A Simulation Study of the (103A) Field, Zuetina Terminal Crude Oil Pipeline

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Abstract

Wax deposit is one of the main problems facing crude oil transportation via pipelines, especially the waxy crude oil types. This problem usually appears at different temperatures where the wax crystals start to deposit at certain conditions causing plugging the production pipelines and viscosity increase, consequently leading to increasing the required power for flowing and fluid pressure, which may cause the pipeline to become environmental and economic losses. The current study introduces several scenarios to simulate a ground crude oil pipeline, 1016 mm (40 inches) diameter and 212 km length buried underground along the distance in depth of 1.5 m. This pipeline is transporting a waxy crude oil with pour point of 39 °C. The software used for this simulation is (HYSYS 3.2). 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 investigates pipeline shutdown simulation to check the temperature profile along the pipeline and pin points the lowest temperature reached with time changing. The results of the first part determined the minimum flow rate allowed to be 79,000 bbl/day at which the temperature will be higher than the pour point (39 °C). The maximum flow rate used in the simulation was 104,000 bbl/day. The results of the second part, where the maximum time specified as 96 hours and other times were (24, 48 and 72 hrs), respectively. It was found that the safest time for shutdown at low temperatures without wax appearing is (3, 5 and 6 hrs) at different ambient temperatures (4, 10 and 15 °C), respectively.

Keywords: Wax appearing; pipeline; minimum flow rate; shutdown.

1. Introduction

One of the problems faced the petroleum industry is the wax deposition in pipeline during transportation of waxy crude oil. Oil companies dealing with waxy crude oil spend millions of dollars in remedial procedures. An ideal design should use an accurate model that would include all salient features of wax deposition and waxy crude oil transportation. Wax deposition in oil production and transportation has always been a serious problem, for which great deals of operational costs are incurred. If waxy crude oil is transported through pipelines in cold ambient temperature, wax crystal appears and deposit on the wall of the pipe by various mechanisms. This phenomenon leads to many problems such as plugging of pipe, decreasing production rate, increasing pressure drop, and so forth [2]. As the wax crystal thickness increases, pressure drop across the pipe needs to be increased to maintain a constant flow rate. As a result, the power requirement for the crude transportation will increase. When the temperature of a waxy crude oil is lowered to its cloud point, first the heavier fractions of its wax content start to freeze out. Upon lowering the temperature to the crude pour point almost all the fractions of its wax content will freeze out. Presently, waxy crude is characterized by its cloud point and its pour point, which are measured according to the ASTM Test Methods D-2500 and D-97, respectively [1].

2. Methods or Techniques Used in the Study

Hysys software is used to carry out the simulation of the case studies in this work. HYSYS is one of the most widely used software packages in chemical and petrochemical industries. The simulation program offers easy and user-friendly environment for process design compared to some programming languages. It saves time and money in the design process. The simulation basis is the first step in this simulation. It is essential to define data such as composition and fluid properties, and then, the fluid package, which is defined based on the data given. The fluid package is responsible for the calculations of the physical properties in terms of equations and calculations. One of the most important equations in the Hysys software is the equations of state such as Peng-Robinson equations (PRE).

3. Case Description

The crude oil pipeline is aimed to transport the crude oil from the oil field (103A) located on to Zuetina terminal at the sea. The pipeline is 212 km long and may face transporting problems in cold climate. The purpose of this study is to determine the thermal gradient profile and the cool-down curve, during shutdown using different scenarios.

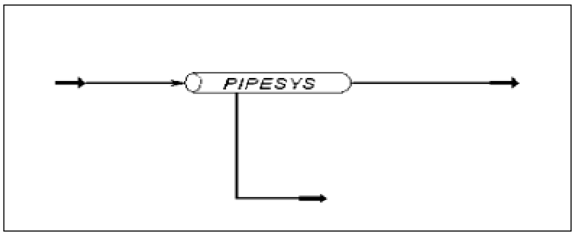

Figure 3.1: Simple schematic sketch of the pipeline

The international system (SI) units were used to represent most the dimensions. However, when the SI system is less common, such as in oil production rate and the pipeline size both the SI and the Field systems were used. In this work, HYSYS 3.2 software was used to study different scenarios, all the units in SI system.

