PARAMETRIC OPTIMIZATION OF ENERGY CONVERSION SYSTEMS BASED ON THERMO ECONOMIC INDICATORS

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Abstract. Modern manufacturing enterprises have a quite complex structure of functioning and management. Moreover, they mostly focused on the issue of not one but several types of products. In this case, there are difficulties of issues to determine the costs of each item of finished goods, and especially of the values of intermediate components of production (semi-finished). Non-obvious is the level of influence on these costs, investments and capital investments, which are related to the acquisition of all types of resources, investment, maintenance of production equipment, its operation (for example, thermodynamic irreversibility of implemented processes in the production process). Thus, now there is a need to create a tool to solve the problems related to complex energy systems that cannot be solved through conventional energy analysis. Under the proposed analysis model for each element of the technical system, its elements, or the whole system equations are compiled, the left side of which grouped all incoming financial flows, and the right side – financial flows leaving the system. Auxiliary equations are of particular importance for determination of the specific values. Their calculates allow to determine the value of the intermediate product industries, and do not change the management decisions even in case of complete failure of production of any end product produced. The proposed method, which is based on justified costs per unit of exergy of mass, heat and work output streams of each element, enables to identify inefficient processes and their impact on the economy of the whole enterprise, that is to carry out a thermo-economic diagnosis of the production process, to evaluate different variants of technical solutions in the design and operation of production facilities from the point of view of profitability. With the proposed method it becomes possible to clarify the costs throughout the technology from the input streams (raw materials) to final products.

Keywords: thermoeconomics, exergy, parametric optimization.

Introduction

Modern production technologies have a highly complicated structure functioning and management. Besides, they often focused on the issue of not one but several types of products. In this case, it causes difficulties to determine costs of each item of finished goods, and especially of the values of intermediate components of production (semi-finished). Also in this case there is not obvious influence on these costs, investments and capital investments associated with the acquisition of the resources (fuel and etc.), investments (loans and etc.), maintenance of production equipment, its operation. There is generated the need for a tool to solve problems related to complex energy systems that cannot be solved through conventional energy analysis. With the help of this tool it will be possible to identify inefficient areas of the technological process, to evaluate alternative options and technical solutions to minimize total production costs, optimize the parameters of the production process, to solve the issues of energy and resource conservation, and conduct energy audits [1].

Materials and methods

The effectiveness of the tool for this task is a thermo-economic approach, which is based on drafting of the equation of the cost of all exergy streams of the system. The methodology of the exergy analysis is drawing up of a mathematical model, which reflects all the elements of the termo-dynamic system. In this case the elements of the model are presented in the form of financial flows. For each element of the technical system (Fig. 1), the group of its elements, or the whole system equation is made (1), on the left side of which all incoming financial flows are grouped and on the right side – financial flows leaving the system.

$$\sum\left(c'_{m,k} \cdot Ex'_{m,k}\right)+\sum\left(c'_{w,k} \cdot Ex'_{w,k}\right)+\sum\left(c'_{q,k} \cdot Ex'_{q,k}\right)+\ldots+Z'_k = \\ =\sum\left(c''_{m,k} \cdot Ex''_{m,k}\right)+\sum\left(c''_{w,k} \cdot Ex''_{w,k}\right)+\sum\left(c''_{q,k} \cdot Ex''_{q,k}\right)+\ldots+Z''_k \quad , \tag{1}$$

where $c'_{m,k}$, $c'_{w,k}$, and $c'_{q,k}$ – unit cost of exergy input component of k-th element respectively mass, mechanical work and heat, monetary unit$\cdot$J^{-1};

$c''_{m,k}$, $c''_{w,k}$, and $c''_{q,k}$ – unit cost of exergy output components of k-th element respectively mass, mechanical work and heat , monetary unit·J^{-1};

$Ex'_{m,k}$, $Ex'_{w,k}$, and $Ex'_{q,k}$ – value of exergy input component of k-th element respectively mass, mechanical work and heat , J;

$Ex''_{m,k}$, $Ex''_{w,k}$, and $Ex''_{q,\ k}$ – value of exergy output components of k-th element respectively mass, mechanical work and heat, J

Z'_k and Z''_k – accordingly, capital cost of purchase of k-th element of the system and its residual value, J

This is schematically depicted in Fig. 1. This equation is solved by relatively outgoing specific costs of exergy $c''_{m,k}$, $c''_{w,k}$, and $c''_{q,k}$. This equation may be unsolvable when the number of unknown values is greater than the number of equations is composed. In this case, it is sometimes possible to equate them with each other. However, in the general case, this approach is flawed and we have proposed an additional (auxiliary) equation (2), that allows to reasonably determine the specific cost of exergy. The unit cost of exergy can be compared in case of invariability of the conditions of functioning of the system [2].

