STUDY OF THE EFFECT OF FLOW MODIFIERS ON THE OPERATION OF HEGLIG -PORT SUDAN PIPELINE

Mysara Eissa Mohyaldinn[1], Rasheed Hamid[2], M. Adil[2] and O. Musa[2]
[1]Faculty of Geoscience and Petroleum Engineering, Universiti Teknologi PETRONAS, Tronoh, Malaysia
[2]College of Petroleum Engineering and Technology, Sudan University of Science and Technology, Khartoum, Sudan
E-Mail: mysara.eissa@petronas.com.my

ABSTRACT

In this paper, the effect of a flow improver (i.e. Pour Point Depressant) on the operation of Heglig-Port Sudan Pipeline has been studied. Two types of PPD, namely PPD 25J1 and PPD 25J2, have been used with different doses and different operation scenarios were presumed. For every scenario, the pressure required to transport the flowing fluid through the pipeline has been calculated and pressure transverse between pump stations has been established. The optimum scenario has been selected based on critical analysis of the operation cost at different operation scenarios and PPD concentrations. It has been found that the optimum operation scenario is obtained by adding the PPD type 25J1 to the flowing fluid at 500 PPM.

Keywords: Heglig-Port Sudan Pipeline, Neem field oil, PPD, dose, PIPESIM, rheology, cost, scenario.

INTRODUCTION

Compare with other ways, pipelines are considered as the most feasible oil and gas transportation method. This feasibility is because of their advantages like safe operation, easy to operate, and positive economic impact. These advantages may, however, be altered by some undesired properties of the transported fluid. For example, high viscosity and high pour point negatively impact the economy of a pipeline by causing very high pressure losses which turn in necessitating putting more pump stations into operation. They also cause difficulty in the pipeline operation and in worst cases they may cause hazard of pipeline rupture due to exceeding of the pipeline internal pressure to its maximum allowable operating pressure. Therefore special precautions should be applied to the operation of pipelines transporting viscous high pour point waxy crudes. Although other methods are applied to assure waxy crude transportation (mechanical, physical and chemical) [1] but adding chemical additives (also referred to as waxy crystal modifiers, flow modifiers, flow improvers, paraffin inhibitors, or pour point depressants PPD) is the most preferable option [2-4]. The characteristics, function, compositions, and mechanisms of PPD was discussed before by many researchers [4-10]. Adding PPD not only facilitates smooth day-to-day operation of the pipeline but also enables safe restartability of a planned or emergency shutdown pipeline. While safe restartability is governed by reduction of pour point and yield stress of the waxy crude, smooth day-to-day pipeline operation is governed by reduction of crude viscosity and friction factor which turn in lessening pressure losses due to friction.

In this paper, flow modifiers used for Neem crude oil transportation via Higlieg-Port Sudan pipeline have been studied. Two selected types of flow modifier have been evaluated by means of the comparison of the operating costs of the pipeline assuming the same flow rate.

METHODOLOGY

The crude oil that is used in this study is the Neem field oil. PIPESIM software is used to simulate the operation of the pipeline with two type of PPDs, namely PPD25J1 and PPD25J2. Different doses of PPD were used to determine the optimum PPD dose and type. The real pipeline data (distance, elevation at one kilometer intervals, inner diameter, roughness, and wall thickness), pump stations data, fluid data and thermal data were used in the simulation. The model (Heglig-Port Sudan pipeline) consists of six pump stations was built as shown in Figure-1.
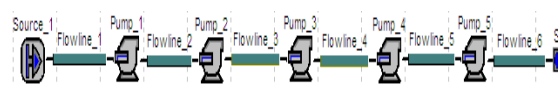

Figure-1. The pipeline physical model in PIPESIM.

The elements of the pipeline model are shown in Table-1.

www.arpnjournals.com

Table-1. Symbols of the model elements.

Component	Symbol
The initial pump station	Source_1
Intermediate pump station	Pump_1
Pipeline	Flowline_1
Terminal station	S1

The source pressure and temperature are set at 68974.572 kpag and 67.65 C, respectively. Pump stations and pipeline data are presented in Tables 2 and 3, respectively.