The pipeline feed conditions:

- Inlet temperature $T_i = 85$ °C (185 °F)
- Inlet pressure $P_i = 395.8$ kPa
- Ambient temperature $T_a = 15.56$ °C (60 °F)

Table 3.1: Pipeline technical data

Data	Unit	Value
Pipe diameter	mm / inch	1016 / 40
Wall thickness	mm	8.738
Length	km	212
Average depth	m	1.5
Soil conductivity (km 108 – 103A)	w/m.hr	0.519
Soil conductivity (km 108 – Zuetina)	w/m.hr	0.692
Capacity	m^3/hr / BPD	688.9/104000
Pour point	°C / °F	39 / 102
Ambient temperature	°C / °F	15.56 / 60

The crude oil specifications:
Crude specs are summarized in Tables 3.2 and 3.3

Table 3.2: Crude oil properties

Data	Unit	Value
Specific Gravity @ 15.56°C	-	0.806
API	-	44
Viscosity at 85°C	cSt	3.0
Pour point, °C	°C	39

4. Results and Discussion

In this study, we performed the simulation with several scenarios by changing the crude oil flow rate approaching to the minimum flow rate in which the pipeline can be put in operation, i.e. arrival temperature higher than the pour point temperature. In addition, we performed the simulation at different ambient temperatures for each crude oil flow rate. In order to achieve the study goals, we defined six scenarios, and each scenario were divided into two parts as following:

Part one (minimum flow rate): At the beginning, the simulation run at the same conditions taking into account the temperature variation in the winter time and during night. The ambient temperatures have been set at 4.4, 10 and 15.56 °C respectively. In addition, we started by minimize the

Table 3.3: Crude oil compositions

No.	Components	Molar Composition	No.	Components	Molar Composition
1	(i-Butane)	0.0090	24	(NBP[0]322*)	0.0243
2	(n-Butane)	0.0097	25	(NBP[0]337*)	0.0265
3	(i-Pentane)	0.0237	26	(NBP[0]350*)	0.0288
4	(n-Pentane)	0.0038	27	(NBP[0]364*)	0.0261
5	(NBP[0]43*)	0.0145	28	(NBP[0]378*)	0.0222
6	(NBP[0]58*)	0.0193	29	(NBP[0]392*)	0.0183
7	(NBP[0]72*)	0.0286	30	(NBP[0]406*)	0.0150
8	(NBP[0]85*)	0.0370	31	(NBP[0]420*)	0.0138
9	(NBP[0]99*)	0.0317	32	(NBP[0]441*)	0.0322
10	(NBP[0]113*)	0.0313	33	(NBP[0]467*)	0.0214
11	(NBP[0]127*)	0.0362	34	(NBP[0]496*)	0.0159
12	(NBP[0]141*)	0.0398	35	(NBP[0]524*)	0.0131
13	(NBP[0]155*)	0.0366	36	(NBP[0]551*)	0.0113
14	(NBP[0]169*)	0.0346	37	(NBP[0]579*)	0.0093
15	(NBP[0]183*)	0.0374	38	(NBP[0]607*)	0.0071
16	(NBP[0]197*)	0.0394	39	(NBP[0]636*)	0.0064
17	(NBP[0]211*)	0.0364	40	(NBP[0]673*)	0.0097
18	(NBP[0]225*)	0.0338	41	(NBP[0]730*)	0.0062
19	(NBP[0]239*)	0.0349	42	(NBP[0]784*)	0.0038
20	(NBP[0]252*)	0.0343	43	(NBP[0]841*)	0.0024
21	(NBP[0]266*)	0.0304	44	(NBP[0]898*)	0.0019

