EXERGETIC ANALYSIS OF RECOVERY ENERGY PROCESSES

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Abstract
The paper presents the results of an applicable research where the aim was to establish the real energy efficiency of the heat pump for industrial practices to recovery energy resources with low thermal potential.
The exergetic analysis put on user's disposal the real figures referring to the energy efficiency of the heat pumps. On a qualitative analysis the paper establishes the real limits of energy efficiency for the heat pumps used into recovery processes of secondary energy resources with low thermal potential.

Keywords
Efficiency, exergy, heat pump, qualitative

1. EXERGETIC EFFICIENCY OF HEATING PROCESSES

Exergetic efficiency may be define as ratio of heat exergy E_Q which is delivered to the warm source and combustion exergy E_B which is necessary for generating heat Q, so:

$$\xi = \frac{E_Q}{E_B} \tag{1}$$

where:

$$E_Q = Q\frac{T_R - T_m}{T_R} \tag{2}$$

where:
T_R is warm source temperature (K)
T_m is environment temperature (K)
and E_B is combustion heat.

If we are taking into account the device's quantitative analysis (energy loss), we can define the device efficiency:

$$\eta = \frac{Q}{E_B} \tag{3}$$

so

$$E_Q = \eta \cdot E_B \cdot \frac{T_R - T_m}{T_R} \tag{4}$$

and

$$\xi = \eta \cdot \frac{T_R - T_m}{T_R} \tag{5}$$

For small power plant the usual average value of efficiency is between 0.7 and 0.9. In situation when t_R=20°C and t_m=-15°C exergetic efficiency ξ is between 0.084 and 0.107.

In case of heating with electrical resistance, electrical energy W will be produced with an efficiency:

$$\eta_e = \frac{W}{E_B} \tag{6}$$

Because the whole electrical energy is changed in heat (W=Q) exergy efficiency for this kind of heating became:

$$\xi_E = \eta_e \cdot \frac{T_R - T_m}{T_R} \tag{7}$$

For η_e=0.35 and the same temperature conditions exergy efficiency is ξ_E=0.042. Is very clear that electrical heating is not a proper method economical and technical speaking. So, electrical heating is better to be removed with heat pump, in all the situations and technological processes.

2. EXERGETIC BALANCE OF PROCESSES WITH HEAT PUMP

For qualitative analysis of process with pump heat we considered the scheme fig. 1.

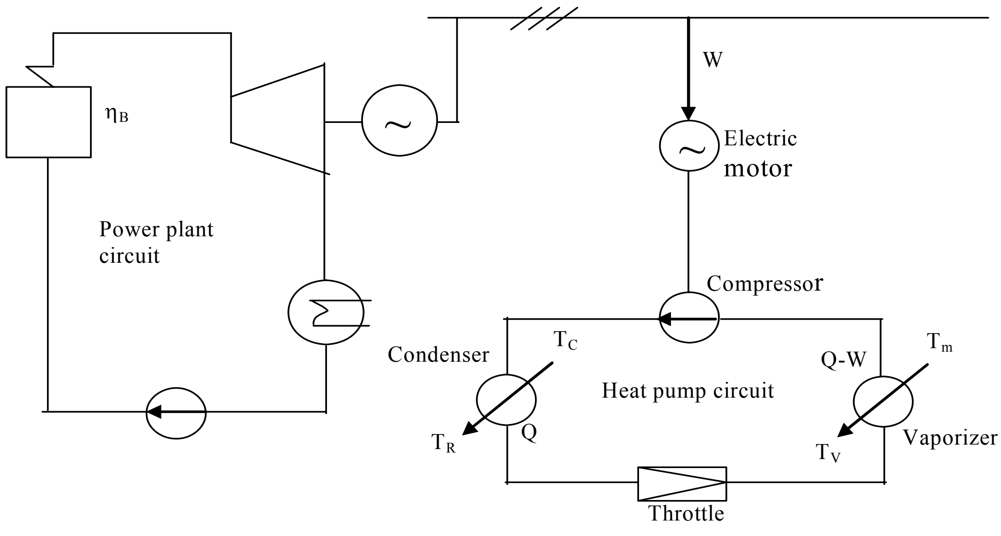

Fig. 1- Heat pump scheme used for exergetic analysis

The T-s diagram of the heat pump process looks like in fig. 2.