Table-2. Discharge pressure of pump stations at 70% efficiency.

Pump station	Discharge pressure, kpag
1	58275.378
2	76617.45
3	58198.574
4	56000.776
5	41117.096

Table-3. Pipeline data.

Parameter	Value
Inner diameter, D	711.2 mm
Roughness, ε	16.7 mm
Wall thickness, δ	0.381 mm
Overall heat transfer coef., U	2.5 W/m^2*K

Basis of pressure drop calculation equations

The overall pressure losses along a pipeline is the sum of elevation pressure loss, frictional pressure loss, and acceleration pressure loss. In equation form:

$$\frac{dp}{dl} = \left(\frac{dp}{dl}\right)_{elev} + \left(\frac{dp}{dl}\right)_{fric} + \left(\frac{dp}{dl}\right)_{ace} \tag{1}$$

Where elevation, friction and acceleration component of pressure drop are given by equations (2) through (4):

$$\left(\frac{dp}{dl}\right)_{elev} = -\rho g \sin\theta \tag{2}$$

$$\left(\frac{dp}{dl}\right)_{fric} = -\frac{f\rho v^2}{2D} \tag{3}$$

$$\left(\frac{dp}{dl}\right)_{ace} = -\rho v \frac{dv}{dl} \tag{4}$$

$\rho \equiv$ is fluid density in Ib/ft^3

$f \equiv$ is the friction factor

$v \equiv$ is fluid velocity in ft/s

$g \equiv$ is gravitational acceleration in ft/s^2

$\theta \equiv$ is the angle of pipe to horizontal

$D \equiv$ is the pipe diameter

$l \equiv$ is length of the pipe

Friction pressure loss is the pressure loss due to flow. It mainly depends on friction factor which is calculated using different models based on flow regime. To identify the flow regime, Renolds number is calculated using Equation 5.

$$Re = \frac{\rho v D}{\mu} \tag{5}$$

$\mu \equiv$ is fluid viscosity $Ib/ft.s$

The friction factor formulae according to flow regime are:

www.arpnjournals.com

1- Laminar flow (Re $<$ 2000)

$$f_{lam} = \frac{64}{Re} \qquad (6)$$

2- Turbulent flow (Re $>$ 4000)

$$\frac{1}{\sqrt{f_{Turb}}} = 1.74 - 2\log_{10}\left(\frac{2\epsilon}{D} + \frac{18.7}{Re*\sqrt{f_{Turb}}}\right) \qquad (7)$$

3- Transition flow (2000$\leq$ Re $\leq$4000)

$$f = \frac{(Re - Re_{min})(f_{Turb} - f_{lam})}{(Re_{max} - Re_{min})} + f_{lam} \qquad (8)$$

