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Perfection of the methodology for developing industrial secondary energy generation systems

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Abstract. The algorithm for selecting an energy-efficient secondary energy generation system for large industrial enterprises is proposed. The updated coefficients of the system use of heat and exergy and the Sankey diagram are given. The software implementation of thermodynamic calculations of complex industrial schemes with secondary energy generation devices is presented.

Introduction

Industrial enterprises are complex combinations of tens and hundreds of elements of equipment that are a consumer or generator of thermal energy. Thermal energy is directed not only to useful needs, but also is lost in significant quantities with waste energy (secondary energy resources (SER)). The issues of SER recycling were considered at the end of the XX century, but the main attention was paid to the utilization of high-temperature and medium-temperature SER [1]. The low-temperature SER for a long time remained unreached [2] due to the lack of appropriate utilization equipment for flows of this potential. The appearance of heat transformers, currently used mainly in the heat supply of buildings [3], opened the possibility of using low-capacity resources in industry [4-6]. Consequently, the issue of organizing secondary energy generation systems at industrial enterprises remains topical. Therefore, the subject of research is the organization of the optimal structure of hardware systems for the recovery of secondary energy flows.

In addition, the devices in the technological scheme of production are interrelated, each connection carries information about pressure, temperature, enthalpy, flow rate of the substance. On large objects, many connections are reversed, that is, they are sent to one of the previous elements [7, 8]. That is, the operation of each device of the scheme can affect the operation of the previous device, as well as the graphics of energy consumption and the output of secondary resources in the technological line in which this connection is included. As a result, the process of calculating such a system with feedbacks can be in the nature of numerous iterations. Therefore, an important task is the choice of methods and means of calculation of complex structured heat power systems. The solution of this problem will allow to find the optimal structure of the energy system of the industrial enterprise, in particular, with the inclusion of secondary energy generation units.

The following method is usually used to select the variant of secondary energy generation system [9]:

- analysis of the structural organization of the initial production, with the waste energy, and organized energy systems of secondary energy generation (1st stage of system analysis);
- analysis of the thermodynamic efficiency of the system (the second stage of system analysis);

-       selection of the SER recycling system with the highest potential and their redirection to the devices with the lowest efficiency.

It is proposed to correct the algorithm for selecting a secondary energy generation system; coefficients of effectiveness evaluation; carry out structural and thermodynamic analysis of the system in a single software product, which will confirm the correctness of improving the methodology for developing industrial secondary energy generation systems.

Evaluation of the efficiency of the secondary energy generation system

As a result of the implementation of this technique, secondary energy generation systems were selected that do not consume all of the waste energy streams of the heat technological scheme of production. For example, for a pyrolysis scheme in the production of ethylene, the streams not found in the secondary energy generation system are presented in Table 1 [10].

Table 1. Flows without potential for use in the scheme

Discharge energy	Flow rate G	Temperature t	Heat flow Q	Exergy of flow E	Heat value factor K=E/Q
	ton/h	°C	KW	KW	
Recycled water of scrubbers	91,8	30	31909	4110,4	0,13
Smoke gases from the recovery boiler unit	2,33	150	1371	505,9	0,37
Total:			33280	4616,3	0,14

The coefficient of system use of heat [9] in such a system of $КСИ_Q$ was 83 %, the coefficient of the systematic use of the exergy $КСИ_Q$ – 72 %.

The flows presented in Table 1 have an impact on the reduction of the final efficiency coefficients; however, all possible to the application of waste energy flows in the production of ethylene are used in the generation system completely [6, 8].

It is proposed to adjust the coefficient of system use of heat $КСИ_Q$ (formula 1), which will determine the true share of the useful use of waste energy in the secondary energy generation system:

$$КСИ_Q = \frac{\Sigma Q^{**}}{\Sigma Q^*} = \frac{\Sigma Q^* - \Sigma D}{\Sigma Q^*} = \frac{\Sigma Q^* - (\Sigma Qn + \Sigma Q^{'}сбр1 + \Sigma Q^{'}сбр2 + \Sigma Q^{''}сбр)}{\Sigma Q^*} \qquad (1)$$

where ΣQ^*- heat supplied to the object; ΣQ^{**} - useful heat used; $\Sigma Qсбр$ - the heat abstracted from the object flows of the substance (particularly with secondary energy); ΣQn - heat loss; ΣD - total losses; the sign «'» means heat with the streams taken away from the object, which can be useful used on a particular object under consideration; the sign «"» means heat with the streams taken from the object, which can not be used for a particular object under consideration in connection with its infrastructure; "1" - the waste energy flow used (in case of use, it is removed from the numerator); "2" is an unused flow of waste energy.

