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Simulation Process of Pipeline Design and Examination The Transportation of Crude Oil Through Three Types of Pipes

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عملية محاكاة لتصميم خط أنابيب وإختيار النوع المناسب من الأنابيب من بين ثلاثة أنواع مختلفة لنقل النفط الخام

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Abstract:
Transporting waxy crude oil through pipelines presents several challenges due to the unique characteristics of the crude oil, including its high paraffin wax content, which can solidify and cause blockages at lower temperatures, leading to the formation of wax crystals inside the pipeline especially in colder climates. This is an actual case study performed by a request of Libyan petroleum company wants to examine the transportation of 1000 bblD of Crude Oil for about 35 km through three pipeline options (Carbon steel “CS”, Thermal Composite Pipe “TCP”, and Insulated TCP) to select the best for this process. The simulation process done by OLGA software and comparison between prices of the three options has been done. The main reason of this simulation and comparison is to find out the best pipeline type with minimum risk of wax deposition inside the pipes side by side with the cost factor. Running the OLGA software was efficient and gave an excellent result to achieve the aims of this study.

Keywords: Waxy Crude Oil, Wax Content, Crude Oil Transporting, Pipeline Design, Olga Simulation.

الملخص:
يُمثل نقل النفط الخام الشمعي عبر خطوط الأنابيب العديد من التحديات بسبب الخصائص الفريدة للنفط الخام، بما في ذلك محتواه العالي من شمع البارافين، والذي يمكن أن يتصلب ويسبب انسدادات في درجات الحرارة المنخفضة، مما يؤدي إلى تكوين بلورات الشمع داخل خط الأنابيب خاصة في المناخات الباردة. هذه دراسة حالة فعلية أجريت بناءً على طلب شركة نفط ليبية تريد فحص نقل 1000 برميل يوميًا من النفط الخام لمسافة 35 كم تقريبًا من خلال ثلاث خيارات لخطوط الأنابيب (الفولاذ الكربوني "CS" والأنابيب المركبة الحرارية "TCP" و TCPالمعزول) لاختيار الأفضل لهذه العملية. تم إجراء عملية المحاكاة بواسطة برنامج OLGA ومقارنة بين أسعار الخيارات الثلاثة. والسبب الرئيسي لهذه المحاكاة والمقارنة هو معرفة أفضل نوع من خطوط الأنابيب مع الحد الأدنى من مخاطر ترسب الشمع داخل أنابيب جنبًا إلى جنب مع عامل التكلفة. كان تشغيل برنامج OLGA فعالًا وأعطى نتائج ممتازة لتحقيق أهداف هذه الدراسة.

الكلمات المفتاحية: النفط الخام الشمعي، نقل النفط الخام، المحتوى الشمعي للنفط، تصميم خط الأنابيب، برنامج أولقا.

Introduction

The selection of pipelines in the petroleum industry is a highly technical process, balancing safety, efficiency, environmental impact, and costs. The right choice of pipeline ensures smooth transportation of oil and gas products while minimizing operational risks and ensuring regulatory compliance. With advancements in technology, the industry continues to evolve in terms of material science, monitoring techniques, and environmental protection measures to improve pipeline performance and safety. The nature of the fluid (e.g., crude oil, natural gas, or refined products) determines the materials and pipeline design. For example, crude oil might require pipelines with more corrosion-resistant materials than natural gas. Longer distances require careful planning in terms of pumping stations and materials to minimize costs and maintain efficiency over long spans [1].

Selecting a pipeline for transporting waxy crude oil requires special considerations to prevent the wax from solidifying, which could lead to blockages and operational downtime. Key factors such as insulation, heat tracing, flow assurance, pipeline diameter, and pressure management all play critical roles in ensuring the successful and efficient transportation of waxy crude oil. Additionally, regular maintenance, monitoring, and the use of chemical additives can help maintain the flow and prevent the formation of wax-related problems. Properly addressing these challenges ensures the safe and efficient operation of pipelines transporting waxy crude oil [2],[3].

Material and methods

This work analysis has been done by using OLGA software and the data entered to software come from the chemical test were carried out the crude oil samples. All tests and treatment of crude oil sample was done in Libyan Petroleum Institute (LPI).

Introduction to OLGA

OLGA (Oil and Gas Simulator) is a sophisticated, dynamic, multiphase flow simulation software developed by Schlumberger, primarily used in the oil and gas industry for simulating and optimizing the behavior of production systems. It is widely recognized for its ability to model complex pipeline and process systems, particularly in offshore and onshore operations where fluids with different phases (oil, gas, water) flow together. OLGA can model complex flow systems, including gas, liquid, and solid phases, which are common in oil and gas pipelines. This feature helps simulate and predict how fluids behave in different pipeline configurations. Moreover, it helps analyze fluid transport through pipelines, considering factors like pressure, flow regime, temperature, and composition. OLGA can simulate flow through both onshore and offshore pipelines, including the behavior of long-distance pipelines. [4],[5],[6]. In summary, OLGA is a powerful tool for professionals in the oil and gas industry, helping them to design, analyze, and optimize fluid transport systems while managing the complexities of multiphase flow in pipelines.

Pipeline Characteristics

Figure (1) below shows the general consideration of pipeline connections in Olga software. All characterizations of pipeline type used in this simulation that include the length, roughness of interior surface, etc. They are interred in the interface of the software. Moreover, to make the calculations more accurate the pipeline section has been divided into 100 sections in this study so the results can be trustable.

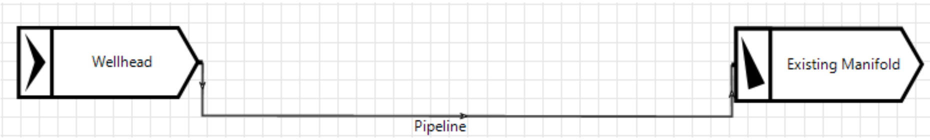


Figure 1. Schematic flow line diagram in the OLGA software.

Process Conditions

In this part below are the operation conditions are considered in this simulation as interring data to Olga software. Also, the inlet and outlet points are considered in the interface of the Olga software, so for Example; the temperature and the fluid flow are identified as inlet components and the pressure selected as outlet component based on the information provided below [7]:

- Pipeline length= 35,000 m (35 km)
- Pipeline depth (horizontal)= 1.7 m
- Environment = Soil at 17 ^{o}C
- Wellhead Pressure= 1305 psi.
- Wellhead temperature= 67 ^{o}C
- Flow rate= 1,000 bbld
- Volumetric flow rate= 169 m^3/d
- Mass flow rate= 5,224.1538 kg/hr and Target temperature= 45 ^{o}C

Specification of the Pipe Options

Three options of pipes available for transport the crude oil. The main specifications of the Pipe options are presented in Table (1). Base on the values of heat transfer coefficients provided in Table (2) the calculations of heat transfer in Olga software can be an important part in the analyzation process. Therefore, coefficients (h_{inwall} & h_{amb}) can be provided in Table (2) (calculation done using Excel file).

Table 1. Specification of the pipe's options [7]

For Carbon Steel				For TCP				For TCP+PUR+PE				
						Properties						
Property	Carbon Steel**			Property	Pipe (TCP)*			Property	Pipe (TCP)*	PUR**	PE***	
Density	7833	kg/m3		Density	1250	kg/m3		Density	1250	35	960	kg/m3
Specific Heat	465	J/kg.K		Specific Heat	1650	J/kg.K		Specific Heat	1650	1500	2100	J/kg.K
Thermal Conductivity	54	W/m.K		Thermal Conductivity	0.6	W/m.K		Thermal Conductivity	0.6	0.022	0.35	W/m.K
						Specifications:						
Nominal Pipe Size (NPS)	4			Nominal Pipe Size (NPS)	4			Nominal Pipe Size (NPS)	4			
OD	4.5	in		OD	4.881889764	in		OD	4.881889764	7.716535433	7.952756	in
	114.3	mm			124	mm			124	196	202	mm
	0.1143	m			0.124	m			0.124	0.196	0.202	m
Thickness (t)	0.337	in		Thickness (t)	0.511811024	in		Thickness (t)	0.511811024	1.417322835	0.11811	in
	8.5598	mm			13	mm			13	36	3	mm
	0.0085598	m			0.013	m			0.013	0.036	0.003	m
ID	3.826	in		ID	3.858267717	in		ID	3.858267717	4.881889764	7.716535	in
	97.1804	mm			98	mm			98	124	196	mm
	0.0971804	m			0.098	m			0.098	0.124	0.196	m
Roughness (e)	0.05	mm		Roughness (e)	0.01	mm		Roughness (e)	0.01	Insulation	Coat	mm
Schedule	80	a										
	XS	b										
	80S	c										
Notes:	*The density of TCP (Thermoplastic Composite Pipe) made by Fibron Pipe typically ranges from about 1.0 to 1.5 g/cm³.											
	*The specific heat capacity can vary, but it is generally around 1.3 to 2.0 J/g·°C.											

Table 2. Overall heat transfer coefficient calculations (U).

