Methods of Analysis of Energy Processing Technological Systems

B.J. Khursanov
Acting Associate Professor, Fergana Polytechnic Institute,
Republic of Uzbekistan, Fergana
E-mail: b.xursanov@ferpi.uz

In the article, the purpose and methods of thermodynamic analysis for the creation of energy-processing technological systems were explained.

Keywords: energy processing, technological, system, thermodynamics, analysis, energy method, entropy method, compressors, turbo compressors, pumps

Introduction

The thermodynamic analysis is necessary to create energy-processing-technological systems (EPTS). This analysis is performed for the following two purposes:

1) To obtain reliable information about the PTS, energy changes in it are determined (values of useful work coefficient of the system and its elements, distribution and character of losses in the system, relative mass of each element of the system, characteristics of the connections between elements, relationship with the environment interaction, etc.). This information is the basis for improving the system and comparing it with other systems in the industry;

2) Various parameters of EPTS elements are optimized to achieve maximum thermodynamic and economic performance. It should be noted that EPTS, which is often thermodynamically efficient, will not be economically efficient.

The simplest method of thermodynamic analysis of EPTS is the energetic method based on the first law of thermodynamics. This method determines the energy losses in the EPTS and its elements, as well as the EPTS elements with the largest process losses. The main drawback of the energetic method is the cost of energy in various forms, that is, the practicality of energy, is not taken into account. This is contrary to the second law of thermodynamics [1-7].

Materials and methods

In real processes, irreversible energy losses occur. Therefore, two methods that take into account the irreversibility of processes are currently used in the thermodynamic analysis of systems: entropy (method of cycles) and exergy methods. Both methods are based on the scientific work of R.K. Clausius, D.V. Gibbs and A.Stodola. In addition, A.I.Andryushenko, V.M.Brodyansky, D.P. Gochstein and others contributed to the development of these methods. Both methods are based on the second law of thermodynamics and are used for the same purpose, that is, to determine energy losses in real processes [8-15].

Entropy method

Based on the laws of thermodynamic analysis of systems, it is possible to determine the relationship between external energy flows (amount of heat and work) and system parameters, as well as some internal parameters. Analysing the heat balance of the system with thermodynamic processes, calculating the coefficients characterizing the system and comparing them to ideal thermodynamic processes. can be compared with similar coefficients. This allows you to determine the loss of work received and consumed in a given system due to the irreversibility of processes. If these data are not enough for the engineering analysis of the system, then the analysis of cycles is completed by calculating the entropy increase in individual parts of the system [16-22].

To evaluate the thermodynamic performance of the system, it is necessary to find answers to the following 4 questions:

1) What is the efficiency of the reverse cycle of the device, what factors does it depend on, and what should be done to increase it?

2) What is the loss due to the irreversibility of processes in the actual device?

3) How are these losses distributed among the elements of the device?

4) Which part of the device should be paid attention to reduce the level of non-return, in particular, to increase the efficiency of the cycle?

According to these tasks, the thermodynamic analysis of the device is carried out in two stages: first, the reversible cycle is analysed, and then the irreversible cycle is analysed, taking into account the main sources of losses. The efficiency of the return cycle is determined from this formula:

$$\eta_t = \frac{q_ц}{q_1} = 1 - \frac{q_2}{q_1} = \frac{l_ц}{q_1} \quad (1)$$

and it is called the coefficient of thermal useful work. And the actual cycle is:

$$\eta_i = \frac{l_ц^Д}{q_1} \quad (2)$$

It is called the internal useful work coefficient. The coefficient of internal useful work characterizes the level of perfection of the processes carried out by the working body [23-31].

