Solution of Local Rheological Nodal Task to Problem of the Maximum Flow of the Minimum Cost in Complicate Branched System of Trunk Oil Pipelines

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Abstract. The paper considers a new approach to identifying the possibility of saving pumping energy for in the oil trunk pipeline system by optimization the mixing ratio of the oils pumped to different directions in complicate branched network. To get the effect of energy consumption reduction, optimal mixing concentrations are calculated on the simplex space characterizing the composition of the oil blend. The problems of calculating the flow rate and required energy by a more explicit function type without iterative methods are considered. Attention is paid to determining the boundaries of possible ratios of blending taking into account the condition of mass balance. An example to solving the task aimed to optimization of oil flows distribution in condition of differences of their rheological properties in the case of the simplest configuration type of the pipeline network is also shown. The considered method presents the local nodal solution of a more complete transportation optimization task – The Maximum flow of the Minimum cost.

1. Introduction

Currently, there are carried out various researches aimed at optimization of oil flows routes and improving the energy efficiency of pumping depending of differences in rheological and qualitative properties of oils transported through the united branched system of trunk oil pipelines [1, 2, 3]. The solution of the task of optimal oil flows distribution in main pipeline systems based on the condition of energy efficiency can be implemented only by solving two interrelated problems - the private (node) rheological, and the general (transportation) task of mathematical programming.

If the problems of developing optimization algorithms of operating modes of separate technological part for and distribution of oil flows in the whole trunk pipeline system have been already studied well [1, 3, 4, 5, 6, 7], and taking into account the current level of computer technology development, the possibility of their practical solving is beyond doubt, then the solution of the second part of the problem (local rheological task in node) is still relevant.

To solve the rheological local task, it is first necessary to develop the model of multicomponent oil blend, that could take into account the difficult process of oil mix formation during the joint oils transportation in branched main pipeline network where last ones could have different rheological characteristics and levels of commercial quality. Since the oil viscosity does not possess linearly additive properties, it is rather difficult to solve the problem of blend modeling without using a
multivariate simplex space that gives an option of reflecting the mutual content of all possible pairs of the original mixed components. Thus, the composition of a mixture with any number of constituent components is determined by the simplex, i.e. the simplest geometric figure having \( k \) vertex in the \((k-1)\)-dimensional space. As for example, for three-component blend such a figure is a concentration triangle, for a four-component blend - a tetrahedron, etc.

2. Flow rate and energy consumption in the system of simplex coordinates

After the model of the blending in the multidimensional simplex space have been obtained it is necessary to transfer it to the real pipeline network considered. In order to decide this task at each oil mixing node (individual simplex) the total energy required for pumping is calculated. To determine the required energy, it is first necessary to find the resulting flow depending of the blend viscosity changes.

The known calculation method of flow rate requires repeated iterative calculations [8, 9] and thus makes it impossible to directly transfer its solution in the form of an explicit equation into simplex coordinates. The resulting flow in the pump-pipe system depends on the parameters of the pumps used, pipeline configuration and oil properties. The solution is determined on the basis of the equality of the head pumped and head loss in pipeline. Widely known empirical head (or pressure) equations, depending of flow regimes [9], are intended for design tasks when the flow rate is known condition, and the aim is only choose equipment required for provide the reliable of operating of pipeline system. Solving the inverse task of determining the flow rate, we obtain rather complex functional dependencies. To solve the problem of transferring a complicated functional dependence to the system of simplex coordinates [10, 11], it is necessary to present flow rate through the blend viscosity by explicit form in already existing system (with constant characters of the pump and pipeline). This way is greatly simplifies the calculations.

Using the Buckingham pi theorem by numerical experiments for conditions of the main pipeline transportation of oil, it was identified the possibility of using a simplified linear dependence of the flow rate on the logarithm of viscosity in the turbulent flow zone over sufficiently wide ranges of viscosity variation.

\[
Q = A \cdot \ln(\nu) + B
\]

\( \nu \) – viscosity of oil blend;
\( A, B \) – constants, depending on the fixed parameters of the pumps and the pipeline.

