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Improving the designing method of thermal networks: bypass connection

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ABSTRACT

The paper presents the results of the development of a model of a heat exchange system with a bypass connection of flows. An analytical model of a bypass for two heat exchange elements in the form of a relationship between the temperature ratio differences of flows and efficiency has been developed. The resulting expression for the efficiency of energy exchange in the system depends on the distribution of elements and flows at the entrance to the system and does not depend on the distribution in the mixing unit. It is shown that the key factor determining both the operation of the designed system and its elements is the correspondence of the direction of the processes in the real system with their direction, hypothetically chosen by the designer when specifying its topology. The distribution of the energy potential dictates the conditions for the operability of the system and its elements through the uncertainty of the values of the average energy measures. The statement of the problem of determining the matrix elements that satisfy the requirement of the minimum uncertainty of the average energy measures leads to the determination of the distribution of the efficiency of the system elements in its topological representation in accordance with the requirements of the second law of thermodynamics. The formulated requirements for the minimality of the uncertainty of the average energy measures and the construction, based on the Shannon principle, make it possible to obtain a solution to the formulated problem as a finite subset of the values of the efficiency of the inter-network and intra-network energy exchange. In addition, the extremeness of solutions (minimum uncertainty of average energy measures) ensures the maximum efficiency of energy transfer from the “hot” network to the “cold” network in its elements and the minimum energy dissipation in the mixing nodes. The urgency of the topic is due to the fundamental need to reduce energy costs of systems. The applied aspect is to minimize the mass, dimensions and energy component in enterprises where thermal transformations are significant.

Keywords: Design; heat exchangers; bypass; analytical methods; optimization; efficiency; energy exchange

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INTRODUCTION

The design of complex chemical engineering systems includes modeling as a necessary component of HEN, since the components of the system can be considered as heat exchangers. The network representation of the system makes it possible to distinguish the following types of connection of elements in it: serial, parallel, loop and bypass. A bypass connection is a type of parallel connection of heat exchange elements, in which part of the heat flow passes without interaction, which makes it possible to use it to increase the dynamics of the system, or indicators of reliability in critical situations. The fundamental direction of minimizing energy consumption in the manufacture of products makes it urgent to solve the problem of optimizing the conversion and use of heat fluxes. Comparison of mathematical and simulation modeling shows that the optimal solution can be achieved only by analytical methods.

LITERATURE REVIEW

The work [1] presents a set of scientific and technical solutions that provide the technical feasibility and economic feasibility of designing heat engineering complexes on the basis of computational and experimental studies. However, the developments are given only for powerful high-temperature energy complexes based on steam turbine technologies without specifying the mathematical and physical models for their implementation. In [2], the methodology for constructing mathematical models of chemical technological processes is considered, mathematical models of the structure of flows, kinetics of chemical reactions, homogeneous chemical reactors, thermal and mass transfer processes are presented. However, when constructing mathematical models by experimental-statistical methods, methods of correlation and regression analysis, methods of optimization, analytical approaches are practically not considered. In [3], theoretical and practical material is presented on the modeling of chemical engineering systems using the ChemCAD software package. The basic principles of construction of chemical technological systems (CTS), tasks and methods of calculation are stated [4]. The construction of models of some of the most common elements of chemical engineering systems is presented. The application of the ChemCAD package for the modeling of chemical engineering systems is described. However, analytical models are practically not represented, although it is analytical models that provide average statistical, stationary and optimal solutions [5]. The involvement of a systematic approach for the design of heat exchangers and heat exchange structures is aimed at improving the modeling capabilities of large complex networks, offering an explicit formulation of the network flow description [6]. This creates problems due to computational complexity and hard starting problems when equations are given in differential-algebraic form. In [7] it is noted that the optimal operation of built-in heat exchangers is a difficult task due to the nonlinearity of the system, disturbances and adequate identification of the model. A neural network intelligent control is proposed for a network of heat exchangers based on a lumped model and accepted constraints. The design of heat exchange systems is also associated with the provision of HEN flow control capabilities in the heat exchanger network, and bypass manipulation provides higher dynamic characteristics of the system [8], as well as increased reliability in the event of equipment failure [9]. Ease of maintaining the flow temperature in the network, changing the outlet flow in the network at set values or changing the outlet flow for new target values is achieved by adjusting the bypass flow in some or all of the heat exchangers [10]. Mathematical models of the system with a bypass, analyzed on the MATLAB / Simulink platform, showed a nonlinear relationship between the coolant flow rate and the outlet temperature [11], which suggests the need for further research. In [12], it is shown that the existing rules of thumb do not provide unambiguous guidance for the designation of the design bypass flow. Simple graphical representations of steady-state heat balances, originally proposed for a traditional design based on heat and mass balances, are proposed, representing an empirical approach. A similar approach is presented in [13], where a numerical model based on the equations of mass, momentum and energy balance is considered for a system with a bypass as applied to a one-dimensional problem of a stationary type for a specific problem of a waste heat boiler. The empirical approach is also dominant in the design of heat exchange equipment with a bypass, heat exchange equipment for heat recovery in the chemical industry [14]. At the same time, the problem of the mathematical representation of a system with a bypass remains relevant, since only an analytical model allows us to speak about the optimization of the system of heat exchangers according to a formal criterion.