For Carbon Steel					For TCP					For TCP+PUR+PE		
Crude Oil Properties	value	unit			Crude Oil Properties	value	unit			Crude Oil Properties	value	unit
Mwt (Molecular. Wt)	151.58				Mwt (Molecular. Wt)	151.58				Mwt (Molecular. Wt)	151.58	
Cp (Specif. heat)	361.81	J/mol.K			Cp (Specif. heat)	361.81	J/mol.K			Cp (Specif. heat)	361.81	J/mol.K
	2386.924396	J/kg.K				2386.924396	J/kg.K				2386.924396	J/kg.K
K (Thermal. Cond.)	0.11209	W/m.K			K (Thermal. Cond.)	0.11209	W/m.K			K (Thermal. Cond.)	0.11209	W/m.K
Density	783	kg/m3			Density	783	kg/m3			Density	783	kg/m3
viscosity	0.00257	Pa.s (kg/m.s)			viscosity	0.00257	Pa.s (kg/m.s)			viscosity	0.00257	Pa.s (kg/m.s)
Q (vol. flow rate)	159	m3/day			Q (vol. flow rate)	159	m3/day			Q (vol. flow rate)	159	m3/day
	0.001840278	m3/sec				0.001840278	m3/sec				0.001840278	m3/sec
Pipe Specifications					Pipe Specifications					Pipe Specifications		
OD	114.3	mm			OD	124	mm			OD	124	mm
	0.1143	m				0.124	m				0.124	m
ID	97.1804	mm			ID	98	mm			ID	98	mm
	0.0971804	m				0.098	m				0.098	m
K (Thermal. Cond.) C.S.	54	W/m.K			K (Thermal. Cond.) TCP	0.6	W/m.K			K (Thermal. Cond.) TCP	0.6	W/m.K
Overall Heat Transfer Coefficient Calculations:					Overall Heat Transfer Coefficient Calculations:					OD1	196	mm
A (cross.s.area)	0.007484394	m2			A (cross.s.area)	0.00761117	m2				0.196	m
v (avg. velocity)	0.245882005	m/sec			v (avg. velocity)	0.24178645	m/sec			ID1	124	mm
Re (Ryenold No.)	7280.04506	[-]			Re (Ryenold No.)	7219.160111	[-]				0.124	m
Pr (Prandtle No.)	54.72741278	[-]			Pr (Prandtle No.)	54.72741278	[-]			K (Thermal. Cond.) PUR	0.022	W/m.K
Nu (Nusselt No.)	140.1900068	[-]			Nu (Nusselt No.)	139.2512628	[-]			OD2	202	mm
hi (Heat	161.6982217	W/m2.K			hi (Heat	159.2721841	W/m2.K				0.202	m

trans. Coeff.)					trans. Coeff.)							
ho (soil heat trans. Coeff.)	5	W/m2.K			ho (soil heat trans. Coeff.)	5	W/m2.K			ID2	196	mm
Ri (Interna. Resistance)	0.020266858				Ri (Interna. Resistance)	0.020403484					0.196	m
Ro (Outer. Resista	0.557255184				Ro (Outer. Resistance)	0.513663448				K (Thermal. Cond.)PE	0.35	W/m.K
Rs (Sectional Resistance)	0.000478466				Rs (Sectional Resistance)	0.06245066				Overall Heat Transfer Coefficient Calculations:		
Uo	4.820542334	W/m2.K			Uo	4.305518014	W/m2.K			A (cross.s.area)	0.00761117	m2

Crude oil properties and characterizations

The crude oil properties presented in Table 3, obtained from the Libyan Petroleum Institute, reveal key insights into the composition, processing behavior, and potential applications of the analyzed sample. With a cut yield volume of 100%, the crude demonstrates excellent distillable potential, while its low sulfur content (0.0623%) classifies it as sweet crude, favoring reduced environmental emissions and minimal refining challenges. The predominance of naphthenes (74.437%) and paraffins (24.209%), with no detectable aromatics or olefins, suggests a chemically stable and relatively unreactive feedstock suitable for producing high-quality naphtha and middle distillates. Flow properties are favorable, with a kinematic viscosity of 5.824 cSt and dynamic viscosity of 0.00475 Pa·s at 50°C, enabling ease of transportation and refining.

Table 3. Crude oil properties and characterization [7].

I	Property (Unit)	Value
1	Cut Yield Vol (%)	100
2	Std Liquid Density (kg/m^3)	815.954
3	Sulfur Wt. (%)	0.0623
4	Kinematic Viscosity (cSt)@ 50 (C)	5.824
5	Paraffins Wt. (%)	24.209
6	Naphthenes Vol. (%)	74.437
7	Olefins Vol. (%)	0.00
8	Arom. Vol. (%)	0.00
9	Pour Point (C)	55.681
10	Freeze Point (C)	40.434
11	Cloud Point (C)	63.299
12	Smoke Pt (m)	0.0239
13	Nitrogen wt. (%)	0.0868
14	Vanadium Wt. (%)	2.1E-05
15	Ash Wt. (%)	0.190
16	RON Clear	2.9102
17	MON Clear	8.596
18	Molecular Weight	327.030
19	Dynamic Viscosity (Pa-s) @ 50 (C)	0.00475
20	Wax Content (%)	27
21	Watson K	12.732
22	Asphaltene Wt. (%)	0.270
23	Sodium Wt. (ppm)	438

However, the relatively high pour point (55.681°C) and freeze point (40.434°C) imply a susceptibility to solidification under low temperatures, necessitating heating or blending strategies for cold climate handling. The low ash (0.190%), vanadium, and sodium contents indicate manageable levels of inorganic contaminants, while the smoke point and RON/MON values reflect limited suitability for direct gasoline blending without upgrading. The Watson K factor of 12.732 further confirms the crude's paraffinic nature, which is advantageous for lubricant and wax production. The low asphaltene content (0.270%) is beneficial in reducing coke formation during thermal processing, although the high wax content (27%) highlights the need for pour point depressants or thermal management during handling. Overall, the crude oil sample is a high-quality, sweet, paraffinic feedstock with favorable refining attributes, albeit requiring operational considerations due to its waxy nature and high solidification temperatures.

Results and discussion

Option 1 (Carbon Steel pipe-CS)

Carbon steel pipe used for oil and gas transmissions Standard: API SPEC 5L, ISO 3183, EN10208. Profile in Figure (2) at a given flow rate, presents the pressure and temperature of crude oil along the pipeline length. Due to the heat loss from the surrounding area of the pipe surface, the temperature of crude oil flowing inside decreased gradually along the length of the pile especially at the first section up to 18.2 °C at 10,069.3 m. as a result of that the wax precipitated inside the pipe causing an increasing in the value of pressure drop inside the system. Consequently, the pipeline length to the target temperature (45 °C) was 1195m.

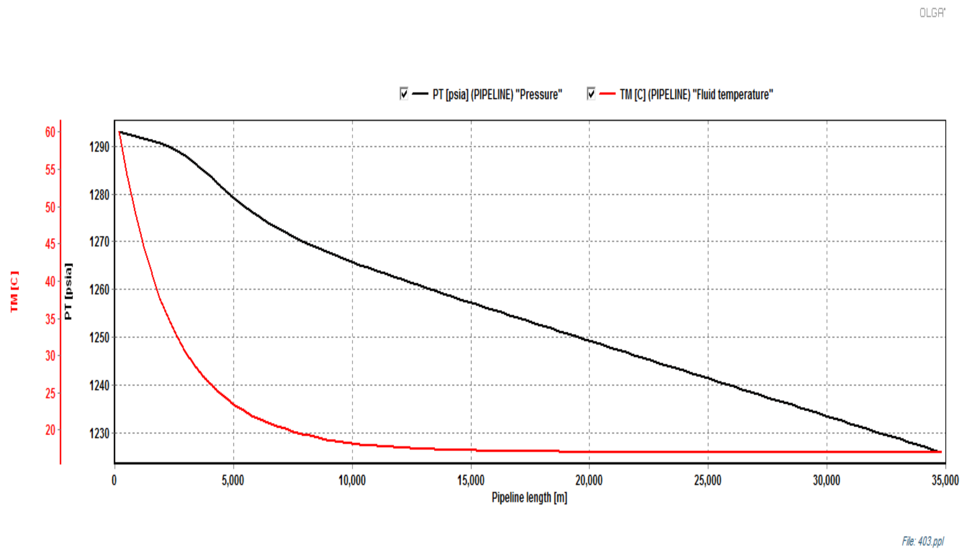


Figure 2. Profiles of the pressure and temperature of the crude oil along the pipeline (Option 1-CS)

The wax deposition principal results from the most important temperature change between the fluid flow inside the pipe and the outside atmosphere. The wax layer thickness deposited on the pipe wall and wax mass participation rate is shown in Figure (3). The process of wax formation starting when the temperature of fluid flow become very close to the corresponding WAT value (51.06 °C) at 616 m with a wax mass participation rate 1.87E-5 kg/s. this will lead to leads to increase the roughness of inside surface of the pipe and a cause to reduce the effective flow area (the diameter of the pipe). The growth of wax increased up to the maximum value at L= 4025 m with 18.4633 mm at wax mass participation rate 0.0045971 kg/s, then gradually decreased up to 1.04E-05 kg/s with a thickens reaches 0.011497 mm at length 23,975 m, then gained a very low thickness till the end of the pipeline.

