Optimization of Oil Blending to Increase the Efficiency of Joint Pumping in the System of Trunk Oil Pipelines

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Abstract. The article proposes a methodology for calculating the factors of rational mixing of oils with various rheological properties that are jointly transported through an extensive system of trunk pipelines to save energy demands for pumping. The calculation is aggravated by the absence of additivity of viscosity of specially formed multicomponent blends of oils that compels the calculation in a simplex place that characterize the possible compositions of oil blends. It is proposed to use the standard polydimensional optimization strategy as the main calculation module. The objective is presented in the form of summarized energy demand for pumping depending on the concentration of oil blend at the nodal points of their blending. There is proposed a method for calculating the objective for any extensive network of oil trunk pipelines using algorithms of constructing a blend tree and determining its properties using traversal tree algorithm.

1. Introduction

Oil plays a key role in both the economic and strategic development of all countries in the modern world. Pipeline networks that connects oil production and consumption points have covered vast areas of our planet. The Configuration of the pipeline system of the Russian Federation is particularly unique. It began to form during the Soviet Union in the postwar years and in theory it was as a single network in the mainstream of the planned economy, which determined its development in a large extent [1; 2; 3; 4]. Its main differences from Western models were and stay the network structure of the system, a high concentration of capacities, centralized management of a single integrated stream of supply [1; 3].

It is created a new techno-economic situation during the maintenance of the formed oil pipeline system in connection with the working of deposits and an increase of parts of production of oil volumes with unfavorable rheological characteristics [5; 6] today.

Oil with complicated rheological characteristics and anomalous quality parameters of the Vankorskoye field (Western Siberia) that production volume has reached 21 million tons [5] is supplied to the Russian system of trunk oil pipelines today. It is planned to connect production facilities of the Russkoye field (Western Siberia) which has similar indicators [5]. Oil intake is started at the Yaregskoye field (Timan-Pechora province) that has complicated rheology and is not transported under standard conditions (“does not leak”) [5]. There is a buildup of receiving of oil with a high content of heavy metals from shippers, an increased content of resins and asphaltenes, a
reduced amount of naphthenic hydrocarbons which in addition to the aggravation of commodity indicators complicate the operational characteristics of the transported oil [5].

In view of this, issues of developing a new optimal energy-saving strategy for management and distribution of oil stream of supply are becoming relevant taking into account changes in the rheological properties of the pumped oil blendings.

The article introduces the following way to solve this problem: choosing of rational routes of the traffic by a network of oil pipelines of blendings of multi-sorted oils specially formed at its nodal points by reference to the requirements of consigners on pumping a given mass of oil and preserving the minimum acceptable quality indicators of delivered oils to consumers. This wording can be called qualitative because it reflects the idea itself.

It is proposed to find the optimal mixing ratios (concentrations) of specially formed blendings at the nodal points of the oil pipeline system for their further transportation to various network directions as a quantitative solution to the problem. The saving of summarized energy for pumping consists in getting such routes of movement of specially selected optimal oil blends in which more viscous oil blendings will be transported in more energy-efficient pumping modes and delivered to the nearest oil receiving points, and less viscous oil will be sent to those directions in which the increase of the viscosity of the pumped medium markedly affects the energy efficiency of the pumping.

2. Theory

To solve the problem generically it is necessary to develop general scientific and theoretical approaches for determining the objective and algorithms for its calculation for any configuration of an extensive oil pipeline network taking into account the volumes and points of various oils entering the system and oil delivery points at the final posts. This calculation is complicated by the absence of viscosity additivity of specially formed multicomponent oil blends that leads to the need for preliminary experiments to determine a model of changing the viscosity of oil blends. The model is constructed in a polydimensional simplex place characterizing the composition of mixtures [7].

The solution to the problem begins with the definition of mixing nodes. Mixing nodes are those network points where it is possible to direct the flows of specially formed oil mixtures with various rheological properties in different directions and/or technological sections of main oil pipelines.

