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OPTIMAL MANAGEMENT OF DEVELOPMENT OF ENGINEERING NETWORKS

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Abstract. The significant volume of construction of various types of pipeline engineering networks in our country makes the task of optimal management of their development one of the most pressing, which in the literature [1, 2.,3] is often called the task of technical and economic calculation of networks at the design stageю Even a small (5-10%) reduction in the amount of reduced costs for the construction and operation of heat, water and gas supply systems on a national scale can lead to a major national economic effect. When designing utility networks, problems of structural and parametric optimization arise [9,10]. The first of these comes down to determining a number of structural parameters - network routing, choosing the location of booster pumping stations, throttles, compressors, etc., and when solving the second, for a given structure, it is necessary to determine a multidimensional vector of parameters for each of the active and passive elements included in the structure. In reality, by combining any sequence of selection of various structures and conducting parametric optimization, for each of them it is possible to find an optimal engineering solution for the network, choosing one or several [10,17] optimization criteria. It should be noted that in a number of cases, due to the inconsistency of the optimization criteria (for example, the criterion of maximum reliability in principle contradicts the criterion of minimum capital investment), problems of multi-criteria optimization arise, for the solution of which a number of methods have been proposed [8], but further research and development are required, as well as their widespread implementation in the practice of designing and operating utility networks.

Key words: design, mathematical models of engineering networks, distribution function, engineering networks, network structure, optimization problems, the process of consuming the target product (PCTP), pipe diameters.

Introduction. Since the present work focuses on the issues of taking into account the stochastic nature of PCTP (the process of consuming the target product) and their impact on flow distribution models and algorithms for its calculation, only existing methods of parametric optimization are analyzed below using the example of water supply system networks [11, 13, 14].

If the reduced costs of construction and operation of the utility network (W) are taken as the optimality criterion for the estimated payback period of capital investments (t), then this criterion can be written as

$$W = (\rho + \mathrm{E})\sum_{i=1}^{\rho}\left(\alpha + b\cdot D_i^{\alpha}\right)\cdot l_i + \sum_{j=1}^{\kappa}\beta\cdot\left(H_0 + \sum_{i\in R} h_i\right)\cdot Q_j, \qquad (1.1)$$

where ρ - depreciation rate;

D_i, l_i - diameter and length of each t-th section of the network calculation scheme;

$\mathrm{E} = \frac{1}{t}$ - capital investment efficiency ratio;

$\alpha + b\cdot D_i^{\alpha}$ - empirical formula for specific (per unit length) construction cost for pipeline sections;

H_0 - piezometric mark of the dictating point of the network at which the required free pressure must be ensured;

Q_j - design load j - oh pumping station;

$\sum_{i \in R} h_i$ - total pressure loss in sections $i \in R$ networks, included in any path R, along the network graph, connecting the source and the dictating point of the network;

β - coefficient depending on the specific conditions of the system [1] - the cost of electricity, specific costs for the construction of pumping stations, etc.

Materials and methods of research If in (I.I), where the main variable is the vector of diameters of network sections, a continuous differentiable dependence is adopted $W = \Phi(D)$, then we arrive at the so-called exact methods of technical and economic calculation of water supply networks [14,18], if D are discrete, then the problem of discrete nonlinear mathematical programming arises. In any case, the search for the minimum value of the criterion occurs taking into account additional restrictions due to the fact that the second term (I.I) can include only those values that satisfy Kirchhoff's laws for the network. Thus, the solution to the parametric optimization problem is always closely related to the problem of calculating the steady-state flow distribution.

One of the traditional ways of minimization in (I.I) is to go to the function:

$$F = W + \lambda_1 \cdot f_1 + \lambda_2 \cdot f_2 + \ldots, \qquad (1.2)$$

where f_1, f_2 - given constraints (Kirchhoff's equations);

λ_1, λ_2 - indefinite Lagrange multipliers.

Since in (I.2) a continuous dependence is adopted, then by differentiating (I.2) and equating the derivatives to zero, it is possible to find the minimum F. In this case, the dimensionality of the problem is reduced due to the known relationship between the magnitude of pressure losses in a section of the network h_i and its diameter D_i [1].

