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Study of Inlet Cargo Temperature of Crude Oil in Transportation Pipeline at a Critical Section to Avoid Gel Formation Using Explicit Method

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ABSTRACT
The gel formation in waxy crudes and the deposition of wax on the inner walls of subsea crude oil pipelines present problem in the production and transportation of oil, so the get the time it takes for the gel to appear in the pipe lines is required to avoid the reduction in flow rate that it causes, as well as to avoid the eventual loss of a pipeline in the event that it becomes completely closed. After shutting down due to any problem during the transportation process the oil will remains stagnant and the crude oil will start gelation after reaching its pour point temperature (PPT), causing a difficulty of offloading the remaining crude oil in the pipeline.

Excel 2010 was used to obtain the required results. The effect of the crude oil entry temperature was examined with the change in the flow rate and the thickness of the insulator on the pipes to predict the arrival time of Pour Point Temperature Reaching Time and to avoid gel formation after shutdown occurs. The results obtained at the temperature of the entry of crude oil 40^{o}C in the submerged section under sea water in the absence of insulator and the flow rate of 5000 m^3/h that the arrival time of the temperature of the gel is 52.7 minutes, when increasing the temperature of entry of crude oil to 50 ^{o}C The arrival time of the temperature of the gel to 166.8 minutes, indicating that the higher the temperature of entry increased the time of arrival of the gel and thus avoid the formation of wax inside the pipe.

Keywords - waxy crude, crude oil, pour point temperature, Cargo Temperature, Pipeline

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I. INTRODUCTION

Crude oils in many reservoirs throughout the world contain significant quantities of wax which can crystallize during production, transportation, and storage. This can cause severe difficulties in pipelining and storage. At sufficiently high temperatures, the waxy crude oils (i.e., oils which contain a great deal of wax), although chemically very complex, are simple Newtonian fluids. As the temperature is reduced, the flow properties of these crudes can radically change from the simple Newtonian flow to a very complex behavior due to the crystallization of waxes [1].

When the oil is cooled to a temperature lower than the crystallization point (generally called pour point), the crystals, growing and agglomerating, entrap the oil into a gel-like structure. Consequently, the flow properties of the oil become distinctly non-Newtonian. A yield-stress (the minimum stress required to start the flow) can be detected. Moreover, the flow properties are complicated by their critical dependence upon their mechanical and thermal "history." The viscosity of the waxy crudes can be greatly reduced by a continued shear. This fact seems to indicate a kind of "thixotropy." The disintegration of large wax agglomerates appears to be the primary cause of the lower viscosity.

Engineering design of waxy crude oil pipelines often involves an economic cost/benefit balance between a heavy-duty brute force mechanical system which will handle all flowing, shutdown and restart situations and a mechanical system which will handle normal situations (i.e., the most likely shutdown and restart situations) and which relies upon well-planned operating procedures to minimize risk due to extremely unlikely shutdown and restart situations. In the case of waxy oils, design also must take into account the need for control of routine deposition of waxy material on interior surfaces of the pipeline [2].

The highest temperature at which the first wax crystals start to appear, upon cooling of a "waxy" crude oil or mixture, is called the wax appearance temperature (WAT).

The WAT is an important parameter in wax precipitation and deposition The WAT is also called the cloud point temperature (CPT) and is essential for determining the tendency of crude oil towards wax precipitation and deposition (i.e., crude oils with a high WAT will be more likely to undergo wax precipitation and deposition).

No wax precipitation or deposition will occur as long as the crude oil temperature is above the WAT, once the temperature drops below the WAT, wax molecules will begin to crystallize out of solution and wax deposition can occur. Factors that favor an increase in WAT also tend to favor increased wax deposition.

An important distinction exists between the liquids temperature and the experimentally determined WAT, The liquids temperature defines the true solid–liquid phase boundary, whereas the experimental WAT is the temperature at which the first crystals are detected upon cooling.

This value can vary depending on the sensitivity of the measurement technique, thermal or cooling history and the cooling rate; hence, it can be very subjective. The experimental WAT would be lower that the liquids temperature and should be within the solid–liquid phase envelope [3].

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Figure 1 shows the deposition of wax in the pipeline [1].

Wax deposition and gel formation have been crucial problems to the oil industries. The deposition of waxes would lead to gelation which blocks flow in pipelines and interrupts steady production of oil at offshore fields

The plugged gel needs to be restarted by applying a pressure that is much higher than the steady pressure in normal production flow, requesting for higher capacity pumps and piping dimensions. However, the available conventional restart pressure over-predicts pumping pressure and pipeline dimensions as it neglects the occurrence of thermal shrinkage and the resulting gas voids formed within the gelled crude oil and assumes waxy crude as single phase and incompressible fluid, The paucity of researches on quantification and locating of voids within the gel across and along the pipelines maintains the assumption made earlier to this date.

