Entropy analysis of heat exchanging appliances

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ABSTRACT

The article describes thermodynamic methods as well as optimization methods of heating and heat exchanging engineering system of sugar industry. The authors suggest noncyclic approach to the analysis of efficiency of heat exchanging apparatus, the basis of which is irrefutable fact that irreversibility as physical reason of inefficiency of technical heat engineering systems really exists. Thermodynamic analysis, which was mentioned in the article, assumes determination of measure of irreversibility of processes in the apparatus and energetic efficiency of apparatus in the whole with the help of exceptionally entropy. The measures taken to improve energetic efficiency of apparatus of saccharine factory on the example of the first group of juice heating in front of evaporator system using the given methodology, were fully analyzed.

Introduction

It is obvious that nowadays such major characteristics as "area of thermoexchange surface" and "coefficient of efficiency" are traditionally used in saccharine industry. That is not enough, as while comparing constructionally different HEAs it makes no sense to compare relation between area of thermoexchanging surface and its characteristics. The usage of exergy method of thermodynamic analysis [3] (which is widely used while analyzing technical systems – work generators) contradicts the fundamental principles of methodology of optimization of thermoexchanging processes and systems.

The issue of choice of analysis of effectiveness of HEA was reviewed by the authors in [1,2], where the expediency of usage of non-cyclic entropy method for thermodynamical analysis and HEA optimization, as well as energetic balance method for composing energy model of HEA performance is substantiated.

Results and discussions

Adhering to producers' terminology, HEA of "condensate-juice" type is called as "heat exchangers", and HEA of "steam-liquid" type – as "heaters".

According to non-cycle entropy method technique [1, 2], integrated thermodynamic analysis assumes the determination of measure of irreversibility of processes, that occurs in HEA, the sources of which are heat exchanging at the finite variance of temperatures, the

dissipation of mechanic energy of heat transfer medium currents and heat exchanging with the environment.

The quantitative characteristics of irreversibility is increasing of entropy of isolated system, which determines from the entropy balance of ABC system (fig. 1), which consists of 3 subsystems: A, B, and C (A is heating heat transfer medium subsystem, B - heat transfer medium subsystem, C – environment subsystem).
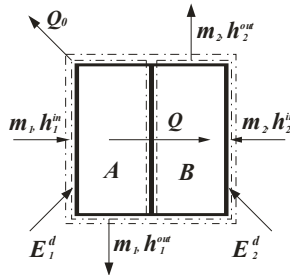

Fig. 1. before the folding of entropy balance of HEA

In general, entropy balance of HEA is agglomerated with the help of following simplifications:

– change of kinetic and potential energy is neglected;

– for heat transfer mediums, in which transition between preset thermodynamic states is followed by temperature changes (fig. 2 a, 2 b), change of thermal qualities is not considerable, which allows to introduce medium thermodynamic temperature:

$$T_m = \frac{T^{in} - T^{out}}{\ln \dfrac{T^{in}}{T^{out}}} \qquad (1)$$
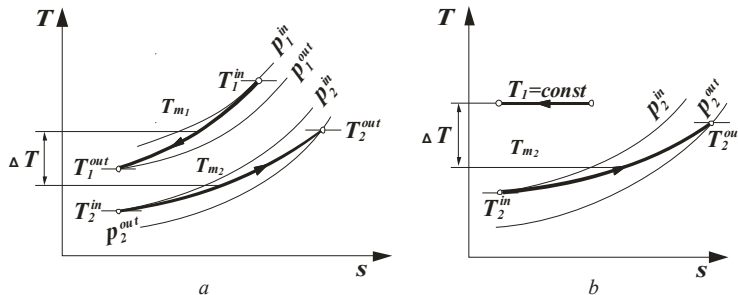

Fig. 2. Change of thermodynamical states of hot and cold heat transfer media:
***a** – in heat transfer medium, **b** – in heater*

Written form of entropy is grounded on its qualities and assumes that all its parts are absolute values; entropy can be either brought in or taken out together with the streams of substance and heat, and increase because of the irreversibility of the processes.

