Comprehensive optimization of field pipelines

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Abstract. The analysis showed that the solution of complex optimization of parameters of field pipelines is not given due attention. Traditionally, this operation is performed manually. The designer, using his experience and intuition, outlines several alternative options, which are then evaluated automatically, which does not provide an optimal solution. The paper proposes a method for indicative and adaptive management of field development and conservation, which allows us to take into account the uncertainties that arise in the future stages of field operation. At each stage of management, it is proposed to perform a comprehensive optimization of the main field pipelines and use the method of redundant design schemes with the solution of circuit-structural and circuit-parametric optimization problems, including the stages of field conservation. Numerical experiments have confirmed the high computational and economic efficiency of the proposed approach and method.

1. Introduction

To commercial gas and gas condensate pipelines, oil and gas fields (PTG) include [1,2]: gas gathering collectors from the strapping gas wells, gas pipelines of raw gas, pipelines, stable and unstable gas condensate, regardless of their length; a pipe for supplying purified gas and inhibitor into wells and other facilities construction of oil pipelines; sewage pressure over 10 MPa to supply it to wells and injection into the absorbing layers; metprolrol; inhibitorbased; neftegazonosnye pipelines (pipelines) for transporting products of oil wells from metering installations to the first stage of oil separation; pipelines for transportation of petroleum gas from installations of oil separation to the processing of gas pipelines for transporting gas or razgazirovanie watered or waterless oil from gathering plant and booster pump station to the Central collection point; pipelines for transportation of gas to producing wells with gas-lift method of production; pipelines to supply gas in productive formations to increase oil recovery; piping systems, water flooding oil reservoirs and systems of burial of the reservoir and wastewater in deep lost circulation horizons; pipelines for the transportation of commercial oil from the Central gathering facilities to the pipeline; pipelines for transporting gas from the Central collection point before the construction of the gas pipeline; inhibitorbased for supply of inhibitors to wells or other oil and gas fields; pipelines of underground gas storage facilities: pipelines between the sites of the individual facilities of underground gas storage facilities, etc.

Management of oil and gas field development is a complex and multi-stage process that depends on the structural, geological, geophysical, hydrological, and other features of the field, its distance from urbanized areas, and geographical location [3-5]. Field development can be divided into two major blocks: technological, which solves all the issues of placement of production and injection wells, their operation period, productivity, and conservation stages; and design, which solves the issues of placement of all collection, separation, and preparation of oil and gas for further transportation through
main pipelines, organization of reservoir pressure maintenance systems, network of main roads and access roads, structure of power and power facilities and cable lines.

Each oil and gas field has its own life cycle, which can be divided into four stages:

The stage of intensive development of the field, in which production wells are built and put into operation for the production of petroleum products, injection wells for flooding and increasing the inter-reservoir pressure of the field.

Stage of maximum production of petroleum products. At the same time, even more water is pumped into the interplastic space of deposits.

Stage of decline in oil production. At the same time, the volume of water being pumped increases significantly and its pressure increases due to high-pressure injection pumping units (about 30 and higher MPa).

Final stage. Production wells and discharge pipelines are being preserved. At the same time, even more water is pumped into the interplastic space of deposits.

Selecting the main field pipelines of the crude oil transportation system and the water supply system to the injection wells, you can graphically represent the life cycle of the field in the form of figure 1. It is obvious that the time of maximum production of oil products and the water used in this process do not coincide [6,7]. Peaks can occur with a difference of 30-50 years. And these systems could be considered and designed separately. At the same time, it is a single complex consisting of hydraulic circuits of water supply, its movement through oil-containing ground layers, pipelines of a mixture of water, oil and gas. This factor should be taken into account at all stages of the field design, construction and operation organization [8]. At the same time, the parameters of pipeline systems do not always correspond in time to the loads of water and oil products [7], which leads to a violation of the hydraulic stability of their operation and to excessive deadening of capital investments. Obviously, designing field pipelines for maximum loads, and then implementing them in stages, as well as preserving them, is one of the ways to solve the problem.