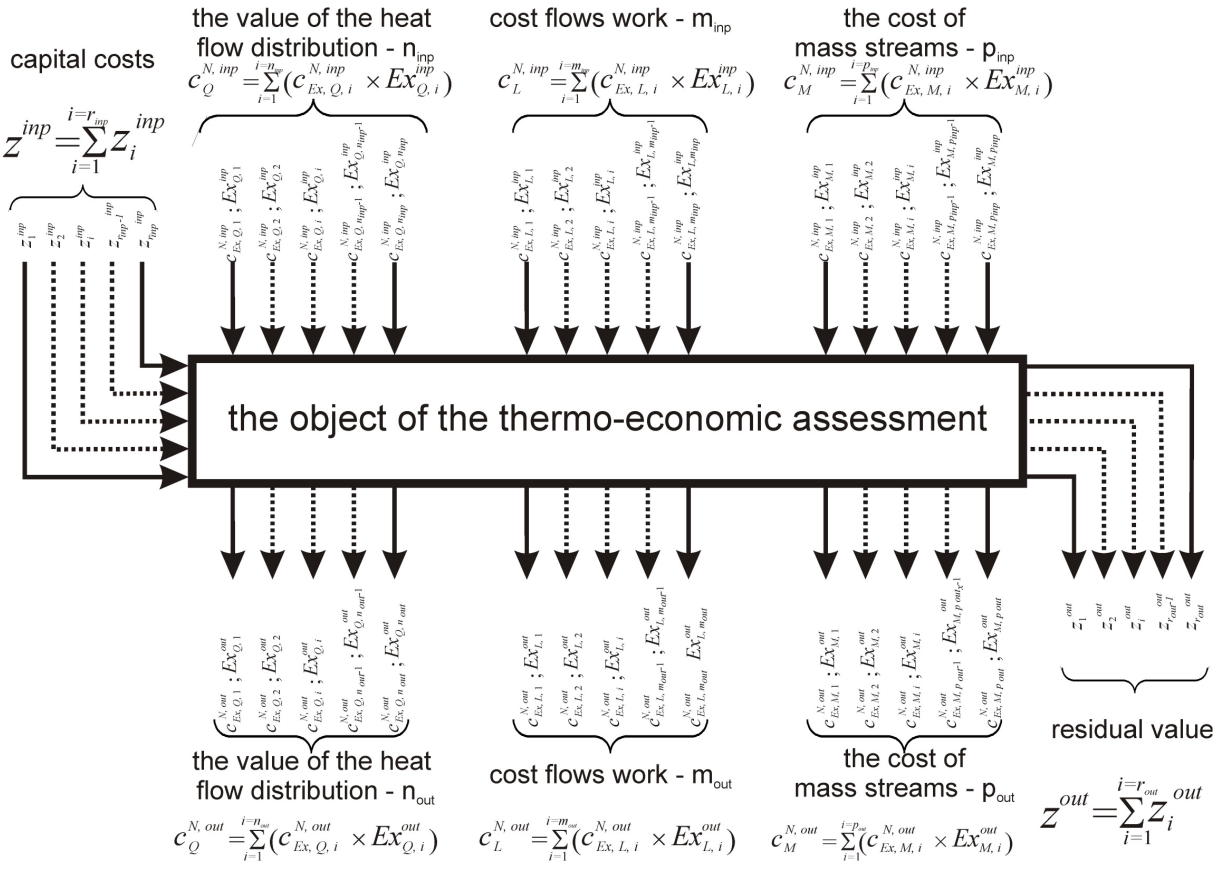

Fig. 1. **Determination of thermo-economic indicators**

Thus, auxiliary equations to determine the specific costs (2) allow not to change the decision even in case of complete failure of production of any end product produced.