THE PURPOSE AND ARTICLE

The aim of the work is to obtain an analytical solution for the distribution of efficiencies in the bypass connection of energy flows.

To achieve the goal, it is necessary to solve the following tasks:

1) to develop an analytical model of the bypass connection of two energy flows;

2) analyze the bypass connection model in terms of design-relevant parameters.

ANALYTICAL MODEL OF THT DYPASS CONNECTION

In engineering and technological systems, a series connection of two devices is often found as subsystems. A bypass or bypass connection is a series of devices connected in series through which only one part of the total process flow (14-13-9-8-5) entering the system passes. The other part of the stream (11–7) bypasses one or more apparatuses and then connects to the main part of the stream (Fig. 1).

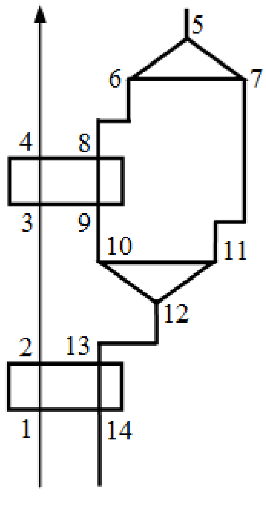

Fig. 1. **Bypass connection**
Source: **compiled by the authors**

The flow entering the system is a direct flow that branches into two parts. One part enters the apparatus – the main flow, which determines, for example, heat exchange in the apparatus. The other part bypasses the apparatus and then connects to the mainstream. It is called a side stream. With a bypass connection, the directions of the main and side streams are the same. Each one passes through any element only once.

This flow pattern is widely used in chemical technologies to create the required temperature regime. The bypass has a beneficial technological effect on the system. The side stream is not chemically converted and has a higher concentration of the starting material. Mixing the side stream with the mainstream allows you to have a high concentration of the initial reagent at a temperature that is required at the inlet to the subsequent apparatus of the technological process.

For the considered flow pattern, the system of conservation equations can be written in the form

$$\begin{aligned} \alpha_1(T_2 - T_4) &= T_9 - T_5 \\ \alpha_2(T_9 - T_{121}) &= T_{122} - T_5 \ , \\ \alpha(T_1 - T_2) &= T_{14} - T_{121} \end{aligned}$$

where α_i is the ratio of the consumption heat capacities of the hot and cold streams.

The incompleteness of the system of equations for the conservation of energy is obvious. In our opinion, the most fundamental addition to the conservation laws is their addition based on the hypothesis that the amount of transferred (used) energy is proportional to the applied potential.

$$\begin{aligned} T_2 - T_4 &= \Phi_1(T_2 - T_5) \\ T_9 - T_{121} &= \Phi_2(T_9 - T_5) \ , \\ T_1 - T_2 &= \Phi_3(T_1 - T_{121}) \end{aligned}$$

where Φ_j is the temperature efficiency of the intra-network exchange.

