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EXERGY ANALYSIS IN MODERN INVESTIGAIONS (REVIEW)

The advance of the exergy method is the universality associated with the usage of exergy allows for the estimation of stocks and flows of all types of energy included in the balance of any energy technology system using a common criterion of efficiency. For this reason exergy approach was used for systems investigation's in different areas such as: traditional energy industry, renewable energy, refrigeration industry, chemical technology, food production and even in medicine. Review of last publication in all these areas showed that the application of the exergy analysis is very efficient due to the fact that the exergy approach allows thermodynamically objectively estimate all types of energy sources, regardless of the specific type of processes occurring in individual elements of the system as well as in the system as a whole. Exergy method due to it universality can be also a base for a high quality innovations and implementations in practice fields of new design and technological solutions as well as provide of complex competency development connected with the application to the educational process in different Universities world wide.

Keywords: review; exergy analysis; optimization; energy and refrigeration sectors; chemical and food technologies.

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ЕКСЕРГЕТИЧНИЙ АНАЛІЗ В СУЧАСНИХ ДОСЛІДЖЕННЯХ (ОГЛЯД)

Перевага ексергетичного методу полягає в його універсальності, пов'язаної з тим, що застосування ексергії дозволяє оцінювати енергетичні потоки різних типів, які включаються в баланси енерготехнологічних систем, з використанням загального показника ефективності. Виходячи з цього, ексергетичний підхід застосовувався для системних досліджень в різних галузях, таких як: традиційна енергетика, відновлювальна енергетика, холодильна промисловість, хімічна технологія, харчова промисловість і навіть медицина. Огляд сучасних публікацій в цих всіх галузях показав, що застосування ексергетичного аналізу є досить ефективним в силу того, що ексергетичний підхід дозволяє термодинамічно об'єктивно оцінювати всі типи енергетичних ресурсів, не залежно від специфіки процесів, які протікають в окремих елементах, а також оцінювати систему в цілому. Ексергетичний метод в силу своєї універсальності може служити базою для високоякісних, інноваційних, практичних застосувань в областях нових технологічних і дизайнерських рішень, а також дає можливість комплексного розвитку компетенцій при впровадженні в навчальний процес різних університетів по всьому світу.

Ключові слова: огляд; ексергетичний аналіз; оптимізація; енергетика і холодильна промисловість; хімічна та харчова технології.

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ЭКСЕРГЕТИЧЕСКИЙ АНАЛИЗ В СОВРЕМЕННЫХ ИССЛЕДОВАНИЯХ (ОБЗОР)

Преимущество эксергетического метода заключается в его универсальности, связанной с тем, что применение эксергии позволяет оценивать энергетические потоки разных типов, включаемые в балансы энерготехнологических систем, с использованием общего показателя эффективности. Исходя из этого, эксергетический подход применялся для системных исследований в различных областях, таких как: традиционная энергетика, возобновляемая энергетика, холодильная промышленная, химическая технология, пищевая промышленность и даже медицина. Обзор современных публикаций в этих всех областях показал, что применение эксергетического анализа является весьма эффективным в силу того, что эксергетический подход позволяет термодинамически объективно оценивать все типы энергетических ресурсов, не зависимо от специфики протекающих в отдельных элементах процессов, а также оценивать систему в целом. Эксергетический метод в силу своей универсальности может служить базой для высококачественных, инновационных, практических приложений в областях новых технологических и дизайнерских решений, а также дает возможность комплексного развития компетенций при внедрении в учебный процесс различных университетов по всему миру.

Ключевые слова: обзор; эксергетический анализ; оптимизация; энергетика и холодильная промышленность; химическая и пищевая технологии.

Introduction. For application of exergy method analysis now is an increased interest. Only in the leading journals in this area *Energy* and *Int. J. of Exergy* during the past 5 years, the number of publications exceeds 200. Only in 2017 in this area was published more papers than for 2014–2016 in total. In contrast to the methods of thermodynamic analysis used earlier, the exergy method takes into account not only the quantity but also the quality of energy flows, which puts this method in first place in its objectivity.

The advance of the exergy method is the universality associated with the fact that the use of exergy allows to estimate stocks and flows of all types of energy included in the balance of any energy technology system using a common criterion of efficiency.

Exergy as an indicator of practical energy efficiency can serve also for an approximate comparative estimation of average energy efficiency indicators, especially in those cases where purely economic criteria for evaluation are absent. This method is also characterized by the simplicity and visibility in calculation.

Exergy method due to it universality can be also a base for a high quality innovations and implementations in practice fields of new design and technological solutions as well as provide of complex competency development connected with the application to the educational process in different Universities world wide.

Applications of exergy analysis. The first Russian-language monographs with detailed description of exergy method are [1], [2]. Subsequently, this method was also described in [3], [4], [5], [6], [7], [8], [9], [10]. Since that the exergy method of thermodynamic analysis was used in the following different areas (the recent publications are given below).