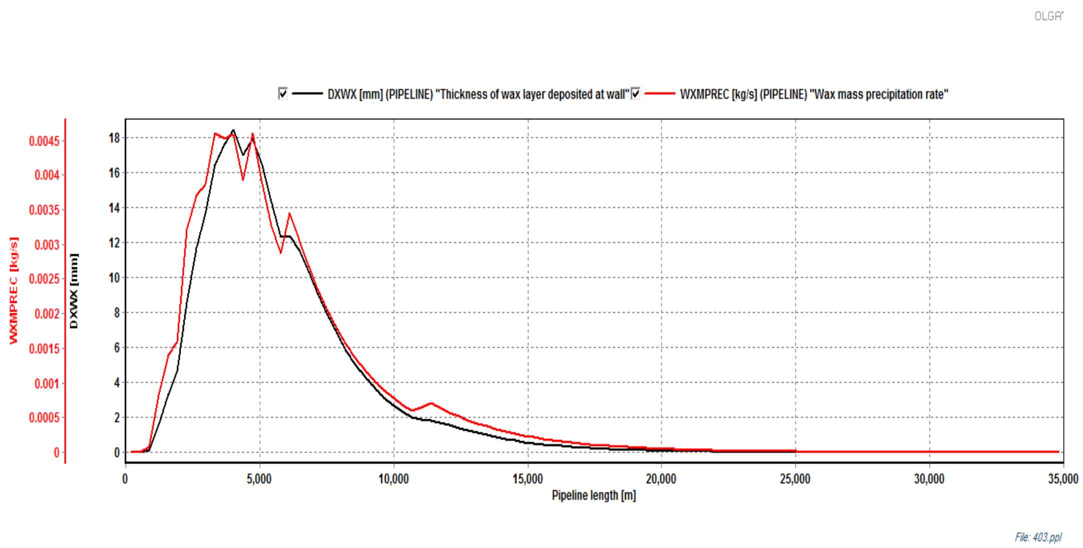


Figure 3. Profiles of the wax layer thickness deposited on the pipe wall, and wax mass participation rate along the pipeline (Option 1- CS)

The simulation process showed that the temperature of the inner pipe wall was less than the wax appearance temperature obtained (51.09 ºC), where a clear increasing in the amount of wax formation is observed causing a decreasing of the mass of wax dissolved in the crude oil as shown in Figure (4) in the first section of the pipeline then increased gradually because the difference in temperature between the fluid flow and the outside atmosphere is too small (negligible) and the flow prevent settle of the wax at the inside surface of the pipe. The increasing in wax thickness in the first section of the pipe line comes from the value of thermal conductivity of the pipe material which actually high. Moreover, the decrease in superficial velocity of the crude oil is attributed to the significant change of bulk temperature observed in such first sections, affecting the density of the liquid phase (crude oil), which is correlated to the superficial velocity. Also, the volumetric flow rate of crude oil reduced gradually due to the deposition of wax at the wall.

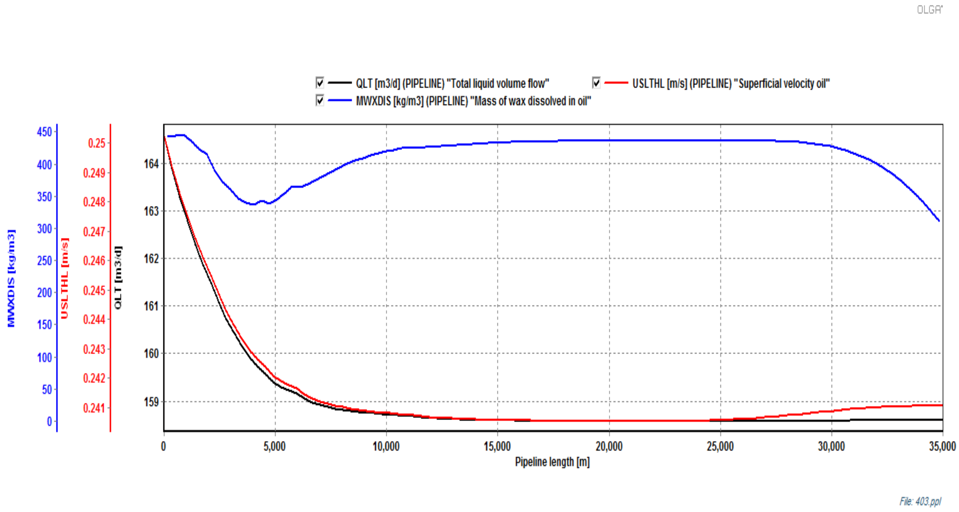


Figure 4. Profiles of mass of wax dissolved in oil, volumetric flow rate, and superficial velocity of crude oil (Option-1 CS)

There was a clear increase in the value of viscosity of crude oil which comes from decreasing the temperature of bulk flow of oil as a result of losing an amount of heat to the ambient through the pipe thickness which consequently, will lead to the formation of wax crystals. Therefore; the oil viscosity increases and tends to transform the crude oil from Newtonian to non-Newtonian behavior as shown in Figures (5 and 6).

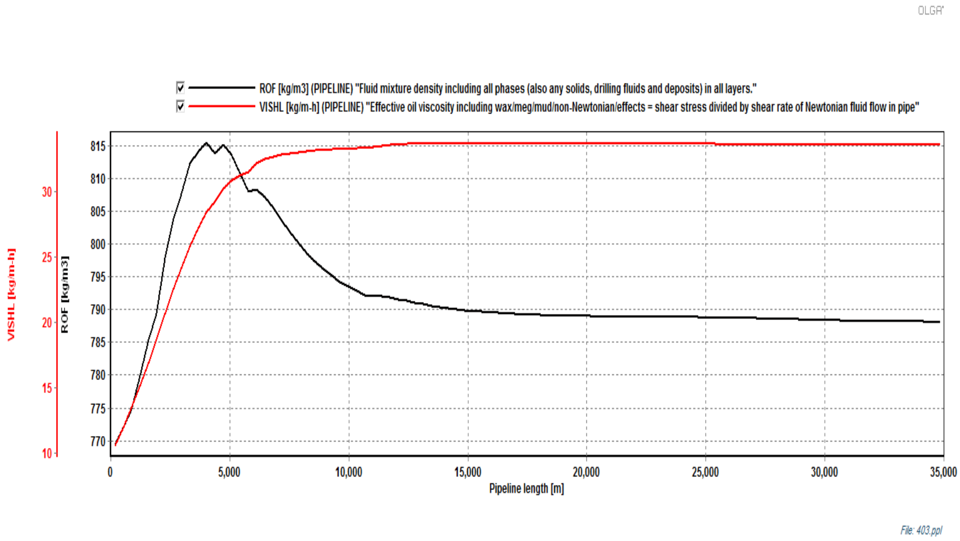


Figure 5. Profiles of viscosity and density of the crude oil along the pipeline (Option 1- CS)

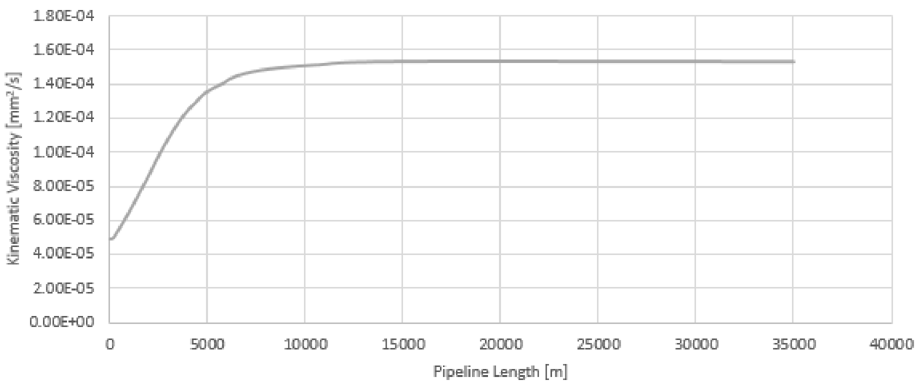


Figure 6. Profile of Kinematic viscosity profile of the crude oil along the pipeline (Option 1- CS)

More details of data presented in Results presented in Table (C.1) for Option 1. The main results of this option are summarized in Table (3).

Table 3. The brief results of the pipeline (Option 1- Carbon Steel)

Data	Unit	Inlet (L_i=0 m)	Outlet (L_f= 35,000 m)	Difference (L_f-L_i)
Pressure	psi	1305	1225.568	-79.432
Temperature	°C	67	17.011	-49.989
Volumetric flow rate	m^3/d	164.579	158.5986	-5.9804
Superficial Velocity	m/s	0.25026	0.241073	-0.009187
Mass of wax dissolved in oil	kg/m^3	442.9157	311.9194	-130.9963
Kinematic Viscosity	mm^2/s	4.88778E-05	1.53E-04	0.000104122
Pipeline	**Unit**	**Value**		
Flow Regime	-	Satisfied		
Wax Appearance Temperature	°C	51		
Pipe length to target temperature (45 °C)	m	1,195		
Pipe length to start Wax participate	m	616		
Pipe length to maximum Wax deposition thickness	m	4,025		
Maximum Wax mass participation rate	kg/s	0.0045971		
Maximum Wax deposited thickness	mm	18.4633		

Option 2 (TCP pipe)

The same behavior occurs here by using TCP pipe; identical to the presented results for CS, with different values as shown in Figures (7-11) and Table (4). This trend occurs due to reducing the overall heat transfer coefficient (U) from 5 W/m^2.K for CS to 4.305 W/m^2.K by TCP as construction material of the pipeline with low roughness (0.01 mm) that leading to reduce the heating loss from the bulk to the ambient. More details of the results are shown in Table (C.2) for Option 2.