$$\left.\begin{aligned} c_{m,k} &= c''_{m,k} / \eta_{m\to El} + C_{m\to El} / Ex''_{m,k} \\ c_{w,k} &= c''_{w,k} / \eta_{w\to El} + C_{w\to El} / Ex''_{w,k} \\ c_{q,k} &= c''_{q,k} / \eta_{q\to El} + C_{q\to El} / Ex''_{q,k} \end{aligned}\right\} c_{m,k} = c_{w,k} = c_{q,k}\ , \tag{2}$$

where $c_{m,k}$, $c_{w,k}$, and $c_{q,k}$ – accordingly, present value of a unit of exergy of mass, heat and work output streams of k-th element, monetary unit·J^{-1};

$c''_{m,k}$, $c''_{w,k}$, and $c''_{q,k}$ – accordingly, unit cost of exergy of mass, heat and work output streams of k-th element, monetary unit·J^{-1};

$Ex''_{m,k}$, $Ex''_{w,k}$, and $Ex''_{a,k}$ – values of exergy of output streams of k-th element respectively of mass, heat and work, J;

$C_m \rightarrow El$, $C_w \rightarrow El$ and $C_q \rightarrow El$ – capital cost of the respective converters into electric energy, monetary unit·J^{-1}.

In addition, the subsidiary equation (2) allows determining the value of the intermediate products of production (Fig. 2). So, Figure 2 in a scale of the width of the stripes reflects the value of exergy of the products and the value of financial investments at all stages of the production process. The ratio of the width of the first and second lines on Figure 2 represent the cost per unit exergy of the product at all stages of production (from raw material to final product). In a scale it is represented in the third strip on Fig. 2.

This allows determining the value of the intermediate products of production not on the basis of losses of the final product, but on the basis of the selected semi-finished product which is the final product.