There have been different researches conducted to prove that the over predicted restart pressure and piping dimensions result in excessive unnecessary cost to oil industries. The transportation of waxy crude oil at offshore fields and the previous researches on the behavior of waxy crude oil in Newtonian and non-Newtonian regions. In addition, the restart-ups process and the associated problems encountered, flow assurance and management of waxy crude oil, flow improvers of waxy crude oil gel following sufficient cooling are thoroughly discussed, It further reviews previous researches on thermal shrinkage and intra-gel voids formation in waxy crude oil which would help in the process of developing vigorous wax deposition model and restart pressure equations. Furthermore, different mechanisms used to ease restart pumping of gelled crude oil in pipelines are highlighted. [4]

NOMENCLATURE

PPTRT	POUR POINT TEMPERATURE REACHING TIME
ΔT	TIME INCREMENT
INS	INSULATION
Q	FLOW RATE
Q	HEAT TRANSFR
TIN	INLET CARGO TEMPERATURE
A	THERMAL DEFUSI
3LPE	3-LAYER POLYETHYLENE
API	AMERICAN PETROLEUM INSTITUTE
ASTM	AMERICAN SOCIETY FOR TESTING AND MATERIAL
GOR	GAS OIL RATIO
GRP	GLASS-REINFORCED PLASTIC
NTT	NO TOUCH TIME
OHTC (U)	OVERALL HEAT TRANSFER COEFFICIENT
PPT	POUR POINT TEMPERATURE
SG	SPECIFIC GRAVITY
WAT	WAX APPEARANCE TEMPERATURE
TW,IN	INNER PIPE WALL TEMPERATURE

II. NUMERICAL ANALYSIS

In this chapter numerical solution to evaluate the time needed to reach PPT after shutdown, once the temperature distribution is known [5], by applying an energy balance to a 3D differential control volume and temperature boundary condition, the temperature distribution may be acquired from the heat diffusion equation:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{q}=\rho C_p\frac{\partial T}{\partial t} \quad (2.1)$$

Where:

$\dot{q}$: Heat generation rate per unit volume of the medium, W/m^3

ρ: Density of the medium, kg/m3

C_p: Specific heat capacity, kJ/ (kg.K)

x, y, z: Coordinates, m

T: Time, second.

The heat diffusion equation for cylinder:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(k\,r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial}{\partial \emptyset}\left(k\frac{\partial T}{\partial \emptyset}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{q}=\rho C_p\frac{\partial T}{\partial t} \quad (2.2)$$

Where:

r, z: Radius and axial directions of cylindrical coordinates;

$\emptyset$: Angle in radius direction.

For most thermal analyses of flow line systems, where the heat transfer along the axial and circumferential directions may be ignored and, therefore, transient heat conduction without a heat source will occur in the radial direction of cylindrical coordinates [6], equation (2.2) is simplified as follows:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(k\,r\frac{\partial T}{\partial r}\right)=\rho C_p\frac{\partial T}{\partial t} \quad (2.3)$$

The temperature change rate depends not only on the thermal conductivity of material , but also on the density, and specific heat capacity. This equation can be solved numerically. For a steady heat transfer, the right side of equation is equal to zero.

In this study a long pipe line from the cargo ship to the tank with 23.55 Km long, divided into four main parts of the pipeline:

1- Offshore pipeline from with 42 inch diameter, 0-9.4 Km.

2- Offshore burial pipeline with 42 inch diameter, 9.4-13.6 Km.

3- Onshore burial pipeline with 42 inch diameter, 13.6-20.12 Km.

4- Onshore burial pipeline with 52 inch diameter, 20.12-23.55 Km.

The overall heat transfer coefficient [OHTC] indicates the ability of losing heat from the system. As U_{VALUE} increases the heat loss increases the temperature drop increases and vice versa. For the offshore unburied pipeline section without insulation for Nile blend is much higher than the other pipeline sections because the buried pipeline sections have a higher thermal resistance [6].

Figure 2 shows the temperature distribution along the whole pipeline where no insulation used , Tin= 45 ^oC and flow rate 5000 m^3/hr, it can be concluded clearly the most affected part in the pipeline is the offshore pipeline Section-1 from 0-9.4Km also from Figure 3 the Inner U which is the inverse of the summation of thermal resistance of the pipeline layers divided by the inner area of the pipeline , U value is larger at the offshore pipeline which means the heat transfer rate in offshore pipeline is so high compared to other the section of the pipeline.