Another option is to design and build pipelines in stages, first at the first stage of development, and then as the load increases – to reconstruct, increasing capacity, and in case of conservation, gradually decommissioning. The first option leads to a significant deadening of investment, the second – to continuous reconstruction. Although the reconstruction can be organized in the form of parallel to the laying of pipelines. But this option is still expensive. The optimal solution lies between the indicated options and can be determined according to the scheme shown in figure 2.

2. Methods
According to this scheme, the entire life cycle is divided into stages of development management and conservation of the field (for example, four stages) and conditionally optimal solutions of possible development options are built up.
As an illustration, let's look at a simple example of a petroleum product transportation system designed to collect petroleum products from five clusters of production wells that are scheduled to be put into operation in stages in five stages. A variant of a prospective scheme of a field oil pipeline system for 15 years is considered. For rice.2A each stage is marked with its own color (black – the first, red – the second, etc.), while the amount of oil products withdrawn from each area of cluster wells should be the same and equal to 0.3 m³/s.

In Fig. 2 b-e shows the dynamics of the pipeline system during its phased construction on first load of the first stage, then second, etc. As can be seen from Fig. 2B, already during the construction of the second stage, it is necessary to replace the pipeline of the first stage with a larger diameter. During the implementation of the entire project, the pipeline of the first stage will need to be reconstructed four times, the second stage – three times, etc. This option of development (permanent reconstruction) is very expensive, but it can take place with minimal investment.

Another option that should be considered when forming prospective schemes for the development of field pipelines is shown in Fig. 3. According to this option, the construction of the first stage of the pipeline is carried out with parameters designed for the passage of oil products from all other stages of construction, etc. At the same time, as can be seen from Fig. 3 a-d, the speed of transportation of petroleum products on the first pipeline will be less than necessary during the implementation of the entire project, the second one is one-time interval less, and so on. This option does not require reconstruction, but requires significant investment at each stage of construction and additional costs during operation for cleaning pipelines.
Figure 2. Calculation of the oil pipeline system taking into account the loads of each stage of commissioning of producing well clusters during their phased construction.

Figure 3. Calculation of the oil pipeline system and its phased construction.
There are other options for the development of the field oil pipeline system, which can be represented as a combination of the options shown in Fig. 2 and Fig. 3. For the five stages of pipeline system development, the number of such options will be 27. Obviously, in order to avoid large investments and the operation of the system at inefficient speeds, it is necessary to arrange parallel pipeline laying according to the following scheme. At the first stage, a pipeline is being built that allows oil products to pass from the first area of cluster wells. During the construction of the second stage, a pipeline is constructed designed to pass oil products from the second district, and at the same time a parallel pipeline is arranged for the first stage, etc. Figure 4 shows a development scenario in which five parallel pipelines will need to be built at different time intervals at stage 1, four at the second stage, three at the third stage, and two at the fourth stage.

Of course, this option of five parallel reservoirs is difficult to implement, but this option may be the only one that provides the required hydraulic parameters when the pipelines are phased out of operation.

![Figure 4. Step-by-step parallel laying of pipelines.](image)

Possible development options are formed on the basis of the field development plan, and take into account possible deviations of a technical and economic nature due to the uncertainty of oil product production forecasts [9,10]. At this stage, the theory of "fuzzy sets" is applied and a fuzzy idea is formed not only about the volume of oil products produced and water needs, but also for other indicators, including the cost of construction and operation of field pipeline systems [20].

For each variant and stage of development, schematic-structural and schematic-parametric problems of substantiating the parameters of field pipelines are solved. When moving to the implementation of the second stage of the system life cycle, it is considered that the first stage has been implemented and requires its reconstruction and construction of new pipelines in order to increase system performance. It is also being implemented for the third and fourth stages, taking into account the development and preservation of pipelines. After increasing the possible options for developing the field, the best one is selected and the construction of its first stage is carried out. At this stage, based on the obtained set of options for the system's life cycle, a risk matrix is formed and the option with the lowest technical and economic risks is selected for the construction of the first stage. As the first stage of construction is implemented, target and planned indicators (indicators) are evaluated, the costs of new equipment and structures are specified, the values of the actual volume of oil products produced are determined, and the intervals of their possible values in the future are formed. All these procedures are repeated.