As the objective was taken the summarized energy spent on pumping the given mass volumes of oil to deliver it to the receiving points.

The determining parameters are the mixing concentrations of the initial oils entering the system at the nodal mixing points.

The optimization condition is the search of the minimum summarized energy $E$ for oil pumping [7]:

$$
E \{x_1; x_2, \ldots, x_k\} \rightarrow \min,
$$

$x_i$ - the concentration of mixing of the $i$-th oil at the mixing nodes;

$k$ - the amount of oil supplied to the pipeline system.

The initial data for the calculation are: 1) the configuration of the oil pipeline system with points of receiving and delivering of oils and their planned mass pumping volumes; 2) parameters of technological sections of the oil pipeline network (length and diameter of pipelines, wall thicknesses of sections of oil pipelines, permitted working pressures, route profile, operational characteristics of pumps installed at oil pumping stations, the possibility or its absence of sequential pumping at technological sections, etc.); 3) physico-chemical and quality controlled parameters of the oils entering the system.

The proposed solution involves solving the following subtasks:
1) Determination of mixing nodes in extensive oil pipeline system where each node \( j \) is characterized by a function of calculating the summarized energy for pumping \( E_\{x_1;x_2;...;x_n\} \) in sections of the oil pipeline system to the next mixing node or end point depending on the selected mixing concentrations. In this case, the first parental simplex nodes in the course of the oil flow in the analytical mixing model will be an integral part of the following nodes that are simplex more complete figures. The resulting simplex figure includes a complete solution and it is the display space of the objective:

\[
E_\{x_1;x_2;...;x_n\} = \sum_{j=1}^{n} E_\{x_1;x_2;...;x_n\},
\]

n - the number of mixing nodes;

2) Determining the boundaries of a possible blend of the oils entering the pipeline system based on maintaining the mass balance and the necessary quality margin at the points of oil receiving that can be represented as a local area of multidimensional simplex place [7].

3) Shaping of plans for preliminary laboratory tests using the simplex lattice method to determine the model of changing the properties of multicomponent oil blends in the obtained local areas of simplex place limited by the zone of possible or permissible blending [7; 9].

There is consideration of the method of finding the objective function using the example of the configuration of the extensive oil pipeline system shown in Figure 1. In total, 10 types of various oils are delivered to various points and the oils are pumped using 9 technological sections. In the diagram, 4 mixing nodes can be pointed out in which the flow is divided into 2 or more pumping directions.

The first mixing unit receives 5 types of various oils. In the second node 2 more types of oil are added, in total 7. In the third - 6. In the fourth - 8 types of oil. The components of the configuration of the pipeline network, the energy consumption of which depends on the choice of the ratio of the separation of oil mixtures at a particular nodal mixing point are outlined by a dotted line.

According to Figure 1, the configuration of the main oil pipeline system is converted into a simpler analytical model that is a parent mixing tree where each node (in this example 4 of them) is characterized by the summarized energy for pumping a portion of the oil pipeline system to the next mixing node or end point depending on the selected mixing concentrations.

To calculate the energy consumption of the first unit \( E_{1\{x_1;x_2;...;x_n\}} \), depending on the choice of the separation ratio of the oil flows of 5 incoming types of oil (if there is the possibility of sequential pumping by the first technological section) the source data are the parameters of pipelines and installed pumps of the first, second and third technological section.

The source data for calculating the energy consumption of the second unit \( E_{2\{x_1;x_2;...;x_n\}} \) that receives 7 source oils are the parameters of pipelines and pumps of the fourth and fifth technological sections.

The source data for calculating the energy consumption of the third unit \( E_{3\{x_1;x_2;...;x_n\}} \) into which 6 source oils are supplied are the parameters of pipelines and pumps of the sixth and seventh technological section.

The source data for calculating the energy consumption of the fourth unit \( E_{4\{x_1;x_2;...;x_n\}} \) which receives 8 source oils are the parameters of pipelines and pumps of the eighth and ninth technological section.