The result of the solution (I.2) can be obtained in the form:

$$D_i = \left[Э \frac{(\sum_{j=1}^{\kappa} Q) \cdot \chi_I}{q_i} \right]^{\frac{1}{\alpha+m}} \cdot q^{\frac{\beta+1}{\alpha+m}}, \qquad (1.3)$$

where q_i - calculated value of flow along the i-th section of the network;

D_i - pipeline diameter in the *t*-th section of the network;

m and β - exponent for diameter and flow in formula determination of pressure losses h_i:

$$h_i = \kappa \frac{q_i^{\beta}}{d_i^{m}} \cdot l_i, \quad m = 5.3, \quad \beta = 2;$$

α - exponent of the D_i diameter in the formula (1.1);

$\sum_{j=1}^{\kappa} Q_j$ - total design load of the system (sum of loads in nodes, the total number of which is equal to κ);

χ - coefficient that takes into account the role of the i-th section of the network in energy costs (required pressure at power sources) for transporting water;

Э - economic factor [1] .

With the usual values of coefficients for water supply systems α, β, m the exponent at in (I.I6) is 0.42, and at the term in square brackets - 0,14. If parametric optimization is carried out with a given flow distribution, that is, in (I.I6) are known q_i, then the diameter is determined by the values Э and χ_i. The coefficients χ_i are called fictitious expenses [1.1] and their essence is that, being determined by the method [13], they ensure compliance with the requirements of Kirchhoff's second law when found D from (I.2). Method of determination χ_i is substantiated in sufficient detail in the works of L.F. Moshnin [14, 15,19].

Let's look at the calculation method Э in (I.3). According to [1,12,13,14] its value is calculated by the formula

$$Э = \frac{24 \cdot 365}{102} \cdot 10^3 \cdot \frac{\sigma \cdot \kappa \cdot m}{\alpha \cdot \eta^b \cdot (\rho + \mathrm{E})} \cdot \gamma, \qquad (1.\ 4)$$

where κ, m - look (1.3); b, α, ρ, E - look (1.1);

σ - cost of electricity; η - efficiency of pumping stations;

γ - coefficient of unevenness of expenditure energy for water transportation.

Thus, the economic factor (1.4) comprehensively takes into account a number of economic parameters of the designed engineering network, the parameters of the hydraulic characteristics of the system and, which is especially important in our case, to some extent takes into account the unevenness of consumption of the target product over time. Considering that the definition χ_i it is often quite difficult, A number of studies have noted that taking $(\sum_{j=1}^{\kappa} Q_j) \cdot \chi_i = q_i$, that is, bringing (I.3) to the form

$$D_i = Э^{0.14} \cdot q_i^{0.42}, \qquad (\ 1.5\ )$$

it is possible to obtain a solution very close to the exact solution (I.2).

This is due to the need to select discrete values at the final stage of the solution D_i, taking them equal to the standard diameters of pipelines produced by industry. For use (1.5), tables of so-called marginal economic costs have been compiled, and parametric optimization is reduced to choosing from these tables D_i with a known value Э.

Results and its discussion. It should be noted that the use of (I.5) essentially leads to the consideration of each of the pipeline sections as operating in isolation from the rest of the network. It is important that in (I.4) the value of the coefficient is taken γ, reflecting only the unevenness of consumption of the target product, in general, throughout the entire water supply system. At the same time, it is obvious that each section of the network operates with an unevenness that is different from the unevenness of the system. Therefore, the problem of clarifying the values arises γ for each of the sections when determining D_i according to (1.3) or (1.5), that is, it is necessary to have an algorithm for determining γ for each stage of network development and the entire estimated service life as a whole. This algorithm will allow finding optimal control actions when considering problems of reconstruction and expansion of networks.

What factors influence the value of the coefficient γ and how can its value be related to the stochastic PCTP indicators? Note that the introduction of the coefficient γ is associated with the need to carry out parametric optimization at one of the possible values of loads and, since these are loads that have a low probability of occurrence, it is necessary to generalize the calculation data for one of the unlikely particular modes of operation of the system and obtain such an integral indicator as the total annual electricity costs at all pumping stations of the system. It is for this transition that the coefficients are required and used. γ [6, 20].