Entropy balance of every subsystem (fig. 1) looks like this:

Entropy balance of subsystem A:

$$m_1 s_1^{in} + \frac{E_1^d}{T_{m_1}} = m_1 s_1^{out} + \frac{Q}{T_{m_1}} + \frac{Q_0}{T_{m_1}} \tag{2}$$

Entropy balance of subsystem B:

$$m_2 s_2^{in} + \frac{Q}{T_{m_2}} + \frac{E_2^d}{T_{m_2}} = m_2 s_2^{out} \tag{3}$$

Entropy balance of subsystem C:

$$\Delta S_C = \frac{Q_0}{T_0} \tag{4}$$

Estimating entropy additivity, in another words, $DS_{ABC} = DS_A + DS_B + DS_C$, and the fact that AB subsystem together with C subsystem create generally isolated adiabatic system ABC (concluded from the boundary line quantities of the system), for which entropy change equals general entropy increase fom irreversibility of the processes: $\Delta S_{ABC} = \Delta S_{irrev}^{tot}$. It can be written in the following way:

$$\Delta S_{irrev}^{tot} = m_1 s_1^{out} + m_2 s_2^{out} - (m_1 s_1^{in} + m_2 s_2^{in}) + \frac{Q_0}{T_0} \tag{5}$$

S

or

$$\Delta S_{irrev}^{tot} = \left(\frac{Q}{T_{m_2}} - \frac{Q}{T_{m_1}} \right) + \left(\frac{Q_0}{T_0} - \frac{Q_0}{T_{m_1}} \right) + \frac{E_1^d}{T_{m_1}} + \frac{E_2^d}{T_{m_2}} \tag{6}$$

We rewrite the equation (6) in general view:

$$\Delta S_{irrev}^{tot} = \Delta S_{irrev}^T + \Delta S_{irrev}^0 + \sum \Delta S_{irrev}^p \tag{7}$$

in which $\Delta S_{irrev}^T = \frac{Q}{T_{m_2}} - \frac{Q}{T_{m_1}}$ - is increasing of system entropy, conditioned by irreverence of

heat exchange between subsystems A and B; W/K; $\Delta S_{irrev}^0 = \frac{Q_0}{T_0} - \frac{Q_0}{T_{m_1}}$ - increasing of entropy

at dissipation of mechanical energy of streams of heat transfer medium (in case of the heaters $E_1^d / T_{m_1} = 0$) W/K.

Thermodynamical efficiency of HEA, considering the irreverence of the processes, is defined by non-dimensional coefficients: entropy coefficient of thermodynamical efficiency:

$$\eta_s^p = 1 - \frac{\Delta S_{irrev}^{tot}}{\Delta S_{irrev}^{max}} \tag{8}$$

Or entropy coefficient of thermodynamical non-efficiency:

$$\eta_s^{imp} = \frac{\Delta S_{irrev}^{tot}}{\Delta S_{irrev}^{max}} \tag{9}$$

While

$$\eta_s^{imp} + \eta_s^p = 1 \tag{10}$$

in which ΔS_{irrev}^{tot} – is increasing of entropy of isolated system, that goes across to two given states, W/K; ΔS_{irrev}^{max} – maximal possible increasing of entropy of adiabatic system – system passes from given state to the state of thermodynamic balance with the environment, W/K.

Coefficients (8) and (9) do not have known (discovered) drawbacks of performance factor (energetic, exergy), as they characterize the degree of diversion of real system from reverent in structure borders of thecond thermodynamic law. Let us explain this.

Including the fact that the state of balance of isolated system is defined by the maximum of its entropy (consequence of the second thermodynamic law) and restrictions, imposed by the nature on the operation of technical systems (energy has technical meaning till it has the potential different from the one of the environment), denominator of equations 8 and 9 is used as the standard of comparison.

