermal resistance of insulation:

$$R_i = \frac{\frac{\log(OD + 2 * T_i)}{OD}}{2 * K_i}$$

Where: T_i = Thinks of the insulation.

K_i = Thermal conductivity of insulation.

OD = Outside diameter.

6- Thermal resistance of pipe:

$$R_P = \frac{\log(\frac{OD}{DI})}{(2 * K_P)}$$

Where: K_P = Thermal conductivity of pipeline.

DI = Inside diameter.

7- Thermal resistance of soil:

$$R_S = \frac{\log(\frac{2 * DEP + \sqrt{4(DEP)^2 + (OD)^2}}{OD})}{2 * K_S}$$

Where: DEP = Depth burial to center line.

K_S = Thermal conductivity of soil.

8- Total thermal resistance:

$$R_t = R_i + R_p + R_S$$

9- Heat flow:

$$q_L = \pi (OD + 2 * T_i) * L * U * (T_1 - T_S)$$

$$q_L = m * Cp * (T_1 - T_2)$$

Where: L = Length of pipe.
U = Overall heat transfer.
T_S = Temperature of soil.

8. Results of Computer Program:

Two experiments were performed to calculate the flow rate; the first option was based on the fixed inlet temperature at different flow rates and then calculate the outlet temperature. The second one was to consider outlet temperature as fixed, and then calculate inlet temperature.

Figure 2 shows the results of temperature profiles and distance at constant inlet temperature. Figure 3 shows the results of the temperature profiles and distance at constant outlet temperature.

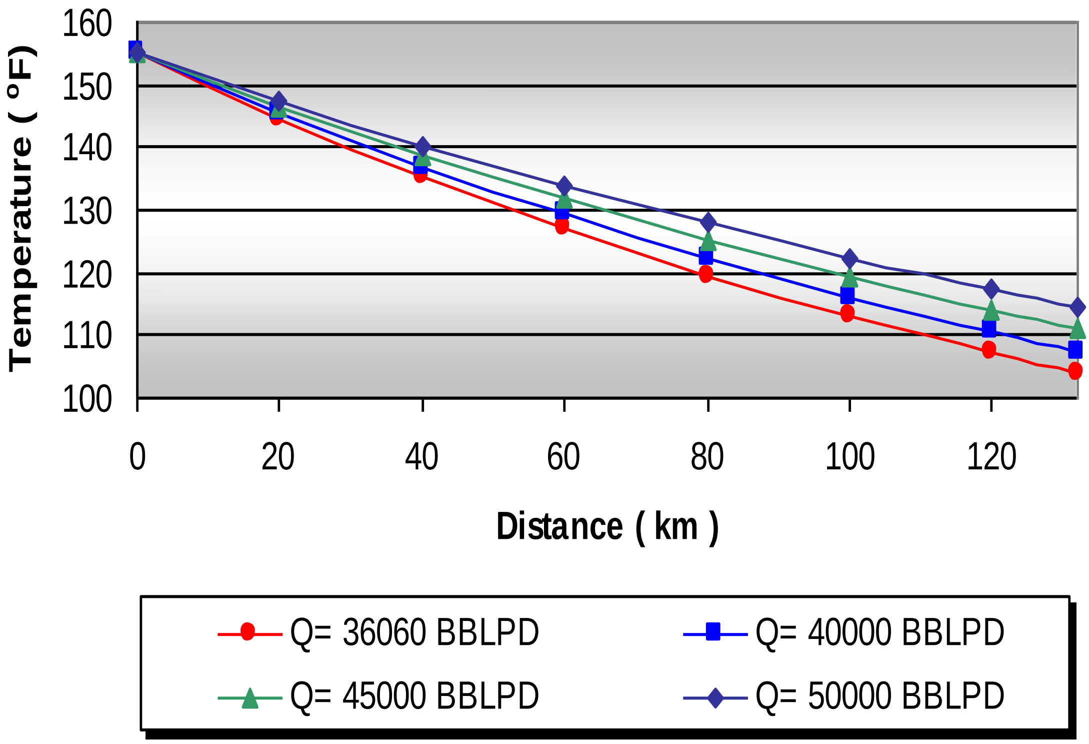

Figure 2: Temperature Profile at Constant Inlet Temperature.

Table 2
Final Temperature for Different Flow Rates at Constant Inlet Temperature.