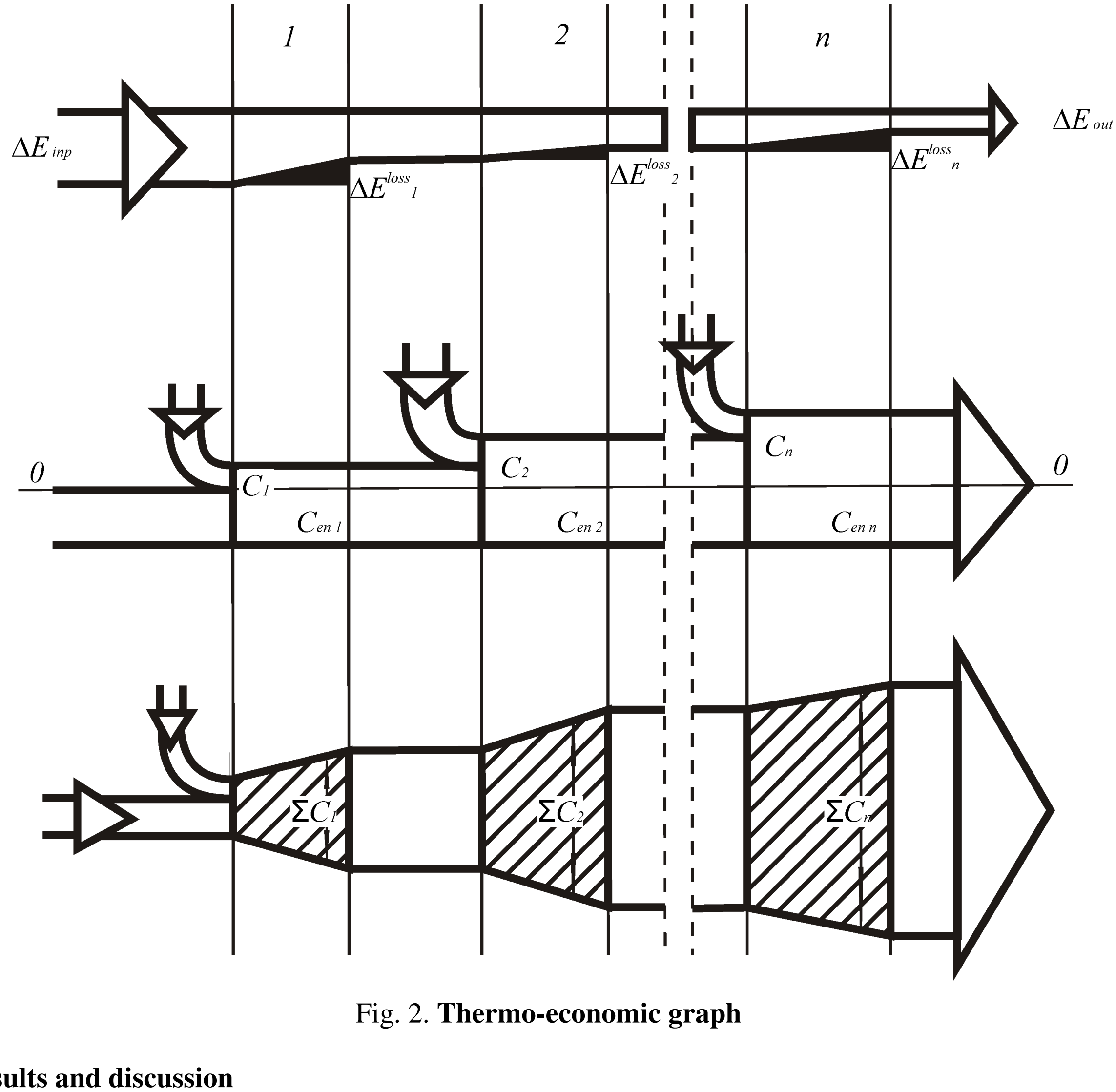

Fig. 2. **Thermo-economic graph**

Results and discussion

The proposed approach was applied to a cogeneration facility Jenbacher JMS 612 GS-B.L, for this setup optimum settings of functioning were found, the specific cost of exergy of thermal and electrical energy was defined. On the basis of the thermo economic approach with our proposed additional equations the optimal operating parameters of the cogeneration plant were determined, as well as the elements of the production process identified, in which there is the greatest loss of funds [3]. Such "weak link" is the device of transformation of energy – the heat engine. In the recycling module of the considered cogeneration unit the biggest loss of funds occurs in the gas-water heat exchangers of exhaust gases (9.6 %) and in the charge-air cooler (0.5 %).

The results of parametric optimization of cogeneration units:

n =1873 min^{-1};

Θ =26.2 deg. p.k.v.;

$T_к$ = 177.18 ºC;

$T_{жс}$ =117.5 ºC;

β = 0.962;

$c_{Ex\ W}$ = 0.51 monetary unit·(kWh)$^{-1}$ = 0.142 monetary unit·MJ^{-1};

$c_{Ex\ Q}$ = 0.365 monetary unit·(kWh)$^{-1}$ = 0.101 monetary unit·MJ^{-1};

where n – rotational speed of the crankshaft of the internal combustion engine;
Θ – ignition timing, deg. p.k.v. ;
$T_к$ – temperature of the charge air, ºC;
$T_{жс}$ – coolant temperature, ºC;
β – load factor (the position of the body of the fuel control);
$c_{Ex\ W}$ – cost per unit of exergy of mechanical work, monetary unit·J^{-1};
$c_{Ex\ Q}$ – cost per unit of exergy of heat, monetary unit·J^{-1}.

Conclusions

Thus, the proposed system of equation based on the thermo-economic methods allows solving the parametric optimization of complex technical systems unsolvable by the conventional energy analysis. This methodic can also identify inefficient processes and their impact on the economy of the whole enterprise, that is to carry out a thermo-economic diagnosis of the production process, to evaluate different variants of technical solutions in the design and operation of production facilities from the point of view of profitability. With the proposed method it becomes possible to clarify the costs throughout the technology from the input streams (raw materials) to final products and evaluate the costs associated with acquisition of the resources (fuel, etc.), investments (loans, etc.), maintenance of the equipment and its operation (perfection of technological processes). Thereby, it becomes possible to minimize the total production costs, optimize the parameters of the production process, to identify ways of saving resources, reasonably allocating the costs across multiple kinds of products, which are produced in the same process. It ensures rational pricing of products on the basis of physical parameters and also allows to conduct energy audits.

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