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Effect of Chemical Additive on Crude Oil Pipeline Pressure Drop

For transportation of crude oil, the pumping power requirement varies as the crude oil viscosity changes. Increasing °API or line average temperature reduces the crude oil viscosity. The reduction of viscosity results in higher Reynolds number, lower friction factor and in effect, lower pumping power requirements.

In the March 2009 tip of the month (TOTM), procedures for calculation of friction losses in oil and gas **pipelines** were presented. The sensitivity of friction pressure drop with the wall roughness factor was also demonstrated. In the August 2009 TOTM, we also demonstrated the effect crude oil °API and the pipeline average temperature on the pumping requirement.

In practical situations, an originating station takes crude out of storage and the midline stations taking suction from the upstream section of pipeline. Oil in the tank is often at ambient temperature, whereas once in the pipeline, the oil cools (or warms) to the same temperature as the ground. In some parts of the world, the tank might be at +38 °C (+100 °F). The first midline pumping station could operate at 18 °C (65 °F), and all subsequent pumping stations might operate at ground temperature, or notionally 9 °C (48 °F) with some seasonal variation. Therefore, a sound pipeline design should consider expected variation in crude oil viscosity which is normally a function of crude oil °API, and the line average temperature. In addition to °API and temperature, chemical additives may also affect crude oil pipeline pressure drop.

To reduce pressure drop and increase pipeline capacity, oil industry has utilized drag reducing agents. **Drag-reducing agents**, or **drag-reducing polymers**, are additives in pipelines that reduce **turbulence** in a pipe. Usually used in **petroleum pipelines**, they increase the pipeline capacity by reducing turbulence and therefore allowing the oil to flow more efficiently [1]. In addition to drag reducing agents, another group of chemicals called "Incorporative Additives", which reduces crude oil viscosity, maybe used. Halloran presented a series of general reading articles on chemical additives [2-4].

In this TOTM, we will demonstrate the effect of an incorporative additive on crude oil viscosity and consequently on pressure drop for crude oil pipeline transportation.

Case Study: Part 1 – Viscosity Reduction

The laboratory measured kinematic viscosity for different °API crude oil samples ***without*** and ***with*** "Incorporative Additive" at 50 °C (122 °F) reported by Oil Flux Americas [6] are shown in Table 1. The calculated density, absolute viscosity and percent reduction in viscosity for each oil sample at 50 °C (122 °F) are also shown in this table. As noted in this table, the lower °API (heavier oil), the greater the reduction in oil viscosity. The measured kinematic viscosities as a function of crude oil °API are shown in Figure 1. The absolute viscosity is calculated by multiplying the measured kinematic viscosity by density. The corresponding calculated absolute viscosities are also shown in Table 1 for crude oil samples "Without" and "With" additive, respectively.

Table 1.Measured kinematic viscosity [6] and absolute viscosity or several crude oil samples at 50 °C (122 °F) without and with chemical additive.

Crude Oil °API	Relative Density		Density		Kinematic Viscosity, cSt		Absolute Viscosity, cP		Viscosity % Reduction
	15 °C (59 °F)	50 °C (122 °F)	kg/m^3 50 °C	lb_m/ft^3 122 °F	Without Additive	With Additive	Without Additive	With Additive	
12.7*	0.981	0.961	990.2	61.8	575.7	437.1	553.0	419.8	-24.1
16.4*	0.957	0.936	965.6	60.3	219.9	174.1	205.8	163.0	-20.8
18.3	0.945	0.924	953.5	59.5	92.7	75.9	85.6	70.1	-18.1
19.3	0.938	0.918	947.2	59.1	76.7	68.8	70.4	63.2	-10.3
21.1	0.927	0.907	936.2	58.4	50.9	40.4	46.1	36.6	-20.7
21.9	0.922	0.902	931.3	58.1	24.5	19.7	22.1	17.7	-19.9
24.2*	0.909	0.888	917.7	57.3	22.0	19.7	19.6	17.5	-10.5
27.3	0.891	0.870	900.0	56.2	19.5	17.7	16.9	15.4	-9.3
32.2	0.864	0.844	873.3	54.5	9.5	8.9	8.0	7.5	-6.3
33.5*	0.858	0.837	866.5	54.1	5.2	5.0	4.3	4.2	-3.7

cSt = (mm)2/s cP = Poise/100 = Pa.s/1000 =kg/m-s/1000 = 0.000672 lbm/ft-sec * Used in the case studies

