ENERGETICALLY AND EXERGETICALLY STUDY FOR TWO VARIANTS OF HEAT EXCHANGER ASSEMBLIES COMPOSED BY "n"UNITS

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Abstract. The work presents two variants of heat exchanger assemblies composed by "n" units where the primary heat carrier series circulates from the last unit to the first and the secondary heat carrier series or parallel circulates. There are analyzed the thermal efficiency, and the exergetic efficiency for both variants.

Keywords: heat exchangers, heat exchanger network, thermal efficiency, exergetic efficiency

1. INTRODUCTION

The author's research for obtaining high performance heat exchangers composed by units assemblies showed that exists many possibilities of units coupling, function of the number, position of units in the assembly and the circulation of the fluids [1, 2, 3 and 4]. This works presents thermal performances: the transferred heat flow and the temperature of both fluids at the output of the assembly. Other works [5, 6 and 7] analyze energetic and exergetic aspects, the thermal efficiency and the exergetic efficiency, that offers a complex and realist perspective on thermal phenomenon and create the possibility to localize sources of loses.

This work presents two alternatives of "n" series and parallel coupling units when the primary fluid (water) circulates from the last unit to the first.

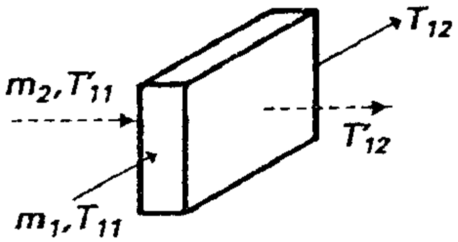

Fig. 1. Heat exchanger unit

2. DEFINITIONS

On define the thermal efficiency of the heat exchanger by the ratio between the thermal flow really transferred and the maximum thermal flow Q_{1max} that can be obtained by the heat exchanger with an infinite heat exchange surface (fig.1):

$$\varepsilon = \frac{Q_1}{Q_{1\max}} = \frac{m_1 c_{p1} \cdot (T_{11} - T_{12})}{m_1 c_{p1} \cdot (T_{11} - T'_{11})} = \frac{m_2 c_{p2} \cdot (T_{12} - T_{11})}{m_2 c_{p2} \cdot (T_{11} - T'_{11})} = \frac{T_{12} - T_{11}}{T_{11} - T'_{11}} . \quad (1)$$

The exergetic efficiency [8] is:

$$\eta_e = 1 - \frac{E_{Q2}}{\left|E_{Q1}\right|} = 1 - \frac{\left(1 - \frac{T'_{11}}{T_{mQ2}}\right) \cdot Q_2}{\left(1 - \frac{T'_{11}}{T_{mQ1}}\right) \cdot Q_1} = \frac{T'_{11} \cdot \left(T_{mQ1} - T_{mQ2}\right)}{T_{mQ2} \cdot \left(T_{mQ1} - T'_{11}\right)}, \tag{2}$$

where m_1, m_2 are the hot and respectively cold fluid mass flow; T_{11}, T_{12} - the hot fluid temperatures at the input and output of the heat exchanger; T'_{11}, T'_{12} - the cold fluid temperatures at the input and output of the heat exchanger; η - the retain coefficient of the heat in the heat exchanger apparatus; Q_1 - the heat flow for a single unit; c_{p1}, c_{p2} - the specific heat at a constant pressure of both fluids; ε - the thermal efficiency; η_e - the exergetic efficiency; E_{Q1}, E_{Q2} - the exergies correspondent to heat flows rate; T_{mQ1}, T_{mQ2} - the average temperatures of both fluids; ΔS_1, ΔS_2 - entropies variation of the hot and respectively cold fluid.
On considers that the retain coefficient of the heat in the heat exchanger apparatus is unitary ($Q_1 = Q_2$),
The exergies are:

$$E_{Q1} = \left(1 - \frac{T'_{11}}{T_{mQ1}}\right) \cdot Q_1 \text{ and } E_{Q2} = \left(1 - \frac{T'_{11}}{T_{mQ2}}\right) \cdot Q_1 \tag{3}$$

and

$$T_{mQ1} = \frac{Q_1}{\Delta S_1},\ T_{mQ2} = \frac{Q_1}{\Delta S_2}. \tag{4}$$

The variation of both fluids entropies are:

$$\Delta S_1 = m_1 c_{p1} \ln \frac{T_{12}}{T_{11}},\ \Delta S_2 = m_2 c_{p2} \ln \frac{T'_{11}}{T'_{12}}. \tag{5}$$

3. FLUID CIRCULATION: SERIES-SERIES

The first studied variant is that where both fluids series circulates (fig. 2).

