Economic Assessment of Magnetic Fluid Conditioning and Chemical Treatment for Wax Deposition Control in Crude Oil

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Abstract

Transportation of crude oil forms an integral part of crude oil production process. The viscous nature of crude oil in low temperature environment poses challenges in its transportation. This is owing to the wax deposition in crude oil. Number of methods like mechanical, electrical and chemical are used for wax deposition control. The choice of any control method is dictated by its efficiency and cost. Chemical methods are widely used but are costly. Another method magnetic fluid conditioning which is considered to be environment friendly is also gaining popularity. Substantial research has been done on this method but the economics has been rarely reported. The present paper attempts to compare the magnetic fluid conditioning method and chemical method based on the economic aspects. Experimentation has been performed on three crude oils with varying wax content. The efficiency of viscosity reduction due to magnetic method and chemical methods such as pour point depressants and diluents has been found. Using a hypothetical crude oil pipeline, the operating cost for each method has been evaluated. Also challenges of implementation of these methods have been discussed. It has been found that the magnetic method is more economical as compared to the chemical method.

Keywords: *magnetic fluid conditioning; pour point depressants; diluents; viscosity; crude oil transportation*

1. Introduction

Transportation of waxy crude oil through pipelines has always been a difficult and costly affair in the petroleum industry. Waxy crude oil has very high viscosity and generates high pressure drop. Pumping such crude requires extra pumping power. In order to reduce the viscosity, a suitable wax deposition control method needs to be applied. These are divided into conventional and non-conventional methods [1]–[3]. Chemical treatment and electrical heating fall under the conventional methods whereas magnetic fluid conditioning, ultrasonic and microbial fall under the non-conventional. The efficiency of these control methods dictate the pumping cost. Hence the limiting factor for the economics of transportation is the wax deposition control method.

The total cost of transportation includes the capital cost of pipelines and their installation and the operating cost of pumping under high pressure drop along with the wax deposition control method. Considering the capital cost to be fixed, it is

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the operating cost which determines the economics of transportation. The requirement of pumping power has been discussed by a number of workers. The factors affecting the pumping power include the wax deposition thickness and the effective pipe diameter. Ajienka and Ikoku have discussed the pumping power required for normal flow, restarted flow and for breaking the gel in a waxy crude oil pipeline situated in the Niger Delta [4]. An economic model for predicting the optimum cost of handling waxy crude oil has been developed by Joseph and Ajienka [5]. Li *et al* [6] have compared the frictional pressure drop calculated by Colebrook, Isaev and Atlas formulae for gelled pipelines and have found an error as high as 71%.Thuc *et al* [7] have shown how the deposition of wax along the length of pipe reduces the diameter actually available for the flow which results in higher pressure drop. Jerome *et al* have observed that a single trunk line is not economical for transportation due to high pressure drop in flow segments [8]. A study on Hungarian crude oil of Algyo field has shown how the cost increases with time as the amount of paraffin deposits increase [9].

Banerjee *et al* have discussed the implementation of drag reducers to decrease the wax deposit thickness [10]. A case study of the Banyu Urip field in Indonesia by Dwitawidi *et al* [11] showed that pour point depressants contribute to 20% of the total operating expenditure. van Engelen *et al* have studied the effective use of PPDs and their effect on restart ability for the high pour point crude from Bombay High, India[12].Irani*et al* have found PPDs with concentration of 200 ppm to be more economical than heating for high pour point (35^0C) Handil crude from Indonesia [13]. Bomba J.G has discussed some methods to avoid restart problems and hence the resultant economic loss[14]. Slater and Davis have discussed the techno-economic analysis of flow through a 40 km long crude oil pipeline with a capacity of 10000 bpd in New Zealand [15]. It was found that pour point depressants were more efficient and less costly as compared to other methods like insulted pipeline, trucking and thermal cracking,

Amongst the non-conventional methods, the magnetic fluid conditioning method (MFC) is claimed to be efficient, environment friendly and cost effective[16]–[18]. The economics of this method has not been discussed much in the literature. Hence this paper attempts to present the economics of the magnetic fluid conditioning method and compare it with the existing popular chemical method. Experimentation on viscosity reduction using magnetic field and chemicals has been done on three crude oils with different wax content. The results have been applied to a hypothetical crude oil pipeline mimicking real life conditions and the economics have been evaluated.

