Investigation of application of anti-turbulent additive "M-FLOWTREAT" brand C on oil pipeline.

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Abstract. The paper presents studies of the application of the anti-turbulent additive (hereafter ATA) "M-FLOWTREAT", brand C, produced by Mirrico LLC (Russia) on the pressure oil pipeline. The authors carried out experimental studies. These studies were conducted in four stages. The tests were carried out at different concentrations (0…30 g/t) of the used additive. In the conditions of the existing oil pumping technology with the use of an additive, an increase in flow was achieved. The efficiencies of various concentrations of the test additive in the pipeline were determined. The authors also determined the possibility of stopping export pumps while preserving the transport of commercial oil. The possibility of reducing the working pressure at the outlet, as well as increasing the flow capacity of the pressure oil pipeline with the help of this additive, was confirmed.

1. Introduction
The effect of reducing the hydrodynamic resistance of turbulent flows by additions at small concentrations discovered almost half a century ago by English chemist Thomes (Thomes's effect) has not only theoretical, but also great practical value in pipe transport of liquids [1].

Currently, the operation of oil and oil product pipelines in our country (Russia) involves the introduction of small doses of polymeric anti-turbulent additives into the pumped stream (hereinafter - ATA). It allows one to reduce turbulent friction and change the pressure characteristics of the pipeline, thereby contributing to the improvement of the technology of pumping hydrocarbon liquids. There is a number of analogues of the antiturbulent additive under investigation. At [2] physicochemical and rheological properties of four import samples of colloidal additives (Baker, Necadd, X-Pand, and LiquidPower) were studied.

The capacity of commonly used additives (such as FLO MXA, Necadd-477, M-Flowtreat, PT FLYDE-H, etc.) can be influenced by:

- stream flow mode;
- molecular and thermophysical properties;
- working fluid (viscosity);
- temperature of the pumped medium;
- diameter of the pipeline;
- content of asphalt-resin-paraffin substances in the stream.

Additives are effective only in a turbulent flow, for values of the Reynolds number are greater than the critical value.
2. Materials and methods
The paper presents studies of oil transportation using ATA M-FLOWTREAT. The concept of the suspension additive M-FLOWTREAT developed in the laboratory anti-turbulent additives of the Scientific and Engineering Center of the group of the company "Mirriko". It is produced by Mirrico Service LLC, in industrial highs according to TU 2458-001-63121934-2010 and has the documentation package necessary for its use. At 20 degrees Celsius, the additive is a suspension from white to light brown in color. The pour point is not higher than \(-45\,^\circ\text{C}\). Density at 20 °C is from 820 to 1200 kg / m³. The Brookfield viscosity at 20 °C is not more than 1000 (1000) mPa·s (cPs).

3. Experimental studies of pipeline transport of oil with the use of additive
To intensify pipeline transport of oil and oil products and to decrease energy expenditures for pumping a liquid unit volume, antiturbulent additives (ATAs) based on polymers with very high molecular masses (M > 1·10⁶) [3-6] are actively used in the last quarter of the century.

Objectives of experimental studies are:
- Determination of the possibility of increasing the oil consumption by reducing the hydraulic resistance in the pipeline with the help of the ATA.
- Determination of the effectiveness of different concentrations of ATA in the pipeline.
- Demonstration of the operational properties of the additive and the advantages of its use.
- Determination of the possibility of stopping external export pumps while preserving the transport of commercial oil.
- Determination of the possibility of increasing the productivity of the pressure oil pipeline, with the pumps stopped external pumping at the intermediate pumping station.

The experimental studies were carried out in accordance with the developed plan. The first stage of the experiments included filling the pipeline section and testing the mode for determining the maximum oil evacuation without the use of a ATA. Also, during the first stage, the pipeline section was filled and the mode for determining the maximum oil evacuation without the use of a ATA was tested.

During the second stage of the experiment, the section of the oil pipeline was filled with oil treated with "M-FLOWTREAT" brand C, with a concentration of 30 g/t with further development of the stationary regime at this concentration.