It is suggested in the choice of the system of generation of secondary energy to highlight and delete the formula component $Q^{''}сбр$. The calculation results for the production of ethylene in this case: $КСИ_Q = 18$ % - if none of the waste energy streams in the production of ethylene is used (useful energy is the energy of production, and all other streams will be considered losses, for example, heat loss with flue gases, condensate etc.); $КСИ_Q = 83$ % - without exception $Q^{''}сбр$; 88 % - with the exception of $Q^{''}сбр$. In the latter case, the coefficient of system use will approach its maximum, that is, the efficiency, if all possible secondary energy flows are recycled in the system, which will

objectively reflect the situation. The exergy coefficient of the system use is calculated similarly (*КСИ*$_E$ "grown" from 65 % to 72 %).

The correction of the coefficient of system use is relevant when production has surplus of waste energy, or does not take into account the impossibility of using the potential of SER. Underestimation of the coefficient of system use in connection with this fact is eliminated.

It is also proposed to take into account the ratio of planned to recycle flows with the possibility of their "acceptance" in the "weak spot" in the available quantity *G*. Previously, the choice of the flow for the production of additional amounts of secondary thermal energy was made on the basis of data on the flow temperature without regard to its flow, hence the value of heat and exergy did not indicate the most energy-intensive flow.

Further, the potential of flow exergy K=E/Q was evaluated. For a visual assessment, Sankey diagrams were used (Fig. 1a). The ratio of the planned recycling streams and their possible "acceptance" in the "weak spot" in the available quantity *G* it is proposed to take into account the modification of the diagram (Fig. 1b).
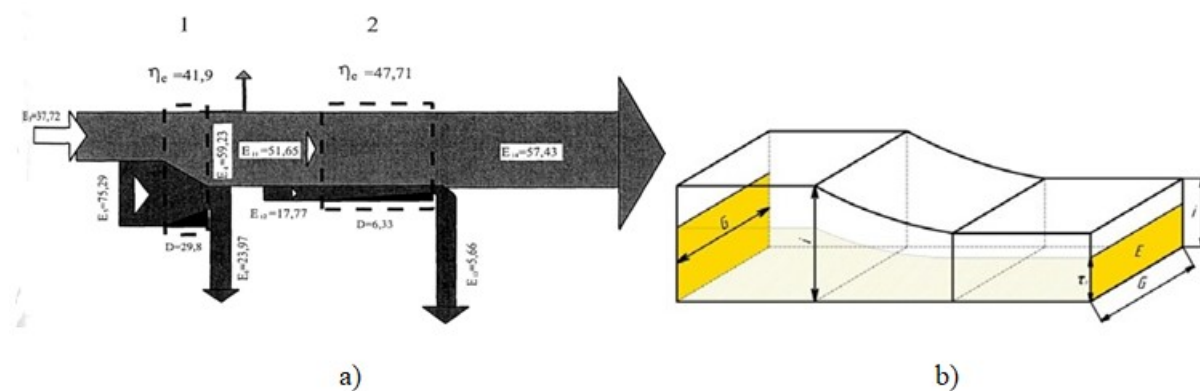

Fig. 1. Flow diagram of exergy for the elements in the schema production: a) Diagram of Sankey for the system of "1" and " 2»; b) addition to the Sankey diagram

So, the sequence of selection of hardware systems of secondary energy generation from the discharge is as follows (after structural and thermodynamic analysis):

1. in order to avoid mistakes when choosing the flow of waste energy and the "place" of its use, it is necessary to initially choose the flows with the greatest exergy $E = f(G, T)$;

2. compare the selected flows by the availability of consumers for them in production, taking into account the value of G in order to reduce the unused "surplus" of secondary energy and to discard flows that do not satisfy any consumer. The problem of "surplus" secondary energy affects the artificial understatement of efficiency;

3. to evaluate the secondary energy generation system in accordance with the above-described criteria.

Software implementation

To calculate the schemes with feedbacks, which are the schemes of industrial enterprises with secondary energy generation systems, to exclude numerous iterations, the software is developed, which carries out the above thermodynamic calculations and analysis of the structural organization of the system in a single product [6, 11]. Example – a section of the ethylene production scheme (Fig. 2), for which the Sankey diagram was constructed (Fig. 1a). As can be seen from Fig. 2, flow rates and enthalpies of flows are associated with each flow of the scheme.

The developed software works as follows (Figure 3):

1. filling in the flow matrix (fig. 3a). It is proposed to denote the flows by specific numbers, so

that the program binds thermodynamic parameters to each flow;

2.   finding connections matrix multiplication, reflecting the connection between the devices (Fig. 3b is formulated as "перемножение матриц") [6, 7, 11]);

3.   search for contours (cycles) - the connection is closed to itself (in Fig. 3c is defined as "поиск циклов");

4.   it is proposed to add search for sequences of unclosed elements (Fig. 3d formulated as "поиск хвостов");

5.   determination of the places of contour rupture (Fig. 3i is formulated as "разбиение циклов");

6.   after the break threads are extracted from the MS Excel file, the specified thread parameters are extracted (Fig. 3f; here "№ потока" – No flow's);