Since the relationship between utility network loads and the required pressure of its power sources is nonlinear, and proper integration of costs is currently impossible due to ignoring the stochastic nature of PCTP, there are proposals [2,14] for a very approximate definition γ for water supply systems. In principle, according to the definition [1,2,6] the coefficient γ is the ratio of energy costs obtained with load values in nodes equal to the calculated ones to the average annual energy costs. Then by simply multiplying the energy costs at the calculated loads by the coefficient γ and for the duration of the system's operation, it is possible to obtain an estimate of the total energy costs. But real recommendations on the values of the coefficient γ are based on the works of N.N. Abramov, who believed [l], that "the actual energy consumed during the calculation period is equal to the energy determined based on the average consumption during the calculation period, corresponding to the average water consumption regime", that is, with loads in nodes equal to their mathematical expectation, At the same time, understanding the low reliability of such a proposal, N.N. Abramov writes [l, page 57]: "... in general, the coefficient of uneven energy consumption should be found as a result of... calculating the system under various operating modes", which determines the need to develop such models of stochastic flow distribution that will ensure the determination of the specified coefficients for each passive element of the pipeline section of the utility network.

He big role of coefficients γ was noted in the works of Verbitsky A.S. [6], which showed that the values of this coefficient strongly depend on the non-uniformity of PCTP and gave a formula for an insulated pipeline

$$\gamma = \frac{1}{3\kappa - 2} \tag{1.6}$$

where $\kappa = \frac{Q^{98\%}}{Q}$ - ratio of the load with 98% probability of non-exceedance (0.98 probability of non-exceedance) to the average annual load γ - that consumer (network node). At the same time, Verbitsky A.S. showed that the variation coefficient for PCTP in engineering networks with an error of no more than 5-6% can be calculated using the formula

$$\upsilon_{Q_j} = \frac{\kappa - 1}{\sqrt{2 \cdot \kappa - 1}} \tag{1.7}$$

that is, by connecting (I.I9) and (1.20) we can obtain

$$\gamma = l^{-2,5 \cdot \upsilon_{Q_j}} \tag{1.8}$$

where l - base of natural logarithms.

Formula (I.8) is only valid for the case when the target product is supplied through one pipeline to a consumer whose PCTP is characterized by a certain value υ_{Q_j}.

In accordance with existing recommendations γ - is taken to be equal to 0.4-0.7 and constant for the entire engineering network as a whole. Also, tables of economic costs and flow rates [l, 2] are compiled for γ = 0,7, which, according to (I.6), is true only if κ = 1.12, that is, for large systems and water pipelines. Sections of trunk networks and networks supplying the target product to consumption nodes operate in modes with κ = 2,0-2,5 and more [3, 6]. Taking all parameters constant (except γ), on which the economic factor depends Э by (I.4), and using (I.5), we write

$$\frac{D}{D_\gamma} = \left(\frac{Э}{Э_\gamma}\right)^{0.14} = \left(\frac{0.17}{\frac{1}{3\kappa - 2}}\right)^{0.14}, \quad (1\ 8)$$

where $\frac{D}{D_\gamma}$ - the ratio of the diameters of a network section determined at a constant value γ (independent of κ) and γ by (I.6).

At κ = 2 calculation according to (1.9) shows that the accepted diameters are 15% higher than the optimal ones. This indicates the possibility of significant savings in reduced costs and metal in the case, if a method for determining is found γ for each section of the utility network*.

Conclusions. Taking into account (I.8), it can be stated that the solution to such a problem is possible if the mathematical model of flow distribution can ensure finding the parameters of the probability distribution functions of flows for all sections of the network. Having data on the mathematical expectation of the flow along the line and its dispersion, it is easy to determine, coefficient of variation υ_{Q_j} , by (I.2I) find γ and finally, by (I.I8) - D_i .

The above considerations on the need to take into account the stochastic nature of PCTP during parametric optimization should be extended to the recommended methods of mathematical programming [8,16,21], each of which also operates with constant values of coefficients for all passive elements of the engineering network γ , It should be noted that the problem of determining γ for each section of the network does not lead to the denial or revision of existing methods of parametric optimization, but can ensure an increase in their efficiency, bringing them closer to the real conditions of operation of pipeline engineering networks.

*Even taking into account the discreteness of pipeline diameters, which always reduces the effect of parametric optimization, cost savings can be quite large. Especially considering the large proportion of the length of pipelines of small (up to 300-400 mm) diameters. These pipelines operate under conditions of highly uneven flow change modes, and it is here that the greatest effect is possible.