In matrix form, such a system of equations has the form

$$\begin{pmatrix} -\alpha_1 & 0 & \alpha_1 & -1 & 0 & 0 \\ 0 & -\alpha_2 & 0 & \alpha_2 & -1 & 0 \\ 0 & 1 & \alpha & 0 & 0 & -1 \\ -1 & 0 & 1-\Phi_1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1-\Phi_2 & 0 & 0 \\ 0 & \Phi_3 & -1 & 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} T_4 \\ T_{121} \\ T_2 \\ T_9 \\ T_{122} \\ T_{14} \end{pmatrix} = \begin{bmatrix} -T_5 \\ -T_5 \\ -\alpha T_1 \\ -\Phi_1 T_5 \\ -\Phi_2 T_5 \\ (\Phi_3 - 1)T_1 \end{bmatrix}$$

.(1)

Let's introduce an independent variable

$$\Theta_n = \frac{T_1 - T_n}{T_1 - T_5} \ . \qquad (2)$$

In these variables, the solution of the equations for the nodal temperatures can be written in the form

$$\begin{pmatrix} \Theta_4 \\ \Theta_{121} \\ \Theta_2 \end{pmatrix} = \begin{bmatrix} \dfrac{\Phi_1 - \Phi_1\Phi_3 + \Phi_3 - \alpha_1\Phi_1\Phi_3 + \alpha_1\Phi_1\Phi_2\Phi_3}{\alpha_1\Phi_1\Phi_2\Phi_3 - \alpha_1\Phi_1\Phi_2 + 1} \\ \dfrac{\alpha_1\Phi_1\Phi_2 - \alpha_1\Phi_1 + 1}{\alpha_1\Phi_1\Phi_2\Phi_3 - \alpha_1\Phi_1\Phi_3 + 1} \\ \dfrac{\Phi_3(\alpha_1\Phi_1\Phi_2 - \alpha_1\Phi_1 + 1)}{\alpha_1\Phi_1\Phi_2\Phi_3 - \alpha_1\Phi_1\Phi_3 + 1} \end{bmatrix}$$

$$\begin{pmatrix} \Theta_9 \\ \Theta_{122} \\ \Theta_{14} \end{pmatrix} = \begin{bmatrix} \dfrac{\alpha_1\Phi_1\Phi_2\Phi_3 - \alpha_1\Phi_1 + 1}{\alpha_1\Phi_1\Phi_2\Phi_3 - \alpha_1\Phi_1\Phi_3 + 1} \\ \dfrac{\alpha_1\Phi_1\Phi_2\Phi_3 - \alpha_1\alpha_2\Phi_1\Phi_2 - \alpha_1\Phi_1\Phi_3 + \alpha_1\alpha_2\Phi_1\Phi_2\Phi_3 + 1}{\alpha_1\Phi_1\Phi_2\Phi_3 - \alpha_1\Phi_1\Phi_3 + 1} \\ \dfrac{(\alpha_1\Phi_1 - \alpha_1\Phi_1\Phi_2 - 1)(\alpha\Phi_3 - 1)}{\alpha_1\Phi_1\Phi_2\Phi_3 - \alpha_1\Phi_1\Phi_3 + 1} \end{bmatrix}$$

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Requirements for equality of temperatures T_{121} and T_{122} allows expressing the ratio of flows in the mixing node through the efficiency within the network energy exchange:

$$\Theta_{121} - \Theta_{122} = \frac{\alpha_1\Phi_1(\alpha_2\Phi_2 + \Phi_2 - 1)(\Phi_3 - 1)}{\alpha_1\Phi_1\Phi_3 - \alpha_1\Phi_1\Phi_2\Phi_3 - 1} \ ,$$

$$\alpha_2 = \frac{1 - \Phi_2}{\Phi_2} \ .$$

And this, in turn, will make it possible to close the task of determining flows, expressing them through the efficiency of the intra-network energy exchange:

$$\begin{pmatrix} \alpha_2 & -1 \\ 1 & 1 \end{pmatrix} \cdot \begin{pmatrix} U_2 \\ U_1 \end{pmatrix} = \begin{pmatrix} 0 \\ U_0 \end{pmatrix},$$

$$\begin{pmatrix} U_1 \\ U_2 \end{pmatrix} = \begin{pmatrix} -(\Phi_2 - 1)U_0 \\ U_0\Phi_2 \end{pmatrix}.$$

