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SYSTEMATIC APPROACH TO THE ASSESSMENT OF ENERGY COMPLEX EFFICIENCY FOR THERMAL ENERGY PRODUCTION WITH HEAT POWER SAVING TRANSFORMER TURNING ON

c.t.s., ass. prof. L.V. Plotnikova[1], pgs. I.I. Chilikova[1], ass. prof. S.Y. Sitnikov[2,1], t.s.d., prof. Efremov G.I.[3]
[1]FSBEI HE "Kazan State Power Engineering University", Kazan, Krasnoselskaya str., 51.
[2]FGAEI HE "Kazan Federal University", Kazan, Kremlevskaya str., 18.
[3]FSBEI HE "Moscow State Technical University", Moscow, Pavla Korchagina str., 22.

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Abstract:

On the basis of systematic analysis the article specified the criteria for energy efficiency evaluation of complex systems, including heat transformers and low-temperature sources designed for the production of additional energy. The variants of heat transformer turning on in different energy systems are presented, taking into account the specified criteria.

Keywords: System analysis, heat, exergy, efficiency, heat transformer

Introduction

One of the pressing issues in heat-power engineering is the problem of energy resources rational use. A promising way of energy efficiency increase concerning energy facilities and industrial enterprises in order to rationalize the use of resources is the organization of energy systems for additional energy production in the form of secondary energy recovery systems. One of the most promising devices for the production of secondary energy are the heat transformers, which allow to use previously unused low-grade energy. Heat transformers can be presented by increased heat pumps of an open or a closed type (vapor compression heat pumps), step-down heat transformers in the form of various types of recycling refrigerators. In order to select the most energy-efficient complex with heat transformer inclusion one should use topical analysis techniques. These methods are the analysis of the original production structural organization, which have secondary energy resources, and organized energy systems, as well as the analysis of the thermodynamic efficiency.

Systematic Analysis of Energetic Facilities

Energy facilities of energetics objects and industrial plants are the complex systems of multiple units with feedbacks. In order to exclude the multiple iterations during the performance of calculations and the evaluation of such complex system efficiency it is proposed to supplement the thermodynamic analysis of systems used for these purposes by the structural analysis. The structural analysis will allow to get rid of a multi-loop and will determine the best sequence of a system calculation. An initial system will be simplified, the unclosed sequences of elements will be calculated separately and the closed ones, i.e. circuits will be broken and will be presented as non-closed ones. I.e. the structural analysis will allow to perform a simple sequential calculation of thermal technological scheme for the analysis of existing technology energy efficiency [1].

Thermodynamic analysis, based on the sequence determined in the structural analysis will allow to calculate a scheme and the thermodynamic potential of streams which can be used effectively in order to improve the energy efficiency of a system. At the moment, there is a technique of recuperation scheme organization for secondary energy resources concerning the production scheme. This technique allows you to choose a scheme upgrade option, taking into account certain criteria - the values of element efficiency from the original scheme, the heat quantities Q and E stream exergy, which are not applied in an original scheme and the coefficient values of heat K = E/Q.

Usually the secondary energy stream selected by K criterion is directed for the recycling and the production of additional amounts of thermal energy in a unit with the lowest efficiency [2, 3]. But focusing only on this criterion, we may not take into account the valuable secondary energy flows, as in accordance with the formula (1) this ratio is an exergic temperature function τ_e, which is a dimensionless value, and which shows only the temperature potential of a flow:

$$K = \frac{E}{Q} = \frac{G \cdot e}{G \cdot q} = \frac{q \cdot \tau_e}{q} = \tau_e, \qquad (1)$$

where E – flow exergy, kW;

e – specific flow exergy kJ/kg;

Q – flow heat, kW;

q – specific flow heat, kJ/kg;

G – the amount of substance, kg/s;

τ_e – temperature exergy function.

Based on the formula (1), the selection of a recycling flow and the production of additional amounts of heat energy is performed on the basis of flow temperature data without taking into account its flow rate, thus, the coefficient K does not indicate the most intensive energy flow.

Formula (1) is written for the case when only the thermal component is considered in the composition of flow exergy. If during the calculation of K we also take into account in the mechanical component of exergy [4], it will lead to even greater ambiguity of this criterion.

The approach described above does not guarantee that the most energy-efficient additional thermal energy production option from the secondary one is selected. It is also conditioned by the fact that during the selection of a recycling "place" the 'character' of disposal and the ratio of an original scheme area - consumer RER and the disposal plant efficiency are not taken into account. One can't say unequivocally that the secondary energy disposal option is an effective one on the area with the lowest energy efficiency.