Further, filling of the oil pipeline section with processed grade "M-FLOWTREAT" brand C, with a concentration of 10 g/t was carried out and the stationary regime at this concentration was worked out.

The third stage of the tests consisted of filling the area with oil treated with M-FLOWTREAT ATA brand C, a concentration of 20 g/t, and a steady-state regime at a given concentration.

During the fourth stage, the site was filled with oil grade M-FLOWTREAT brand C, at a concentration of 10 g/t, and then a stationary regime at this concentration was developed. Later, the site was filled with oil with an additive concentration of 30 g/t and a stationary pumping regime was developed at this concentration.

In the fifth stage of the tests, a stationary mode of oil transfer was worked out at the Oil Pump Station (OPS) concentration of 30 g/t, with the pump station of the OPS disconnected. The transportation of oil was carried out in transit through two track oil heaters to the OPS via the oil pipeline.

The results of all the test stages are shown in Table 1.
Table 1. Results of experimental studies

| Additive concentration, g/t | Stage 1 mode without ATA | 2 stage stationary mode | 3 stage stationary mode | 4 stage stationary mode | Stage 5 stationary mode, switched off OPS |
|-----------------------------|--------------------------|-------------------------|-------------------------|-------------------------|------------------------------------------|
| Duration, hours             | 9                        | 8                       | 4                       | 8                       | 5                        | 6 | 6 | 6 | 6 | 5 |
| Average oil consumption at the outlet, t/h (m³/h) | 457 (575) | 428.5 (535) | 524.6 (657.0) | 494.8 (610.24) | 524.1 (656.4) | 561 (700.5) | 520 (652.3) | 586.4 (734.79) | 463.3 (577.3) | 524.1 (656.4) |
| Average pressure, kgf/cm²: | - at the output of the OPS | 75.0 | 63.8 | 35.4 | 63.7 | 48.6 | 53.9 | 69.7 | 47.7 | 66.95 | 48.6 |
| - at the input of the Pipeline Commissioning Station (PCS) or OPS | 1.9 | 2.8 | 2.3 | 2.4 | 2.1 | 2.2 | 2.3 | 2.3 | 2.3 | 2.1 |
| Average oil temperature, ºС: | - at the exit of the OPS | 55.3 | 56.4 | 55.3 | 57.5 | 55.1 | 56.5 | 55.0 | 56.5 | 56.5 | 55.1 |
| - at the input of the PCS or OPS | 30.0 | 36.2 | 34.2 | 36.3 | 32.6 | 37.2 | 33.9 | 37.3 | 37.3 | 32.6 |

4. Processing of experimental results

The efficiency of the ATA (relative decrease in hydraulic resistance) for a stationary mode of operation of the oil pipeline [7] is determined by the formula:

\[
DR = 1 - \left( \frac{\Delta P_f}{\Delta P_0} \cdot \left( \frac{Q_0}{Q_f} \right)^{2-m} \cdot \left( \frac{\nu_0}{\nu_f} \right)^m \right) \cdot 100\%
\]  

(1)

where the indices f and 0 correspond to the flow of commercial oil with and without additive; 
\(\Delta P\) - pressure loss for friction, kg/cm²; 
\(Q\) - volumetric flow, m³/h; 
\(\nu\) is the kinematic viscosity coefficient of commercial oil at an average flow temperature, m²/s; 
m is the index of the fluid motion regime. For the turbulent flow regime in the zone of smooth pipes, \(m = 0.25\), and for the turbulent regime in the zone of mixed friction, \(m = 0.123\). 
The loss of pressure on friction \(\Delta P\) [8,9] during the flow of both an oil with an additive and without
it is found by the formula:

\[ \Delta P = P_1 - P_2 - g(\rho_2 Z_2 - \rho_1 Z_1), Pa \]  \hspace{1cm} (2)

where \( P_1 \) is the pressure at the inlet to the linear part of the oil pipeline, Pa;
\( P_2 \) - pressure at the end of the pipeline, Pa;
\( \rho_1, \rho_2 \) - density of commercial oil at the inlet and outlet of the pipeline, respectively, kg / m³;
\( Z_1, Z_2 \) - geodetic marks of the beginning and end of the pipeline route, respectively, m.