The concentration will be on the offshore pipeline and since U value is the largest and almost constant for that section then it will have the tendency to reach the PPT after shutdown from the initial conditions at steady state, the temperature is higher and decreases as long getting farther from the inlet of the pipeline to reach minimum temperature at 9.4 Km, which means at 9.4 Km the crude will reach PPT faster in the offshore pipeline and it will be the critical section in the this study. this study the simulation will be only carried the section of offshore pipeline at distance of 9.4 Km from the inlet of the pipeline, in the radial direction, all that work used to simplify the study because the large amount of calculation will be used also to save time and storage space which will make the simulation more realistic.

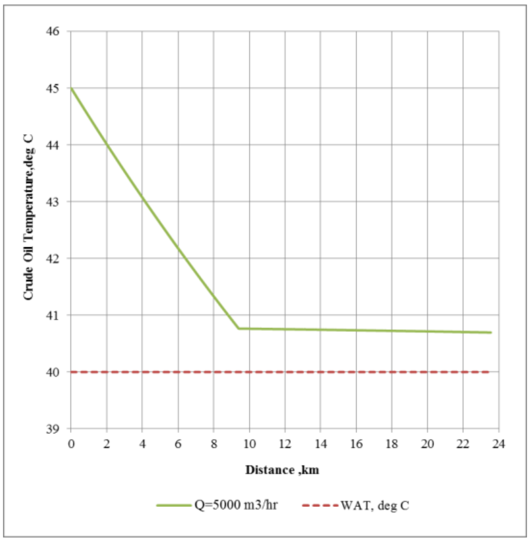

Figure 2 Temperature distribution along the pipeline where no insulation, 5000 m3/hr flow rate, and inlet cargo temperature is 45 °C [5].

Mathematical model will be developed in order to calculate the time to reach PPT after shutdown and temperature distribution along radial direction of the cross section selected part from the pipeline. The approximate or numerical solution is normally solved by writing a code and programming because of the complexity of the analysis where method will be used in this analysis as a comparison. However, a few conditions can be assumed so that the problem can be simplified as following:

1- One-dimensional heat transfer from the center of the pipe “crude oil” to the ambient “seawater” [7].

2-The initial temperature of the crude oil assumed to be uniform along radial direction

3- All thermodynamic properties of the crude oil and pipeline layers are independent of temperature.

4- No heat generation and only heat loss along radial direction.

5- The ambient temperature is constant at the worst conditions where ambient temperature is the minimum.

All the assumptions above considered before put into place to meet the criteria to satisfy the mathematical equation. In this study, the numerical solution is solved by using finite difference method approach; Microsoft Macro Excel 2010 is used to perform the calculations. A set of parameters used to provide that model and already reviewed in next Chapter. The result of the computation of explicit.

Next section will consider finite difference method to simulate the problem. Explicit method will be presented for of solution. The model consisted of a circular cylinder with length L of uniform properties with constant heat flux at steady state and specified initial temperature distribution (initial conditions) along the radial direction and constant outer-surface temperature equal to the sea water temperature as it is the ambient liquid for this part of pipe line.

The assumption mentioned above will be applied to the radial direction of the pipe will be divided into nodes for each material layer in which nodes will be as following:

•Central node •Interior nodes
•Intersection nodes •Outer nodes

Using the explicit method for all node types and by applying the energy balance equation as following:

$$\dot{E}_{in} = \dot{E}_s \qquad (2.4)$$

Derivation of equation for each node as following:

1. Central Node:

This node is at the center of the crude oil in which r=0, and by applying energy balance equation:

$$T_i^{\,t} = \frac{4\alpha_m \Delta t}{\Delta r_m^{\,2}} T_{i+1} + \left(1 - \frac{4\alpha_m \Delta t}{\Delta r_m^{\,2}}\right) T_i \qquad (2.5)$$

The stability criterion on the time step may be determined from the coefficient for T_i greater or equal to zero to make the solution stable

After arranging equation (2.5) can be written:

$$\Delta t < \frac{\Delta r_m^{\,2}}{4\alpha_m} \qquad (2.6)$$

The same procedure will be applied for the next nodes by applying energy balance and stability criterion method.

2. Interior Nodes:
Applying energy balance equation to the interior node:

$$T_i^{\,t} = \frac{\alpha_m \Delta t}{(r_{ref}+n_m\,\Delta r_m)\Delta r_m^{\,2}}\left[\left(r_{ref} + \left(n_m - 0.5\right)\Delta r_m\right) T_{i-1} + \left(r_{ref} + \left(n_m + 0.5\right)\Delta r_m\right) T_{i+1}\right] + \left(1 - \frac{2\,\alpha_m \Delta t}{\Delta r_m^{\,2}}\right) T_i \qquad (2.7)$$

Where:

r_{ref}:is the reference radius for the node interested on, for example if the interested node is interior nodes of crude oil then reference is equal to zero r_{ref}=0, but if the interested node is interior nodes of the pipeline then r_{ref}= inner pipe wall radius, it means that the r_{ref} is the previous material radius of that node we are interested on and that relation concluded after simplifying the huge number of interior nodes equations and make them in one general equation.

n_m: is the number of node in the interested material from zero until the end of number of node of this material layer.