$\epsilon \equiv$ is pipe roughness ft

Cost estimation

The main function of adding PPD material to the transported crude oil is to reduce its pour point and viscosity. Under operation conditions, reduction of viscosity highly reduces friction pressure loss, and hence, lower pumping pressure is required. For a pipeline already equipped with constructed pump stations, this can be sought of as dispensing of one or more of the intermediate pump stations. By that, the operating cost of the stopped pump station is saved. Therefore, to evaluate the feasibility of PPD addition we should compare its cost with the saving resulted from pump station (s) shutdown due to the PPD effect on decreasing viscosity. The following flow chart summarizes the steps followed to determine the optimum operation scenario.
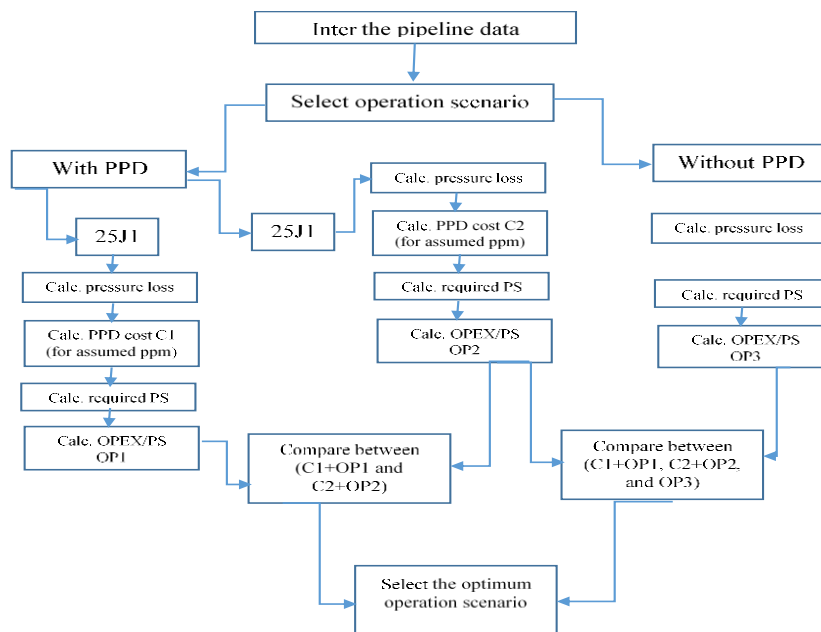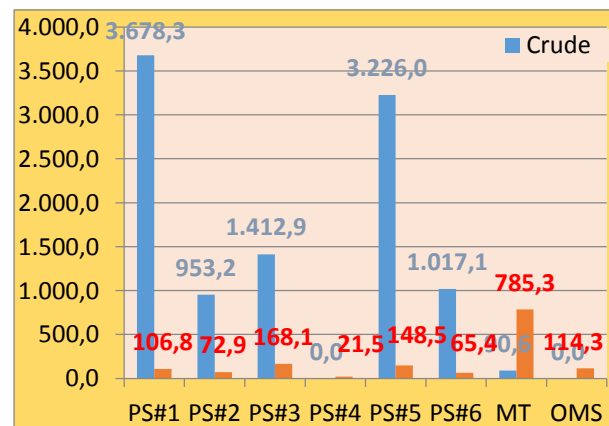

Figure-2. Calculation steps.

The key factor to carry on the optimization is the day-to-day operating cost. Figure-3 shows daily operation fuel consumption of the pump stations along the pipeline under study.

Figure-3. Diesel and crude consumption during year 2013, $m^3/$ station stations.

Addition of PPD is considered feasible if it the following condition comes true

$$OPEX_O + C_{PPD} < OPEX_{NPPD} \qquad (9)$$

Where,

$OPEX_O$ is the operating cost of the operated pump stations with addition of PPD.

C_{PPD} is the cost of PPD

$OPEX_{NPPD}$ is the operation of the pipeline without pump station

The operation cost is calculated for every pump station using the following formula:

$$OPEX = U_{PPD}Q_{PPD} + U_c Q_c + U_d Q_d \qquad (10)$$

Where

U_{PPD}, U_c, and U_d are the cost of PPD, crude, and diesel, respectively

Q_{PPD}, Q_c, and Q_d are the quantity of PPD (ton), crude (bbl), and diesel (bbl), respectively

RESULTS AND DISCUSSIONS

Table-4 contains a summary of the calculation results. Column 2 in the table contains the type of the PPD and concentration, column 3 contains the operated pump stations, column 4 contains the distance to which the oil can be transported based on the available pressure from the operated pump stations and the oil properties at the PPD concentration, and the last column contains the remaining pressure at the point to which oil arrives. It can be noted from column 4 that not all the proposed scenarios can deliver the oil to the terminal (at 1502 km). The results shown in the table and presented in Figures 4-11 were obtained by entering viscosity data at different PPD concentration to PIPESIM software. At every case, the pipeline profile is obtained after specifying the running pump stations and their performance data. From the profile the distance to where the oil can be delivered along with the pressure at this distance are obtained.

Table-4. The calculation results.