Therefore, it is important to take into account the ratio of streams planned for disposal with the possibility of their "adoption" in a "weak spot" within the existing amount of G.

Efficiency Criteria of Heat Energy Production Facilities

Let's consider the evaluation of secondary energy disposal system efficiency to generate an additional amount of heat energy using the example of an energy facility for ethylene production.

On the basis of the previously developed method [2] the recuperation system of the secondary energy was proposed - **Fig. (1)**.

The recuperation system was developed on the basis of all available secondary energy flows evaluation during production. Table. 1 shows all identified secondary flows of thermal energy.

The application of systemic heat use factor KSI_Q [3] will allow to determine the use share in the system connected to a heat object:

$$KSI_Q = \frac{\sum Q^{**} + \sum Q_{\text{сбр}} + \sum Q_{\text{пот}}}{\sum Q^{*}}, \qquad (2)$$

where ΣQ^{*} - heat supplied to an object;

ΣQ^{**} - efficiently used heat;

$\Sigma Q_{\text{сбр}}$ - the heat with substance flow diverted from an object (in particular, with the secondary energy resources);

$\Sigma Q_{\text{пот}}$ - heat losses.

Similarly, the ratio of exergy systemic use $КСИ_E$ was calculated.

Among the diverted streams (Table 1) a significant part represents the flows discharged into the environment, i.e., heat losses which can be useful. Most of the identified streams shown in Table. 1, was used in the recovery system with the inclusion of heat pumps on the chiller 7, and as a steam jet compressor 6 for the production of additional thermal energy (Fig. (1)). The system is designed for steam production of 0.6 MPa in the steam jet compressor 6, the heating of raw material in the heat exchanger 10, the generation of cold in the cooling machine 7 for pyrolysis cooling, and for a partial coverage of heating and hot water loads (app. 11).

Unused streams are presented in Table 2.

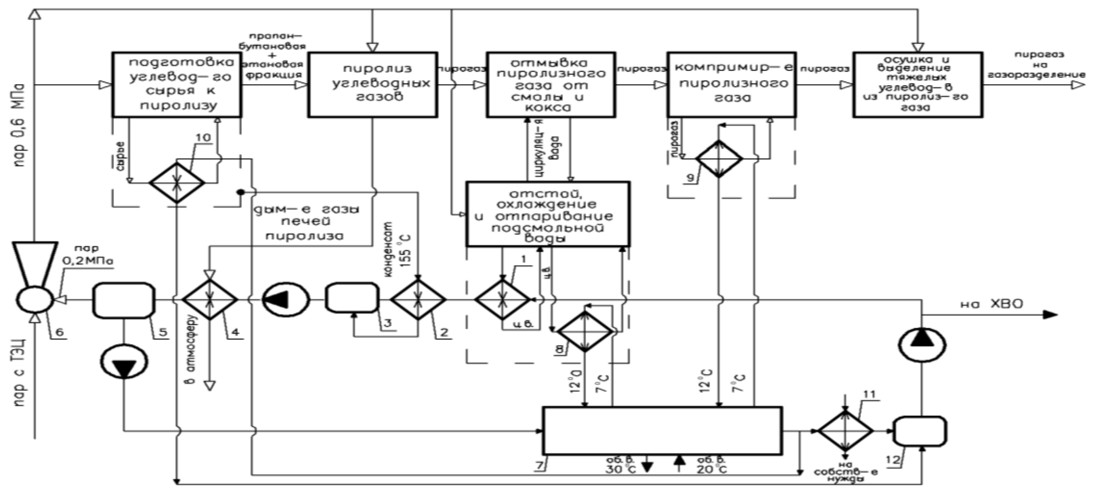

Fig. (1) – The energy complex of secondary energy recuperation with the inclusion of heat transformers [1]: c.w. - Circulating water of scrubbers; r.w. - recycled water; CWT - chemical water treatment; 1, 8 - heat exchanger of scrubber circulation water cooling; 2 - heat exchanger of circulating water heating in a recycling loop; 3, 12 - intermediate vessel; 4 - heat exchanger of pyrolysis furnace flue gas cooling; 5 - flashing steam separator; 6 - heat pump in the form of vapor jet compressor; 7 - a heat pump of the absorption chiller; 9 - heat exchanger of pyrolysis gas cooling; 10 - the heat exchanger of raw material heating; 11 - heat exchanger for the heating of water for own needs

Thus, let's calculate KSI with for a source system with the energy losses shown in Table 1, and for additional energy production from the secondary one. If we use none of the streams (Table 1) then the useful energy is the production energy and all other flows will be considered as losses (the losses of heat with flue gases, condensate, etc.). In this case, KSI will make 18% for the initial system. Earlier during the calculation of KSI the value $\sum Q_{сбр}$ was regarded as a useful component even at the non-use of secondary energy potential flows, which overestimated KSI of the original system. The authors propose to consider the component $\sum Q_{сбр}$ heat losses of until the moment of its useful life.