2. Materials and Methods

Three different crude oils C_1, C_2 and C_3 having properties as shown in Table 1 were obtained from western parts of India.

Table 1: Characteristics of crude oil samples

	C_1	C_2	C_3
Density (g/cc) at 15^0C	0.8754	0.877	0.887
^{0}API	30.1	29.8	28
Wax content (%)	25.1	35.5	45.7
WAT (^{0}C)	30	43	50
Viscosity at WAT (Ns/m^2)	0.0693	0.0554	0.0821

The reduction in the viscosity of the 50 ml samples was measured after treating them with magnetic field, pour point depressant and diluent. Accurately measured crude oil sample (C_1, C_2 and C_3) was held stationary between the pole pieces of the electromagnet (EMU-50V) and was exposed to the magnetic field of 6000 gauss for the specified time interval of 1 minute as discussed by Tao and Xu [17]. Ethylene vinyl acetate (EVA-18)obtained from Sigma Aldrich was dissolved in solvent xylene (from MERCK) in required proportions such that the final concentrations in the crude oil sample (50 ml) was 200 ppm. Likewise, 10% of *n*-hexane (obtained from MERCK) was mixed in crude oil and the changes in viscosity were measured. All the viscosities were measured and recorded at the Wax Appearing Temperature (WAT) of the oil.

3. Results and Discussion

3.1 Changes in viscosity

The viscosity obtained after treatment due to various methods is shown in Table 2.

Table 2. Viscosities of crude oil samples with and without treatment

Crude Oil	Viscosity (Ns/m^2)				
	Without treatment at 15^0C	Without treatment at WAT	Magnetic Field at WAT	PPD at WAT	Diluent at WAT
C_1	0.1619	0.0693	0.0514	0.0124	0.0284
C_2	3.3620	0.0554	0.0434	0.0182	0.0163
C_3	168.91	0.0821	0.0497	0.0191	0.0225

These viscosities were used to calculate the friction factor and the pressure drop.

3.2 Hypothetical situation considered

The economic assessment of various methods in the present experimentation is done by applying the above results to a hypothetical pipeline representing real world situation. Consider a 200 km long 16 inch diameter pipeline having maximum elevation of 150 m along the route transporting 10000 barrels per day of crude oil at an ambient temperature of 15^0C. The crude oils considered above are transported through this pipeline.

3.3Cost incurred for different methods

3.3.1 Magnetic field

The magnetic field around the pipeline can be generated with the help of Helmholtz coil. It consists of two circular coils which are separated by a distance equal to the radius of the coils. The coils have equal number of windings on each loop. The details of a Helmholtz coil can be found in the literature by Bhatt *et al* [19]. The magnetic field intensity is given by

$$B = 8.99 \times 10^{-7} \frac{NI}{r} \quad (1)$$

A Helmholtz coil having the following specifications is considered: Radius of coil = 0.8128 m, Diameter of wire = 7.35×10^{-3} m, Length of wire = 5104.3 m, AWG (American Wire Gauge) of wire = 5, Resistivity of copper = 1.79×10^{-8} ohm-m, Resistance of wire = 2.15 ohm. The power required for generating 6000 gauss of magnetic field by the coil per day is found out to be 296603.58 W. The cost of electricity per day (@Rs.7.07 per kWh) is Rs.50327.70.

3.3.2 Pour point depressants

Flow rate of oil (Q)is 10000 bpd i.e18.4 lit/s. Flow rate of injected chemical (Q_c) can be taken as 10% of the oil flow rate i.e 1.84 lit/s. PPDs are dissolved in appropriate amount of solvent. In order to have 200 ppm resultant concentration of PPD in 18.4 lit/sec of oil, 2.2 grams of PPD has to be dissolved in 1.84 lit/s of solvent. Hence the amount of PPD required is equal to 190.08 kg per day. Cost of EVA is Rs. 95 per kg. Hence the cost of EVA required will be Rs.18057.6 per day. Solvent required is 10% of the oil flow rate which is equal to 1.84 lit/s or 158976 lit/day. If the density of xylene is taken as 870 kg/m^3, then the solvent required is 138309.12 kg/day. The cost of solvent (@ Rs. 45/kg) is found out to be Rs.6223910.40. Hence the total cost due to PPD is Rs.6241968.