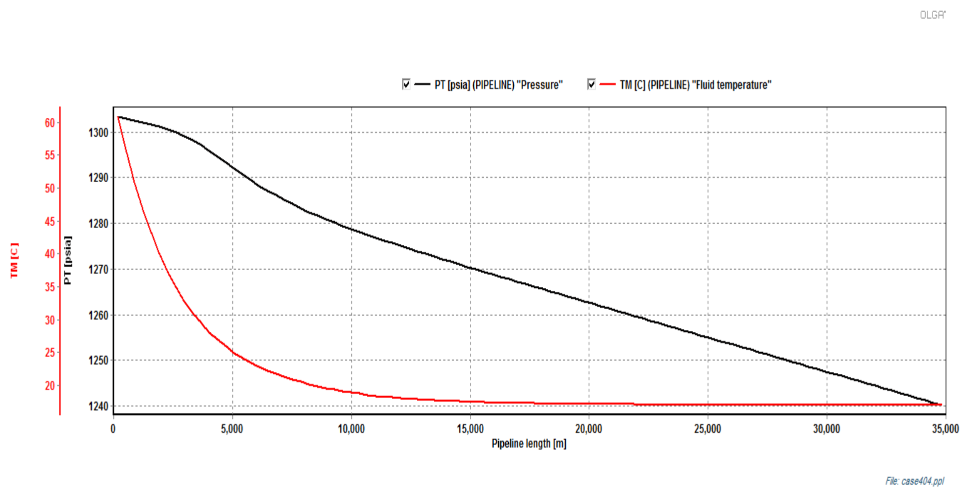


Figure 7. Temperature and pressure profiles of the crude oil along the pipeline (Option 2-TCP)

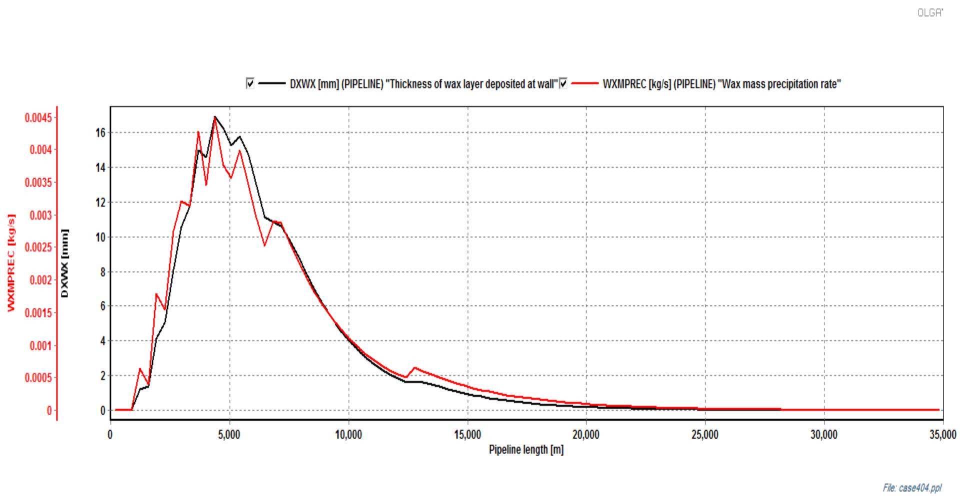


Figure 8. The thickness of wax layer deposited on the interior pipe surface, and the mass of wax formation rate along the pipeline (Option 2- TCP)

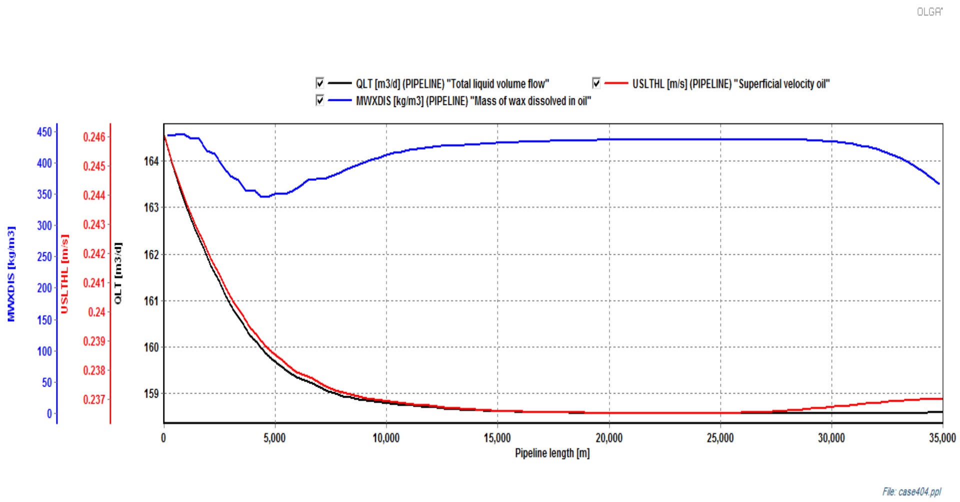


Figure 9. Profiles of mass of wax dissolved in oil, volumetric flow rate, and superficial velocity of crude oil along the pipeline (Option-2 TCP).

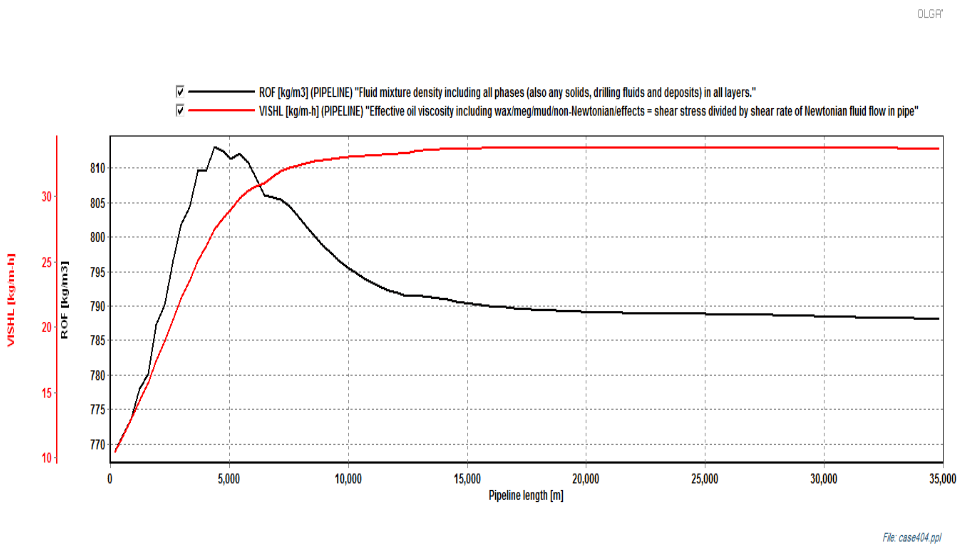


Figure 10. Density and Viscosity profiles of the crude oil along the pipeline (Option 2- TCP)

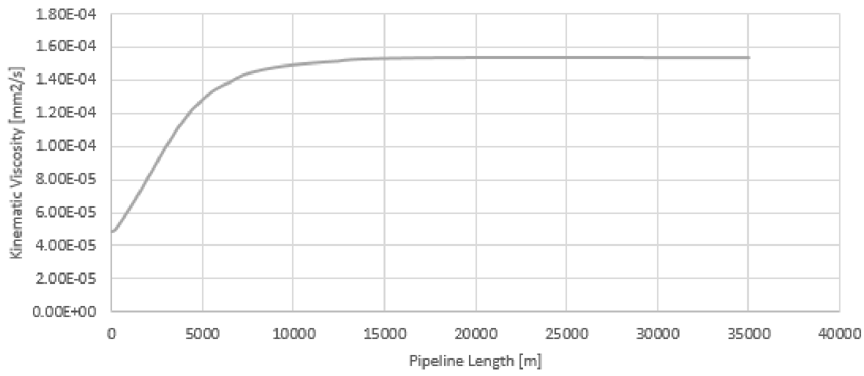


Figure 11. Profile of Kinematic viscosity profile of the crude oil along the pipeline (Option 2- TCP).

Table 4. The brief results of the pipeline (Option 2- TCP)

Data	**Unit**	**Inlet (L_i=0 m)**	**Outlet (L_f= 35,000 m)**	**Difference (L_f-L_i)**
Pressure	psi	1305	1240	-65
Temperature	ºC	67	17	-49.988
Volumetric flow rate	m^3/d	164.567	158.584	-5.983
Superficial Velocity	m/s	0.2461	0.237	-0.0091
Mass of wax dissolved in crude oil	kg/m^3	442.991	365.999	-76.992
Kinematic Viscosity	mm^2/s	4.81E-05	0.000153773	0.000105615
Pipeline	**Unit**	**Value**		
Flow Regime	-	Satisfied		
Wax Appearance Temperature	ºC	51		
Pipe length to target temperature (45 ºC)	m	1,370		
Pipe length to start Wax participate	m	876		
Pipe length to maximum Wax deposition thickness	m	4,375		
Maximum Wax mass participation rate	kg/s	0.004499		
Maximum Wax deposited thickness	mm	16.9258		

Option 3 (Insulated TCP pipe)

The same behavior occurs here by using insulated TCP pipe; identical to the presented results for TCP, with different values as shown in Figures (12 -16) and Table (5). This trend occurs due to reducing the overall heat transfer coefficient (U) from 4.305 W/m^2.K for TCP to 0.423 W/m^2.K by insulated TCP as construction material of the pipeline by TCP with insulation and coat that leading to reduce the heating loss from the bulk to the ambient. Generally, notes that, a thickness of the wax deposited at wall has a wavy behavior as shown in Figure (13), this trend due to decrease in heat loss leads to the wax crystals forming, therefore; the oil viscosity increases and tends to transform the crude oil from Newtonian to non-Newtonian behavior due to presence of the wax dissolved in the crude oil as shown in Figure (15).