The average temperature of the oil flow in the pipeline was calculated by the formula:

\[ t = \frac{t_1 + t_2}{2}, ^\circ C \]  \hspace{1cm} (3)

where \( t_1 \) and \( t_2 \) - oil temperatures at the beginning and end of the pipeline, respectively, °C.

The increase in oil consumption during the application of ATA was determined by the formula:

\[ \chi = \left(\frac{M_f}{M_0} - 1\right) \cdot 100, \% \]  \hspace{1cm} (4)

where \( M \) is the mass flow rate, t/h;
f and 0 are indices that correspond to the flow of oil with and without additive.

To assess the fluid flow in an oil pipeline, the Reynolds number [10] is determined by the formula:

\[ Re = \frac{4Q}{\rho \nu D} \]  \hspace{1cm} (5)

where \( D \) is the internal diameter of the pipeline, m;
\( Q \) - volumetric hourly flow rate of oil, m³/h;
\( \nu \) - kinematic viscosity of oil, m²/s.

To determine the zone of a turbulent flow, the values of the Reynolds transient numbers [11] are determined by:

\[ Re_{trans1} = 10 \cdot \frac{D}{\Delta_e} = 10 \cdot \frac{0.366}{0.15 \cdot 10^{-3}} = 24400 \]

\[ Re_{trans2} = 560 \cdot \frac{D}{\Delta_e} = 560 \cdot \frac{0.366}{0.15 \cdot 10^{-3}} = 1220000. \]

In the calculation, we assume that the equivalent roughness \( \Delta_e \) of the pipe is equal to \( \Delta_e = 0.15 \) mm = 0.15 \( \cdot 10^{-3} \) m.

Consequently, for all modes, we have a turbulent flow regime in the zone of mixed friction. Therefore, to determine the efficiency according to formula (1), the index of the fluid motion regime will be \( m = 0.123 \).

The results of calculating the efficiency of the M-FLOWTREAT ATA brand C and the degree of increase in oil consumption in the surveyed sections relative to the baseline operation of the oil pipeline are presented in Table 2.

**Table 2.** Results of calculating the efficiency of the M-FLOWTREAT ATA brand C and the degree of increase in oil consumption in the section of the pipeline being examined

| Mode No. | Consumption of ATA, g/t | Outlet pressure, kgf/cm² | Pressure at the inlet of the OPS, kgf/cm² | Volumetric flow, m³/h | Efficiency DR,% | Increase in consumption,% |
|----------|------------------------|--------------------------|------------------------------------------|----------------------|-----------------|--------------------------|
| 1        | -                      | 63.8                     | 2.8                                      | 535.00               | -               | -                        |
| 2        | 10                     | 63.7                     | 2.4                                      | 610.24               | 21.59           | 14.06                    |
| 3        | 20                     | 53.9                     | 3.2                                      | 700.50               | 49.86           | 30.93                    |
| 4        | 30                     | 47.7                     | 2.6                                      | 734.79               | 59.08           | 37.34                    |
| 5        | 30                     | 66.95                    | 2.3                                      | 581.50               | 55.24           | 8.69                     |

Below, in Tables 3-6, the calculation of the throughput capacity of the section of the pressure oil pipeline is presented on the basis of the experiments conducted by the ATA "M-FLOWTREAT"
brand C.