Then the stability time increment or time step for interior nodes is

$$\Delta t < \frac{\Delta r_m^{\,2}}{2\,\alpha_m} \qquad (2.8)$$

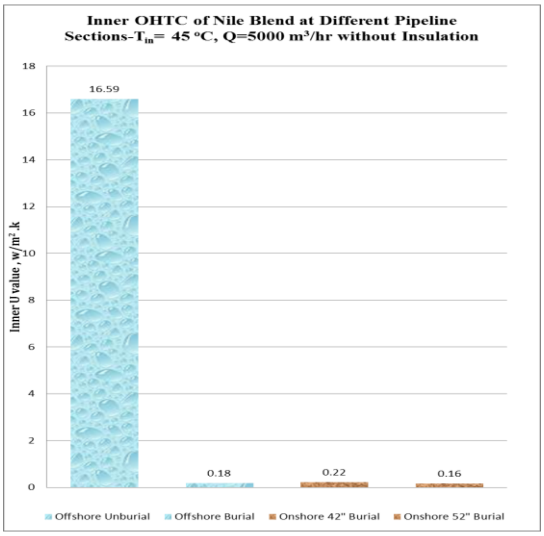

Figure 3 Inner U value average for each section of the pipeline with no insulation, 5000m³/hr flow rate, inlet cargo temperature of 45 ⁰C [8]

3. Interference Nodes:
By applying Energy balance equation to the interference node as following:

$$T_i^{\,t} = \frac{2\,\Delta t\left[\frac{K_{-m}}{\Delta r_{-m}}\left(r_i-\frac{\Delta r_{-m}}{2}\right)T_{i-1}+\frac{K_{\mp m}}{\Delta r_{+m}}\left(r_i+\frac{\Delta r_{+m}}{2}\right)T_{i+1}\right]}{\rho_{-m}\,C_{-m}\,\Delta r_{-m}\left(r_i-\frac{\Delta r_{-m}}{4}\right)+\rho_{+m}\,C_{+m}\,\Delta r_{+m}\left(r_i+\frac{\Delta r_{+m}}{4}\right)} + \left[1 - \frac{2\,\Delta t\left(\frac{K_{-m}}{\Delta r_{-m}}\left(r_i-\frac{\Delta r_{-m}}{2}\right)+\frac{K_{\mp m}}{\Delta r_{+m}}\left(r_i+\frac{\Delta r_{+m}}{2}\right)\right)}{\rho_{-m}\,C_{-m}\,\Delta r_{-m}\left(r_i-\frac{\Delta r_{-m}}{4}\right)+\rho_{+m}\,C_{+m}\,\Delta r_{+m}\left(r_i+\frac{\Delta r_{+m}}{4}\right)}\right] T_i \qquad (2.9)$$

The stability criterion for interference nodes is

$$\Delta t < \frac{\rho_{-m}\,C_{-m}\,\Delta r_{-m}\left(r_i-\frac{\Delta r_{-m}}{4}\right)+\rho_{+m}\,C_{+m}\,\Delta r_{+m}\left(r_i+\frac{\Delta r_{+m}}{4}\right)}{2\left(\frac{K_{-m}}{\Delta r_{-m}}\left(r_i-\frac{\Delta r_{-m}}{2}\right)+\frac{K_{\mp m}}{\Delta r_{+m}}\left(r_i+\frac{\Delta r_{+m}}{2}\right)\right)} \qquad (2.10)$$

4. Outer surface Node:
The surface node is the last contact node from the last pipe layer which is cement to the environment which is the sea water, after applying Energy balance at this node:

$$T_i^{\,t} = \frac{2\alpha_m \Delta t\left(r_i-\frac{\Delta r_m}{2}\right)}{\Delta r_m^{\,2}\left(r_i-\frac{\Delta r_m}{4}\right)} T_{i-1} + \frac{2h_\infty\, r_i\, \Delta t}{\rho_m\, C_m\, \Delta r_m\left(r_i-\frac{\Delta r_m}{4}\right)} T_\infty + \left[1 - \frac{2\alpha_m \Delta t\left(r_i-\frac{\Delta r_m}{2}\right)}{\Delta r_m^{\,2}\left(r_i-\frac{\Delta r_m}{4}\right)} - \frac{2h_\infty\, r_i\, \Delta t}{\rho_m\, C_m\, \Delta r_m\left(r_i-\frac{\Delta r_m}{4}\right)}\right] T_i \qquad (2.11)$$

For the stability criterion

$$\Delta t < \frac{\rho_m\, C_m\, \Delta r_m\left(r_i-\frac{\Delta r_m}{4}\right)}{2K_m\left(\frac{r_i}{\Delta r_m}-0.5\right)+2h_\infty\, r_i} \qquad (2.12)$$

After derivation of equations for Explicit they need to solve them by Excel 2010.