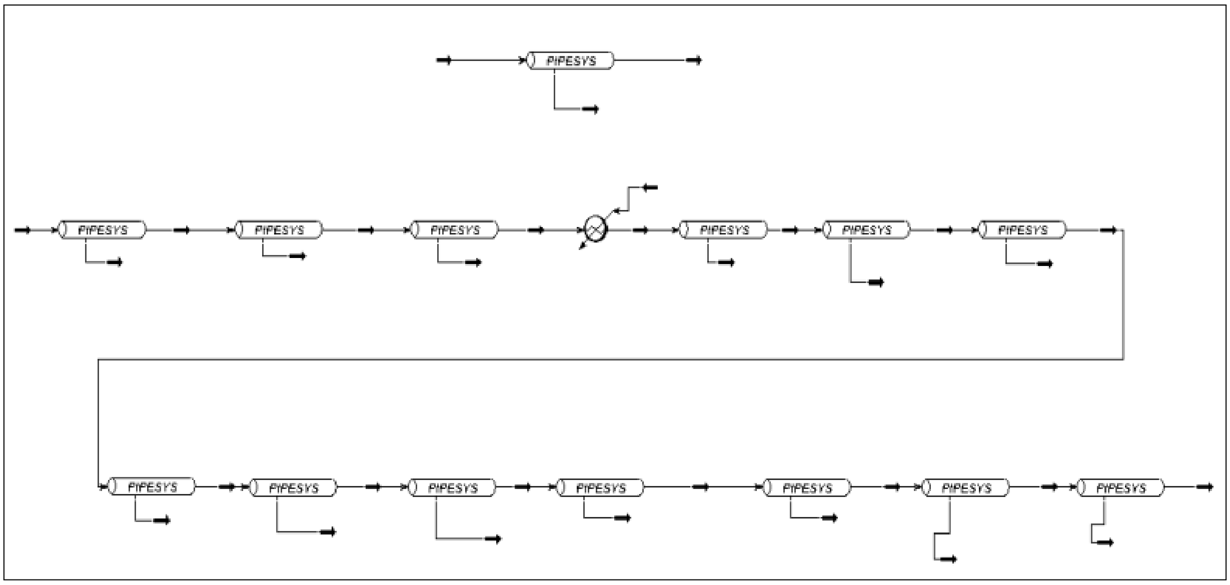

Figure 3.2: A detailed schematic sketch of the pipeline

flow rate in equal ratios – 5000 bbl/day – in each scenario.

Part two (minimum safe time after shutdown): The same parameters in the part one is used to perform a simulation after shutdown for each scenario. The temperature profile, heating profile, and cool-down curve after and before shutdown are estimated. The maximum shutdown time used is 96 hours, and the 72, 48, and 24 hours were used respectively.

4.1. First Scenario

Part I: A simulation has been carried out to finding the minimum arrival temperature with maximum flow rate of 104000 bbl/day at ambient temperatures of 4.4, 10, 15.56 °C respectively.

It is observed from the simulation results that the temperature approaches from the pour point to reach 46.95, 43.98 and 41.47 °C.

In this situation, which is repeated by a flow rate of 104000 bbl/day. We notice the variations along the longitudinal line as the temperature increases the wax formation decreases in addition to the domination of other problems.

Part II: A simulation has been carried out to finding the maximum safe time after pipeline shutdown without wax appearing. At flow rate of 104000 bbl/day, maximum time started with 96 hours and first, second and third intermediate times were used are 24, 48, 72 respectively. Temperature profiles, heat content and cool-down temperature were obtained at specified time after pipeline shutdown.