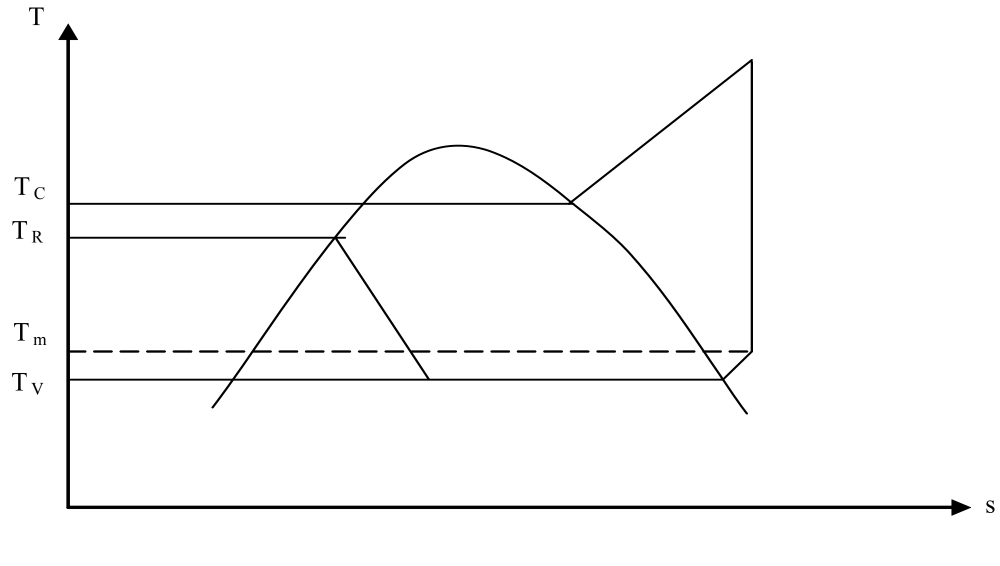

Fig.2- T-s diagram

In Fig.3 the exergetic balance of the heat pump process is shown. In the ideal process (zero losses) the energy of the compressor electric motor equals the exergy of heat Q (E_Q).

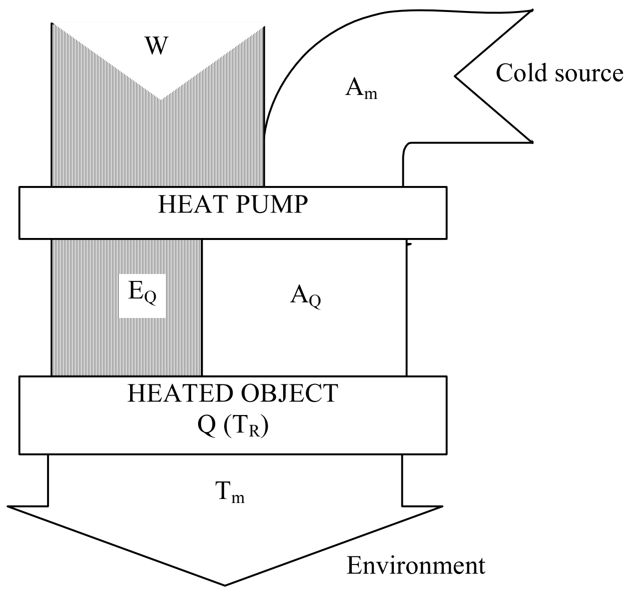

Fig.3- Sankey diagram of the process

In the real process two types of loss affect the process quality ($W>E_Q$):
- Mechanic and electric losses of the heat pump driving system ($\eta_m \cdot \eta_e$). The internal irreversibility of the process must be considered also (η_i).
- The external irreversibility of the process as result of the finite temperature difference of the heat transfer process over the condenser and vaporizer ($\xi_{\Delta T}$).

For the real process conditions $T_C > T_R$; $T_m>T_V$; $\eta_i<1$ it means that $\xi_{\Delta T} < 1$.