For Explicit method for solving the equations and finding the temperature distribution also the time needed to reach PPT for each case there are Δt limitation, which will be defined by the criterion for each layer and the minimum Δt will be the limitation to give stable solution, the disadvantage of Explicit

method in which with small time increment Δt it will need a large amount of memory because the large amount of calculation for each time step.
The next flowchart for method and how to insert the data to the Excel software. The results are shown in with further details.

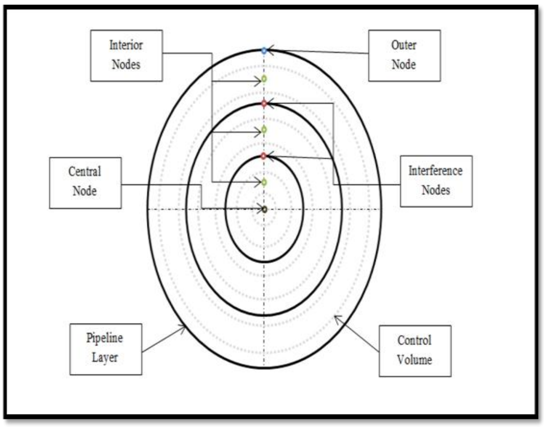

Figure 4 Nodes and Control Volume for Transient Analysis

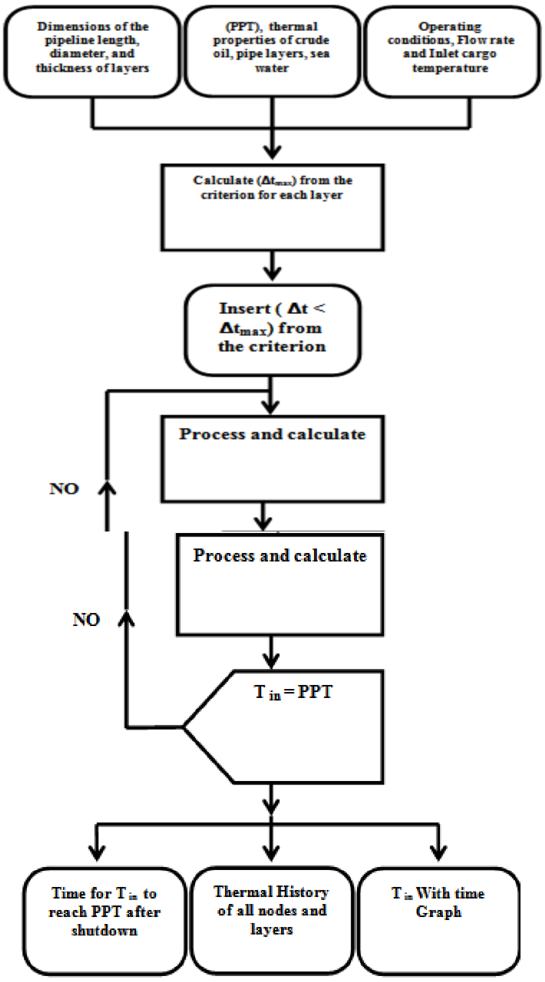

Figure 5 Flowchart for Explicit methodology software input and output.

III. DATA AND SYSTEM DESCRIPTION

The pipeline will pass four different environmental conditions respectively as follow:
1. Offshore unburied pipeline with 42 inch inner diameter.
2. Offshore buried pipeline with 42 inch inner diameter.
3. Onshore buried pipeline with 42 inch inner diameter.
4. Onshore buried pipeline with 52 inch inner diameter.

All the data are obtained from Report [11].
Insulation requirement will be for prevention of wax deposition or gelling of crude in the pipeline.The thickness of the insulator shall be three parameters (0, 0.5, 1) inch.
Transient analysis will be performing using Excel Macro 2010

Fluid Properties and Pipeline Properties [8]

Table 1: Fluid properties for Nile blend

Description	Nile
°API	32.76
SG at 60°F	0.8610
Kinematic Viscosity (cSt) @ 40°C @ 70°C	41.15 11.39
Dynamic Viscosity (cP) @ 40°C @ 70°C	35.43 9.81
Thermal Conductivity (W/ m.°C)	0.1622
Heat Capacity, J/kg. °C	1750
Sulfur Content (%wt)	0.045
Water & Sediment (%vol)	0.25
Pour Point (°C)	33
Wax Content (%wt)	30.9
Wax Appearance Temperature, °C	40

Table 2 Pipeline properties

Pipeline Material	Carbon Steel
Density	7850 kg/m^3
Thermal Conductivity	50 W/m.K
Design Pressure	26.41 $kg/cm^2(g)$
Design Temperature	75°C

