Metering the flow of oil with drag-reducing agents

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Abstract. The bulk of oil and petroleum products is carried by oil and petroleum trunklines. The performance of such transport depends on many factors, including the process parameters (the pipeline diameter, the number of booster stations, and the power of trunkline pumps) and the parameters of the carried medium itself, mainly its viscosity. Most energy it spent to overcome the loss of pressure due to the friction between the fluid layers. These losses increase with the turbulence of the flow. Turbulence can be reduced by drag-reducing agents (DRA) that level off the flow of the fluid. However, this might jeopardize the calibration of the turbine and ultrasonic flow meters. This paper presents experimental research into such flow meters used for metering the flow of oil with and without DRA. The findings suggest that when using a DRA, the flow meters should be calibrated with the DRA, in which case the measurement error will be within the standard-required 0.15%.

1. Introduction

Pipelines are the most efficient transport for delivering liquid and gaseous hydrocarbons from the extraction point to the end user. Oil and gas trunklines cover nearly all of Russia. How effectively liquid hydrocarbons, in particular oil, are pumped through a trunkline depends on its throughput. According to [1], the throughput of a trunkline is its ability to carry a specific volume of oil or petroleum products over a specific time; the volume depends on the physico-chemical properties of the transported products as well as on the equipment and the condition of the trunkline. The definition makes clear that the throughput of a trunkline may change regardless of the operator’s volition and effort, as it is affected, in particular, by changes in the oil viscosity that may in turn be affected by its composition or the fluctuations of outside temperature. A greater viscosity will impose a greater load on the pumping stations, as greater pressure is required to pump viscous oil.

The main way to improve the performance of a trunkline is to raise the power of the power units at the pumping stations (booster stations) [2]. However, there are limitations on how many pumping stations could be present in the system or how powerful a single station could be, as changing these parameters will alter the system pressure. Loopings and inserts are used as additional means [3]. However, using them is a technical challenge that carries significant extra costs. This is what motivates research into reducing the hydrodynamic losses of oil pumping by improving the pipeline performance without changing the power unit specifications.

Loss of pressure due to the internal friction between the layers of the transported fluid is the main cause of consuming extra electricity to pump the fluid through a pipeline. Whether in a laminar or in a turbulent flow, the mechanical energy of ordered motion is dissipated and converted into the energy of chaotic motion of fluid particles [4]. For turbulent flows, this transition is multistaged. The mechanical
energy of motion is first converted into large-scale vortices of the turbulent medium, then becomes the pulsating motion of low-scale vortices until the forces of viscosity convert it into the thermal energy of the fluid. This is why interfering with the structure of turbulent flows is an important step towards energy loss reduction [2]. This can be done by adding a specific quantity of polymers known as drag-reducing agents (DRA) to the oil flow. However, they affect not only the rheology of the fluid, but also the operation of pipeline instrumentation, mainly that of flow meters. This effect must be analyzed to assess its implications in the sense of metering error.

2. Relevance and Overview of the Existing Solutions
When transported through a trunkline, oil or petroleum products mainly exhibit vortical or turbulent motion, whereby the velocities of particles change chaotically at every point. Turbulence essentially means that an increasing flow velocity results in the spontaneous emergence of multiple nonlinear fractal waves alongside with normal linear waves of varying size. Fractal means herein a complex geometric figure that features self-similarity, i.e. each of its constituents resembles the entire figure. Such waves may emerge whether in the absence of or in the presence of external random disturbances [5, 6].

Velocities pulsate in the turbulent flow, which causes the fluid particles flowing axially to also exhibit transverse motion; the flow intermixes transversely, which entails greater energy intensity of moving such a fluid as compared to a laminar flow.

Turbulence might be reduced by adding polymer additives to the flow; this effect was discovered by the English chemist B.A. Toms in 1946 and was then dubbed the Toms effect [7].

An additive like that is referred to as a drag-reducing agent; such agents help improve oil and petroleum product transport by reducing the hydraulic drag and pressure losses in pumping.