7.   When the flow data is set, the calculation of thermodynamic parameters is started (Fig. 3g; here "Расчет параметров контура" - this is "Contour parameters calculation", "Расчет закончен, т.к. поток с № 3 разорван" - "The calculation is finished, because the flow number 3 is broken").
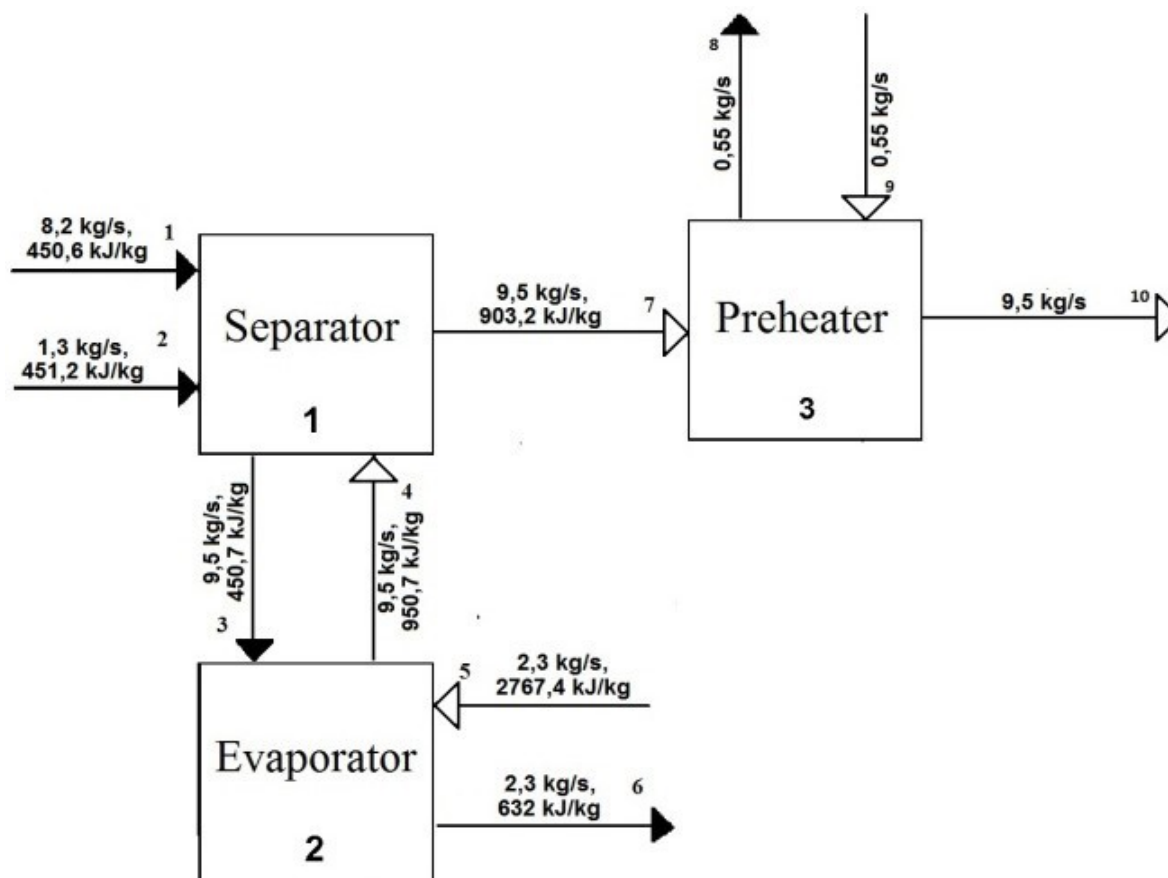

Fig. 2. Heat power system section: 1 - separator; 2 - evaporator; 3 – heater

In Fig. 3f it can be seen that the raw data is taken from Fig. 2

In Fig. 3g it can be seen that the enthalpies of the flux are calculated for the circuit of Fig. 2.

In the same block (Fig. 3g) also incorporated the calculation of the calculated effectiveness ratios of elements and system as a whole.

Summary

The scientific significance of the work lies in the fact that it offers an improved method of finding energy-efficient options for circuit solutions for the organization of systems of complex use of

secondary energy. New criteria for the choice of options for the inclusion of secondary energy generation units are substantiated.

The method of system modeling and its software implementation in the C# programming language in Microsoft Visual Studio to assess the energy efficiency of industrial thermal technological schemes is developed.

On the basis of the materials of this article, the optimal complexes of recovery of secondary energy for petrochemical production, gas separation processes, chemical production, pulp and paper production are developed [5, 6, 8, 12].

a) The matrix presentation of flows

b) Results of multiplication of the adjacency matrix

c) Search results for paths (cycles)

d) Search results for open sequences

i) The matrix circuits and the results of the search for optimal tear streams

f) The flow variables defined in the MS Excel file

g) Calculation of flow parameters

Fig. 3 Software for structural and thermodynamic analysis

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