Table 3: Pipeline / Hose details [8]

Section	Length, m	Inner Diameter, mm	Wall Thickness, mm	Roughness, mm
Onshore 42"	6523 [Note 1]	1031.2	12.5	0.0457
Onshore 52"	3427 [Note 2,3]	1290.3	15.2	0.0457
Offshore 42"	13600[Note 4]	1016.0	25.4	0.0457
Submerged Hose	50	584.2	12.7	0.023
Floating Hose	50 / 250	406.4 / 584.2	12.7	0.023

Table 4: Material Properties [11]

Description	Density, kg/m^3	Conductivity, W/m. K	Capacity, J/kg.K
Concrete Coating	3040	1.7	880
Insulation Coating	750	0.17	2000
Corrosion Coating	900	0.346	1850

Table 5 Environmental condition [8]

Seawater Density	1020.9 kg/m^3
Seawater Specific Heat Capacity	4026.55 J/kg.K
Seawater Thermal Conductivity	0.59 W/m.k
Seawater Temperature[Note 1]	Min: 25°C Max: 28.6°C
Air Temperature	Min: 21.5°C Max: 36.7°C
Soil Thermal Conductivity	0.17 W/m.k
Wind Speed [Note 2,4]	2 year: 6.481 m/s 10 years: 9.465 m/s 100 years: 13.169 m/s
Sea Current Speed [Note 3,4]	2 year: 1.46 m/s 10 years: 1.70 m/s 100 years: 1.89 m/s

Assumption [1]
1. Concrete coating thermal conductivity assumed to be 1.7 W/m.K
2. 3mm3LPE coating thermal conductivity assumed to be 0.346 W/m.K
3. Crude oil GOR and water cut assumed to be zero.

Additional Information [8]
1. Velocity criteria for pipeline are between 0.9 m/s (min) and 4.57 m/s (max).
2. Maximum velocity inside floating hose is 15 m/s.
3. Storage tank height is +45m [from sea level]
4. Tie in point and storage tank elevation difference = 20 m
5. Distance between flushing pump to tie-in point = 2270 m
6. Distance between loading pump to tie-in point = 1360 m
7. Typical bulk cargo offloaded is 2,000,000 barrels
8. Maximum offloading Cargo temperature is 57°C
9. Min period for bulk cargo offloading is 36 hours
10. Max period for bulk cargo offloading is 72 hours
11. During offloading, only one crude type will be offloaded
12. For typical offloading hose (double carcass), the design pressure is between 15 to 21 bar (g)
13. For typical offloading hose (double carcass), the maximum product temperature can be as high as 82 °C
14. No-touch-time (NTT) considered is 1 hour, 2 hour, 4 hour and 8 hours.

Note: NTT is the time that operations require for troubleshooting any issues with the terminal

IV. RESULTS AND DISCUSSION

Results obtained after coding the equations and creating the MACRO EXCEL 2010 software for Explicit.

The results are mainly Graphs and tables in which the graphs are showing the thermal history for the inner pipe wall temperature from the initial condition until reaching PPT for Explicit method.

The main parameters will be used in this study are:
1.Pipeline of 42 inch Diameter and insulation thickness of 0, 0.5, and1 inch.
2. Flow rate of 5000, 8000, and 10000 m^3/hr.
3. Inlet Cargo Temperature Two step from 40 ^{o}C to 58 ^{o}C for sensitivity analysis.
4. The Effect of Time Increment (Δt) from 0.1 s to 300 s.

In this study the effect of minimum and maximum operating parameters have been used to evaluate the effect of most parameter.

The time increment used from (0.1s) to (100s) where from (0.1s) to (1s) time increment was (0.1s) step, from (1s) to (10s) by (2s) step, and from (10s) to (100s) by (10s) step.

Figure 6 is for non-insulated pipe line showing the effect of Time Increment (Δt) on the inner pipe wall temperature with lowest operating flow rate of 5000 m^3/hr , and The inlet cargo temperature 42 ^{o}C , and Figure 7 is for 1inch insulation thickness pipe line are showing the effect of Time Increment (Δt) on the inner pipe wall temperature with High operating flow rate of 10000 m^3/hr , and The inlet cargo temperature 56 °C to study the effect of Time Increment (Δt) in the time of inner pipeline wall temperature to reach PPT after shutdown .

For more details please check the tables in the Appendices.

As show on the figure (6) as the time step increases the round of error increases but with a small range about (5 minutes) after Δt= 10 seconds.

For the critical of stability for this work Δt should not be exceed (0.99 s), and that is why in this work Δt= 0.5 s.

The effect of time increment Δt has a small effect and could be neglected, for both studies in this work for minimum and maximum parameters used to study the effect of Δt on this work as the time increment decreased the time consumed to obtain the final result increases that is why (0.99 s) used.