And, therefore, determine the ratio of flows in the conservation equations under the assumption of a unit heat capacity of the interacting flows:

$$\begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{pmatrix} = \begin{pmatrix} \dfrac{\alpha}{1 - \Phi_2} \\ \dfrac{1 - \Phi_2}{\Phi_2} \\ \alpha \end{pmatrix} \qquad \alpha = \frac{G_0}{U_0} \ .$$

The most general requirement for a system can be formulated as the ratio of the amount of energy in it to the applied energy potential [5]

$$E = \frac{T_1 - T_4}{T_1 - T_5} \ .$$

In essence, in such a setting, the formulated problem is the problem of determining the elements of the matrix by the value of the ratio of determinants, since

$$E = \frac{\Phi_1\Phi_3 - \Phi_1 - \Phi_3 + \alpha\,\Phi_1\Phi_3}{\alpha\,\Phi_1\Phi_3 - 1}.$$

The resulting expression for the efficiency of energy exchange in the system depends on the efficiency of the elements and the ratio of flows at the inlet to it and does not depend on the distribution of flows in the mixing unit. For example, the design goal is to ensure the efficiency of energy exchange in the "cold" flow bypass system to achieve the specified temperatures of the cooling or heating media at the inlet to the second apparatus. From the presented calculations, it follows that in the counter-current version of the movement of flows in the system, this can be realized by regulating the flows in the first apparatus.

ANALYSIS OF THE BYPASS CONNECTION MODEL

The generally accepted logic of solving the formulated problem leads to the replenishment of conservation laws with models of elements [6, 7], [8] and iterative schemes for its solution [9, 10], [11]. The disadvantages of this approach are well known (see, for example, [15]).

The key factor that determines both the operation of the designed system and its elements is the correspondence of the direction of the processes in the real system with their direction hypothetically chosen by the designer when specifying its topology. It is well known that the direction of processes and their performance is determined by the second law of thermodynamics and, as a consequence, is associated with the uncertainty of the values of average energy measures both in the elements of the system and in its networks [16, 17]. In other words, the distribution of the energy potential dictates the conditions for the operability of the system and its elements through the uncertainty of the values of the average energy measures. The statement of the problem of determining the matrix elements that satisfy the requirement of the minimum uncertainty of the average energy measures leads to the determination of the distribution of the efficiency of the system elements in its topological representation in accordance with the requirements of the second law of thermodynamics. The continuity of the set of values of the elements of matrix (1) satisfying requirement (2) is obvious. However, the formulated requirements for the minimality of the uncertainty of the mean energy measures and the construction based on the Shannon principle allow one to obtain for the subsystem shown in Fig. 1, the solution of the formulated problem as a finite subset of the values of the efficiencies of the inter-network and intra-network energy exchange depending on E and α. In addition, the extremeness of solutions (minimum uncertainty of average energy measures) ensures the maximum efficiency of energy transfer from the "hot" network to the "cold" network in its elements and the minimum energy dissipation in the mixing nodes.

Formally, the formulation of the problem on the value of the efficiency of the elements of the system (Φ_n) for the given efficiency of the system (E) and the ratio of flows at the input to it (α) determines the finite set of functionals that depend both on the designer's choice of the elements themselves and their design at the next design stage based on the system requirements for their integral characteristics (energy exchange efficiency).

The solutions obtained on the basis of the minimality of the uncertainty of the average energy measures determine two groups of roots for the energy exchange efficiency depending on the required value of the system efficiency:

$$1 > E > 0$$

$$\Phi_1 = \Phi_3 = \frac{\sqrt{(E\cdot\alpha - 1)\cdot(E-1)} - 1}{E\cdot\alpha - \alpha - 1},$$

$$1 > E > 0{,}65$$

$$\Phi_1 = \frac{2E - 2E^2\alpha + 2E\alpha + \sqrt{4E - 4E^2\alpha + 4E\alpha - 3} - 1}{\left(\sqrt{4E - 4E^2\alpha + 4E\alpha - 3} + 1\right)\cdot(\alpha - E\alpha + 1)},$$

$$\Phi_3 = \frac{\sqrt{4E - 4E^2\alpha + 4E\alpha - 3} - 1}{2(E\alpha - \alpha - 1)}.$$

The roots for the efficiencies of the elements form cyclic groups.