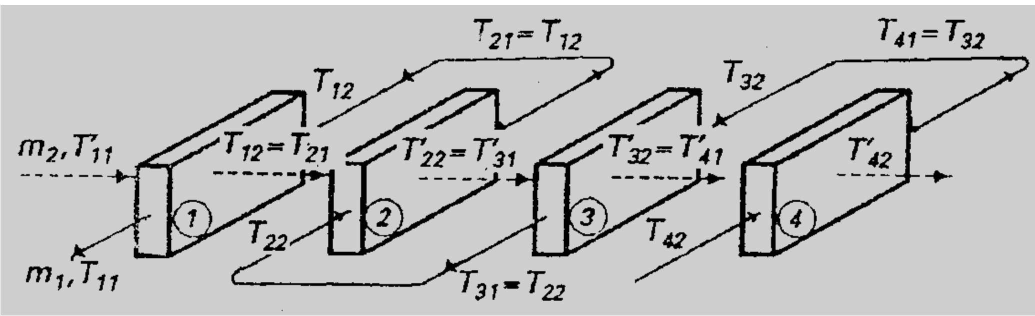

Fig. 2. Schema of fluid circulation in the variant where both heat carrier fluids series circulates

Aided by relations obtained in [7], after the generalization of the results for the assembly composed by “n” units on obtain successively:

$$Q_{ss} = \frac{1-\left(\frac{1-\gamma}{\beta}\right)^n}{1-\frac{1-\gamma}{\beta}} \cdot Q_1 . \tag{6}$$

$$T_{n2} = \left[\left(\frac{1-\gamma}{\beta}\right)^{n-2} + \gamma \frac{1-\left(\frac{1-\gamma}{\beta}\right)^{n-2}}{1-\frac{1-\gamma}{\beta}}\right] \cdot \left(T_{11} - T'_{11}\right) + T'_{11} ; \tag{7}$$

$$T'_{n2} = \gamma \cdot \frac{1-\left(\frac{1-\gamma}{\beta}\right)^n}{1-\frac{1-\gamma}{\beta}} \cdot \left(T_{11} - T'_{11}\right) + T'_{11} , \tag{8}$$

where:

$$\beta = \frac{(1-\varphi)\exp\frac{(\varphi-1)kS}{\eta m_1 c_{p1}}}{1-\exp\frac{(\varphi-1)kS}{\eta m_1 c_{p1}}} ; \tag{9}$$

$$\gamma = \frac{\varphi\left[1-\exp\frac{(\varphi-1)kS}{\eta m_1 c_{p1}}\right]}{1-\varphi\cdot\exp\frac{(\varphi-1)kS}{\eta m_1 c_{p1}}} ; \tag{10}$$

$$\varphi = \eta \frac{m_1 c_{p1}}{m_2 c_{p2}} , \tag{11}$$

where k is the overall heat transfer coefficient and S - the heat transfer surface area for a single unit. This case, the thermal efficiency of the assembly is:

$$\varepsilon_{ss} = \frac{T'_{n2} - T'_{11}}{T_{11} - T'_{11}} . \tag{12}$$

After calculus results:

$$\varepsilon_{ss} = \gamma \frac{\beta^n - (1-\gamma)^n}{\beta^{n-1}(\beta+\gamma-1)} . \tag{13}$$