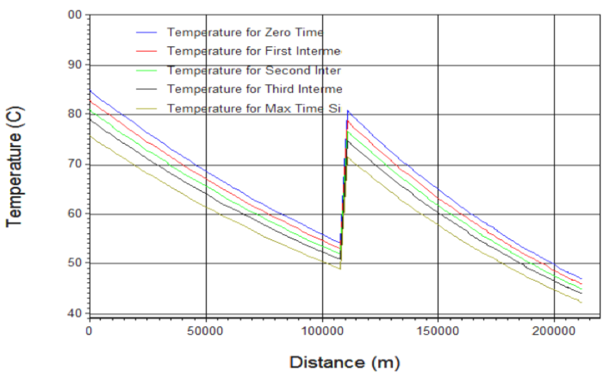

Figure 4.1: Cool down temperatures for times since shutdown at ambient 15.56 °C

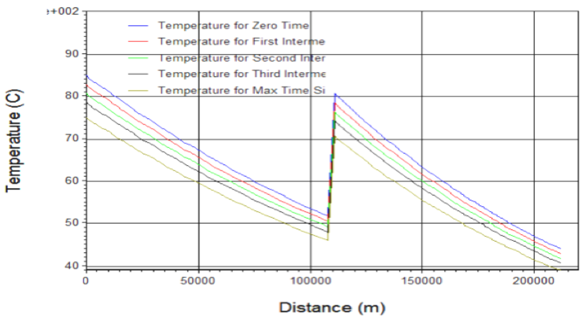

Figure 4.2: Cool down temperatures for times since shutdown at ambient 10°C

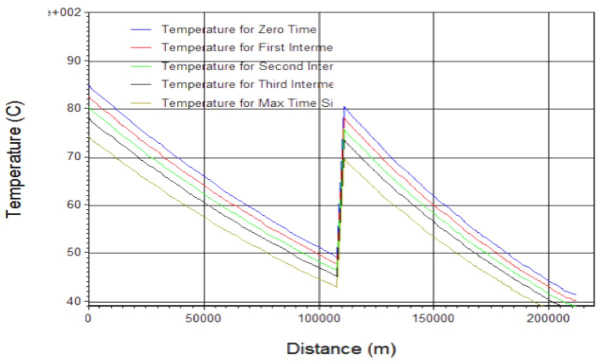

Figure 4.3: Cool down temperatures for times since shutdown at ambient 4.4°C

Table 4.3: Temperature profile obtained at specified time after shutdown

Temp profile	Time
Temperature for zero time	Zero
Temp. for first intermediate time	24 hour
Temp. for second intermediate time	48 hour
Temp. for third intermediate time	72 hour
Temp. for max time since shutdown	96 hour

It is observed from the simulation at ambient temperature 15.56 °C and from 0 to 96 hours flowing time, the absence of wax formation. More precisely the temperature deviates away from the pour point 39 °C. The same results were obtained when the temperature is 10°C and 4.4°C.

4.2. Last Scenario:

Part I: In this simulation, the crude oil flow rate changed from 84000 to 78000 bbl/day, where we used a lower flow rate to obtain new results with consideration of different temperatures in winter time

Table 4.1: Field (103A) crude oil conditions

Property	Unit	Value (TLPS)	NT	NT	NT
Temperature	°C	85	46.95	43.98	41.47
Pressure	kPa	395.75	978.12	973.48	969.33
Flow rate	m^3/h	688.94	688.94	688.94	688.94

Table 4.2: Field (103A) crude oil along the pipeline at different ambient temperatures

Distance (km)	T_1 at ambient 15.56 °C	T_2 at ambient 10 °C	T_3 at ambient 4.4 °C
0	85	85	85
88	58.75	56.62	54.47
96	56.92	54.63	52.33
108	54.26	51.75	49.24
108	82.22	82.22	82.22
144	67.12	65.85	64.58
164	60.19	58.33	56.47
168	58.91	56.94	54.97
173	57.38	55.28	53.17
188	53.00	50.52	48.05
200	49.85	47.11	44.38
204	48.850	46.03	43.22
206	48.38	45.52	42.69
208	47.89	44.99	42.17
210	47.43	44.49	41.74
212	46.95	43.98	41.47

at the night period. Accordingly, we applied several scenarios at 4.4, 10 and 15.56 °C respectively.