For a correct comparison between heat pump and the other heating processes we must taking into account that electrical energy is produced into a power plant with an efficiency $\eta_e = W/E_B$ and in this situation the exergy efficiency of the heat pump process (ξ_{PC}) became:

$$\xi_{PC} = E_C/E_B = W/E_B{*}Q/W{*}E_Q/Q = \eta_i\xi_{\Delta T} \tag{8}$$

If is considered that in condenser and vaporizer heat transfer processes are running at the constant temperatures:

$$\xi_{\Delta T} = Q/W \cdot E_C/Q = Q/W \cdot (W - E_V)/Q \tag{9}$$

where E_V is lost exergy in condenser and vaporizer heat transfer processes, and

$$E_V = QT_m\left(\frac{1}{T_R} - \frac{1}{T_C}\right) + (Q - W)T_m\left(\frac{1}{T_V} - \frac{1}{T_m}\right) \tag{10}$$

If the process follows Carnot conditions:

$$\frac{Q}{W} = \left(\frac{T_C}{T_C - T_V} + \frac{1-\eta_i}{\eta_i}\right)\eta_i\eta_m\eta_{el} \tag{11}$$

and

$$\xi_{\Delta T} = \eta_i\eta_m\eta_{el}\left(\frac{T_C}{T_C - T_V} + \frac{1-\eta_i}{\eta_i}\right)\frac{T_R - T_m}{T_m} \tag{12}$$

3. HEAT TRANSFER INFLUENCE

The heat exchange through the condenser is directly proportional with temperature difference:

$$Q \sim (T_C - T_R) \sim (T_R - T_m), \text{ so } (T_C - T_R) / (T_R - T_m) = K = \text{const} \tag{13}$$

$$Q \sim T_V / T_C \sim (T_R - T_m);\ T_V / T_C \sim (T_m - T_V),$$

so

$$\frac{T_m - T_V}{T_R - T_m} \cdot \frac{T_C}{T_V} = V = const \tag{14}$$

K and V are two constants that characterize qualitative behavior of condenser and vaporizer. Considering all these, the exergetic efficiency of heat pump became:

$$\xi_{PC} = \eta_e\eta_m\eta_{el}\eta_i\left[\frac{1 + (V + K)\cdot\left(1 - \frac{T_m}{T_R}\right)}{1 + (V + K)} + \frac{1-\eta_i}{\eta_i}\cdot\left(1 - \frac{T_m}{T_R}\right)\right] \tag{15}$$

The graphic analysis of ζ_{PC} = f (V+K, $T_R - T_m$) allow us to reach the conclusions that:
- heat pump works in good conditions for $T_R - T_m = (10 - 30)\ ^oC$;
- for low environment temperatures heat pump exergetic efficiency increase.

5. LIMITING VALUES OF HEAT PUMP EFFICIENCY

By definition, the heat pump efficiency is:

$$\varepsilon = Q / W \tag{16}$$

Using relations 11 and 16 results:

$$\varepsilon = \eta_m \eta_{el} \eta_i \left[\frac{1 + (V + K)\left(1 - \frac{T_m}{T_R}\right)}{(1 + V + K)\left(1 - \frac{T_m}{T_R}\right)} + \frac{1 - \eta_i}{\eta_i} \right] \tag{17}$$

Setting limiting conditions regarding the fuel consumption that means fuel amount used by power plant to produce heat Q equals fuel amount used to produce electric energy W for driving the heat pump compressor, and heat pump thermal charge is Q, the following relation can be write: $\varepsilon_{min} = \eta_B / \eta_e$.

6. CONCLUSIONS

One of the conclusions is that the heat pump can be used when $\varepsilon > \varepsilon_{min}$, because in this situation is a proper fuel consumption.

Making a graphical and experimental analysis of function ε_{PC} = f (V+K, $T_R - T_m$) some conclusions regarding the heat pump efficiency limits were drawn:
-is recommended $\varepsilon > 2.6$ for the units with power plant in cogeneration;
-is recommended $\varepsilon > 2$ for the units with power plant;
- is recommended $\varepsilon > 1$ when heat pump replaces electric heating.

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