Table 1: Secondary energy flows from ethylene production.

Item №	Heat carrier	*G* consumption, kg/s	Temperature *T*, К	Pressure *P*, MPa	Heat *Q*, kW	Exergy *E*, kW	Ratio *K*=*E*/*Q*
1	Condensate	0,12	430	0,58	217,07	42,65	0,197
2	Water vapor	1,959	453	1,0	6355,86	2327,41	0,367
3	Flue gases	5,648	533	0,3	1727,97	683,61	0,396
4	Recycled water	10,2	318	0,34	13551,7	1696,96	0,126
5	Air	12,5	313	0,1	7625,81	246,84	0,032
6	Antifreeze	0,23	280	0,14	198,73	4,35	0,022
7	Recycled water	5,4	318	0,34	7176,17	929,56	0,13
8	Hydrocarbon steams	0,3	393	0,56	768,61	208,3	0,271
9	Recycled water	0,9	318	0,34	1267,20	163,54	0,13
10	Tar water	0,71	313	0,56	1035,21	173,97	0,168
11	Recycled water	0,3	318	0,34	398,67	49,91	0,125
12	Recycled water	20,2	318	0,34	26844,2	3435,29	0,13
13	Recycled water	0,3	318	0,34	398,67	49,91	0,125
14	Recycled water	8,2	318	0,34	10897,1	1364,25	0,125
15	Recycled water	4,2	318	0,34	5581,48	698,77	0,125
16	Antifreeze	1,0	280	0,14	1242,09	20,76	0,017
17	Recycled water	0,4	318	0,34	531,57	66,55	0,125
18	Recycled water	8,2	318	0,34	11138,9	1364,25	0,123
19	Antifreeze	2,0	280	0,14	2484,15	76,05	0,031
20	Recycled water	0,4	318	0,34	531,57	66,55	0,125
21	Recycled water	6,2	318	0,34	8239,32	1031,51	0,125

22	Recycled water	5,4	318	0,34	7176,17	898,40	0,125
23	Antifreeze	2,0	280	0,14	248,43	4,14	0,017
24	Refrigerant	0,8	254	0,49	728,34	50,25	0,069
25	Water steam	0,9	431	0,6	3509,41	1000,22	0,285
26	Recycled water	4,2	318	0,34	4797,88	613,39	0,13
27	Methane-hydrogen fraction	0,57	421	0,86	2274,64	544,25	0,239
28	Refrigerant	0,71	243	0,5	609,35	55,81	0,092
29	Recycled water	1,6	318	0,34	2126,26	283,45	0,133
30	Recycled water	0,9	318	0,34	1196,02	149,72	0,125
31	Refrigerant	0,42	255	0,5	369,28	21,34	0,058
32	Recycled water	1,65	318	0,34	2192,71	274,51	0,125
Total:					133440,5	18596,47	0,139

Also, during the calculation of KSI_Q the energy which is absolutely impossible to use at the considered production can be included in the composition of $\Sigma Q_{сбр}$. That is, even when all other secondary energy flows possible for disposal are used usefully KSI_Q will not be 100% still. In other words, KSI will not be close to its maximum, i.e., to efficiency, if left at least one unused stream of secondary energy is left. Therefore, the authors are recommended to deduct the element $\Sigma Q_{сбр}^{'}$ from $\Sigma Q_{сбр}$ for the flows with the inability of use for this industry. This approach will allow to choose the most energy-efficient option of secondary energy system use in order to produce the additional quantity of heat energy for the specific production. In this case the formula (2) would be transformed into the following form:

$$KSI_Q = \frac{\sum Q^{**} + \sum Q_{сбр} - \sum Q_{сбр}^{'} + \sum Q_{пот}}{\sum Q^{*}}, \qquad (3)$$

where $\Sigma Q_{сбр}^{'}$ - the heat with the matter flows withdrawn from the substance object that can be used usefully at a particular object in regard to its infrastructure.

Table 2: The flows of heat and exergy not used in the system of additional energy production from the secondary one.