Table 3. Calculation of total head losses during the transportation of oil through the section of the pipeline without the use of the ATA.

| Consumption t/day | Velocity, m/s | Re Coefficient of hydraulic resistance | Loss of head, m on friction | Outlet pressure MPa | Outlet pressure kgf/cm² |
|-------------------|--------------|----------------------------------------|-----------------------------|---------------------|-------------------------|
| 0                 | 0.0          | 0.0                                    | 0.0                         | 0.0                 | 0.0                     |
| 7000              | 368.0        | 0.10                                   | 104644                      | 0.020               | 393.7                   | 419.5                   | 3.2                  | 32.82               |
| 8000              | 420.6        | 0.12                                   | 119593                      | 0.019               | 504.1                   | 529.9                   | 4.1                  | 41.46               |
| 9000              | 473.1        | 0.13                                   | 134542                      | 0.019               | 627.5                   | 653.2                   | 5.0                  | 51.11               |
| 10000             | 525.7        | 0.15                                   | 149492                      | 0.019               | 763.7                   | 789.5                   | 6.1                  | 61.77               |
| 10176             | 535.0        | 0.15                                   | 152123                      | 0.019               | 789.0                   | 814.8                   | 6.3                  | 63.75               |
| 11000             | 578.3        | 0.16                                   | 164441                      | 0.019               | 912.8                   | 938.6                   | 7.2                  | 73.43               |
| 11600             | 609.8        | 0.17                                   | 173410                      | 0.019               | 1008.5                  | 1034.3                  | 7.9                  | 80.92               |
| 13315             | 700.0        | 0.19                                   | 199048                      | 0.018               | 1307.3                  | 1333.1                  | 10.2                 | 104.29              |
| 13976             | 734.7        | 0.20                                   | 208929                      | 0.018               | 1432.5                  | 1458.3                  | 11.2                 | 114.09              |
| 15000             | 788.6        | 0.22                                   | 224337                      | 0.018               | 1637.5                  | 1663.3                  | 12.8                 | 130.13              |

Table 4. Calculation of total head losses during the transportation of oil through the section of the pipeline with the ATA, concentration of 10 g / t.

| Consumption t/day | Velocity, m/s | Re Coefficient of hydraulic resistance | Loss of head, m on friction | Outlet pressure MPa | Outlet pressure kgf/cm² |
|-------------------|--------------|----------------------------------------|-----------------------------|---------------------|-------------------------|
| 0                 | 0.0          | 0.0                                    | 0.0                         | 0.0                 | 0.0                     |
| 7000              | 368.2        | 0.10                                   | 104690                      | 0.015               | 296.3                   | 317.0                   | 3.4                  | 24.77               |
| 8000              | 420.8        | 0.12                                   | 119645                      | 0.015               | 379.4                   | 400.1                   | 3.1                  | 31.27               |
| 9000              | 473.3        | 0.13                                   | 134601                      | 0.014               | 472.2                   | 492.9                   | 3.8                  | 38.52               |
| 10000             | 525.9        | 0.15                                   | 149557                      | 0.014               | 574.8                   | 595.5                   | 4.6                  | 46.54               |
| 10176             | 535.2        | 0.15                                   | 152189                      | 0.014               | 593.8                   | 614.5                   | 4.7                  | 48.02               |
| 11000             | 578.5        | 0.16                                   | 164512                      | 0.014               | 687.0                   | 707.7                   | 5.4                  | 55.31               |
| 11600             | 610.1        | 0.17                                   | 173486                      | 0.014               | 759.0                   | 779.7                   | 6.0                  | 60.93               |
| 13315             | 700.3        | 0.19                                   | 199135                      | 0.014               | 983.9                   | 1004.6                  | 7.7                  | 78.51               |
| 13976             | 735.1        | 0.20                                   | 209020                      | 0.014               | 1078.1                  | 1098.8                  | 8.4                  | 85.87               |
| 15000             | 788.9        | 0.22                                   | 224335                      | 0.014               | 1232.4                  | 1253.1                  | 9.6                  | 97.93               |

Table 5. Calculation of total head losses during the transportation of oil through the section of the pipeline with the ATA, concentration of 20 g / t.