The degree of perfection of a given cycle is characterized by comparing its coefficient of thermal useful work with the coefficient of thermal useful work of the Carnot cycle. The comparison is made in the same temperature range and is called the relative thermal efficiency coefficient:

$$\eta_{ot} = \frac{\eta_t}{\eta_к} \quad (3)$$

To assess how imperfect a given actual (irreversible) cycle is compared to the theoretical (reversible) cycle, the concept of relative internal efficiency is introduced:

$$\eta_{oi} = \frac{\eta_i}{\eta_t} = \frac{l_ц^Д}{l_ц} \quad (4)$$

But in the operation of the device in real conditions η_{oi}. In addition to the irreversible losses represented by (losses in the processes that create the working body), some losses occur due to the irreversibility of thermal, mechanical, chemical and electrical processes. Therefore, the efficiency of the actual device is the effective useful work coefficient, which is equal to the ratio of the amount of energy supplied to the external consumer (in the form of heat or work) to the amount of energy transferred to the device (in the form of heat or work)η characterized by The efficiency of the system can also be expressed by its exergy: by calculating the exergetic losses in each element, the exergetic losses of the whole system can be found [32-34].

The main element of the system is devices that perform compression processes at the expense of external work (compressors, turbo compressors, pumps, etc.) and devices that perform work at the expense of expansion (steam and gas turbines, turbo expanders). The actual compression and expansion processes are irreversible. is, and the relative internal efficiency coefficient of each j-element of the system is determined as follows:

For expansion devices

$$\eta_{oi,j}^P = \frac{l_{P,j}^Д}{l_{P,j}} \quad (5)$$

here $l^{Д}_{P,j}$ ва $l_{p,j}$ - real and theoretical expansion works of system element j;
for compression devices

$$\eta^{c}_{oi,j} = \frac{l_{c,j}}{l^{Д}_{c,j}} \quad (6)$$

here $l_{c,j}$ ва $l^{Д}_{c,j}$ - the theoretical and actual work done by the element j of the system at the expense of external energy; in which more energy is used in the actual compression work than in the theoretical process $\left(l^{Д}_{c,j}\right)$ have to spend.

So the return of the loop in the device is:

$$l_{ц} = \sum_{j=1}^{j=n} l_{P,j} - \sum_{j=1}^{j=n} l_{c,j} \quad (7)$$

And irreversible work:

$$l^{Д}_{ц} = \sum_{j=1}^{j=n} l^{Д}_{P,j} - \sum_{j=1}^{j=n} l^{Д}_{c,j} \quad (8)$$

or if we consider formulas (5) and (6):

$$l^{Д}_{ц} = \sum_{j=1}^{j=n} l_{P,j}\ \eta^{P}_{oi,j} - \sum_{j=1}^{j=n} \left(l_{c,j} / \eta^{c}_{oi,j}\right) \quad (9)$$

Then, taking into account the formula (4):

$$\eta_{oi} = \frac{\sum_{j=1}^{j=n} l_{P,j}\ \eta^{P}_{oi,j} - \sum_{j=1}^{j=n} \left(l_{c,j} / \eta^{c}_{oi,j}\right)}{\sum_{j=1}^{j=n} l_{P,j} - \sum_{j=1}^{j=n} l_{c,j}} \quad (10)$$

Internal efficiency of the cycleη_jConsidering formulas (1), (7) and (10):

$$\eta_i = \eta_{oi}\ \eta_t = \frac{\sum_{j=1}^{j=n} l_{P,j}\ \eta^{P}_{oi,j} - \sum_{j=1}^{j=n} \left(l_{c,j} / \eta^{c}_{oi,j}\right)}{l_{ц}} \cdot \frac{l_{ц}}{q_1} = \frac{\sum_{j=1}^{j=n} l_{P,j}\ \eta^{P}_{oi,j} - \sum_{j=1}^{j=n} \left(l_{c,j} / \eta^{c}_{oi,j}\right)}{q_1} \quad (11)$$