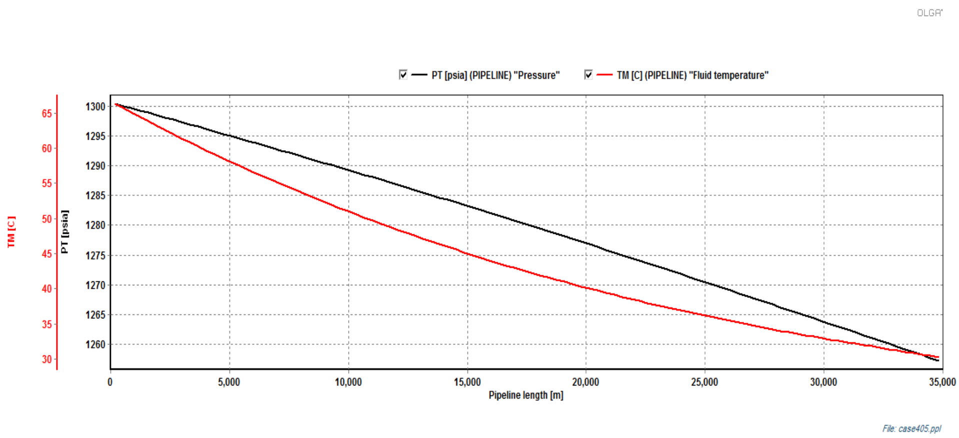


Figure 12. Temperature and pressure Profiles of the crude oil along the pipeline (Option 3-Insulated TCP).

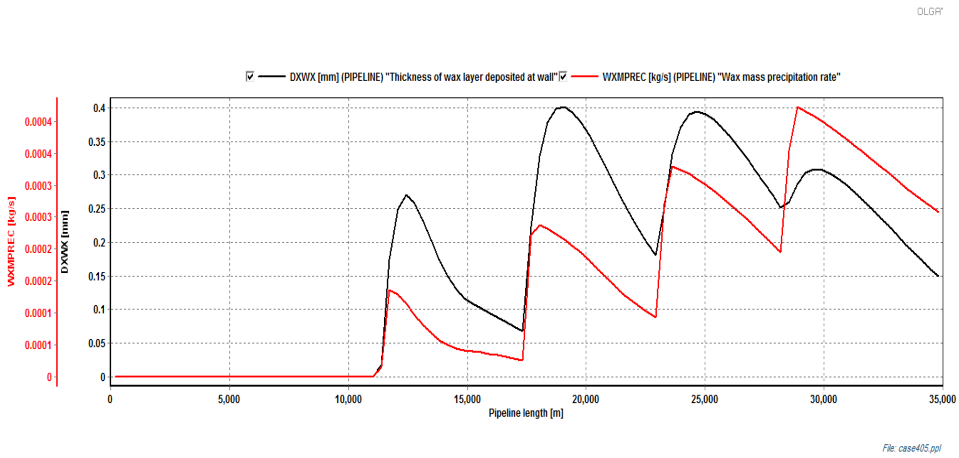


Figure 13. The thickness Profiles of the wax layer formed on the interior pipe surface, and wax mass formation rate along the pipeline (Option 3- Insulated TCP)

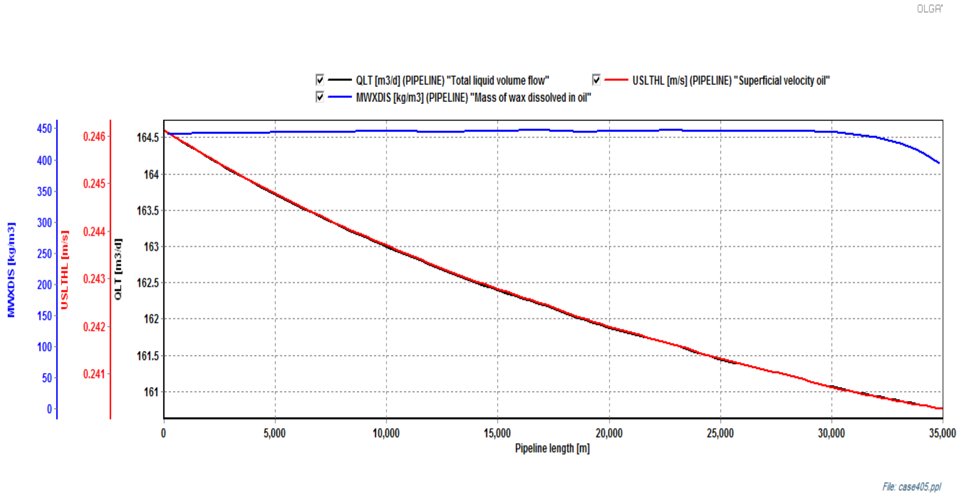


Figure 14. Profiles of mass of wax dissolved in oil, volumetric flow rate, and superficial velocity of crude oil along the pipeline (Option-3 Insulated TCP)

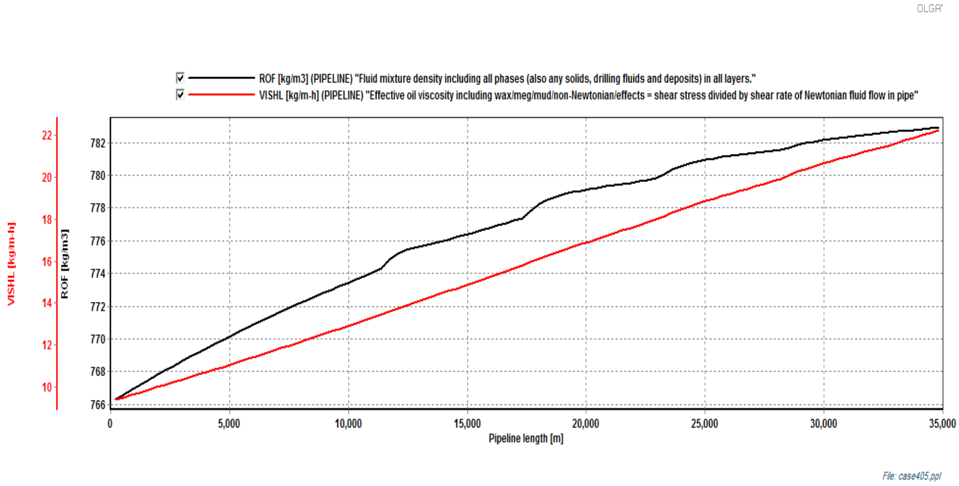


Figure 15. Density and Viscosity Profiles of the crude oil along the pipeline (Option 3- Insulated TCP)

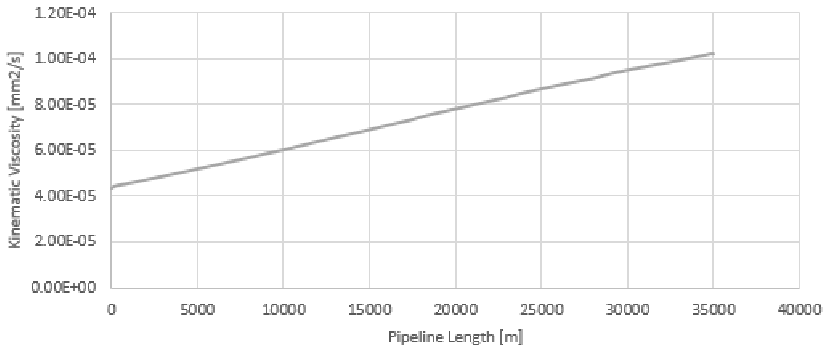


Figure 16. Profile of Kinematic viscosity profile of the crude oil along the pipeline (Option 3- Insulated TCP)

Table 5. The brief results of the pipeline (Option 3- Insulated TCP).

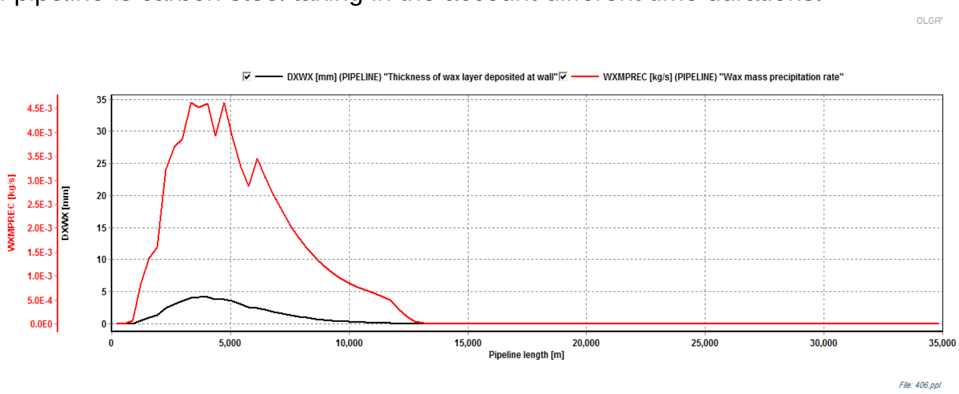
Data	**Unit**	**Inlet (L_i=0 m)**	**Outlet (L_f= 35,000 m)**	**Difference (L_f-L_i)**
Pressure	psi	1305	1257	-48
Temperature	°C	67	30.24486	-36.75514
Volumetric flow rate	m^3/d	164.6	160.76	-3.84
Superficial Velocity	m/s	0.2461	0.2403	-0.0058
Mass of wax dissolved in oil	kg/m^3	441.3334	394.5929	-46.7405
Kinematic Viscosity	mm^2/s	4.31724E-05	0.000102273	5.91006E-05
Pipeline	**Unit**	**Value**		
Flow Regime	-	Satisfied		
Wax Appearance Temperature	°C	51		
Pipe length to target temperature (45 °C)	m	15,013		
Pipe length to start Wax participate	m	11,027.4		
Pipe length to maximum Wax deposition thickness	m	19,046.8		
Maximum Wax mass participation rate	kg/s	0.000421 (at 28,934.1 m)		
Maximum Wax deposited thickness	mm	0.401 at (19,046.8 m)		