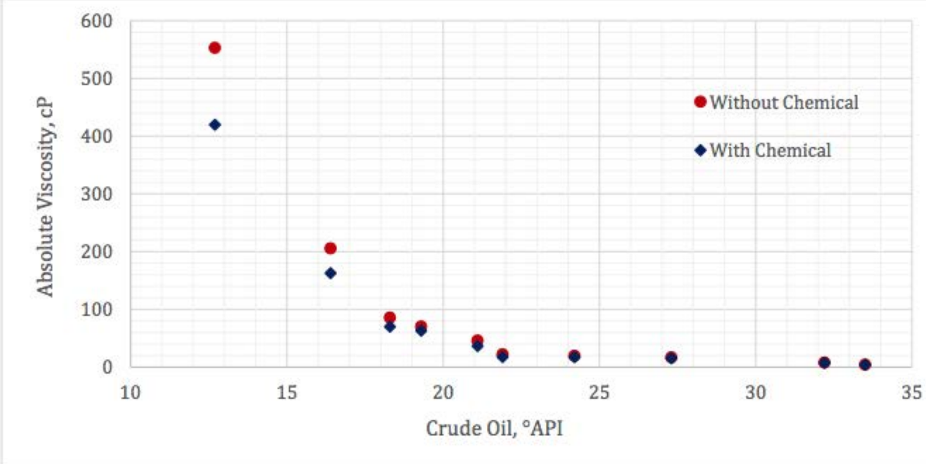

Figure 1. Effect of chemical additive on crude oil absolute viscosity at 50°C (122 °F)

The absolute viscosities (μ) at 50 °C (122 °F) are fitted to a quadratic equation as follows:

$$\mu = e^{(12.1796 - 0.5485API + 0.007074API^2)} \quad \text{For crude without additive} \quad (1)$$

$$\mu = e^{(11.7633 - 0.5365API + 0.00705API^2)} \quad \text{For crude with additive} \quad (2)$$

The absolute viscosities and the fitted correlations are shown in Figures 2 and 3 for crude oil samples "without" and "with" chemical additive, respectively.

Case Study: Part 2 – Pressure Drop Calculations

For a case study, we will consider a 55 km (34.18 miles) pipeline with an outside diameter of 406.4 mm (16 in) carrying crude oil with two separate flow rates of 7,950 and 15,900 m3/d (50,000 and 100,000 bbl/day). The wall thickness was estimated to be 5.7 mm (0.225 in). The wall roughness is 46 microns (0.0018 in) or a relative roughness (ε/D) of 0.0001. The procedures outlined in the March 2009 TOTM were used to calculate the line pressure drop due to friction. Since the objective is to study the effect of incorporative chemical additive, we will ignore elevation change.

It is also assumed the line temperature is constant at 50 °C (122 °F). The change in pressure drop (ΔP) due to changes in crude oil viscosity for this case study will be calculated and presented in the following sections.

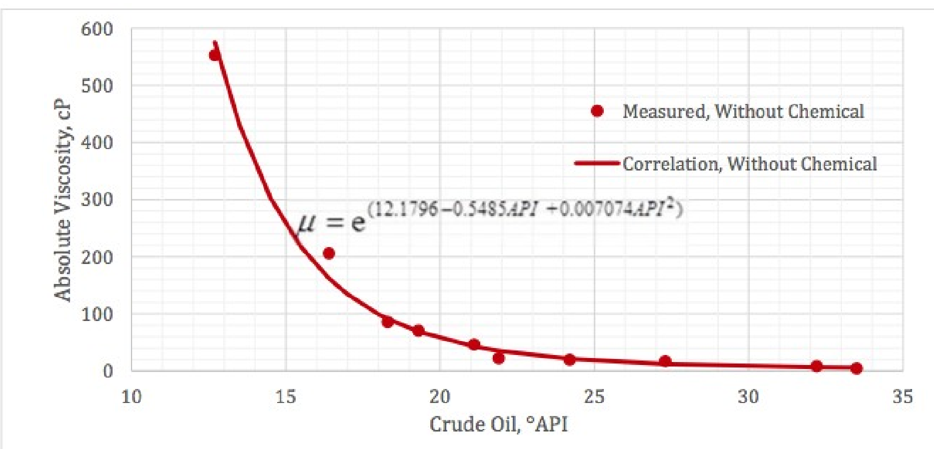

Figure 2. Measured absolute viscosity at 50°C (122 °F) for crude oils without chemical