As a result, the principle of indicative and adaptive management of field development and conservation is implemented. Figure 5 shows a structural graph that implements five stages of construction of pipelines for field development. Each vertex in this graph models the possible performance of oil pipelines, and the arcs of the graph show possible options for the development of the system.
Important and complex are the issues of tracing the listed PTGS, and at the same time they are among the most complex tasks of their design [7]. However, in the current practice, these tasks are reduced to the analysis of one or two variants of routes. However, it is not difficult to make sure that even these two options, when they overlap, generate a redundant scheme that already contains hundreds or more options for tracing pipelines. It should be noted that all technological pipelines are laid along roads on one side, and energy facilities on the other. This rule is fixed by law and specified in the regulatory framework [1,2]. However, the configuration of roads and pipelines will depend on many factors, including the presence of water intakes (surface or underground), the complexity of the terrain, the presence of water barriers, swamps, and other factors.

Among the first works on automation of pipeline route selection are the works of Professor P. P. Borodavk and others [11], which formulated criteria for optimal selection of pipeline routes, and related mathematical problems of finding the optimal pipeline route between two points. Based on the Steiner-Weber problem [12], methods for finding the optimal pipeline route with bends are proposed. However, in this setting, it was almost difficult to avoid possible restrictions on the terrain and other subjective factors.

It is proposed to formulate the problem of choosing the optimal configuration and parameters of field systems of gas and oil pipelines according to the criterion of life cycle costs as follows. Let's assume a redundant scheme that includes all possible connections between existing and new fields, well clusters, gas storage facilities, possible water intakes, and other structures. Figure 6 shows the redundant pipeline diagrams of the first stage of field development, respectively for water (blue), for petroleum products (red), including possible open water intakes (s), underground water intakes (s), and oil and gas processing points (APG). Dashed lines extending from node S model hydraulic and cost parameters of water intakes. The dashed lines included in node t model the cost indicators of petroleum products processing.
Figure 6. Redundant scheme of the first stage of field development.

It is necessary to select a subnet in this scheme that would meet the minimum total costs for the construction and operation of APG FOR the entire life cycle of the field.

It is not difficult to notice that the redundant circuit is transport and has an input node and an output node for threads. For such a network and in such a formulation, the problem of circuit and structural optimization can be solved by flow models, as is proposed for drainage systems in [13 - 15].

In this case, the mathematical formulation of the problem of minimizing the life cycle costs can be formulated as the problem of finding the maximum flow of the minimum cost [21]:

\[ 3\mathbf{K} \mathbf{U} \rightarrow \min, \quad \text{when} \quad \frac{\mathbf{g}_i}{\mathbf{x}} \leq x_i \leq \frac{\mathbf{e}_i}{\mathbf{x}}, \quad A \cdot x = q_{cp}, \quad (1) \]

With constant operating costs, the life cycle costs for field pipelines can be recorded:

\[ 3\mathbf{K} \mathbf{U} = K_{\frac{T}{tp}} + T \cdot (0.11 \cdot K + C_{x_{kr}}) \quad (2) \]

Capital investment \((K)\) and electricity expenditure \((SELC)\) as a function of expenditure \((x, \text{m}^3/\text{s})\) of petroleum products:

\[ K = (21377.2 \cdot x^{0.7853} - 6716.82 \cdot x^{0.393} + 5363.6) \cdot L \quad (3) \]

\[ C_{x_{kr}} = 108 \cdot z_{x_{kr}} \cdot (8.82173 \cdot L_i \cdot x^{0.8995} + p_i \cdot x_i). \quad (4) \]