Losses in each element of the system, the effective efficiency of these elements$\eta_{e,j}$ is also represented by By multiplying all the effective useful work coefficients of the elements of the system by the absolute internal useful work coefficients of the cycle, we get the effective useful work coefficient of the entire system:

$$\eta_e = \eta_{oi}\ \eta_t \prod_{j=1}^{j=n} \eta_{e,j} \quad (12)$$

here $\prod_{j=1}^{j=n}$ - the multiplier of the effective useful work coefficient characterises irreversible losses in all n elements of the system. η_e useful work coefficient shows how much of the heat released from the system was given to the external consumer and turned into useful work in it:

$$l_{пол} = \eta_e\ q_1 \quad (13)$$

It is known that

$$\Delta q = \left(1 - \eta_e\right) \cdot q_1 \quad (14)$$

The quantity is a part of the heat q1 that has not been converted into work, and this part is from the heat q2 supplied to the cold source, as well as the irreversible processes occurring in the device elements due to friction, temperature difference, and heat loss $\Delta Q_П$, consisting of environmental and other losses.

It is known that

$$\Delta q_П = l_ц - l_{пол} \quad (15)$$

Where l_{ts} is the work received in the return process.

Given formulas (1) and (13), the following can be obtained:

$$\Delta q_П = \eta_t\ q_1 - \ \eta_e\ q_1 = \left(\eta_t\ - \eta_e\right)\ q_1 \quad (16)$$

Since the maximum return cycle work can be obtained only in the Carnot cycle, with the maximum exergetic loss in the system Δl_P (which is equal to the maximum value of Δq_P) is equal to:

$$\Delta l_П = q_1\left(\eta_к\ - \eta_e\right) \quad (17)$$

In EPTS, unlike energy devices, there are technological devices that do not perform any work along with machines. But due to temperature differences, chemical reactions and other factors, there will be big losses in these devices [34-39]. They are the effective efficiency of the device in the entropy thermodynamic method η_{eat} is taken into account when determining. But it is very difficult to determine these losses, therefore, when using this method, it is very important to evaluate the performance of all elements of EPTS - machines and technological devices. Energy losses in EPTS are calculated as follows:

$$\Delta l^{ЭКТС}_{éóê} = T_0 \Delta S^{ЭКТС} \quad (18)$$

The change in entropy of the system is equal to the sum of the entropy changes in its individual elements, i.e.:

$$\Delta S^{ЭКТС} = \sum_{i=1}^{i=n} \Delta S_i \quad (19)$$

Multiplying the ambient temperature by T0, we get the following form:

$$\Delta l^{ЭКТС} = T_0 \Delta S^{ЭКТС} = \sum_{i=1}^{i=n} T_0 \Delta S_i = \sum_{i=1}^{i=n} \Delta l_i \qquad (20)$$

that is, the energy loss of the whole system is equal to the sum of energy losses in its individual elements. The found values of Δl_i indicate in which elements of EPTS the irreversible processes affect Δl^{EPTS} more. Therefore, it indicates which processes in these elements need to be improved first.

Exergetic method

The exergetic method of thermodynamic analysis of EPTSs is based on the use of exergy. The exergy of a substance is the maximum work done by a substance in the feedback process with the environment, which is considered a source of heat. At the end of this process, all types of matter must be in thermodynamic equilibrium with all components of the environment.

The exergetic method is a universal way of thermodynamic analysis of processes of different transformations of energy in EPTS. All real processes are irreversible and are a factor that reduces the perfection of the process. Irreversibility is not due to the loss of energy, but due to its quality reduction, because energy is not lost in irreversible processes. For example, the throttling of the working body does not change its energy (i_1-i_2) but reduces its workability or the ability to use it in heat exchange devices.

Conclusion

Thus, every irreversible process is a loss of energy. The universality of the exergy method of EPTS thermodynamic analysis is that the nature of the analysed system (for example, closed or open) does not matter in principle: the approach to solving the problem and the method of solving it does not change. In the exergetic method of thermodynamic analysis of EPTS, all elements of the system are considered separate independent systems. Evaluation of the performance of each EPTS element is done by comparing the exergy input to that element with the exergy loss due to irreversible processes in it. Thus, in determining the exergy losses in each element of the researched EPTS, the reasons for the imperfection of its processes are identified and quantified. This, in turn,

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