Matter flow	G	t	Q	E	K=E/Q
	t/h	°C	kW	kW	
Recycled water from the element 7, **Fig. (1)**	91,8	30	31909	4110,4	0,13
Flue gases from the element 4, **Fig. (1)**	2,33	150	1371	505,9	0,37
Total:			33280	4616,3	0,14

Thus, KSI will be increased, namely KSI_Q will be increased from 83% to 88%, and KSI_E - from 65% to 72% for the given production by using the formula (3) instead of the formula (2). This growth is conditioned by the inability to use the flows shown in Table 2 at a particular production; thus KSI decrease is eliminated in regard to this fact.

Thus, during the finding KSI system use coefficient one should subtract the waste heat of secondary energy resources, which can't be applied in the system. In this case KSI will be closer to the real value, reflecting the situation in a particular industry. This allows you to select the most energy-efficient version of additional energy production system from the secondary one. Thus, the selection algorithm of hardware systems for additional energy production from the secondary one is the following. In order to avoid mistakes during the choice of secondary energy stream and the "place" of its recuperation, one should initially choose the flows with the highest exergy E = f(G, T). Then you need to compare the selected streams by the presence of consumers in them, taking into account the value Q in order to reduce an unused "surplus" of secondary energy and discard the streams that do not satisfy any consumer. The problem of secondary energy "surplus" makes an impact on efficiency, as it is not possible to bring the efficiency to 100% even at full use of all possible secondary streams. On the basis of these criteria use the efficient energy production systems were chosen from low-temperature sources: the heat of the exhaust air, **Fig.(2)** and product separation heat, **Fig.(3)**.

Energetic Facilities of Heat Energy Production with the Inclusion of Jeat Transformers

In order to dispose the low potential thermal waste energy resources available at the pulp and paper production it is possible to use heat transformers due to the presence of low-temperature waste energy resources significant amount.

The performed analysis of the test production showed that a considerable exergy power is demonstrated by the outgoing air flows of a paper machine, warm water during liquor cooling and warm water during the condensation of water-alcohol vapors of alcohol and methanol columns during the stage of alcohol production. These streams can be used in vapor compression heat pumps. A heat transformer turning on circuit for the disposal of the exhaust wet air of a paper machine drying section, in order to bring the parameters of moistened air to the desired settings of the heating dry air Fig. (2): cold air enters a heat pump condenser, where it is heated to the desired temperature and directed into the drying chamber [5]. In the drying chamber due to heat and mass exchange the air temperature is decreased, and the moisture content increases. The moisture is removed from the product. The moistened air is directed to a heat pump evaporator, where it is cooled. The removal of the precipitated water takes place simultaneously with the cooling process. The heat transformer is presented here by one of the options - a heat pump. The results of calculations showed that the heat of outgoing air is sufficient for air heating supplied to a drying unit. Using the circuit with a heat pump 6245.89 kW of additional heat energy were obtained through the use of 3122.9 kW of wet flue gas energy. Obviously, the heat transformation ratio is equal to 2. In the case of a dryer scheme use with a conventional disposer - air-heater 3789.24 kW of energy will be spent additionally in an electric heater. After the use of heat pumps the energy resource saving is achieved up to 90% taking into account KSI.

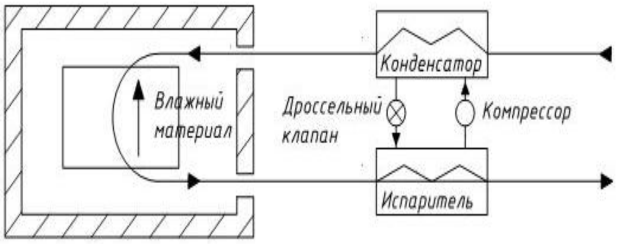

Fig. (2) – Drying unit with a heating pump.

During the next stage of alcohol production, as well as at different parts of petrochemical production, where the separation according to condensation-rectification or absorption-rectification schemes is carried out including a significant number of rectification columns, they also use the heat pumps efficiently for low-potential energy separation. So, the analysis of the thermal and thermodynamic efficiency of the gas separation section during petrochemical production showed that the rectification columns are characterized by the highest thermal and exergy losses among the heat and mass transfer devices of this area, and the flows of output products for rectification columns have a large exergic flows power.

It is proposed to reduce energy consumption through the organization of a heat use system of a compressed upper product with the inclusion of a heat pump in industrial rectification processes [6]. The system "rectification column - heat pump" may be used at the separation of light hydrocarbons, "water-alcohol" mixture, etc. The scheme of a heat pump classical configuration inclusion with an intermediate heat carrier is presented on Fig. (3). In this case, the saving of a heating medium in a boiler is achieved by using the heat of the column top product [6].