3.3.3 Diluents

Diluents concentration of 10% is used for treatment. Hence the amount of diluents used for 10000 barrels per day will be 159000 liters. Taking the density of *n*-hexane as 655 kg/m^3, the quantity required would be 104145 kg. The cost @ Rs. 40 per kg will be Rs.4165800.

3.4 Pressure drop calculations

The total pressure drop across a pipeline is the sum of the pressure drops due to frictional losses, elevation of the pipeline and minor losses. Given: Flow rate of oil, Q (m^3/s),Length of the pipe, L (m), Diameter of the pipe, D (m), Density of the fluid, ρ, (kg/m^3), Viscosity of the fluid, μ, (Ns/m^2), Absolute roughness, k (m), Relative roughness,ε= k/D.

The pressure drop due to friction by the Darcy-Weisbach equation is

$$\Delta P_1 = f\frac{\rho L U^2}{2D} = 8.9\times 10^5 \text{ Pa} \quad (2)$$

Pressure drop due to elevation

$$\Delta P_2 = z\times\rho\times g = 1.29 \times 10^6 \text{ Pa} \quad (3)$$

Pressure drop due to minor losses

Pressure drop due to minor losses have been approximated as 20% of the total pressure drop due to friction and elevation.

$\Delta P_3 = 4.36\times 10^5$Pa

Total Pressure drop in the pipeline

$$\Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3 = 2.61\times 10^6 \text{ Pa} \quad (4)$$

If the efficiency of centrifugal pump (η) is 65% then the pumping power as,

$$W_1 = \frac{Q\Delta P}{\rho\eta} = 7.4\times 10^4 \text{ watt} \quad (5)$$

Cost of pumping crude oil = Pumping power (kWh) × Energy cost per unit

The pumping cost per day is found out to be 74 kW ×24 hours × 7.07 Rs./kWh = Rs.12556.65

3.6 Cost comparison for average values of MF, PPD and Diluent

The total cost in rupees is given below. The pipeline is assumed to be insulated so that the temperature is maintained around the wax appearance temperature (WAT).

Table 3. Pumping cost vs pressure drop for different crudes for different methods

	Cost (Rs)				
	Pumping	MF @ 6000 gauss	PPDs @ 200 ppm	Diluents @ 10%	Total
C_1	12556.65				12556.6
C_1+ MF	9054.04	50327			59381.0
C_1+ PPD	7817.83		6241968		6249785.8
C_1+ Diluent	8223.56			4165800	4174023.6
C_2	114006.5				114006.5
C_2+ MF	8814.03	50327			59141.0
C_2+ PPD	8015.24		6241968		6249983.2
C_2+ Diluent	7942.34			4165800	4173742.3
C_3	5361669.2	50327			5361669.2
C_3+ MF	9098.54		6241968		59425.5
C_3+ PPD	8128.59			4165800	6250096.6
C_3+ Diluent	8179.30				4173979.3

Figures 1, 2 and 3 compare the efficiency with the cost of different methods for different crude oils. It is seen that although the chemical methods have more efficiency, the total operating cost is exorbitant. Magnetic methods has less efficiency but the cost required is less. As seen from the figures the efficiency of MFC changes from crude to crude and it is more economical for C_3i.e for crude oils having higher wax content.

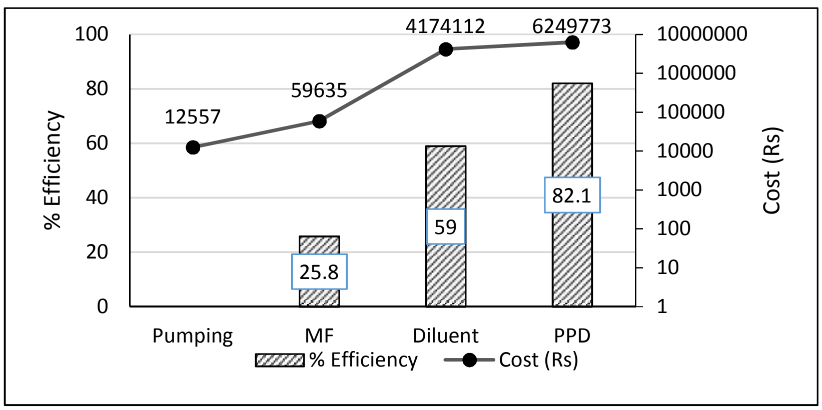

Figure 1. Efficiency vs Cost for Crude Oil 1 (C_1)