Scenario number	PPD Type	Operated pump stations	Distance reached, km	Remaining pressure, bar
1	NA	6	431878.6090	2.1577
2	25J1 500	1,2,4,5,6	1502453.57	253.3228
3	25J1 750	1,2,4,5,6	1502453.57	260.9134
4	25J1 1000	1,2,4,5,6	1502453.57	284.1585
5	25J1 1250	1,2,4,5,6	1502453.57	302.8905
6	25J2 500	1,2,4,5,6	602012.138	2.5571
7	25J2 750	1,2,4,5,6	1502453.57	208.5
8	25J2 1000	1,2,4,5,6	1502453.57	231.2447
9	25J2 1250	1,2,4,5,6	1502453.57	329.1671
10	25J1 500	1,3,4,5,6	1502528.57	253.287
11	25J1 750	1,3,4,5,6	1502528.57	260.8935
12	25J1 1000	1,3,4,5,6	1502528.57	315.7554
13	25J1 1250	1,3,4,5,6	1502528.57	302.8825
14	25J2 500	1,3,4,5,6	501874.074	2.3276
15	25J2 750	1,3,4,5,6	1502528.57	331.7423
16	25J2 1000	1,3,4,5,6	1502528.57	474.6198
17	25J2 1250	1,3,4,5,6	1502528.57	329.1532

www.arpnjournals.com

| 18	25J1 500	1,2,3,4,6	1500496.39	261.4471
19	25J1 750	1,2,3,4,6	1500496.39	288.3792
20	25J1 1000	1,2,3,4,6	1500496.39	291.3091
21	25J1 1250	1,2,3,4,6	1500496.39	351.3665
22	25J2 500	1,2,3,4,6	1500496.39	627.8178
23	25J2 750	1,2,3,4,6	1500496.39	216.0557
24	25J2 1000	1,2,3,4,6	1500496.39	457.1504
25	25J2 1250	1,2,3,4,6	1500496.39	466.5838
26	25J1 500	1,2,4,6	1502491.57	261.0699
27	25J2 500	1,2,4,6	1502491.57	339.7782
28	25J1 750	1,2,4,6	1502491.57	452.9372
29	25J2 750	1,2,4,6	1502491.57	215.8491
30	**25J1 500**	**1,4,6**	**1504500.58**	**261.0244**
31	25J2 500	1,4,6	452862.055	.84140
32	25J1 750	1,4,6	1504500.58	268.28
33	25J2 750	1,4,6	764265.587	.1170
34	25J1 1000	1,4,6	1504500.58	291.1498
35	25J2 1000	1,4,6	764265.587	.61720
36	25J2 1250	1,4,6	1504500.58	335.3187
37	25J1 500	1,6	901509.539	.6180
38	25J2 500	1,6	452867.057	.83770
39	25J1 750	1,6	1021390.75	.19190
40	25J2 750	1,6	764268.584	.11610
41	25J1 1000	1,6	1239391.15	.13170
42	25J2 1000	1,6	764268.584	0.61610
43	**25J1 1250**	**1,6**	**1503717.76**	**313.7107**
44	25J2 1250	1,6	1503717.76	340.247

www.arpnjournals.com
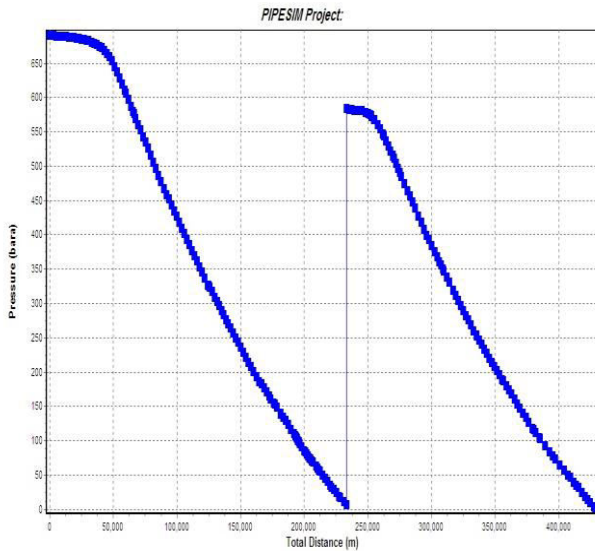
Figure-4. Pressure-Distance profile (6 pump stations without PPD injection).