The math dependence obtained on experimental points in general form is sufficient to transfer the flow rate function of a fixed pump-tube system into simplex coordinates. Then the coefficients of the linear logarithmic equation are easily found by approximating the known dependences [9].

Energy for pumping a given mass of oil is determined as follows:

\[
E = G \cdot g \cdot \left( a - b \cdot Q^2 \right) / \left( c + d \cdot Q + e \cdot Q^2 \right)
\]

\( G \) – the mass of oil must be transported in the period of time;
\( a, b, c, d, e \) – constants of pumps used;
\( g \) – acceleration of gravity.

3. Results of approbation the model for rheological optimization of blending node

As an example it is considered the simplest task of determining the optimal distribution of oil flows for 2-branched oil pipeline system showed at Fig.1.
At the head station receives 3 different types of oil in a ratio of 0.5: 0.2: 0.3 of the volume flow (Figure 2). Then, the three-component blend is pumped into two various directions by different pipelines. The first pipeline, with a diameter of 1020 mm and a length of 200 km, has 2 parts divided by one pumping station in the middle of distance. The second pipeline has a diameter of 1220 mm and a length of 100 km.

The parameters of the three-component blend viscosity model are determined by the following equations (Fig. 3 and 4):

$$\lg (\lg (v_{mix} + 1.537)) = y \cdot \lg (\lg (v_1 + 1.537)) + y \cdot \lg (v_2 + 1.537))$$  \hspace{1cm} (3)

$$y = x_3 \cos (8.526^\circ) + x_2 \cos (60^\circ + 8.526^\circ)$$  \hspace{1cm} (4)

where $v_{mix}$ – resulting viscosity of oil blend;

$v_1, v_2, v_3$ – viscosity of the initial oils blending at the main pumping station;

$x_1, x_2, x_3$ – mass fraction of oil blend components.
Figure 3. A map of the level lines obtained from the results of modelling three-component blend on simplex coordinates.

Figure 4. Results of modelling three-component blend on composition-properties diagram.

Based on the results of made hydraulic calculations, the coefficients of equation (1) have been found. The form of equations obtained for each pipelines is shown in Figure 5. The graphs proves the correctness of the conclusions outlined above.

Figure 5. Results of hydraulic calculations for each pipelines in flowrate-viscousity coordinates.

The boundaries of oil blend variants based on the mass balance condition are shown in Figure 2 in the form of a shaded area.
Figures 6 and 7 show the results of calculating the energy savings of the whole system by formula (2), depending on the ratio of the oils in the blood pumped through the first pipeline.

**Figure 6.** A map of the level lines, obtained from the results of modelling presenting an amount of saved energy.

**Figure 7.** Results of modelling on composition-properties diagram presenting an amount of saved energy.

**Figure 8.** Results of calculating the optimum ratios of the oil blends composition pumped through each pipeline.

It was calculated that the initial ratio of oils coming to the main station (P) should be divided into a blend P1 (viscosity of 9.715 cSt) pumped through the first pipeline and blend P2 (viscosity of 17.143 cSt) pumped to the second direction (Figure 8). The algorithm for choosing the optimal mixing concentrations for obtaining two blends pumped to different directions by each pipeline is as follows: first selects any point on AA' characterizing the composition of the blend pumped to the first direction; then the point of cross of the BB' and the straight line passing through the points P and the first selected point , will give the concentration of the oil blend for the second pipeline (Figure 8). The amount of saved energy for the considered configuration of the pipeline network is $3.394 \times 10^{11}$ J or 94.17 MW·h per year.

4. **Conclusions**

It is shown the new way of saving pumping energy based on optimally distribution of oil flows with different rheological properties in a complex branched system of main oil pipelines. The solution of the problem is based on the simplex model of the blend viscosity and subsequent calculation of the
energy consumption by (1) and (2). The considered method after the corresponding modification presents the nodal solution of a more complete transportation optimization task – The Maximum flow of the Minimum cost [2].

5. References

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