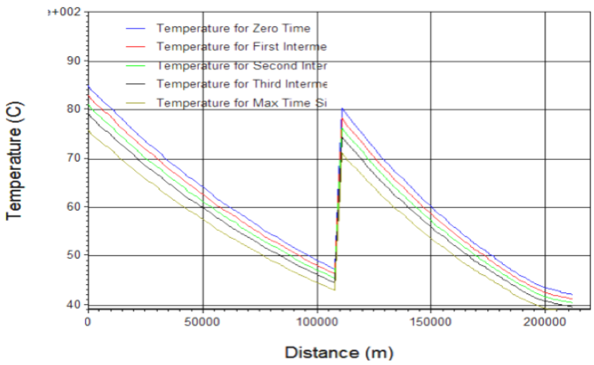

Figure 4.4: Cool down temperatures for times since shutdown at ambient 15.56°C

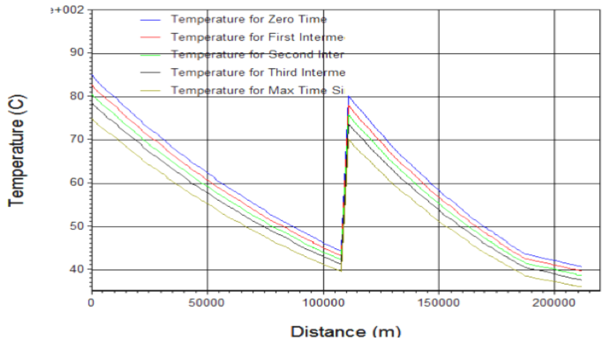

Figure 4.5: Cool down temperatures fort times since shutdown at ambient 10°C

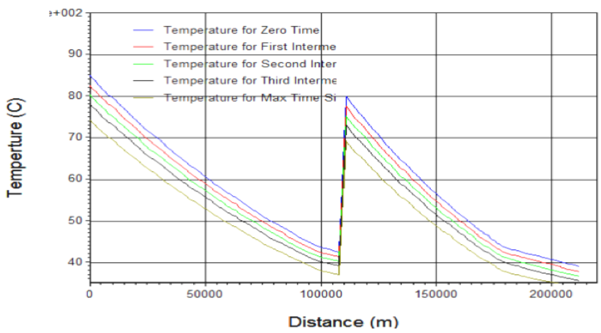

Figure 4.6: Cool down temperatures for times since shutdown at ambient 4.4°C

In this scenario as shown in Table 4.5, the crude oil temperature at both T_1 and T_2 are dropped significantly until it has reached 42.17 and 40.65 °C respectively, where they are very close to the pour point. But it is dropped significantly at ambient temperature of 4.4 °C till it is reached to 39.00 °C, which is equal to the pour point of the crude oil.
In this step, it has been noticed that in all cases, temperature has dropped to the lowest levels compared to the simulation results at the beginning.

1. In the first case,, the temperature dropped to 39 °C and at the end the temperature reached 39 °C.
2. In the third stage, the temperature dropped significantly to 37 °C, also dropped to the same temperature at 96 km and 106 km.

Table 4.4: Field (103A) crude oil conditions

Property	Unit	Value (TLPS)	NT	NT	NT
Temperature	°C	85	42.17	40.65	39.00
Pressure	kPa	395.75	1028.43	1026.34	1023.41
Flow rate	m^3/h	516	516	516	516

Table 4.5: Field (103A) crude oil along the pipeline at different ambient temperatures

Distance (km)	T_1 at ambient 15.56 °C	T_2 at ambient 10 °C	T_3 at ambient 4.4 °C
0	85	85	85
88	52.36	49.70	47.04
96	50.28	47.45	44.66
108	47.34	44.33	42.55
108	82.22	82.22	82.22
144	62.89	61.26	59.63
164	54.59	52.26	49.92
168	53.11	50.64	48.14
173	51.35	48.74	46.13
188	46.44	43.69	42.39
200	43.45	42.13	40.67
204	43.01	41.63	40.10
206	42.81	41.40	39.84
208	42.58	41.14	39.54
210	42.38	40.900	39.27
212	42.17	40.65	39.00

It has been concluded that the best time for shutdown is less than 24 hours at minimum flow rate equivalent to 78000 bbl/day.