Obviously, when all pump stations are operated and no PPD is injected, the pumped fluid losses the ability to reach the terminal station. Operation with 5 or 4 pump stations is enhanced by the addition of either PPD 25J1 or PPD 25J2. Using 4 or 5 pump stations, with addition of PPD the pumped fluid will regain its ability to reach the terminal station in almost all scenarios with remaining pressure far higher than the atmospheric pressure.
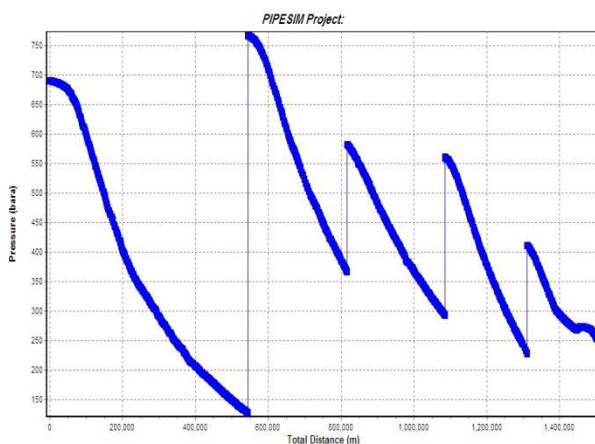
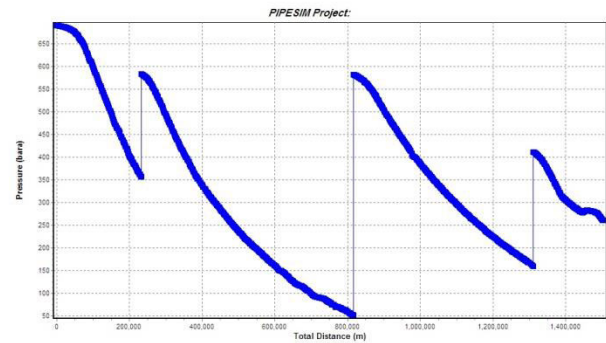**Figure-5.** Pressure-Distance profile (5 pump stations with PPD injection).

Figure-6. Pressure-Distance profile (4 pump stations with PPD injection).

Superiority of PPD 25J1 over PPD 25J2 can be observed when 3 pump stations are operated. All injection doses of PPD 25J1 have the ability to deliver the pumped fluid to the terminal station with a sufficient amount of remaining pressure, while this is not the case when PPD 25J2 is added. Therefore, only the scenarios that involves the injection of PPD 25J1 will be considered in cost analysis. Finally, operation with 2 pump stations is applicable in both cases.
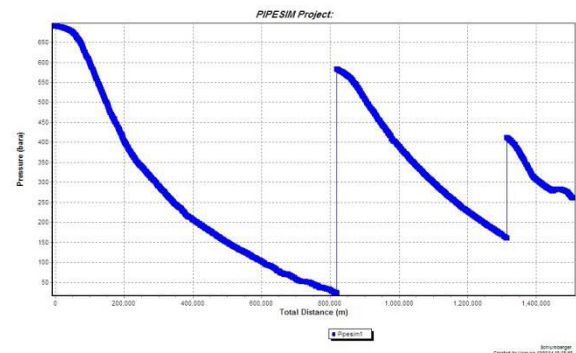

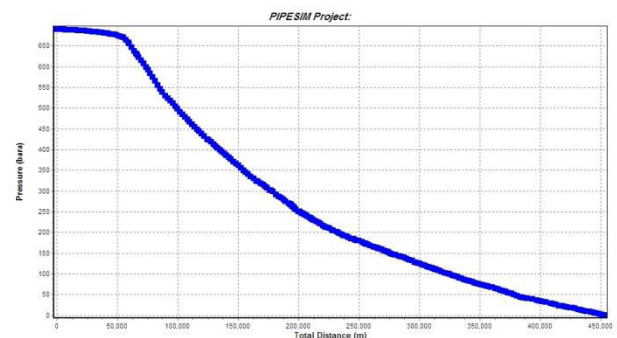**Figure-7.** Pressure-Distance profile (3 pump stations with PPD 25J1 injected).