Wax deposition

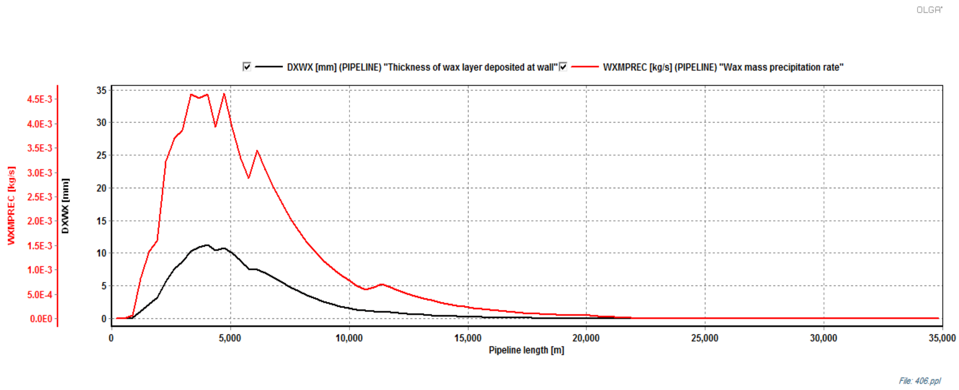
This part of study will look for the thickness of wax layer formation along the interior wall of the pipeline for the all distance (35 km) taking in the account the time required to achieve the maximum thickness for the three types of pipes considered in the OLGA®. Simulation analysis.

Wax deposition profile

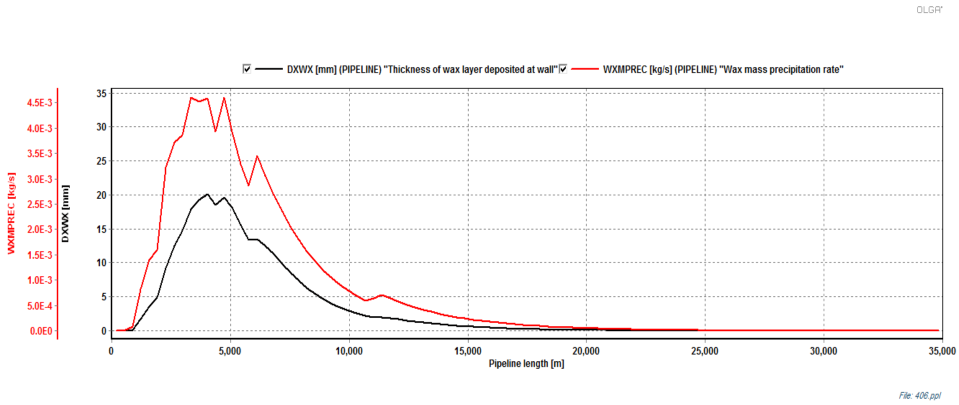
This part of analysis will show the thickness of wax layer formed on the interior surface of the pipeline for the three cases considered in OLGA® simulation running. Figure (17) presents the thickness of wax layer formed on the interior surface of the pipeline for the first option of this study that considered the material of pipeline is carbon steel taking in the account different time durations.



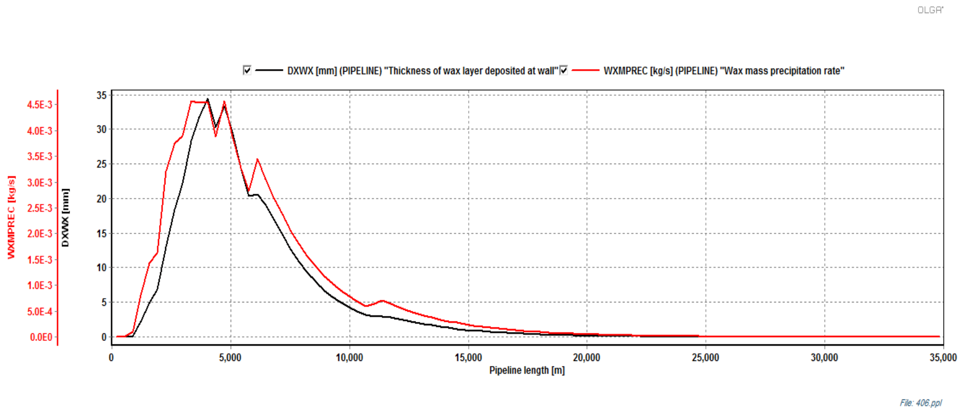
0.6 day



1.2 days



1.8 days



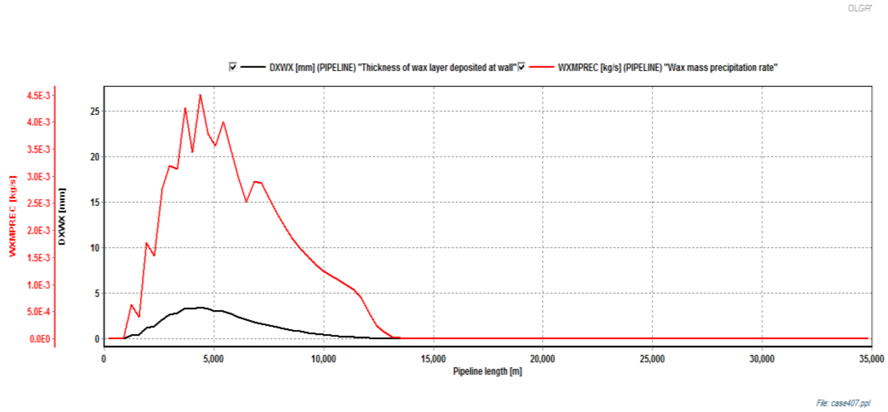
2.4 days

Figure 17. Wax deposition profile of Option 1 (Carbon steel pipe)

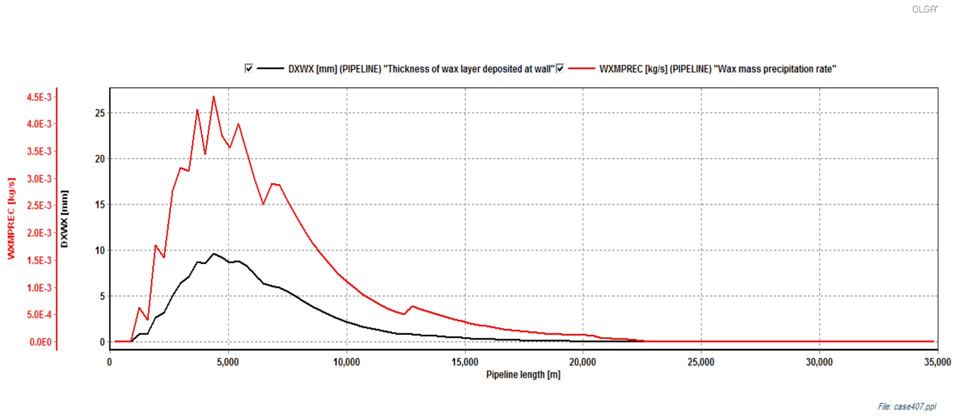
In general, when the temperature of pipe wall surface decreases to the value of wax appearance temperature (WAT) the first point of wax deposition was obtained. The maximum of wax precipitated layer has been shown by Olga simulation analysis. And also, the analysis has shown the maximum difference in temperature between the bulk flow and the outside atmosphere which causes the wax layer achieves its maximum thickness. On the other hand, when the thermal equilibrium occurs, this difference will decrease to the value of zero. The same behavior will be shown for wax deposition profile as shown in Olga outcomes presented in the above explanation. This behavior identical with the obtained results by F. Montero [3].

In addition, the OLGA® simulation analysis shows how the thickness layer of wax formed inside the pipeline change along the pipe length where after the layer achieves its maximum thickness starts to decrease continuously to value of zero where this behavior explained in the above section for the difference of wax precipitated temperature between the bulk flow and the ambient which seems to be the responsible for the shape presented by the deposit wax layer.