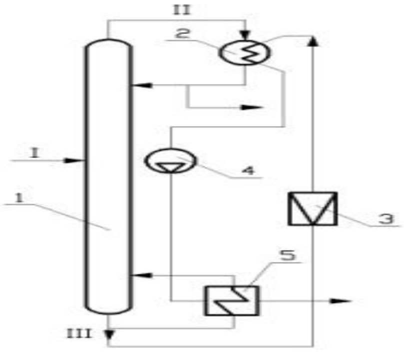

Fig. (3) – Rectification column with the use of an intermediate coolant 1 - rectifying column; 2 - reflux condenser - evaporator; 3- throttle valve; 4 - compressor; 5 - condenser-boiler; I - raw materials; II - top product; III- low product

It was found that the inclusion in the rectification column of a heat pump with an intermediate coolant is relevant at the reconstruction of columns. In the case of a new separation unit design a more economical scheme is possible with one heat exchanger represented by a heat pump of an open type. **Fig. (4)**.

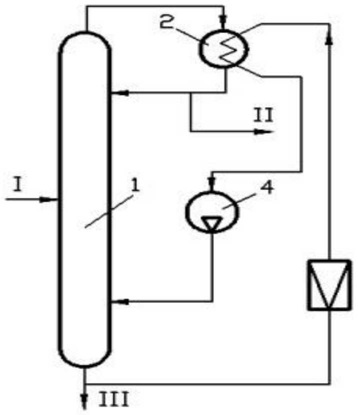

Fig. (4) – Rectification column with a heat pump on low product: 1 - rectifying column; 2 - dephlegmator 3 - reboiler; 4 - compressor; I - separated mixture; II - top product; III - low product.

Thus, the following data (Table 3) were obtained during the analysis of abovementioned schemes:

Table 3: Comparative evaluation of heat transformer inclusion effectiveness in separation processes.

Process specifications and parameters	Traditional scheme of a rectification unit	Rectification unit scheme with a closed heat pump	Rectification unit scheme with an open heat pump
Pressure, MPa, top of the column after the	1,92	1,92	0,85

compressor	-	1,67	1,25
Temperature, ° C, top of the column, bottom of the column	42,7 55	14,2 25	14,2 25
Column diameter, m	5100	4780	4300
Column height, m	78	65	57
Reflux ratio	14	10,5	9.25
Conversion factor	-	6,21	10,3
Relative vapor flow	45,5	15,7	8,7
Relative equipment cost and energy costs, % Columns Heat exchangers Compressor	64,6 14,3 -	24,6 8,9 28,5	9,2 7,3 16,1

Table 3 shows that during the use of heat pumps in rectification processes the overall and physical parameters of a rectification plant are reduced, which leads to energy consumption decrease and to the economic efficiency increase. The selection of a heat pump inclusion scheme depends on secondary energy parameters. The use of a heat pump all components increases the cost and complicates the structure. Consequently, the task of appropriate option selection is an actual one. In this regard there are the prerequisites for the creation of a new rectification structure, which will allow to reduce energy and material costs. In order to improve the energy efficiency of an open heat pump it is offered to install "a rectification column - a heat pump" of a heat exchange unit of "pipe in pipe" type. The space inside the tubes of a rectification column may be filled with a nozzle, and the pipe walls may have a corrugated shape [7]. Rectification schemes with a classic heat pump inclusion provide the energy consumption reduction by 25-30%. The use of an upgraded installation "a rectification column - a heat pump" of "pipe in pipe" type allows you to increase the energy efficiency of the system "rectification column - heat pump" up to 35-40% and reduce their metal content. Heat transformers are widely used at heat supply. The combination of boiler units with heat pumps is offered, as with a significant temperature difference of a heating and a heated coolant heat pumps become inefficient as compared to conventional boilers. At higher temperatures of a heating season only heat pumps are offered to operate and conventional boilers are included for "peak" loads removal. When you use the heat pumps with gas motor drive for the hot water supply system the high rates of economic efficiency are produced: gas saving made 72% as compared to a boiler, the investment payback period makes 1.3 years, and the gas flow rate may be reduced to 2 - 4 times. Thus, the application of heat transformers allows to reduce the energy intensity of industrial technological and power generating processes through the use of secondary energy [8].

Conclusions

The selection criteria and the evaluation of thermal energy production systems were clarified using the example of low-potential secondary energy transformations in heat transformers.

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