| Consumption t/day | Velocity, m/s | Re Coefficient of hydraulic resistance | Loss of head, m on friction | Outlet pressure MPa | Outlet pressure kgf/cm² |
|-------------------|--------------|----------------------------------------|-----------------------------|---------------------|-------------------------|
| 0                 | 0.0          | 0.0                                    | 0.0                         | 0.0                 | 0.0                     |
| 7000              | 368.2        | 0.10                                   | 104713                      | 0.010               | 197.9                   | 228.8                   | 1.8                  | 17.90               |
| 8000              | 420.8        | 0.12                                   | 119672                      | 0.010               | 253.4                   | 284.3                   | 2.2                  | 22.24               |
| 9000              | 473.5        | 0.13                                   | 134631                      | 0.010               | 315.4                   | 346.3                   | 2.7                  | 27.09               |
| 10000             | 526.1        | 0.15                                   | 149590                      | 0.009               | 383.9                   | 414.8                   | 3.2                  | 32.45               |
| 10176             | 535.3        | 0.15                                   | 152223                      | 0.009               | 396.6                   | 427.5                   | 3.3                  | 33.44               |
| 11000             | 578.7        | 0.16                                   | 164549                      | 0.009               | 458.8                   | 489.8                   | 3.8                  | 38.31               |
| 11600             | 610.2        | 0.17                                   | 173524                      | 0.009               | 506.9                   | 537.8                   | 4.1                  | 42.07               |
| 13315             | 700.4        | 0.19                                   | 199179                      | 0.009               | 657.1                   | 688.0                   | 5.3                  | 53.82               |
| 13976             | 735.2        | 0.20                                   | 209067                      | 0.009               | 720.0                   | 751.0                   | 5.8                  | 58.74               |
Table 6. Calculation of total head losses during the transportation of oil through the section of the pipeline with the ATA, concentration of 30 g/t.

| Consumption (t/day) | Velocity, m/s | Re | Coefficient of hydraulic resistance | Loss of head, m | Outlet pressure, m³/s |
|--------------------|---------------|----|-----------------------------------|----------------|----------------------|
| 5000               | 0.0           | 0.0| 0.000                             | 0.00           | 0.00                 |
| 7000               | 0.10          | 0.97| 0.018                            | 0.13           | 0.01                 |
| 8000               | 0.12          | 1.11| 0.018                            | 0.13           | 0.01                 |
| 9000               | 0.13          | 1.25| 0.018                            | 0.13           | 0.01                 |
| 10000              | 0.15          | 1.39| 0.018                            | 0.13           | 0.01                 |
| 10176              | 0.15          | 1.41| 0.018                            | 0.13           | 0.01                 |
| 11000              | 0.16          | 1.53| 0.018                            | 0.13           | 0.01                 |
| 11600              | 0.17          | 1.61| 0.018                            | 0.13           | 0.01                 |
| 13315              | 0.19          | 1.85| 0.018                            | 0.13           | 0.01                 |
| 13976              | 0.20          | 1.94| 0.018                            | 0.13           | 0.01                 |
| 15000              | 0.22          | 2.08| 0.018                            | 0.13           | 0.01                 |

Pressure characteristics of oil pipeline section during transportation of oil with the ATA, concentrations of 10, 20 and 30 g/t and without it are shown in Figure 1.

Figure 1. Pressure characteristic of the section of the oil pipeline during the transportation of oil from the M-FLOWTREAT ATA brand C at a concentration of various concentrations and without it.

5. Conclusion

In the course of the tests, the goals were achieved. It was found that in terms of the existing technology for pumping oil from the M-FLOWTREAT ATA brand C at the pipeline section at concentrations of 10, 20, 30 g/t, the efficiency of the ATA application was 21.59%, 49.86% and 59.08% respectively.

The possibility of transporting oil from the M-FLOWTREAT ATA brand C at a concentration of 30 g/t under a pressure oil pipeline with a disconnected OPS was confirmed. Transportation was carried out in transit through two track oil heaters at the OPS via the oil pipeline. The efficiency of ATA at this concentration was 55.24%
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