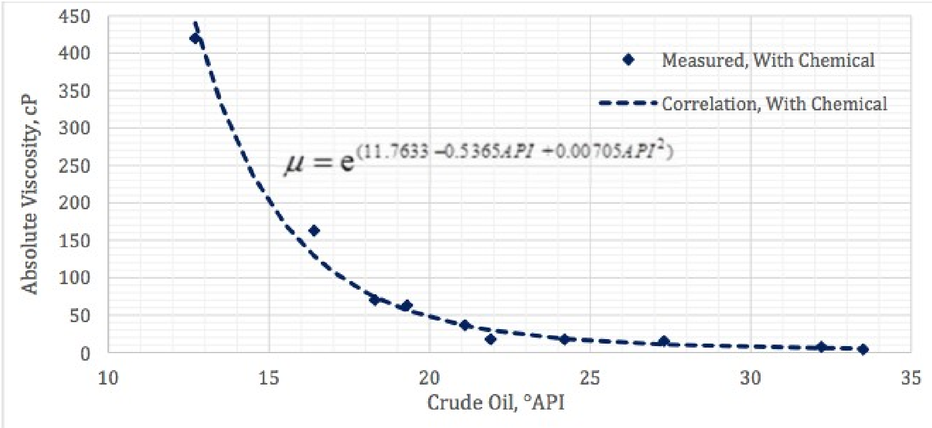

Figure 3. Measured absolute viscosity at 50°C (122 °F) for crude oils with chemical

Tables 2a and 2b show the calculated pressure drop for four different crude oils with varying viscosities in System International (SI) and field units (FPS – Foot, Pound and Second), respectively. The measured absolute viscosities were used to calculate pressure drops for all cases. The oil flow rate is 7,950 m3/d (50,000 bbl/day). Table 2 indicates that by using incorporative additives a reduction of up to 24% in pressure drop is achieved for this case study. The results in this table also indicate that the percent reduction in pressure drop (0.5% for the lightest oil) is not as high as the percent reduction in viscosity (3.7% for the lightest oil). Another observation is that the reduction in viscosity and consequently in pressure drop for light crudes oils is not as significant as for the heavy crudes.

Table 2a. Pipeline pressure drop for four different crude oils without and with additive at 50 °C and oil flow rate of 7,950 m3/d

°API Gravity	Density	μ, cP		μ % Reduction	ΔP, MPa		ΔP % Reduction	ΔP/L, kPa/km	
	ρ, kg/m^3	Without	With		Without	With		Without	With
12.7	960.5	553.0	419.8	-24.08	4.684	3.555	-24.10	85	65
16.4	936.0	205.8	163	-20.80	1.743	1.381	-20.77	32	25
24.2	888.0	19.6	17.5	-10.49	1.057	1.031	-2.41	19	19
33.5	836.8	4.33	4.17	-3.68	0.775	0.771	-0.49	14	14

Table 2b. Pipeline pressure drop for four different crude oils without and with additive at 122 °F and oil flow rate of 50,000 bbl/day

°API Gravity	Density	μ, lb_m/ft-sec		μ % Reduction	ΔP, psia		ΔP % Reduction	ΔP/L, psi/mile	
	ρ, lb_m/ft^3	Without	With		Without	With		Without	With
12.7	59.9	0.372	0.282	-24.08	679	515	-24.10	20	15
16.4	58.4	0.138	0.110	-20.80	253	200	-20.77	7	6
24.2	55.4	0.013	0.012	-10.49	153	149	-2.41	4	4
33.5	52.2	0.003	0.003	-3.68	112	112	-0.49	3	3

Table 2c. Reynolds number and friction factor for the cases in Table 2a and 2b

°API Gravity	Reynolds Number		Flow Regime		Moody Friction Factor	
	Without	With	Without	With	Without	With
12.7	515	679	Laminar	Laminar	0.124	0.094
16.4	1349	1703	Laminar	Laminar	0.0470	0.0380
24.2	13440	15050	Turbulent	Turbulent	0.0303	0.0296
33.5	57320	59520	Turbulent	Turbulent	0.0236	0.0235

Similarly, for an oil flow rate of 15,900 m3/d (100,000 bbl/day), Tables 3a and 3b show the calculated pressure drop for the same four crude oils with varying viscosities. Tables 3a and 3b indicate that as flow rates are increased, less reduction in pressure drop is obtainable if the flow becomes turbulent. For the case of 16.4 °API, the reduction in pressure drop is 6.6% compared to 20.7 reduction when the flow rate was of 7,950 m3/d (50,000 bbl/day). The calculated Reynolds number, Moody friction factors for the cases of lower and higher oil flow rates are shown in Tables 2c and 3c, respectively.

