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PROCESS INTEGRATION-EXERGY LOSES OF THE HEAT EXCHANGER NETWORK

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Abstract. *In this paper, the exergy loses of the heat exchanger network, designed by Pinch method, is analised. On analitical way, the exergy changes and the exergy loses is defined, as in standalone heat exchanger, also in heat exchanger network. The result of this work is the fact that heat exchangers network, generated by pinch design rules and plus/minus principle, is the solution with best performance according to minimum exergy loses.*

Key words: *Pinch desighn method, heat exchanger network, exergy loses*

INTRODUCTION

Pinch design method is the widely used technology for solving the *HENS* (heat exchanger network synthesis) problems[1]. In this paper we tried to analyze the probability of generating the minimum exergy loses on appropriate heat exchangers network, design by this method. In the other words, we tried the get the answer:" Could be the initial solution of heat exchangers network, generated by pinch design rules and plus/minus principle in the phase of targeting, be the solution with best performance according to the II low statement?"

1.EXERGY CHANGES AND EXERGY LOSS OF STREAM REPRESENTED IN *T-H*[1] DIAGRAM

As the pinch method belongs to the group of HENS sequential methods, in the first step it would be analyzed the portion of stream exergy changes, as in the temperature interval, also in the whole space of the problem. In the Fig. 1., the stream *p* is represented in *T-H* diagram, from the starting temperature T_1 till the ending temperature T_{R+1} , through the *R* temperature intervals. For the process in heat exchangers, involving only heat

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[1] *T-H (Temperature vs. Entalpy)*

transfer under constant pressure (*cp=const.*), the relation between enthalpy and entropy change for one stream could be expressed as:

$$\frac{\Delta H}{\Delta S}=\frac{\int_{T_{out}}^{T_{in}}\dot{m}cp}{\int_{T_{out}}^{T_{in}}\dot{m}cp\frac{dT}{T}}=\frac{\dot{m}cp(T_{in}-T_{out})}{\dot{m}cp\ln\frac{T_{in}}{T_{out}}} \tag{1}$$

Simplifying the (1):

$$\Delta S=\Delta H\frac{1}{\frac{(T_{in}-T_{out})}{\ln\frac{T_{in}}{T_{out}}}}\approx\Delta H\frac{1}{\frac{(T_{in}+T_{out})}{2}}=\frac{\Delta H}{\Delta T_{Am}} \tag{2}$$

exergy change of one stream, heated/cooled from the starting till the ending temperature in heat exchanger, could be expressed as:

$$\Delta Ex=\Delta H-Exl=\Delta H-T_o\Delta S=\Delta H\left(1-\frac{\Delta H}{\Delta T_{Am}}\right) \tag{3}$$

According to that, in the case of stream *p* (stream has the constant direction $\Delta H_{p,r}$ / $\Delta T_{Amp,r}$= *const.*), its exergy change could be got as the sum of interval's exergy changes, no matter the number or the size of interval:

$$\begin{aligned}\Delta Ex_p&=\Delta H_p-Exl_p=\Delta H_p\left(1-\frac{T_o}{\Delta T_{Amp}}\right)=\\&=\sum_{r=1}^{R}\left(\Delta H_{p,r}-To\frac{\Delta H_{p,r}}{\Delta T_{Am,p,r}}\right)=\sum_{r=1}^{R}\Delta Ex_{p,r}=\sum_{k=1}^{N}\Delta Ex_{p,k}\end{aligned} \tag{4}$$

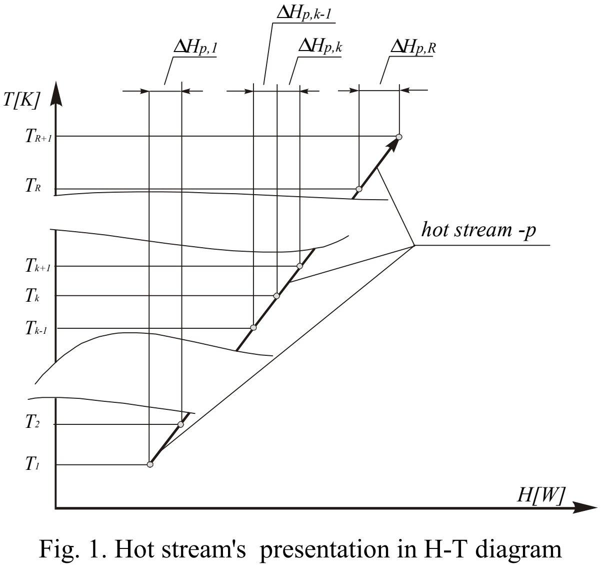

Fig. 1. Hot stream's presentation in H-T diagram

In the next step the composite curve was analyzed (Fig. 2). Exergy changes of all M streams in interval k could be expressed as in (5):

$$\Delta Ex_{M,k} = \sum_{m=1}^{M} \left(\Delta H_{m,k} - T_o \frac{\Delta H_{m,k}}{\Delta T_{Am,m,k}} \right) = \left(1 - \frac{T_o}{\Delta T_{Am,k}} \right) \sum_{m=1}^{M} \Delta H_{m,k} = \sum_{m=1}^{M} \Delta Ex_{m,k} \qquad (5)$$