Figure-8. Pressure-Distance profile (3 pump stations with PPD 25J2 injected).
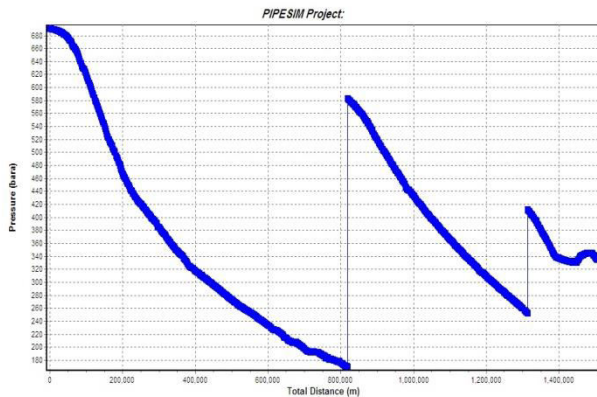
www.arpnjournals.com

Figure-9. Pressure-Distance profile (2 pump stations with PPD 25J2 at 1250 PPM).

Selection of the optimum scenario

Based on the results shown in Table-4, it can be stated that PPD 25J1 is more effective than PPD 25J2. This is because a wide range of PPD 25J1 doses can be used for the purpose of delivering the flowing fluid to the terminal station. Scenarios that involve the injection of PPD 25J1 are, therefore, only considered in the cost analysis.

Both scenarios (30) and (43) are selected among all other scenarios. That's because those two scenarios are characterized by the least requirement of pump stations and the injected PPD concentration.

Comparison must be done between scenarios (30) and (43) to select the best scenario of all. The comparison is based on total cost (sum of the operation cost and the cost of PPD) of each scenario.

Scenario 30

This scenario consists of three pump stations (pump station number 1, pump station number 4 and pump station number 6), with PPD 25J1 injected at 500 PPM. The Pressure-Distance profile of this scenario is shown in Figure-10.
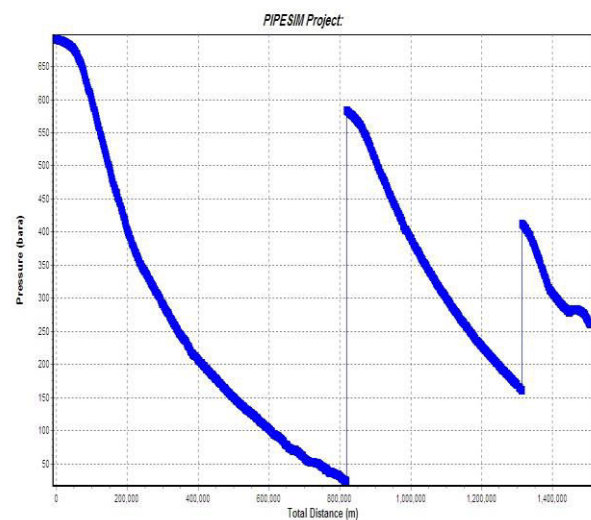

Figure-10. Pressure-Distance profile of scenario 30.

Table-5. Crude and diesel consumption in pump stations operated in scenario 30.

Pump station number	Crude consumption, bbl/year	Diesel consumption, m³/year
1	3678.3	106.8
4	0	21.5
6	1017.1	65.4

Using equation 10, the result is shown in Table-6:

Table-6. Expenses of pump stations operation in scenario 30.

Component	Expenses/cost, $/year
Crude consumption	149149
Diesel consumption	3042008.798
Labor	96000
PPD	1323246
Sum	4610403.798

SCENARIO 43

This scenario consists of two pump stations (pump station number 1 and pump station number 6), with PPD 25J1 injected at 1250 PPM.
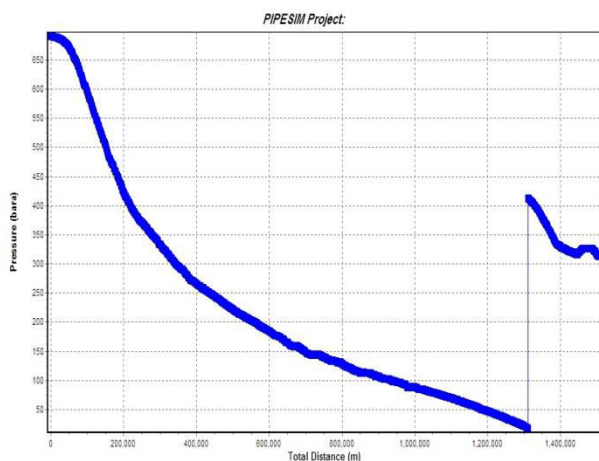
www.arpnjournals.com

Figure-11. Pressure-Distance-Distance profile of scenario 43.