Table 3a. Pipeline pressure drop for four different crude oils without and with additive at 50 °C and oil flow rate of 15,900 m3/d

°API Gravity	Density ρ, kg/m^3	μ, cP Without	μ, cP With	μ % Reduction	ΔP, MPa Without	ΔP, MPa With	ΔP % Reduction	ΔP/L, kPa/km Without	ΔP/L, kPa/km With
12.7	960.5	553.0	419.8	-24.08	9.367	7.111	-24.08	170	129
16.4	936.0	205.8	163	-20.80	6.734	6.290	-6.59	122	114
24.2	888.0	19.6	17.5	-10.49	3.690	3.618	-1.94	67	66
33.5	836.8	4.33	4.17	-3.68	2.877	2.868	-0.32	52	52

Table 3b. Pipeline pressure drop for four different crude oils without and with additives at 122 °F and oil flow rate of 100,000 bbl/day

°API Gravity	Density ρ, lb$_m$/ft^3	μ, lb$_m$/ft-sec Without	μ, lb$_m$/ft-sec With	μ % Reduction	ΔP, psia Without	ΔP, psia With	ΔP % Reduction	ΔP/L, psi/mile Without	ΔP/L, psi/mile With
12.7	59.9	0.372	0.282	-24.08	1358	1031	-24.08	40	30
16.4	58.4	0.138	0.110	-20.80	976	912	-6.59	29	27
24.2	55.4	0.013	0.012	-10.49	535	525	-1.94	16	15
33.5	52.2	0.003	0.003	-3.68	417	416	-0.32	12	12

Table 3c. Reynolds number and friction factor for the cases in Table 3a and 3b

°API Gravity	Reynolds Number Without	Reynolds Number With	Flow Regime Without	Flow Regime With	Moody Friction Factor Without	Moody Friction Factor With
12.7	1030	1357	Laminar	Laminar	0.0620	0.0470
16.4	2698	3406	Critical Zone	Critical Zone	0.0460	0.0430
24.2	26870	30100	Turbulent	Turbulent	0.0265	0.0260
33.5	114600	119000	Turbulent	Turbulent	0.0219	0.0218

In order to show the impact of chemical on pipeline capacity for the same pressure drop, let's consider the heavy crude oil with 12.7 °API. As shown in Table 2a and 2b for an oil flow rate of 7,950 m3/d (50,000 bbl/day) the pressure drop without chemical was 4.684 MPa (679 psia). For the same pressure drop and using the reduced viscosity due to addition of chemicals, the capacity increases to 10,472 m3/d (65,865 bbl/day). This is equivalent of 31% increase in pipeline capacity. Similarly, referring to Tables 3a and b for an oil flow rate of 15,900 m3/d (100,000 bbl/day) for the case of without chemical, the pressure drop was 9.367 MPa (1358 psia). The calculated capacity for the same pressure drop is 20943 m3/d (131,730 bbl/day). Again, a 31 % increase in pipeline capacity is observed.

Conclusions:

The following conclusions can be made based on this case study:

1. The mechanisms of how drag reducing agents work are different from incorporative chemical additives. Incorporative chemical additives reduce viscosity.
2. Utilizing incorporate chemical additives can reduce crude oil viscosity and consequently reduces the pipeline pressure drop significantly. For existing pipelines this means an increase in the capacity of the line and/or reduction in pump power requirement.
3. The reduction of viscosity and pressure drop are more significant for heavier crude oils. As the oil

gets lighter the effect of chemical additives is diminished. At lower temperatures the oil viscosity increases; therefore, the effect of chemical additives may become more significant for lighter crude oils, too.

4. The percent reduction in pipeline pressure drop is not always as large as the percent reduction for viscosity.
5. The incorporative chemical additives are most effective for laminar flow and/or heavier crude oils.
6. A total cost analysis based on hydraulic design and chemical additives with consideration for HSE (health, safety, and environment) should be made for effective design and operation.

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Dr. Mahmood Moshfeghian

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Written on June 1, 2015 at 12:00 am, by Dr. Mahmood Moshfeghian