The effect of temperature on crude oil is very large, the temperature of crude oil is higher than PPT when entering or flowing through pipes.

The Calculated PPTRT From temperature 40 °C to 58 °C, is increased by 0.2 °C at each step of the previous step when all the conditions are either maximum or minimum conditions.

Figure 8 ,Figure 9 and Figure 10 are showing the effect of the inlet cargo temperature on the inner pipe wall temperature with operating flow rate of 5000 m^3/hr, 8000 m^3/hr and 10000 m^3/hr in non-insulated pipe line and insulated pipe line by 0.5 inch, 1 inch respectively, The inlet cargo temperature ranged from 40 °C to 58 °C as mentioned before to study the effect of the inlet cargo temperature and also the inner pipeline wall temperature to reach PPT after shutdown.

For non-insulated pipe line the heat transfer loss will be higher compared with insulated pipeline make it crude oil to reach PPT faster.

For insulated pipe line 0.5 inch and 1 inch the heat transfer loss will be small compared with non insulated pipeline, crude oil will reach PPT slowly.

From the figure shown, the effect of the temperature of the entry of crude oil in non-insulated pipes As well with at insulation 0.5inch and 1inch, When Increasing T_{in} increases with it PPTRT. at insulation 1inch there is no change in (PPTRT) from 57.6 °C to 58 °C, solution because the rate of heat loss in the tube is very low due to the insulating layer on the pipe.

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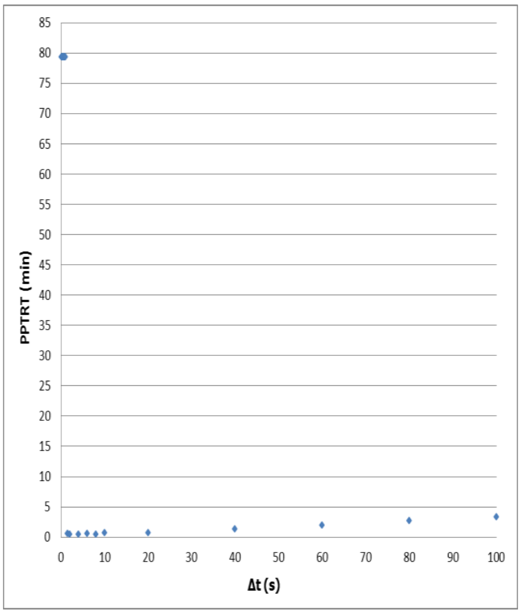

Figure 6: the effect time increment on PPT for no insulated pipeline and 5000 m^3/hr flow rate, Tin 42 ° C.

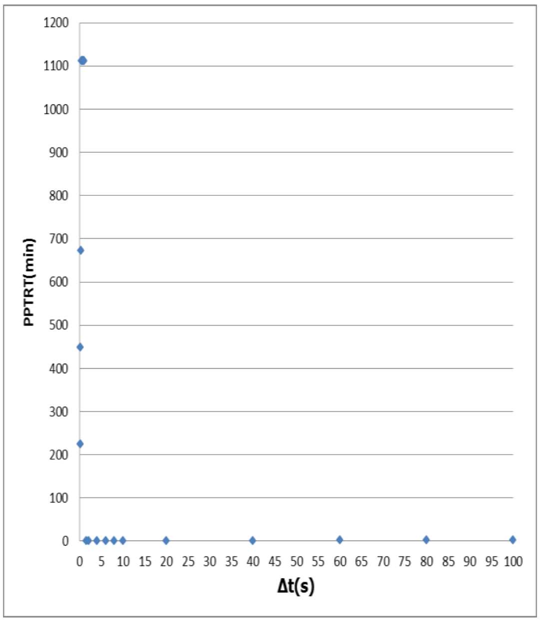

Figure 7: The effect time increment on PPT for 1 inch insulated pipeline and 1000m^3/hr flow rate, Tin 56 ° C.

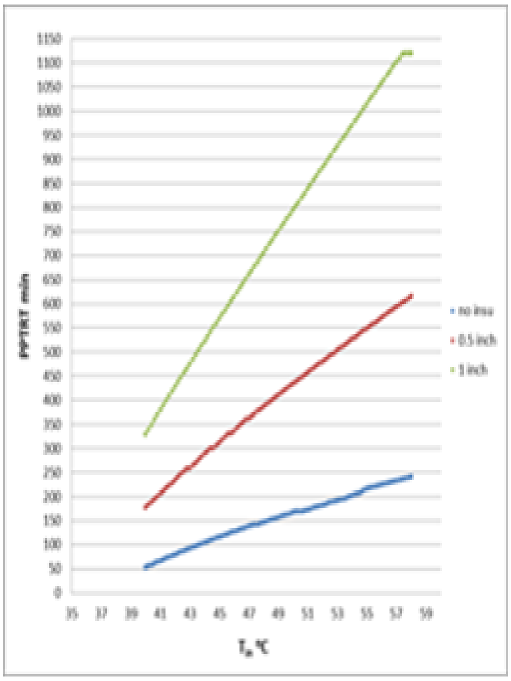

Figure 8: The effect of inlet cargo temperature on the inner wall temperature with 5000 m^3/hr flow rate at no insulation, insulation 0.5 inch, and insulation 1inch.