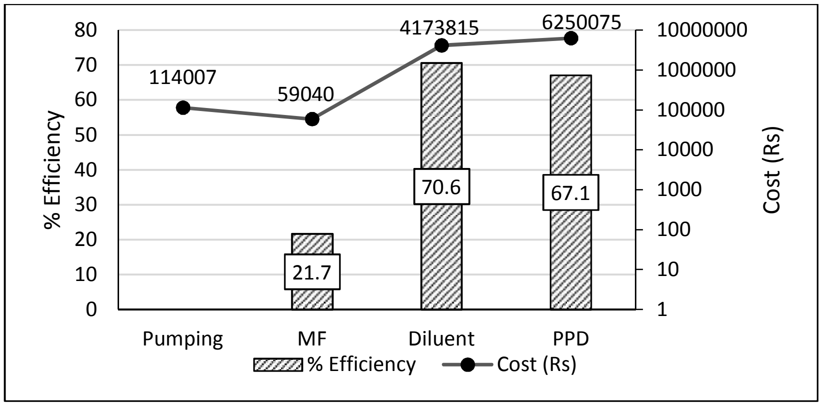

Figure 2. Efficiency vs Cost for Crude Oil 2 (C_2)

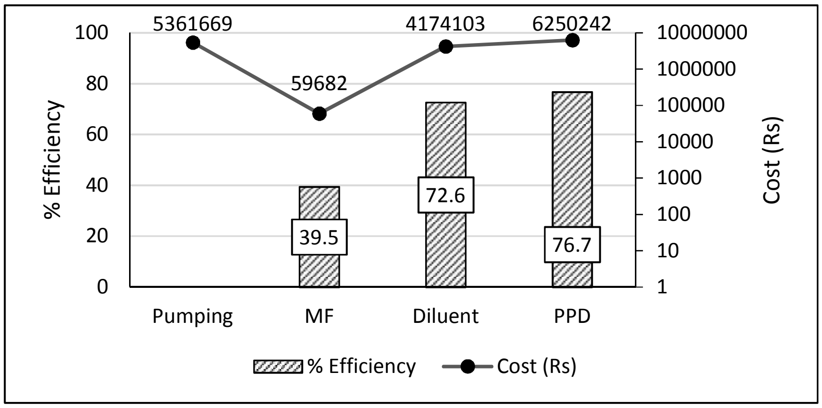

Figure 3. Efficiency vs Cost for Crude Oil 3 (C_3)