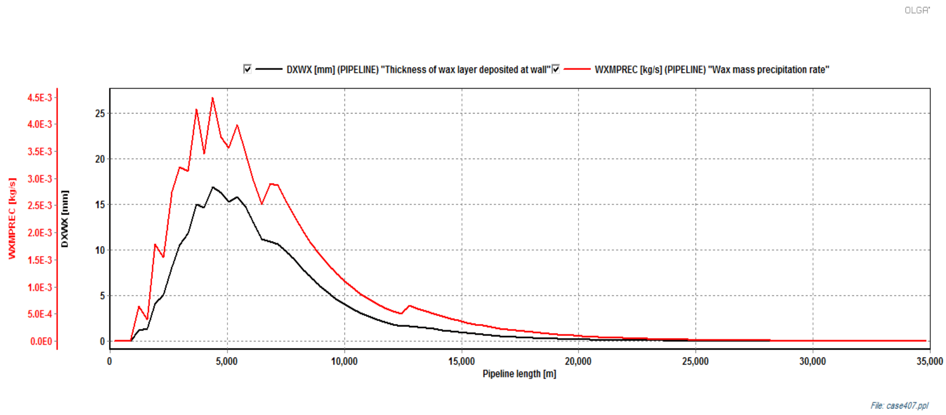
For the first option (Carbon steel pipe), after 2.55 days, the pipeline will be clogged at the first section of the pipeline as shown in Figure (17) if methods to reduce wax formation are not used. This trend due to the wax deposited on the inner wall, reaches 32.1mm. The same behavior is presented in Figure (18) that shows the obtained results of wax layer thickness along the pipeline for this case (Option 2 for TCP pipe) at different time periods.



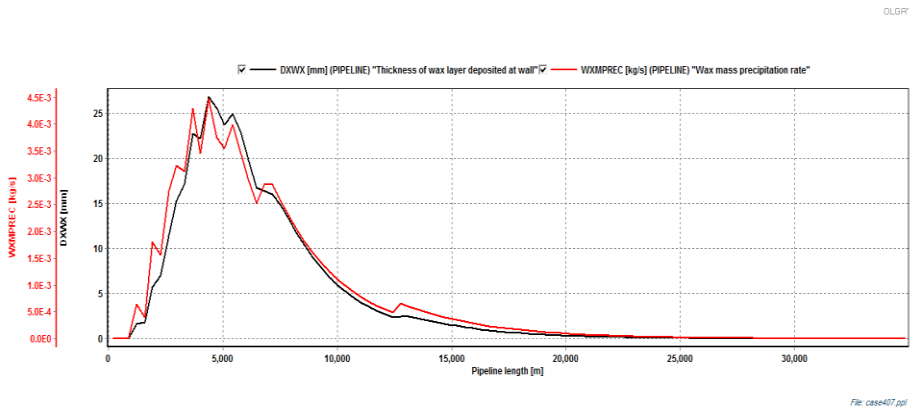
0.6 day



1.2 days



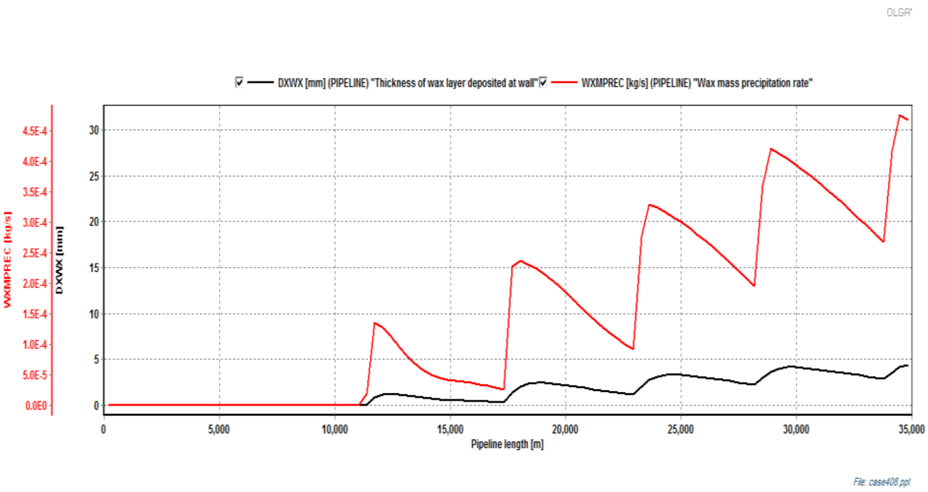
1.8 days



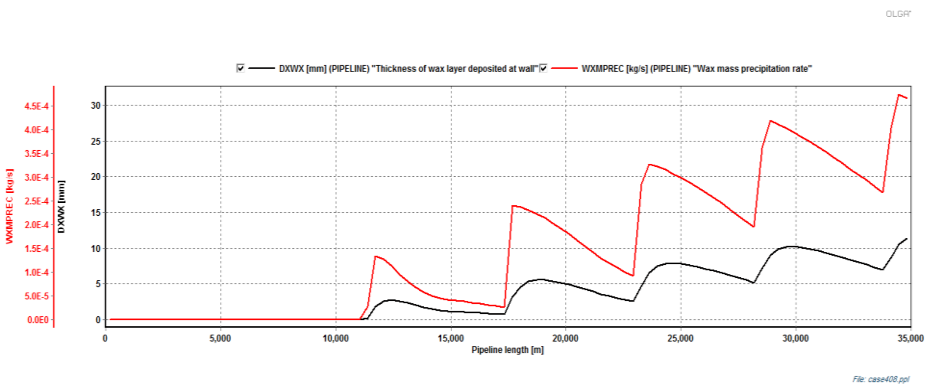
2.4 days

Figure 18. Wax deposition profile of Option 2 (TCP pipe)

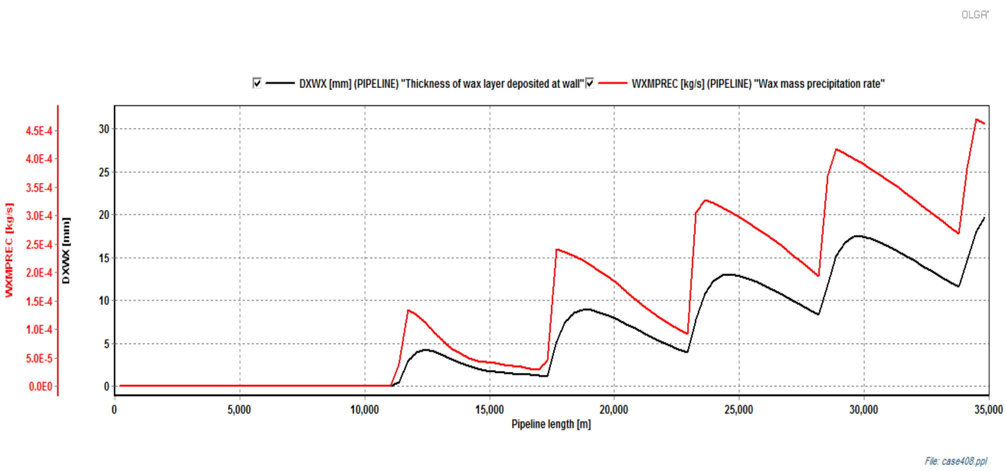
For the second option (TCP), before reaches 3 days at 2.88 days, the pipeline will be clogged at the first section of the pipeline as shown in Figure (18) if methods to reduce wax formation are not used. This trend due to the wax deposited on the inner wall, reaches 22.26 mm. Finally, Figure (19) shown the results of wax layer thickness along the pipeline for this case of study that related to one of the options of study (Option 3 for insulated TCP pipe) at different time durations.



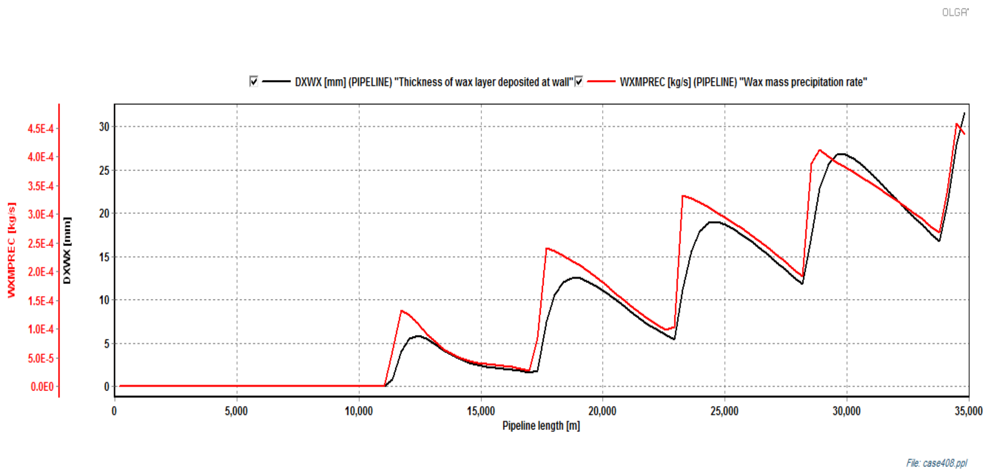
6 days



12 days



18 days



24 days

Figure 19. Wax deposition profile of Option 3 (Insulated TCP pipe)

For the third option (Insulated TCP pipe), after 28 days, the pipeline will be clogged at the last section of the pipeline as shown in Figure (19) if methods to reduce wax formation are not used. This trend due to the wax deposited on the inner wall, reaches 45.694 mm. For the three cases when the results compared a stratified flow obtained with study cases options. Moreover, a clear difference is presented regarding the wax layer thickness where option (3) (Insulated TCP) showed the lowest of wax layer which consequently comes from the small difference in temperature between the crude oil (Bulk) and the ambient revealing this pipeline having a lower heat transfer coefficient compared to other options.

The assessment of Wax deposition with time

In this part of study, the three types of pipes will be tested by OLGA® software to find out the best option regarding the wax deposition and the thickness of wax layer will be occur by considering the factor of time. In the study cases related to options selected, the analyses of the wax deposition assessment with time are performed for different durations. But, for study cases related to main cases (Option 1 CS, Option 2 TCP, & Option 3 Insulated TCP), the wax evolution analyses are done for the front section, further the wax deposition appears. For options 1 & 2 is the front section, while for the option 3 is the last section.