It means that $\Delta S_{irrev}^{\max}$, being the result of heat exchanging of hypothetical TS (system A) with the environment (system C) (fig. 3), which quantitatively characterizes maximal irreversibility at given characteristics of environment and is calculated with the help of the following equation (fig. 3):

$$\Delta S_{irrev}^{\max} = m_1(s_0 - s_1) + \frac{Q_0}{T_0} + \frac{E_1^d}{T_0} + \frac{E_2^d}{T_0} \tag{11}$$

in which s_0 - is specific entropy of heating heat transfer medium at the temperature of environment, J/(kg/K).
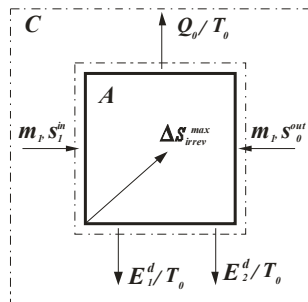

Fig. 3. Hypothetic TS

While analyzing the heaters in equation (6) $T_{m1} = T_{1s}$ - the temperature of saturation of dry saturated steam, and $E_1^d / T_0 = 0$.

The efficiency of functioning of HEA – local effectiveness of potential usage of heat transfer medium (temperature), including dissipation processes in given temperature interval – defined entropy coefficient of HEA effectiveness:

$$\eta_s = \frac{\Delta S_{irrev}^{\min}}{\Delta S_{irrev}^{tot}} \tag{12}$$

in which $\Delta S_{irrev}^{\min}$ - is a minimal entropy increasing because of heat exchanging `irreverence in HEA, $\Delta S_{irrev}^{\min} = Q \left(T_{m_1}^{\min} - T_{m_2} \right) / \left(T_{m_1}^{\min} T_{m_2} \right)$, W/K, Q – true heat effectiveness of HEA, W; T_{m2} - medium thermodynamic temperature of the heating up heat transfer medium, K; $T_{m_1}^{\min}$ - minimal possible medium thermodynamic temperature of heating heat transfer medium, K. For heaters $T_{m_1}^{\min} = T_{1s}^{\min}$ (fig. 4 a); for heat transfer media with large mass account thermal capacity of heating heat transfer medium according to equation 6 and fig. 4 b $T_{m_1}^{\min} = \left(T_{1\min}^{in} - T_{1\min}^{out} \right) / \left(\ln T_{1\min}^{in} / T_{1\min}^{out} \right)$, thus $T_{1\min}^{in} = T_2^{out}$; for heat exchangers with larger mass

account thermal capacity of heating up heat transfer medium $T_{m_1}^{\min}$ is calculated analogically, including $T_{1\min}^{out} = T_2^{in}$ (fig. 4 c).
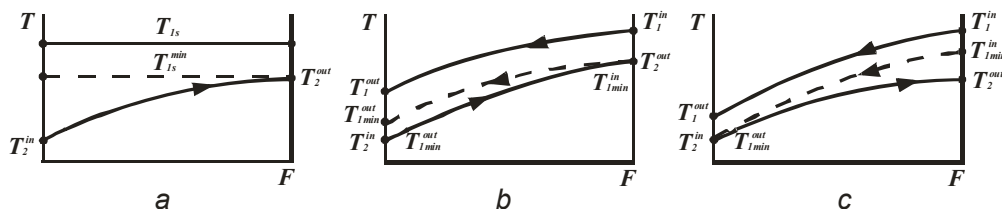

Fig. 4. Before defining $\Delta S_{irrev}^{\min}$

a - in the heater; b - in the heater with bigger mass consumptive thermal capacity of heat transfer medium; c - in heater with bigger mass consumptive thermal capacity of heating heat transfer medium

Conclusions

Suggested technique of thermodynamic analysis assumes scientifically proved systematic approach to comparative analysis and different construction, that, obviously, is suitable to do with the help of entropy coefficient of efficiency, as well as for defining their thermodynamic efficiency in margins of sugar plant. The last can be achieved with the help of using entropy coefficient of thermodynamic efficiency and allows to analyze different heat exchanging systems for defining the level of their influence on general energetic efficiency of sugar plant.

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