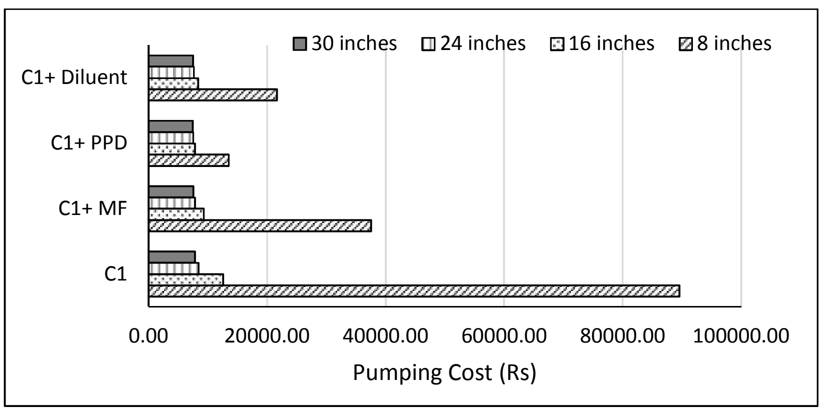

Figure 4. Variation of pumping cost for various methods with different diameters

It is observed from the Figure 4 that larger is the diameter of the pipeline, lesser is the cost when pipelines are operated without any supportive methods. But pipelines having larger diameters are difficult to install and operate. This is consistent with Jerome *et al* [8] who have found that for a pipe diameter ranging from 80 mm to 500 mm, the cost of material, labor, right of way and miscellaneous costs increases from 400,000 dollars to 1,000,000 dollars per ton. The capital cost of such installation is very high when used for longer distances. Hence using smaller diameter pipeline provides a more economical solution. But as seen from the figures, the pressure drop increases steadily with decrease in diameter upto 16 inches but shoots up for 8 inches. This is evident from the increase in flow velocity which changes the flow from laminar to turbulent for a given throughput. Hence additional pumping is needed which can be satisfied by increasing the number of pumping stations which increases the operating cost[20].

Among the different methods used for wax control, it is observed that the cost increases with decrease in pipe diameter. The cost is least for application for PPDs followed by diluents and then by magnetic field. Therefore if a pipeline of smaller diameter is to be used, PPDs help in reducing the pumping cost. This will reduce the installation cost.

3.7 Overall economics of MFC, PPDs and Diluents

Magnetic Field:

1. MFC is a flexible method as the magnetic field can be changed to achieve the desired results. Hence major construction changes or additional capital cost is avoided.
2. The method is very cheap as compared to the chemical method.
3. Additional units like storage and pumps for chemicals, transfer lines or solvent recovery units are not needed.
4. However, MFC requires the temperature to be near WAT for efficient functioning. Hence in order to maintain the temperature near WAT, the pipeline should be insulated appropriately which will increase the capital cost.
5. Application of magnetic field to very high flow rates may not be possible. Since the exposure time found out experimentally is around 1 minute. One solution may be to increase the residence time. It may be done by the use of expanders or by passing the crude through a by-pass with higher cross section area. This may lead to additional cost for pipe line modifications.
6. MFC may not reduce viscosity at the startup or restart of gelled pipelines as done by chemical method. It is a method which will not allow the viscosity to rise after it has been reduced to some extent. Hence it is to be complemented initially by other methods like heating which will increase the overall operating cost.

Chemical method (PPDs and Diluents)

1. The PPD has to be mixed homogenously in the solvent for proper administration. Hence it requires proper mixing system with heating facility. Schematic is shown Figure 5.
2. The chemical has to be injected at a specified location. This calls for a pumping system to transfer the resultant mixture.
3. Although the quantity mixed is less, the chemical properties of crude change and this may affect the downstream processing. A solvent recovery system is required at the downstream.
4. Corrosive solvents demand better material of construction (MOC) for handling.

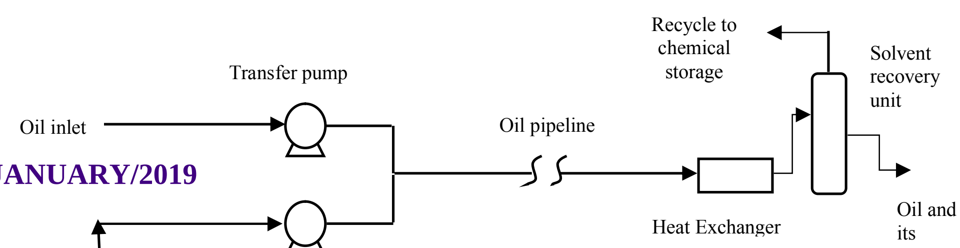

Figure 5: Scheme of addition of chemicals

5. Location of mixing plant and the subsequent transfer may cause problems at remote locations.
6. Abundant availability of cheap diluents is a concern and oil companies have to rely on costly proprietary chemicals.

4. Conclusion

The major factor affecting the cost of transportation of waxy crude oil through pipelines is the wax deposition control method. Economics of the magnetic fluid conditioning and chemical methods was discussed. It was found through experimentation that the efficiency of viscosity reduction by the pour point depressants (PPDs) and diluents was greater than the magnetic conditioning method. The average cost for transportation per day for MFC was found to be 105 times less than the PPDs and around 70 times less as compared to diluents. Although MFC was found to be economical as compared to the chemical methods, its economics during restart of flow using combined methods of chemical or electrical heating may be studied further.

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