5. Discussion

The simulation process started with flow rate of 104000 bbl/day, and the flow rate decreased to 78000 bbl/day on stages. Six trials have been worked on between the two limits. At flow rate of 99000 bbl/day, the simulation showed that there is no big difference along the pipeline and the same result obtained at 94000, 89000 and 84000 bbl/day respectively. At flow rate of 78000 bbl/day at 212 km, the temperature has dropped below 39.00 °C. Taking into account that wax formation appears at 39 °C, it will not be problem especially at ambient temperature of 15.56 °C and 10 °C, but at ambient temperature of 4.4 °C, temperature drops to below 39.00 °C at 212 km and goes down the pour point of 39 °C. So,

Table 5.1: The results of the first part at arrival pipeline point

Flow rate (bbl/day)	T_1 at 15.56 °C	T_2 at 10 °C	T_3 at 4.4 °C
104000	46.95	43.98	41.47
99000	45.78	42.76	41.10
94000	44.54	42.03	40.68
89000	43.30	41.66	40.21
84000	42.68	41.22	39.73
78000	42.17	40.65	39.00

the minimum safe flow rate in which the transportation pipeline can be put in operation without wax formation is at flow rate of 79000 bbl/day.
It is noticeable that one of the most important properties that impacted and changed are pressure and viscosity. Pressure changes according to the elevation of the pipeline and viscosity change according to temperature gradient.
The results of the second part, where the maximum time specified as 96 hours and other times were 24, 48 and 72 hours respectively, we found that the safest time for shutdown at low temperatures without wax appearing is less than 24 hours as maximum is 6 hours.

6. Conclusion

A study of waxy crude oil transportation is performed using HYSYS 3.2 software. Maximum flowrate started at 104000 barrel/day and minimized by 5000 bbl/day for each scenario. The minimum flow rate without wax formation is found to be 79000 bbl/day. This study highlighted that temperature has significant impact on wax formation and the oil viscosity. In all scenarios, the safe shutdown time was at a lower flow rate, it is found to be three hours at ambient temperature of four degrees Celsius and five hours at ambient temperature of ten degrees celsius and six hours at a temperature of fifteen degrees Celsius and Will be less than four and twenty hour in all cases at a lower flow rate. We further note that

Table 5.2: The results of the second part at arrival pipeline

Flow rate (bbl/day)	Ambient temperature	Arrival temperatures °C				
		Zero (hrs)	24 (hrs)	48 (hrs)	72 (hrs)	96 (hrs)
104000	15.56 °C	47	46	45	44	42
	10 °C	44	42	41	40	39
	4.4 °C	41	40	39	38	37
99000	15.56 °C	46	44	43	42	41
	10 °C	43	41	40	39	38
	4.4 °C	41	40	39	38	37
94000	15.56 °C	44	43	42	41	41
	10 °C	42	41	40	39	38
	4.4 °C	41	39	38	37	36
89000	15.56 °C	43	42	41	40	39
	10°C	41	40	39	38	37
	4.4 °C	40	39	37	36	35
84000	15.56 °C	42	41	39	38	37
	10 °C	40	39	38	37	36
	4.4 °C	40	39	36	35	34
78000	15.56 °C	42	40	39	38	37
	10 °C	41	39	38	37	36
	4.4 °C	39	37	35	34	33

Table 5.3: Field (103A) crude oil conditions

Time (hrs)	Ambient Temp. (°C)
6	15.56
5	10
3	4.4

the effect of pressure is not directly on the wax formation, but as secondary effect. The viscosity has significant effect on the temperature and in return temperature impacts to the wax formation.

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