The final objective will have the following form according to (2):

\[
E_\{x_1 - x_{10}\} = E_1\{x_1 - x_5\} + E_2\{x_1 - x_5\} + E_3\{x_1 - x_5\} + E_4\{x_1 - x_5\} + x_6 - x_{10} + x_7 - x_{10} + x_8 - x_{10} + x_9 - x_{10} + x_{10}.
\]

The solution of the task is to find the mixing ratio of 10 types of oil at all 4 nodal points at which the summarized energy for pumping \( E_\{x_1; x_2; x_3; x_4; x_5; x_6; x_7; x_8; x_9; x_{10}\} \) by the pointed system of trunk pipelines is minimal.
As a result, we can distinguish 2 important presented procedures that will be used in the final task:

1) the construction of a blend tree, the properties of the nodes of which are calculated in a multidimensional simplex place.

2) Obtaining the properties of the mixing tree using tree traversal algorithms.

### Results

The results of energy consumption calculation can be presented in a multidimensional simplex place where for each of its points the summarized energy consumed for pumping is calculated at given mixing concentrations (simplex coordinates) at the nodal points of the main oil pipelines. Since the function of a large number of variables is rather difficult to display for determining the minimum one can use the optimum search algorithms [8] as far as there is no need to construct a mathematical model of the objective function.

**Figure 1.** Definition of the objective function.
There can be used the following methods of finding the optimum region: simplex method, Gauss-Seidel method, gradient methods, steep ascent method (Box-Wilson), random search method, etc. [8].

Taking into account all the solved subtasks, the final algorithm was obtained for calculating the optimal properties of oil mixing at the nodal points of the main oil pipeline system that is shown in Figure 2.

**Figure 2.** Algorithm of calculating the optimal parameters of oil mixing at the nodal points of the main oil pipeline system.

It is proposed to use the standard multidimensional optimization algorithm as the main calculation module.

The objective is determined by using the algorithms for constructing the mixing tree, and its numerical value as the properties of the resulting simplex figure is determined using standard algorithms for traversing the mixing tree [11].

### 4. Discussion

The possibility of energy savings in the redistribution of oil flows with different viscosities was demonstrated in [10]. However, the previous article did not describe the calculation method for various configurations of extensive networks of oil trunk pipelines. This study contains general scientific and theoretical approaches to determining the objective function and algorithms for its calculation for any configuration of an extensive oil pipeline network.

The proposed solution will be of one place with binary separation of the output stream at the nodal mixing points (binary mixing tree). When dividing the flow into three or more directions there will already be infinitely many solutions which will complicate the choice of the optimal mixing ratio as far as it will be necessary to use several independent simplex spaces or one changing simplex space. Evolutionary optimization algorithms may be suitable for solving problems with multithreaded outputs.
from nodal mixing points. In the framework of this dissertation only two exits from the nodal point are considered. In practice, more than two effluents from a unit are quite rare in the pipeline system.

The work considers a simplified model of determining the cost of electricity when the costs are determined only on the basis of the cost of electricity. In fact, at most domestic oil pipelines electricity costs are determined at the two-part tariff, when the consumer pays for both the electric power consumed during peak hours of the power system and electric energy.

Also, the solution does not take into account the interaction of technological sections of main oil pipelines considering the final dimensions of the capacities of the tank farms of the head oil pumping stations.

These restrictions don’t raise doubts about the applicability of the proposed methodology but only reduce additional opportunities for optimizing the pumping process that were not investigated in the framework of this article.

5. Conclusion
As a result, in the framework of the present study a new problem was formulated and analytically solved for the formation of routes for the movement of various types of oils and their mixtures through an extensive system of main oil pipelines in order to minimize the total energy consumption for pumping that differs by taking into account the changing rheological parameters of the oils when they are mixed and the possibility of forming “energy-efficient” mixtures at the nodal points of the system.

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