These analyses shown in Figures (20-22) for three options respectively. The results showed for the options studied that related to the main cases (option 1 -CS & option 2 -TCP) consider the increasing trend of the first point where the wax layer begin to appear in the. Moreover, for option 3 – Insulated TCP wax layer begin to appear in the pipeline or the last of the wax deposition layer.

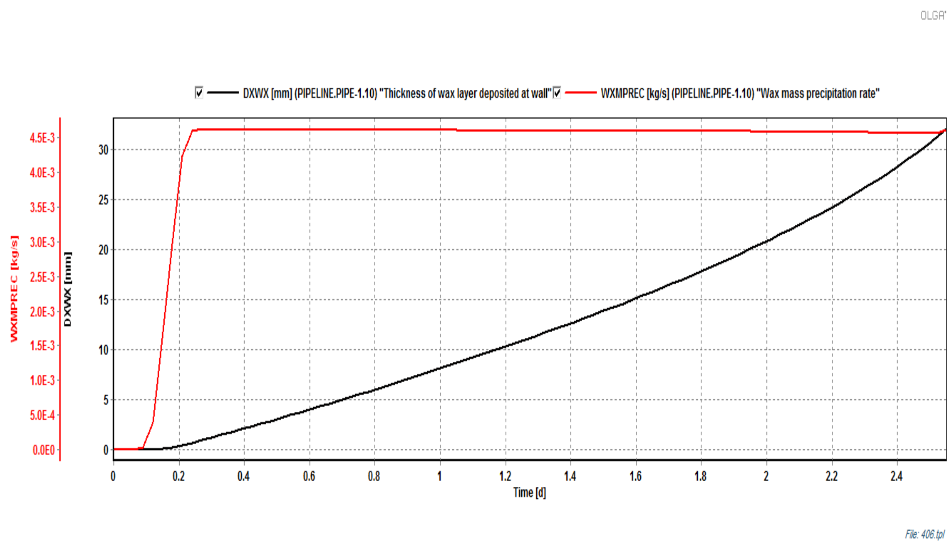


Figure 20. Wax deposition trend of Option 1 CS (The front section of the pipeline)

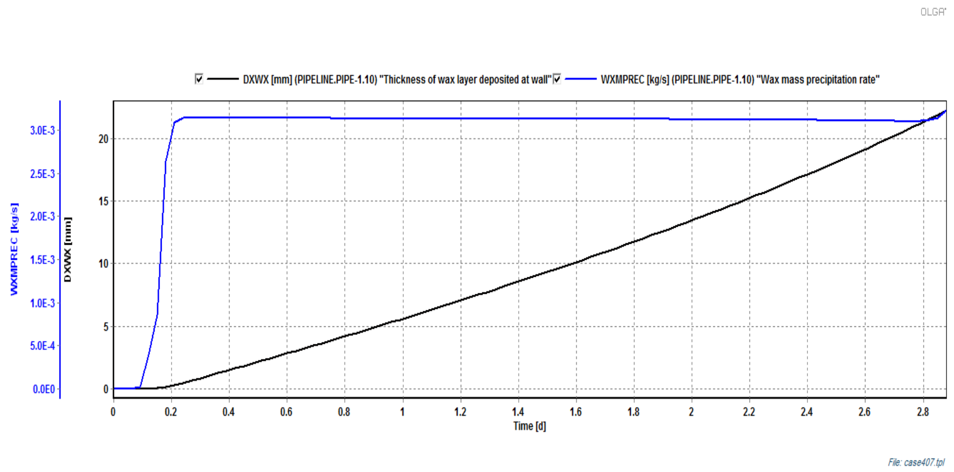


Figure 21. Wax deposition trend of Option 2- TCP pipe (The front section of the pipeline)

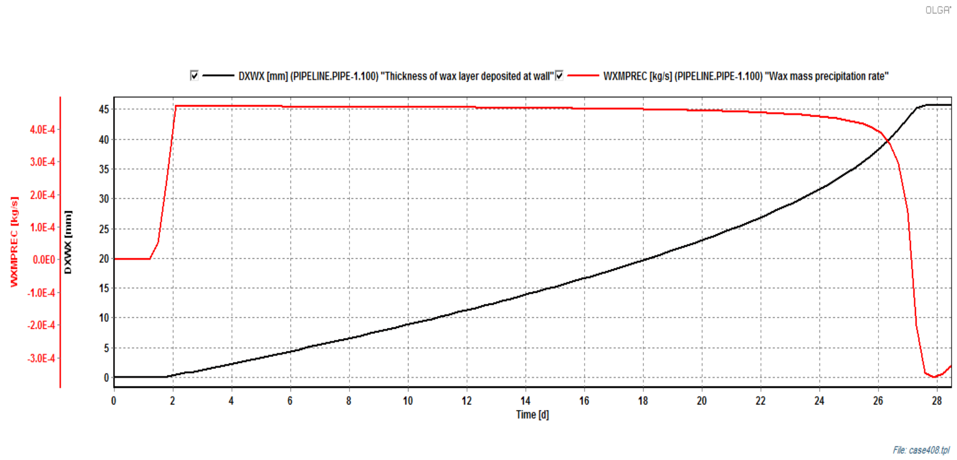


Figure 22. Wax deposition trend of Option-3 Insulated TCP pipe (The last section of the pipeline).

Since the expanding trend exhibits more asymptotic behavior after number of days of deposition, the previously described exponential-like tendency followed by OLGA® software may be readily seen in the results pertaining to days of deposition time. OLGA generally exhibits an exponential growth tendency in wax precipitation at the maximum thickness of the wax layer. This behavior is connected to the heat transfer phenomenon's ongoing modifications throughout time. These alterations are caused by the constant deposition of wax on the pipe's inner surface, which lowers the gap between the bulk flow and wall temperatures via altering the overall heat transfer coefficient (OHCT). These alterations are caused by the constant deposition of wax on the pipe's inner surface, which lowers the gap between the bulk and wall temperatures via altering the overall heat transfer coefficient (OHCT). Furthermore, it's critical to realize that a fresh inner wax layer creates a thermal isolating effect by covering both the wall surface and the layers that were previously deposited. Consequently, this lowers the temperature differential between the pipeline's new inner surface and its bulk, which lessens the force that drives the wax deposition phenomenon.

Pipeline Cost Estimation

Carbon steel cost estimation

The costs of the pipe material and the actual installation or labor charges make up the pipeline cost. The entire cost of pipe material can be computed using the price per ton of pipe material. Determine the labor cost for building the pipeline in addition to the construction cost per unit length of pipe. Also, calculation of labor cost for installing the pipeline is required. The cost of pipe required for a given pipeline length is found as [8];

$$PMC = 0.0246(D - T)TLC \quad (1)$$

Where;

PMC = pipe material cost, $

L = length of pipe, km

D = pipe outside diameter, mm.

T = pipe wall thickness, mm.

C = pipe material cost, \$/ton (\$/ton 2,600)
For Carbon steel type API 5L X70 Pip, and SCH No. 80 XXS [9].
So, for this case;

$$\text{PMC} = 0.0246\ (114.3 - 8.5598)8.5598 * 35 * 1750 = \$\ 2{,}026{,}190.358$$

Dollars per pipe length can be used to reflect the labor cost of installing the pipeline. In a specific construction setting, the labor cost for a given size pipe could be \$60 per foot or \$316,800 per mile. However, the cost of installing a pipe can occasionally be stated as follows: dollars per inch of pipe diameter per mile [8]:

Pipe installation cost (PIC) (\$) = CL×D×L (2)

Where;
C_L = Typical installation costs for pipelines (9,000 average cost in \$/in. diam/mi for 4 in. NPS of pipelines) [8]. This number must be verified by discussions with construction contractors who are familiar with the construction location.
L = length of pipe, mi
D = pipe outside diameter, in.
So, for this case;
PIC (\$) = 9,000×4.5×21.748 = \$ 880,794
So, the total pipeline with labor cost becomes [8];

Total Pipeline cost (\$) = PMC+PIC (3)

Total Pipeline cost (\$) = 2,026,190.358 + 880,794= \$ 2,906,984.358
This cost not include the welding cost, fittings cost, and Shipping and transportation cost. It is expected to reach the same value according to international prices.
Total Pipeline cost (\$ = \$ 5,813,968.716 (for carbon steel to Libya)
Then according to the international currency change [16]; € 1 = \$ 1.07
Total Pipeline cost (€) = € 6,220,946.526 (for carbon steel to Libya)

TCP cost

Average price of TCP according to the provider for 35km [7] is Insulated TCP 4'' is € 4,904,588 (CIF Benghazi), and TCP 4'' without insulation is €3,923,670.4.

Conclusion

Based on the results obtained from the simulation of the three options of pipelines carrying a waxy crude composition.

- There is a good match of results of wax deposition when utilizing two software programs (*Olga*).
- The rate of wax deposition on pipe wall is direct proportional to temperature difference between the bulk oil and the pipeline and time duration. Found of insulation thickness is one of the methods that can use to decreasing wax through a pipeline.
- Option 3 (Insulated TCP) is the best option that recommended to use for the operating and cost considerations.
- Chemical wax inhibitor injection processes are necessary that use special chemical to improve oil flow and to prevent the formation layers of wax in during crude oil transportation via pipelines.

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