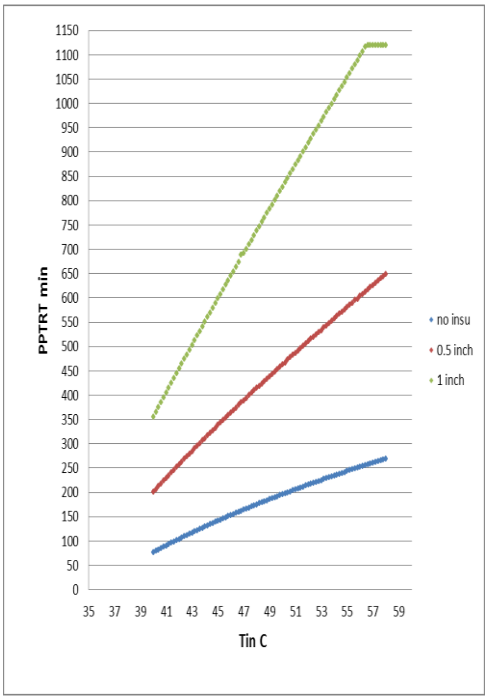

Figure 9: The effect of inlet cargo temperature on the inner wall temperature with 8000 m^3/hr flow rate at no insulation, insulation 0.5 inch, and insulation 1inch

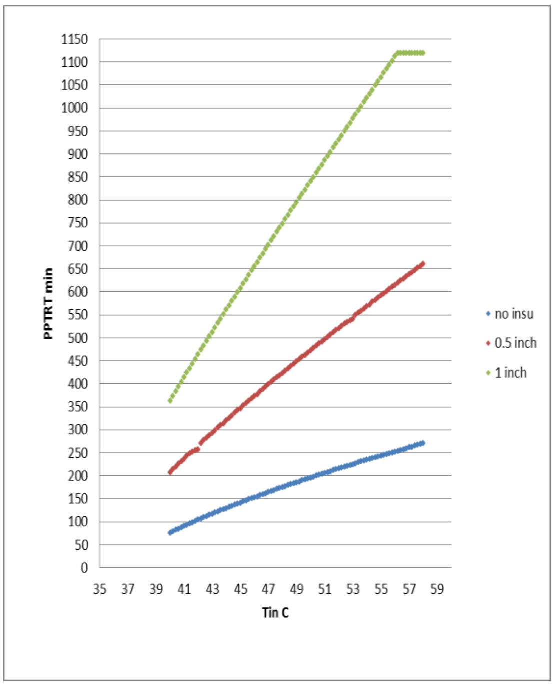

Figure 10: The effect of inlet cargo temperature on the inner wall temperature with 10000 m^3/hr flow rate at no insulation, insulation 0.5 inch, and insulation 1inch

V. CONCLUSIONS

In this study of gel formation in crude oil in pipe line after shutting down, conclude that the temperature has an effect on the process of gel formation with the rate of flow and insulation around the pipes.

The effect of time increment and its importance in the solution and the temperature is very important, When high is better to avoid the appearance of wax in the crude oil inside the pipes, and lack of access to PPT in a faster time.

Flow rate helps to maintain temperature during crude oil transport, as well as the insulation in pipeline.

From the previous results we conclude the following:

1. The effect of time increment (Δt) on PPT We conclude that the solution is limited both In the worst and best case, the effect time increment on PPT for minimum operating condition for non-insulated pipeline and 5000 m^3/hr flow rate, T_{in} 42 ^{o}C and for maximum operating condition The effect of time increment on PPT for 1inch insulated pipeline and 1000 m^3/hr flow rate, T_{in} 56 ^{o}C .

The time increment (Δt) used should be fit or lower than (Δt) maximum criteria .

2. The effect of the input inlet temperature T_{in} on non-insulated pipe line to reach PPT at the flow rate 5000 m^3/hr, 8000 m^3/hr , 10000 m^3/hr .

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3. The effect of the input inlet temperature T_{in} on insulated pipe 0.5inch and 1inch line to reach PPT at the flow rate 5000 m^3/hr , 8000 m^3/hr , 10000 m^3/hr.
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5.By increasing flow rate(Q), the PPT will take more time to appear , and In general idea the insulation thickness is having big effect on the time to reach PPT

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