In some cases, it becomes necessary to bypass not the "cold" flow, but the "hot" one. The system of equations for the subsystem shown in Fig. 1, taking into account the change in the direction of heat fluxes, will be written in the form

$$\begin{array}{ll} \alpha_1(T_5 - T_9) = T_4 - T_2 & T_5 - T_9 = \Phi_1(T_5 - T_2) \\ \alpha_2(T_5 - T_{121}) = T_{122} - T_9 & T_5 - T_{121} = \Phi_2(T_5 - T_9) \\ \alpha(T_{121} - T_{14}) = T_2 - T_1 & T_{121} - T_{14} = \Phi_3(T_{121} - T_1) \end{array}.$$

Or in matrix notation

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$$\begin{pmatrix} -\alpha_1 & 0 & 0 & -1 & 1 & 0 \\ 1 & -\alpha_2 & 0 & 0 & 0 & -1 \\ 0 & \alpha & -\alpha & 0 & -1 & 0 \\ -1 & 0 & 0 & 0 & \Phi_1 & 0 \\ \Phi_2 & -1 & 0 & 0 & 0 & 0 \\ 0 & 1-\Phi_3 & -1 & 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} T_9 \\ T_{121} \\ T_{14} \\ T_4 \\ T_2 \\ T_{122} \end{pmatrix} = \begin{pmatrix} -\alpha_1 T_5 \\ -\alpha_2 T_5 \\ -T_1 \\ (\Phi_1 - 1)T_5 \\ (\Phi_2 - 1)T_5 \\ -\Phi_3 T_1 \end{pmatrix}.$$

Let's introduce an independent variable

$$\Theta_n = \frac{T_5 - T_n}{T_5 - T_1}.$$

In these variables, the solution of the equations for the nodal temperatures can be written in the form

$$\begin{pmatrix} \Theta_4 \\ \Theta_2 \\ \Theta_{122} \end{pmatrix} = \begin{pmatrix} -\dfrac{(\alpha\Phi_3 - 1)(\alpha_1\Phi_1 - 1)}{\alpha\Phi_1\Phi_2\Phi_3 - 1} \\ \dfrac{\alpha\Phi_3 - 1}{\alpha\Phi_1\Phi_2\Phi_3 - 1} \\ \dfrac{(\alpha\Phi_3 - 1)\Phi_1(\alpha_2\Phi_2 - 1)}{\alpha\Phi_1\Phi_2\Phi_3 - 1} \end{pmatrix},$$

$$\begin{pmatrix} \Theta_9 \\ \Theta_{121} \\ \Theta_{14} \end{pmatrix} = \begin{pmatrix} \dfrac{(\alpha\Phi_3 - 1)}{\alpha\Phi_1\Phi_2\Phi_3 - 1} \\ \dfrac{(\alpha\Phi_3 - 1)\Phi_1\Phi_2}{\alpha\Phi_1\Phi_2\Phi_3 - 1} \\ \dfrac{\Phi_1\Phi_2\Phi_3 - \Phi_3 - \Phi_1\Phi_2 + \alpha\Phi_1\Phi_2\Phi_3}{\alpha\Phi_1\Phi_2\Phi_3 - 1} \end{pmatrix}.$$

Requirements for equality of temperatures and allows expressing the ratio of flows in the mixing node through the efficiency within the network energy exchange:

$$\Theta_{121} - \Theta_{122} = \frac{(\alpha\Phi_3 - 1)\Phi_1(\alpha_2\Phi_2 + \Phi_2 - 1)}{\alpha\Phi_1\Phi_2\Phi_3 - 1},$$

$$\alpha_2 = \frac{1 - \Phi_2}{\Phi_2}.$$

Using the obtained relation, we define the ratio of flows in the elements of the subsystem

$$\begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{pmatrix} = \begin{pmatrix} \alpha\Phi_2 \\ \dfrac{1-\Phi_2}{\Phi_2} \\ \alpha \end{pmatrix}.$$