In the energy sector for: thermodynamic evaluation of air cooling systems [11], absorption heat pump analysis [12], Brighton supercritical carbon cycle research [13], thermodynamic analysis of Renkin's organic cycle [14], [15], gas turbine installation study [16], the thermodynamic analysis of the thermoelectric battery [17], the study of a three-generation system using pneumatic motors [18], [19], [20], [21], the development of new three-generation thermodynamic cycles with two-phase expander and compressors [22], the definition of exergy losses due to the improvement of steam boilers [23], [24], [25], the study of the operation of aviation turbines [26], the study of pneumatic energy accumulation systems [27], [28], the study of steam boilers with a boiling layer [29], analysis of impact at environment of gas turbine plants [30], the study of boiling fluid boilers [31], the analysis of the operation of thermal power plants [32], [33], [34], [35], the analysis of plate heat exchangers [36], the analysis of tubular heat exchangers [37], turbine engine research [38], pneumatic transport systems research [39], is investigation of processes in the work of turbomachines [40], [41], gas turbine optimization [42], research of processes in heat pipes [43], optimization of secondary energy resources use in industry [44], analysis of high-temperature combustion chambers [45], research of transport systems [46], improvement of thermal power plants [47], [48], [49], [50], optimization of regenerative cogeneration systems [51], [52], thermodynamic analysis of compressed air storage [53], optimization of heat exchanger systems [54], optimization of operating modes of power units of thermal power plants [55], investigation of a buildings heating [56].

In renewable energy for: analysis of renewable energy sources use in multigeneration systems [57], research of the solar absorption refrigeration system [58], analysis of processes in solar ponds [59], research on electricity generation for biofuels [60], research of solar gas turbine cycle combined with the transformation of fuels [61], the study of flat solar collectors [62], the thermodynamic analysis of a solar receiver [63], an investigation of the Renkin organic cycle with a solar energy source [64], investigation of the hybrid type systems [65], the study of the absorption refrigerators using solar energy [66], the study of gasification processes in the production of biofuels [67], the study of biomass production processes [68], [69] , thermodynamic analysis of diesel fuel on biofuels [70], solar collector studies [71].

In the refrigeration industry for: thermodynamic analysis of ejector refrigeration cycles on neural networks [72], the development of cryoaccumulators [73], the design of cryoaccumulators, combined with liquefied gas regasifiers [74], evaluation of low-temperature processes [75], research of cooling processes [76], improvement of the processes of operation of ejector refrigeration systems [77], research of cooling processes of hydrogenerators [78], analysis of cryogenic systems [79], analysis of irreversibility of processes in solar absorption refrigerators [80].

In chemical technology for: research on the hydrogen production system [81], the analysis of reactors for the production of methyl [82], the study of rotary furnaces for the production of ferronickel alloys [83], the study of anode gases in fuel accumulators [84], optimization of industrial ammonia production [85] , comparison of various cycles of ammonia synthesis processes [86], calculation of generalized exergy functions of chemical processes [87], analysis of recycle gas processes [88], study of mass transfer processes [89], research of processes in boiling layer dryers with obtaining of soda [90], the study of filtration processes [91], the study of regeneration processes in the production of sulfuric acid [92], the improvement of the properties of structural materials [93], the analysis of liquid ammonia storage [94], the experimental study of gas-solids reactors [95], the analysis of carbon dioxide absorption processes [96], gas gauge studies [97], the analysis of the diffusion air pollutants from the chimney [98], the study of gasification processes of fuel [99].

In food technology for: improvement of cogeneration systems in sugar production [100], investigation of environmental impact of ethanol and sugar production [101], optimization of sugar plant [77], [94], thermodynamic analysis of milk pasteurization [102], optimization of food preparation processes [103], improvement of tea leaves drying process [104], [105], strawberry straw growth studies in greenhouses and open soil [106].

And even in medicine for: studying the comfort of Fanger with the use of exergic loss of man [107], research on the work of the heart on the exergy model [108]. From the last years Papers of authors in this area can be mentioned as follows. In [109–111] exergy analysis was applied to a typical technological scheme of a sugar production factory with a capacity of 3000 tons/day, and determined the corresponding exergy characteristics (tabl. 1).

In the initial preparing of product, the greatest loss of exergy (187 kW) falls on the process of obtaining affinity sugar with a minimum value of the degree of thermodynamic perfection 0,5. This is due to dissipative losses of centrifugation processes, mechanical separation and grinding, diffusion, in which energy is used on the equipment drives. In the processes of syrups heating the exergy losses caused to heat transfer irreversibility at sufficiently high temperature differences, and the dissipative losses of the product transportation process in the subsequent processing steps.