Despite numerous post-discovery laboratory tests, experimental and industrial DRA-enhanced transport of oil and petroleum products [8–15], the mechanism of this effect remains obscure. This, however, does not prevent its application.

DRAs were first used industrially in 1979 in the Trans-Alaska Pipeline System. The agents have since then been put to an efficient use by international oil giants: Fillips Pipe Line, Shell Pipeline, Chemlink petroleum, Lakehead Pipe Line, Petroleos del Equador. Russia’s first industrial tests of DRAs were carried out in 1985 at the final segment of the Lisichansk-Tikhoretsk line [16].

As noted above, despite numerous studies into how a small quantity of polymer additives could significantly reduce the hydraulic drag, there is still no complete theoretical explanation of this phenomenon that involves such disciplines as polymer physics, polymer chemistry, rheology, and hydrodynamics [17].

![Figure 1. How DRAs affect the flow.](image-url)
vortices emerge. Fluid from this layer gets injected into the core, which causes turbulence and omnidirectional dissipation of energy.

A state-of-the-art DRA is a gel or suspension of a high molecular weight (HWM) hydrocarbon polymer dissolved in the carrier. HWM polymers of a molecular weight of \((0.3 \text{ to } 10) \cdot 10^6\), e.g. polyalkylacrylates, methacrylates, polyisobutylene, polystyrene, polyolefins, etc. are used as DRAs for liquid hydrocarbons. For carrier, they use hydrocarbon solvents: kerosene, mineral or vegetable oils, etc. The concentration ranges from 10 to 120 g/m\(^3\).

A DRA boosts the near-wall flow velocity and enlarges the buffer zone, which ultimately increases the throughput. The mechanism behind this is as follows: the pumped medium moves together with a layer of a hydrodynamically active polymer that contains coils of macromolecules, see Figure 2. These coils are being continually deformed and are destroyed when moving on the surface of the adjacent layer. Once in a turbulent flow, hydrocarbons cause a DRA to unfold into long molecular chains along the pipeline. These molecular ‘threads’ extinguish the turbulent vortices in the flow, causing the hydrocarbons to flow in a straight line. Thus, they alter the flow structure and reduce the energy (pressure) loss in pumping.

A DRA is thereby active throughout the volume of the hydrocarbon fluid flow it affects.

![Figure 2. How a DRA works in an oil flow.](image)

When transporting oil and petroleum products through the existing pipelines, use of DRAs helps:
- improve the throughput of the existing trunklines at the maximum permissible pressure;
- reduce the output pressure of a booster station without compromising its throughput;
- improve the trunkline reliability by reducing the pressure its walls are exposed to;
- reduce the power consumption of booster stations and prolong the service life of pumps by disabling them and putting them on standby while not compromising the transport performance.

However, aside from the apparent advantages of injecting a DRA, such injection might cause difficulties, as DRAs affect the metrological performance of the flow transducers used for oil and petroleum product metering [18, 19]. It is therefore relevant to research this phenomenon.

3. Statement of Problem

The need to use DRAs to transport oil and petroleum products is undeniable, as they help reduce costs and comply with the parametric requirements. However, as DRAs affect the metrological performance of flow transducers, metering the DRA-enhanced flow remains an unresolved issue. This paper dwells upon testing the effects of DRAs on the key flow transducer types to draw practical guidelines.

4. Theory

Oil is metered using the so-called oil quantity and quality instrumentation that provides direct or indirect metering. The indirect dynamic metering is mostly implemented by turbine flow meters. There are also ultrasonic flow meters, which, however, are substantially rarer.

A turbine flow meter (TFM) converts the energy of the fluid flow passing through the meter and and moving the rotor. The rotation causes the magnetic-inductive sensors to generate signals of a flow-proportionate frequency. The key specification of a TFM is its K factor, p/m\(^3\), which is essentially the number of output signal pulses per unit of volume, usually a cubic meter. Then the instrumentation system calculates the volumetric flow. Depending on how the TFM is calibrated in the data processing system (DPS), its K-factor can be given as [20]:
– a constant value over the entire flow range \((K_f, \text{p/m}^3)\);
– constant values for specific subrange \((K_{ss}, \text{p/m}^3)\);
– computable conversion factors linked to flow subrange points, or as the flow (TFM frequency) to viscosity ratios \((K_{cfj}, \text{p/m}^3)\).