Table-7. Crude and diesel consumption in pump stations operated in scenario 43.

Pump number	Crude consumption, bbl/year	Diesel consumption, m3/year
1	3678.3	106.8
6	1017.1	65.4

Using equation 10, the result is shown in Table-8:

Table-8. Expenses of pump station operation in scenario 43.

Component	Expenses $/year
Crude consumption	132594
Diesel consumption	3042008.798
Labor	96000
Cost of PPD	3308115
Sum	6578717.798

Comparing the results of Tables 7 and Table-8, it is clear that scenario 30 involves less expense than scenario 43. Therefore, it's safe to state that, among all other options (scenarios), scenario 30 is the most economical one to ensure the deliverability of the pumped fluid to the terminal station.

CONCLUSIONS

Study of the transportation of Neem field oil through Heglig-Port Sudan pipeline has been conducted using PIPESIM simulator. From investigation of the simulation results alongside economical evaluation, the following outcomes can be drawn:

Pumping the crude, with the desired flow rate, without PPD treatment, results in failure of the crude to reach the terminal station. Therefore, PPD must be added to enhance the flow of Neem field oil and facilitate its transport to the terminal station.

For the sake of transporting of the Neem field oil through Heglig-Port Sudan pipeline with the minimum allowable possible cost, a comparison study has been conducted on the effect of addition of two types of PPD, namely PPD 25J1 and PPD 25J2 at several injection doses. This comparison study utilized PIPESIM software to calculate pressure losses along the pipeline. The results obtained from PIPESIM simulation, the cost of operation of pump stations, and the cost of PPD together have been used as a basis for the comparison.

Two scenarios were found feasible, namely scenario 30 (3 pump stations with 500 ppm 25J1) and scenario 43 30 (2 pump stations with 1250 ppm 25J1). The cost analysis of the two scenarios indicated that scenario 30 serves best in delivering the pumped fluid to the terminal station at the minimum cost.

REFERENCES

[1] Ribeiro, F. S., Mendes, P. R. S., Braga, S. L., 1997. Obstruction of pipelines due to paraffin deposition during the flow of crude oils. Int. J. Heat Mass Transf. 40, 4319-4328.

[2] Dong, L., Xie, H., Zhang, F. 2001. Chemical control techniques for the paraffin and asphaltene deposition. In Proceedings of the SPE International Symposium on Oilfield Chemistry, Houston, TX, February13-16, SPE-65381-MS.

[3] Pedersen, K. S., Ronningsen, H.P., 2003. Influence of wax inhibitors on wax appearance temperature, pour point, and viscosity of waxy crude oils. Energy Fuels. 17, 321-328.

[4] Ana Erceg Kuzmic, Marko Radosevic, Grozdana Bogdanic, Vlasta Sric a, Radivoje Vukovic. 2008. Studies on the influence of long chain acrylic esters polymers with polar monomers as crude oil flow improver additives, Fuel. 87: 2943-2950.

www.arpnjournals.com

[5] Burger DE, Perkins KT, Striegler HJ. 1981. Studies of wax deposition in the trans-Alaska pipeline. J Petrol Technol. pp. 1075-1086.

[6] Wang LS, Flamberg A, Kikabhai T. 1999. Select the optimum pour point depressant. Hydrocarb Process. pp. 59-62.

[7] Svetgoff J. 1984. Paraffin problems can be resolved with chemicals. Oil Gas J Technol. pp. 79-82.

[8] Price CR. 1971. Flow improvers for waxy crudes. J Inst Petrol. 57: 106-109.

[9] El-Gamal MI, Kashif I. 1998. Performance of comb-type polymeric pour point depressants in Umbarka crude oil by X-ray. Bull WRC Egypt. 23: 409-423.

[10] Holder AG, Winkler J. 1965. Crystal-growth poisoning of n-paraffin wax by polymeric additives and its relevance to polymer crystallization mechanisms. Nature. 207: 719-721.