The exergetic efficiency is related by the equation (2) where:

$$T_{mQ1} = \frac{Q_{ss}}{\Delta S_{ss}} \tag{14}$$

Using the calorimetric equation:

$$Q_1 = m_1 c_{p1} \left(T_{11} - T_{12} \right) \tag{15}$$

and

$$T_{12} = \beta \left(T_{11} - T'_{11} \right) + T'_{11} \,, \tag{16}$$

results:

$$Q_{ss} = m_1 c_{p1} T'_{11} \left(\delta - 1 \right)\left(1 - \beta \right) \frac{1 - \left(\frac{1-\gamma}{\beta} \right)^n}{1 - \frac{1-\gamma}{\beta}} \,. \tag{17}$$

On note:

$$\delta = \frac{T_{11}}{T'_{11}} \,. \tag{18}$$

The entropy variation is:

$$\Delta S_{ss} = m_1 c_{p1} \ln \frac{T_{11}}{T_{n2}} \,. \tag{19}$$

Substituting results:

$$\Delta S_{ss} = m_1 c_{p1} \cdot \ln \frac{\delta \left(\beta + \gamma - \delta \right)}{\beta \left[\left(\beta - 1 \right) \left(\frac{1-\gamma}{\beta} \right)^n + \gamma \right] \left(\delta - 1 \right) + \left(\beta + \gamma - 1 \right)} \tag{20}$$

and therefore:

$$T_{mQ1} = \frac{\left\{ \beta \left[1 - \left(\frac{1-\gamma}{\beta} \right)^n \right] \left(\delta - 1 \right)\left(1 - \beta \right) T'_{11} \right\}}{\left\{ \left(\beta + \gamma - 1 \right) \ln \frac{\delta \left(\beta + \gamma - 1 \right)}{\beta \left(\delta - 1 \right) \left[\left(\beta - 1 \right) \left(\frac{1-\gamma}{\beta} \right)^{n-1} + \gamma \right] + \left(\beta + \gamma - 1 \right)} \right\}} \,. \tag{21}$$

Similarly results:

$$T_{mQ2} = \frac{Q_{ss}}{\Delta S'_{ss}}; \tag{22}$$

$$Q_{ss} = m_2 c_{p2} \left(T'_{12} - T'_{11}\right) \frac{1 - \left(\frac{1-\gamma}{\beta}\right)^n}{1 - \frac{1-\gamma}{\beta}}, \tag{23}$$

but:

$$T'_{12} = \gamma\left(T_{11} - T'_{11}\right) + T'_{11} \tag{24}$$

and so:

$$Q_{ss} = m_2 c_{p2} T'_{11}\, \gamma(\delta - 1) \frac{1 - \left(\frac{1-\gamma}{\beta}\right)^n}{1 - \frac{1-\gamma}{\beta}}. \tag{25}$$

The variation of the entropy is:

$$\Delta S'_{ss} = m_2 c_{p2} \ln \frac{T'_{n2}}{T'_{11}}, \tag{26}$$

and after substitutions:

$$\Delta S'_{ss} = m_2 c_{p2} \cdot \ln \frac{\beta}{\beta + \gamma - 1} \left\{ \gamma(\delta - 1)\left[1 - \left(\frac{1-\gamma}{\beta}\right)^n\right] + (\beta + \gamma - 1) \right\}; \tag{27}$$

$$T_{mQ2} = \frac{\left\{ \beta\gamma(\delta - 1)\left[1 - \left(\frac{1-\gamma}{\beta}\right)^n\right] T'_{11} \right\}}{(\beta + \gamma - 1) \cdot \ln \frac{\beta}{\beta + \gamma - 1} \left\{ \gamma(\delta - 1)\left[1 - \left(\frac{1-\gamma}{\beta}\right)^n\right] + (\beta + \gamma - 1) \right\}}. \tag{28}$$

The exergetic efficiency becomes:

$$\eta_e = \frac{A - B}{B(A - 1)} \tag{29}$$

where:

$$A = \frac{T_{mQ1}}{T'_{11}} \text{ and } B = \frac{T_{mQ2}}{T'_{11}}. \tag{30}$$

4. FLUID CIRCULATION: SERIES-PARALLEL

The second analyzed variant is that where the first fluid (water) circulates series from the last unit to the first, and the second fluid (air) circulates parallel likely figure 3.
Using the above relations, after calculus and generalization of results, on obtain for the assembly composed by "*n*" units:

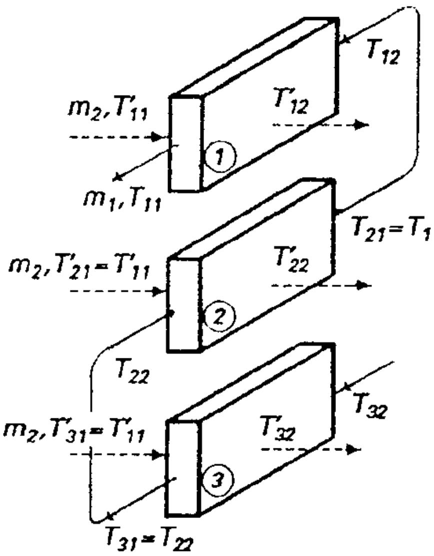

Fig. 3. Schema of fluid circulation in the variant with series-parallel heat carrier fluids circulation

$$Q_{sp} = \frac{1-\frac{1}{\beta^n}}{1-\frac{1}{\beta}} \cdot Q_1 ; \tag{31}$$

$$T_{n2} = \frac{1}{\beta^{n-2}}\left(T_{11} - T'_{11}\right) + T'_{11} ; \tag{32}$$

$$T'_{n2} = \frac{\gamma}{\beta^{n-1}}\left(T_{11} - T'_{11}\right) + T'_{11} \quad . \tag{33}$$

The thermal efficiency of the assembly calculated with relation (12) is:

$$\varepsilon_{sp} = \frac{\gamma}{\beta^{n-1}} . \tag{34}$$

The exergetic efficiency results from the relation (2) where:

$$T_{mQ1} = \frac{Q_{sp}}{\Delta S_{sp}} , \tag{35}$$

with:

$$Q_{sp} = m_1 c_{p1} T'_{11} (\delta - 1)(1-\beta) \frac{1-\frac{1}{\beta^n}}{1-\frac{1}{\beta}} \tag{36}$$

and:

$$\Delta S_{sp} = m_1 c_{p1} \ln \frac{T_{11}}{T_{n2}} = m_1 c_{p1} \ln \frac{\delta \beta^{n-2}}{(\delta - 1) + \beta^{n-2}} . \tag{37}$$

Results:

$$T_{mQ1} = \frac{\beta(1-\delta)\left(1-\frac{1}{\beta^n}\right)}{\ln \frac{\delta \beta^{n-2}}{(\delta - 1) + \beta^{n-2}}} T'_{11} . \tag{38}$$

Analogously:

$$T_{mQ2} = \frac{Q_{sp}}{\Delta S'_{sp}}\,; \tag{39}$$

$$Q_{sp} = m_2 c_{p2} T'_{11}\,\gamma(\delta - 1)\frac{1-\dfrac{1}{\beta^n}}{1-\dfrac{1}{\beta}}\,. \tag{40}$$

$$\Delta S'_{sp} = m_2 c_{p2} \ln\frac{T'_{n2}}{T'_{11}} = m_2 c_{p2} \ln\frac{\gamma(\delta-1)+\beta^{n-1}}{\beta^{n-1}}\,. \tag{41}$$

So results:

$$T_{mQ2} = \frac{\gamma(\delta-1)\dfrac{1-\dfrac{1}{\beta^n}}{1-\dfrac{1}{\beta}}}{\ln\dfrac{\gamma(\delta-1)+\beta^{n-1}}{\beta^{n-1}}}\cdot T'_{11}\,. \tag{42}$$

The exegetically efficiency, in conformity with the relation (2) becomes:

$$\eta_e = \frac{A'-B'}{B'(A'-1)}\,, \tag{43}$$

where:

$$A' = \frac{T_{mQ1}}{T'_{11}} \text{ and } B'_{11} = \frac{T_{mQ2}}{T'_{11}}\,. \tag{44}$$

5. CONCLUSIONS

The above presented analyze from the point of view of the efficiency and exergetic efficiency and the obtained relations offers a complex and realist perspective on the thermal phenomenon.

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