Ultrasonic flow meters (UFM) rely on how the ultrasound wave speed changes as ultrasound propagated through a moving flow of fluid. It measures the ultrasound propagation time both upstream and downstream. If the fluid velocity vector is co-directed with the ultrasound oscillation vector, the ultrasound speed increases or decreases by the value of flow velocity depending on whether the sound propagates upstream or downstream. The axial flow velocity is calculated in real time as a function of the upstream/downstream ultrasound propagation time.

All metering equipment is subject to verification. However, it is only the metrological performance that is subject to routine control between verifications. This applies especially to flow transducers (FT). Thus, TFM\s are subject to testing the metrological performance at least once a month.

The procedure is designed to find the actual K-factor on the site within the operating flow range \((K_f, K_{ss}, \text{or } K_{cfj})\) and its relative deviation from the K-factor set or calculated by the secondary FT or DPS machinery.

FR performance is tested against a verification bench, a control or reference FT. Absolute values of the relative K-factor deviations must not exceed 0.15\% \[20\].

The K-factor of a TFM depends on many factors such as the flow velocity, the fluid rheology (viscosity, the yield, the water affinity), the TFM sensor contamination, etc. DR\s alter the oil rheology, which affects the K-factor and thus causes an extra error.

5. Materials and Methods

The research team has run experiments to find how DR\s could affect the metrological performance (MP) of flow transducers. The experiments were designed to assess the operational stability of turbine and ultrasonic flow meters after injecting 5 g of DR\s per ton of oil.

The experiments involved one turbine flow meter (TZN-250, Faure Herman, France) and one ultrasonic flow meter (DFX Du 200, OOO ENHA, Russia). MP was tested several times using a verification bench. First it was tested without any DR\s. Second test was run with DR\s, and the resulting calibration was further used as the baseline. Two more DRA-affected tests were run to find whether they could destabilize the flow transducer. Figure 3 shows the test results.

6. Experimental Results and Practical Significance

The findings for TZN-250 are:
– K-factor deviation exceeds the permissible threshold of \(\pm0.15\%\) when comparing the calibrations with and without DR\s;
– K-factor deviation is within \(\pm0.05\%\) when comparing the tests run at a stable DRA concentration.

Similar tests were run for the DFX ultrasonic FT. Before testing, aside from setting the UFM ‘zero’, the team recalibrated the device using the metrological performance values derived by testing it on DRA-free oil and on oil with 5.0 or 8.0 grams of DR\s per ton.

Figure 4 shows the test results.

In the figure, dashed lines show permissible deviations within \(\pm0.15\%\) against the baseline calibration (8 g/t DRA).

The DFX findings are:
– the calibration is highly linear when using the DR\s;
– the K-factor at the minimum flow point deviates by more than \(\pm0.15\%\) when comparing DRA-based and DRA-free calibrations;
– K-factor deviation is within \(\pm0.065\%\) when comparing the tests run at different DRA concentrations (5 vs 8 g/t).
Figure 3. TZN-250 TFM test results.

Figure 4. DFX UFM test results.
7. Conclusion
This research has produced the following findings.

Drag-reducing agents do create a laminar near-wall flow, reducing its drag and increasing its velocity, which, all other things being equal, speeds up the TFM rotor. Therefore, the TFM needs to be recalibrated when using DRAs. At higher DRA concentrations, the K-factors rise for each operating point of the flow.

UFM behaves stably whether in the presence or in the absence of a DRA. However, such stable operation requires time-consuming preliminary configuration, which should be done by the manufacturer’s engineers or appropriately qualified specialists.

Turbine flow meters are the most common type in commercial use, which is why they must be verified both with and without DRAs. This will bring the calibrations used between verifications in line with the actual pumping conditions.

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