The efficiency of the system according to the accepted ratio is determined by an expression of the form

$$E = \frac{\Phi_1\Phi_2\Phi_3 - \Phi_3 - \Phi_1\Phi_2 + \alpha\Phi_1\Phi_2\Phi_3}{\alpha\Phi_1\Phi_2\Phi_3 - 1}.$$

It is easy to see that, in contrast to the previous case, the efficiency of the system depends on the efficiency of the on-grid energy exchange in the bypass:

$$1 > E > 0$$

$$\Phi_1 = \begin{pmatrix} \dfrac{\sqrt{3E^2\alpha - 3E - 3E\alpha + 4} + 2}{y(\alpha - E\alpha + 1)} \\ \dfrac{\sqrt{3E^2\alpha - 3E - 3E\alpha + 4} - 2}{\Phi_2(E\alpha - \alpha - 1)} \end{pmatrix},$$

$$\Phi_3 = \begin{pmatrix} \dfrac{\sqrt{3E^2\alpha - 3E - 3E\alpha + 4} + 2}{3(E\alpha - \alpha - 1)} \\ \dfrac{\sqrt{3E^2\alpha - 3E - 3E\alpha + 4} - 2}{3(E\alpha - \alpha - 1)} \end{pmatrix},$$

$$\Phi_2 = \sqrt{\frac{3(3E^2\alpha - 3E - 3E\alpha - 2\sqrt{3E^2\alpha - 3E - 3E\alpha + 4} + 5}{(E-1)(E\alpha - 1)}}$$

When a “hot” flow is bypassed, a requirement arises either to the efficiency of the system (E) or to the ratio of flows at the inlet to the system (α). Due to the unambiguousness of the solution to the problem, it is not possible to satisfy three requirements.

$$1 > E > 0{,}65$$

$$\Phi_1 = \begin{pmatrix} \dfrac{2E^2\alpha - 2E - \sqrt{E(\alpha - E\alpha + 1)(4E - 4E^2\alpha + 4E\alpha - 3} - 2E\alpha}{3\Phi_2(E\alpha - \alpha - 1)} \\ \dfrac{2E^2\alpha - 2E + \sqrt{E(\alpha - E\alpha + 1)(4E - 4E^2\alpha + 4E\alpha - 3} - 2E\alpha}{3\Phi_2(E\alpha - \alpha - 1)} \end{pmatrix}$$

$$\Phi_3 = \begin{pmatrix} \dfrac{2E^2\alpha - 2E - \sqrt{E(\alpha - E\alpha + 1)(4E - 4E^2\alpha + 4E\alpha - 3)} - 2E\alpha}{3(E\alpha - \alpha - 1)} \\ \dfrac{2E^2\alpha - 2E + \sqrt{E(\alpha - E\alpha + 1)(4E - 4E^2\alpha + 4E\alpha - 3)} - 2E\alpha}{3(E\alpha - \alpha - 1)} \end{pmatrix}.$$

The obtained formal requirements show the possibilities of designing the system, which are determined by objective reasons, and not by subjective wishes.

DISCUSSION OF THE ANALYSIS RESULTS

The analytical principle of the flow representation provides the possibility of solving the inverse problem, i.e., the determination of the matrix elements by the output characteristics of the system. The resulting dependences include the efficiency of the intra-network energy exchange, which are controlled temperature ratios, and the solution of the problem is reduced to calculating the ratio of determinants.

The design task is most often to ensure the conditions for achieving the maximum efficiency of the system with a minimum of weight and size characteristics. NTU is determined by solving the elementary transcendental equation

$$\Phi = \frac{1-\exp[-X(1-\alpha)]}{1-\alpha\exp[-X(1-\alpha)]}\ .$$

$$X = NTU = \frac{\ln\left(\frac{\Phi-1}{\alpha\Phi-1}\right)}{\alpha-1}$$

The relationship between NTU (the required heat exchange surface and, accordingly, the mass and size characteristics, which is extremely important for onboard systems) and the efficiency of Φ_2 with counterflow at E = 0.6 and α = 0.75 is shown in Fig. 2.