Similar dependencies for the pressure water supply system:

\[ K = (12639.6 \cdot x^{0.7956} - 3282.658 \cdot x^{0.3978} + 5363.6) \cdot L \quad (5) \]

\[ C_{x_{kr}} = 108 \cdot z_{x_{kr}} \cdot (5.2797 \cdot L_i \cdot x^{0.8749} + p_i \cdot x_i) \quad (6) \]

\[ x_i - \text{the desired flow on the branches of the redundant or transport network;} \]

\[ \mathbf{g}_i, \mathbf{e}_i - \text{lower and upper limits on the flow} \ x_i, \text{assigned from the speed modes of transportation of oil, gas and water products, as well as restrictions on the performance of structures;} \]

\[ A - \text{matrix of connections of nodes and branches of the network;} \quad q_{cp} - \text{vector of productivity of injection and production wells, m}^3/\text{s}. \]

To solve this problem, we propose a modified method for finding the maximum flow of the minimum cost, based on the works [16 - 20]. As a result of solution (1) - (6), a variant of the scheme shown in figure 7 is obtained.
3. Conclusions and discussions
Optimization of development, reconstruction and conservation of oil and gas fields require special attention and should be considered at all stages of the life cycle. For optimal management of these processes, we propose a method of indicative and adaptive management of the development and conservation of the field. At each stage of this method, it is proposed to perform a comprehensive optimization of the main field pipelines and use the method of redundant design schemes with the solution of circuit-structural and circuit-parametric optimization problems, including the stages of field conservation.

References
[1] Economics of water supply and sanitation: a methodological guide for the study of the discipline and for independent work of full-time students 2013 p 32
[2] Gogina E S and Gurinovich A D 2016 Application of the LCC methodology for evaluating the effectiveness of wastewater treatment plant Projects Water supply and sanitary equipment 9 pp 36-41
[3] Bazhenov V I, Pupyrev E I, Samburski G A 2018 Berezin S E 2018 Development of a methodology for calculating the life cycle cost of equipment systems and structures for water supply and sanitation Water supply and sanitary equipment 2 pp 10-19
[4] Preparation of the technical and economic part of projects for off-site water supply and Sewerage systems 1991 p 80
[5] Merenkov A P 1985 Theory of hydraulic circuits p 278
[6] Abramov N N, Pospelova M M and Somov M A 1983 Calculation of water supply networks p 273
[7] Lyubanskaya Z G and Osipov P P 2012 Economics of water supply and sanitation systems. Calculation of operating costs in water supply and sanitation systems: guidelines and tasks
for the implementation of control work for students of the specialty 270112.65 "Water supply and sanitation" and bachelors in the direction of "Construction" p. 16

[8] Manual on water supply and Sewerage in urban and rural areas 1992 p 120
[9] Turevski I S 2011 The Economics of the industry. Road transport p 288
[10] Tozik A A 2005 Economics of road transport p 140
[11] Chupin R V and Pham N M 2019 Optimization of the structure and parameters of developing group water Supply Systems Water supply and sanitary equipment 1 pp 30-36
[12] Chupin R V 2018 Optimization of promising schemes for the development of water disposal systems in conditions of limited funding Water supply and sanitary equipment 2 pp 67-74
[13] Chupin R V and Melekhov E S 2011 Development of theory and practice of modeling and optimization of water supply and sanitation systems p 323
[14] Chupin R V 2015 Optimization of developing water disposal systems p 418
[15] Taha H 1985 Introduction to operations research p 476
[16] L R Ford and Fulkerson D R 1963 Flows in networks p 216
[17] Hu T 1974 Integer programming and flows in networks p 520
[18] Chupin V R 2019 Optimization of developing district water supply systems taking into account variability of perspective water consumption IOP Conf. Series: Materials Science and Engineering 667 012018
[19] Chupin V R 2019 Optimization of the sewerage systems scheme of cities and populated areas IOP Conf. Series: Materials Science and Engineering 667 012017
[20] Melekhov E S, Chupin V R and Chupin R V 2016 Certificate of state registration of the computer program № 2016615463 TRACE-VR
[21] Kalashnikov M P 2020 Study of the air environment state in the building for the storage of perishable products Proceedings of Universities. Investment. Construction. Real estate 10(2) pp 206–211
[22] Melekhov E S and Shlepnev O K 2018 Development and reconstruction of district water supply systems Proceedings of Universities. Investment. Construction. Real estate 8(4) pp 114–127 DOI: 10.21285/2227-2917-2018-4-114-127