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ИНЖЕНЕРЛІК ЖЕЛІЛЕРДІ ДАМЫТУДЫ ОҢТАМАЛДЫ БАСҚАРУ

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Аңдатпа. Біздің елімізде әртүрлі типтегі құбыр желілерін салудың айтарлықтай көлемі олардың дамуын оңтайлы басқарудың ең өзекті мәселелерінің бірі болып табылады, ол әдебиеттерде [1, 2, 3] жобалау кезеңінде желілерді техникалық-экономикалық есептеу мәселесі ретінде жиі аталады. Жылумен, сумен және газбен жабдықтау

жүйелерін салуға және пайдалануға республикалық көлемдегі қысқартылған шығындар көлемін шамалы (5-10%) азайтудың өзі үлкен ұлттық экономикалық нәтижеге әкелуі мүмкін. Инженерлік желілерді жобалау кезінде құрылымдық-параметрлік оңтайландыру мәселелері туындайды [9, 10]. Олардың біріншісі бірқатар құрылымдық параметрлерді анықтауға қысқарады - желіні бағыттау, күшейткіш сорғы станциялары, дроссельдер, компрессорлар және т.б. орналастыру орындарын таңдау, ал берілген құрылым үшін екіншісін шешу кезінде құрылымға кіретін белсенді және пассивті элементтердің әрқайсысы үшін параметрлердің көп өлшемді векторын анықтау қажет. Шын мәнінде, әртүрлі құрылымдарды таңдаудың кез келген тізбегін біріктіру және параметрлік оңтайландыруды жүргізу арқылы олардың әрқайсысы үшін бір немесе бірнеше [10,17] оңтайландыру критерийлерін таңдау арқылы оңтайлы желілік инженерия шешімін табуға болады. Бірқатар жағдайларда оңтайландыру критерийлерінің сәйкес келмеуіне байланысты (мысалы, ең жоғары сенімділік критерийі ең төменгі капитал салымының критерийіне принципті түрде қайшы келеді) көп критерийлі оңтайландыру мәселелері туындайтынын атап өткен жөн, оларды шешу үшін бірқатар әдістер ұсынылған [8], дегенмен, оларды одан әрі зерттеу және дамыту тәжірибесін кеңейту қажет. инженерлік желілер.
Түйін сөздер: жобалау, инженерлік желілердің математикалық модельдері, тарату функциясы, инженерлік желілер, желі құрылымы, оңтайландыру есептері, мақсатты өнімді тұтыну процесі (ПТР), құбыр диаметрлері.

ОПТИМАЛЬНОЕ УПРАВЛЕНИЕ РАЗВИТИЕМ ИНЖЕНЕРНЫХ СЕТЕЙ

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Аннотация. Значительный объем строительства различных видов трубопроводных инженерных сетей в нашей стране делает одной из наиболее актуальных задачу оптимального управления их развитием, которую в литературе [1, 2, 3] часто называют задачей технико-экономического расчета сетей на стадии проектирования. Даже небольшое (на 5-10%) снижение размера приведенных затрат на строительство и эксплуатацию систем тепло-, водо- и газоснабжения в масштабах страны может привести к крупному народнохозяйственному эффекту. При проектировании инженерных сетей возникают задачи структурно-параметрической оптимизации [9, 10]. Первая из них сводится к определению ряда структурных параметров - трассировке сети, выбору мест размещения повысительных насосных станций, дросселей, компрессоров и т. д., а при решении второй для заданной структуры необходимо определить многомерный вектор параметров для каждого из активных и пассивных элементов, входящих в структуру. В действительности, комбинируя любую последовательность выбора различных структур и проводя параметрическую оптимизацию, для каждой из них можно найти оптимальное инженерное решение сети, выбрав один или несколько [10, 17] критериев оптимизации. Следует отметить, что в ряде случаев из-за противоречивости критериев оптимизации (например, критерий максимальной надежности в принципе противоречит критерию минимума капиталовложений) возникают задачи многокритериальной оптимизации, для решения которых предложен ряд методов [8], однако требуются дальнейшие исследования и разработки, а также их широкое внедрение в практику проектирования и эксплуатации инженерных сетей.
Ключевые слова: проектирование, математические модели инженерных сетей, функция распределения, инженерные сети, структура сети, задачи оптимизации, процесс потребления целевого продукта (ППЦП), диаметры труб.