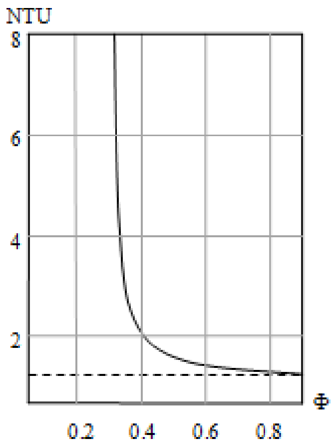

Fig. 2. **Dependence of NTU on system efficiency for counter flow**
***Source:* compiled by the authors**

For direct flow (Fig. 3).

Comparison of Fig. 2 and Fig. 3 confirms the conclusion about the higher efficiency of the counter-current scheme in comparison with the direct-flow one.

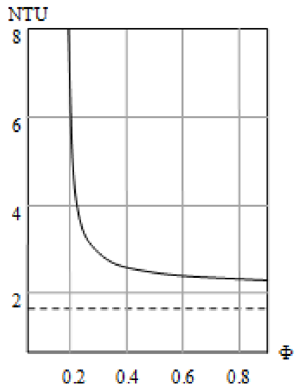

Fig. 3. **Dependence of NTU on system efficiency for direct flow**
***Source:* compiled by the authors**

Example

Let us set the ratio of flows at the system input = 0.3 for the required system efficiency E = 0.8.
For one device, we get X_0 = NTU_0 = 1.9071.
Efficiency of the first element = 0.3972.
The efficiency of the second element = 0.8861.
System efficiency = 0.7146.
The result of solving the transcendental equation is E = 0.8000.
NTU of the first unit NTU_1 = 0.4763.
NTU of the second unit NTU_2 = 1.4467.
The result of solving the transcendental equation is E = 0.8000.
NTU of the first unit NTU_1 = 0.4763.
NTU of the second unit NTU_2 = 1.4467.

The error in relation to one apparatus (when the system operates as one apparatus and the material consumption is equal to one apparatus) = 0.84 %.

CONCLUSIONS

1. An analytical solution to the problem of flow distribution and energy exchange efficiency in a system with a bypass connection is obtained.

2. The analysis of the mathematical model is carried out; the fundamental possibility of determining the required efficiency of the constituent elements of the system is shown.

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Вдосконалення методу проектування теплових мереж: байпасне з'єднання потоків

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АНОТАЦІЯ

В роботі представлено результати розробки моделі теплообмінної системи з байпасним з’єднанням потоків. Розроблено аналітична модель байпасного з’єднання для двох теплообмінних елементів у формі зв’язку перепадів температур з відношенням потоків і ефективністю. Одержаний вираз для ефективності енергообміну в системі залежить від ефективності елементів і відношення потоків на вході у неї і не залежить від розподілу потоків в вузлі змішування. Показано, що ключовим фактором, який визначає як роботу системи, так і її елементів, є відповідність направленості процесів в реальній системі з їх направленням, гіпотетично вибраним проектувальником при заданні її топології. Розподіл енергопотенціалу диктує умови працездатності системи і її елементів через невизначеність значень середніх мір енергії. Постановка задачі визначення елементів матриці, яка задовольняє умові мінімальної невизначеності середніх мір енергії, що приводить до визначення розподілу ефективностей елементів системи у її технологічному представленні у відповідності з вимогами другого початку термодинаміки. Сформульовані вимоги мінімальності невизначеності середніх мір енергії і побудови, засновані на принципі Шенона, дозволяє одержати рішення сформульованої задачі як кінцеву підмножину значень ефективностей міжмережового і внутрішньо мережевий обмін енергією. Крім того, екстремальність рішень (мінімум невизначеності середніх мір енергії) забезпечує максимальну ефективність передачі енергії від “гарячої” мережі до “холодної” в її елементах і мінімальну дисипацію у вузлах змішення. Актуальність тематики обумовлено фундаментальною потребою зниження енергетичних витрат функціонування систем. Прикладний аспект полягає в мінімізації маси, габаритів і енергетичної складової у підприємствах, в яких теплові перетворення є значущими.

Ключові слова: проектування; теплообмінні апарати; байпас; аналітичні методи; оптимізація; обмін енергією

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