Flow rate (BBLPD)	Final Temperature (^{o}F)
36060	104.0038
40000	107.4792
45000	111.2838
50000	114.5457

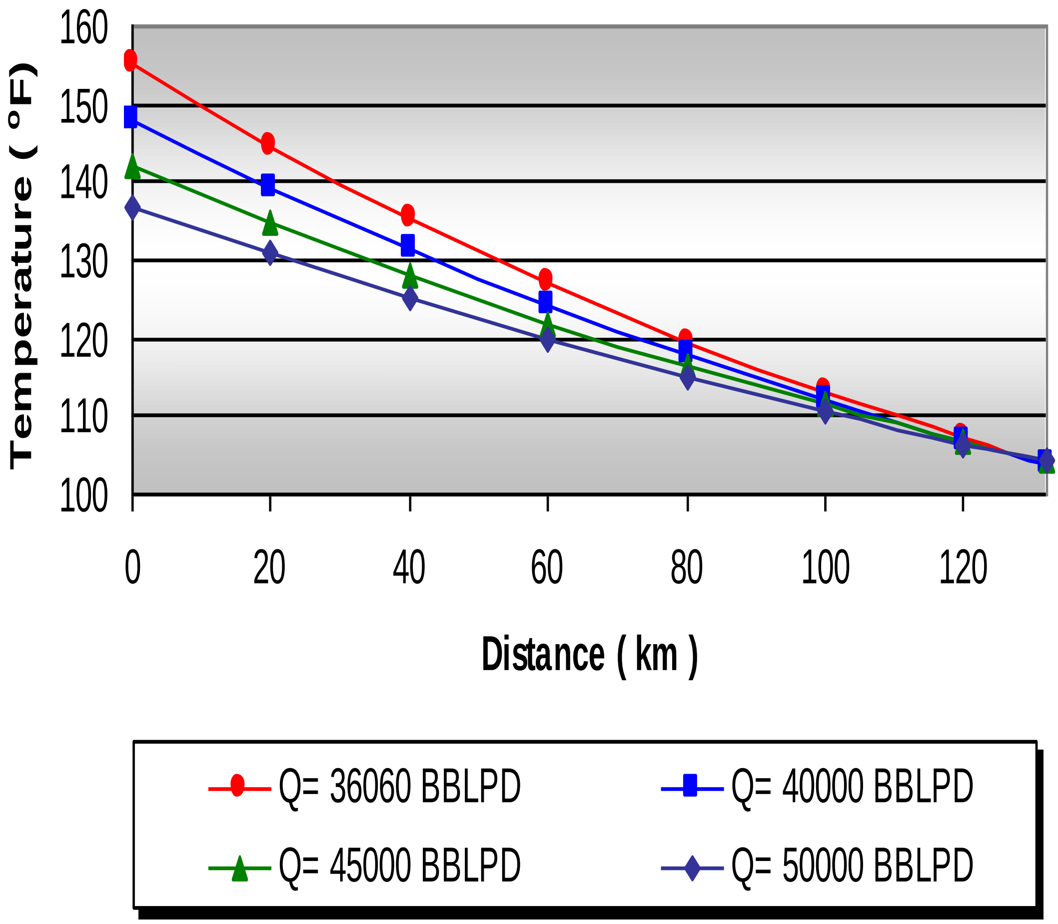

Figure 3: Temperature Profile for Constant Final Temperature.

Table 3
Inlet Temperatures for different Flow Rates at Constant Final Temperature

Flow rate (BBLPD)	Inlet Temperature (^oF)
36060	155.0
40000	148.0
45000	142.0
50000	137.0

9. Conclusion:

The variable that was the most significant for the waxy crude oil was the temperature, which was inversely proportional to the pressure again. Because of the large amount of wax that was presented in the crude oil, once the WAT was achieved by lowering the temperature, a large amount of paraffin crystallized and contributed to increasing the pressure change in the system. The flow rate was also significant and was inversely proportional to the pressure again. This effect occurred because low flow rates caused a longer residence time for the oil in the line, thereby causing further heat loss and consequently decreased temperature.

From results of computer program, it can be seen that at fixed outlet temperature of the crude oil in pipeline near the pour point is more suitable when there were changes in the inlet temperature at different flow rate.

10. References:

[1] Kelland, M. A.; Production Chemicals for the Oil and Gas Industry; CRC Press: New York, 2009.
[2] Elsharkawy, A. M.; Al-Sahhaf, T. A.; Fahim, M. A.; Fuel 2000, 79, 1047.
[3] Freund, M.; Csikós, R.; Keszthelyi, S.; Mózes, G.; Paraffins Products; Elsevier: New York, 1982.
[4] Ajienka J. A. & Ikoku C. U., "Criteria for the design of waxy crude oil pipelines: maximum pump (horsepower) pressure requirement", Journal of Petroleum Science and Engineering 13 (1995) 87-94.
[5] E1-Gamal I. M., " Combined effects of shear and flow improvers: the optimum solution for handling waxy crudes below pour point", Physicochemical and Engineering Aspects, 135 (1998) 283-291.
[6] Davidson M., Nguyen Q., Chang C. & Ronningsen H., "A model for restart of a pipeline with compressible gelled waxy crude oil", Journal Non-Newtonian Fluid Mech. 123 (2004) 269-280.
[7] Frigaard I., Vinay G. & Wachs A., "Compressible displacement of waxy crude oils in long pipeline startup flows" Journal of Non-Newtonian Fluid Mechanics (June 2007) 1-39.
[8] Max S. Peters & Klans D. Timmerhaus, "Plant design and economics for chemical engineers ", International Student Edition, Third Edition, (1980).