Table 1 – Exergy characteristics of sugar production

No	Groups of production processes	Exergy at the input, kW	Exergy at the output, kW	Exergy losses, kW	The degree of thermodynamic perfection
1	Initial preparing	1022	665	357	0,65
2	Syrups heating	1034	831	203	0,80
3	Evaporation of syrups	8236	4448	3788	0,54
4	Syrups collecting	309	284	25	0,92
5	Filtration of syrups	1122	1020	102	0,91
6	Processing of products	899	815	84	0,91
7	Sugar cleaning	1669	949	720	0,57
Total		14291	9012	5279	0,63

The largest losses of exergy (93 kW) fall on the process of heating the syrup of affinity sugar at a low value of the degree of thermodynamic perfection 0,77.

For syrup evaporation the greatest exergy loss (kW 1451) occur in the process of primary refined (as well as a low value of 0,55 degree thermodynamic perfection), which results to a large heat flows and an irreversibly of heat transfer processes at high temperature differences.

In the processes of collecting syrups, loss of exergy caused by dissipation in transportation of the product from several locations with subsequent mixing and direct losses of a heat to the environment from the equipment due to imperfect thermal isolation. The largest losses of exergy (10 kW) fall on the process of collecting the syrup 2 product at a sufficiently high value of the degree of thermodynamic perfection 0,92.

During filtration, the greatest loss of exergy (30 kW) falls on the process of filtering the syrup before sulphation at a sufficiently high value of the degree of thermodynamic perfection 0,89. This is due to the dissipative processes during filtration and the low quality of filtration material. As follows from the consideration of the results for system of sugar production as a whole, the greatest exergetic losses are observed during the process of syrup evaporation (more than 70 % of the exegetic losses of the whole process of sugar production). These processes are also characterized by the lowest degree of thermodynamic perfection from all the processes under consideration (0,54), therefore, for these processes have been given the most attention.

In [112–116] was considered exergy application with a graphs method on a base of exergy flow graph for investigating of Power systems on example of gas turbine installation. The exergy flow graph of a system with arbitrary structurecan can be expressed as a graph, $E = (A, \Gamma) = (A, U)$, where A is nodes multitude corresponds to systems elements $A=\{a_1, a_2, ..., a_i, ..., a_m\}$, U is the arcs multitude corresponds to the exergy flows distribution in the system $U=\{a_i, a_l\}$; $i \neq l$; $i = 1, 2, ..., m$; $l = 1,2, ..., m$, and Γ represents a multivalued display of multitude A into itself.

The generalization of characteristic and exergy flow graph gives the possibility to avoid multi-types of graph models in analysis of power intensive systems. Also it provides a common exergy-topological approach in the systems investigation.

For gas turbine installation exergy losses in the turbines and in the turbo compressor are the result of dissipation of expansion (pressure) processes in a real installation.

Degree of thermodynamic perfection of turbines and turbocompressors are sufficiently high. Usually, the bigger the difference between average parameters of the working fluid and the environment, the smaller the exergy losses.

The same situation is also true for heat exchangers. Higher temperature level in regenerative refrigerator (as compared with intermediate refrigerator) gives a higher degree of thermodynamic perfection of the heat exchanger.

Exergy losses in other elements of the system are caused by dissipation of the flow transport in the pipelines or by mechanical losses. For the system as a whole the degree of thermodynamic perfection is less than the same characteristics for any element of the system in result of the mutual influence of one elements to the others in the system.

Conclusion.

1. The exergy method of thermodynamic analysis of systems is actively used not only in various industries (energy, refrigeration, renewable energy, construction industry, chemical, pharmaceutical and food technologies), but also in areas which are quite unusual for its application, for example, in medicine

2. The application of the exergy analysis is very efficient due to the fact that the exergy approach allows thermodynamically objectively estimate all types of energy sources, regardless of the specific type of processes occurring in individual elements of the system.

3. Exergy method due to it universality can be also a base for a high quality innovations and implementations in practice fields of new design and technological solutions as well as provide of complex competency development connected with the application to the educational process in different Universities world wide.

4. Thermodynamic analysis of sugar production systems was carried out based on the application of the First Law of Thermodynamics (energy characteristics) as well as on the joint application of the First and Second Law of Thermodynamics (exergy characteristics). Based on this analysis, three groups of energy-saving options were formed: using waste energy resources; changing energy parameters; based on structural changes in the system. It is shown that the identified energy-saving potentials can serve as a basis for the subsequent optimization of sugar production systems. However, the final decision on the application of these energy-saving options requires a thermo-economic approach, since the implementation of most of them requires significant capital investment.

5. The main exergetic characteristics of a typical sugar production scheme with a capacity of 3000 tons of sugar per day have been calculated, analysis of which showed that the main source of exergy losses (more than 70 %) in sugar production systems are the boiling processes, which also have a low degree of thermodynamic perfection (0.54). Losses of exergy in these processes as well as in others are caused by big heat fluxes and irreversibility of heat exchange processes at significant temperature drops, and as dissipative losses of centrifugation processes, mechanical separation, diffusion and transport of streams.

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