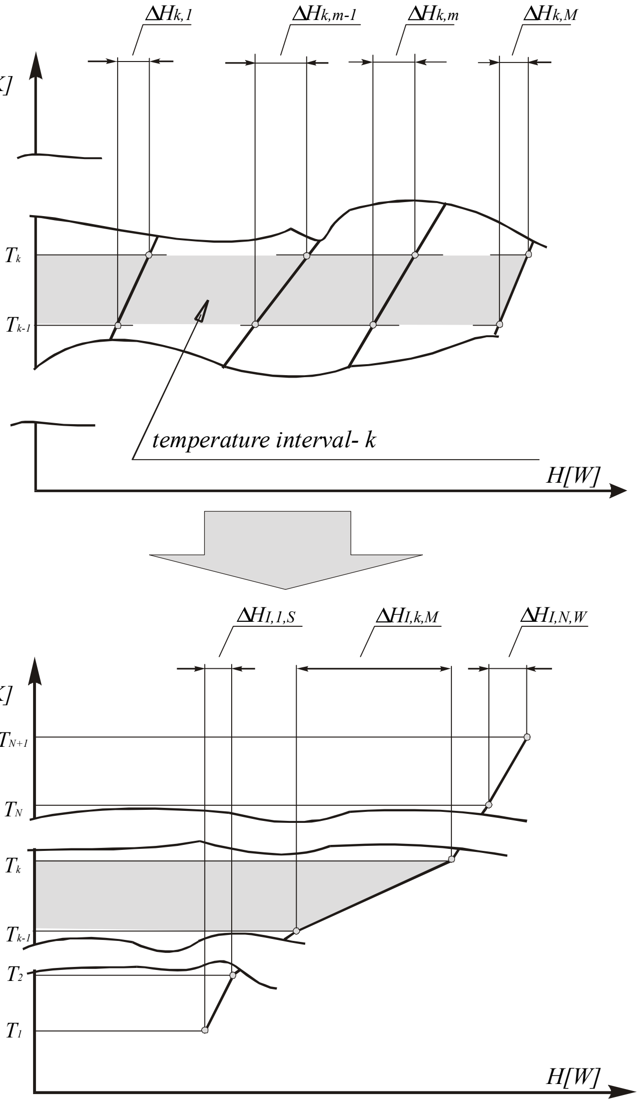

Fig. 2. Composite curve's presentation in H-T diagram

If the *HENS* task involve P number of streams ($P \geq M$), it is obvious that the exergy change of the stream which doesn't pass trough the k-interval has to be equal to 0, so the (5) could be expanded:

$$\Delta Ex_{M,k} = \sum_{m=1}^{M} \Delta Ex_{m,k} = \sum_{p=1}^{P} \Delta Ex_{p,k} \tag{6}$$

Now, the appropriate relation for composite curve for all streams, trough the overall temperature intervals, is:

$$\Delta Ex_I = \sum_{k=1}^{N} \sum_{m=1}^{M} \Delta Ex_{m,k} = \sum_{p=1}^{P} \left(\sum_{k=1}^{N} \Delta Ex_{p,k} \right) = \sum_{p=1}^{P} \Delta Ex_p = \sum_{p=1}^{P} \left(\Delta H_p - T_o \frac{\Delta H_p}{\Delta T_{Am,p}} \right) \tag{7}$$

Exergy changes and also exergy losses of the all hot/cold streams involving in *HENS* problem are represented in table 1.

Table 1. Exergy change and exergy loss of stream

	Exergy change	Exergy loss
Hot stream	$\Delta Ex_{I,Hs} = \sum_{h=1}^{Hs} \Delta Ex_h$	$Exl_{I,Hs} = \sum_{h=1}^{Hs} Exl_h$
Cold stream	$\Delta Ex_{I,Cs} = \sum_{c=1}^{CS} \Delta Ex_c$	$Exl_{I,Cs} = \sum_{c=1}^{Cs} Exl_c$

2. EXERGY CHANGES AND EXERGY LOSSES OF STREAMS IN STANDALONE HEAT EXCHANGER

In the next part of the paper, individual heat exchanger, with only two streams is analyzed. Target temperatures of streams could only be reached by the addition external cooling or heating. For the purpose of simplifying the problem external heating /cooling is carried out with only one utility stream of constant temperature level :T_{ExCs} for cold utility and T_{ExHs} for hot utility. Exergy balance of such system (in this case only the balance of exergy losses) can be expresed as the sum of exery loses in hot utility heat exchanger, heat exchanger, and cold utility heat exchanger:

$$\Delta Exl = Exl_{HU} + Exl_{HE} + Exl_{CU} \tag{8}$$

First, the energy optimal temperature levels of the streams, with maximum heat recovery and minimum hot and cold utility are presented in Fig. 2. Obviously this case was defined with $\Delta Tmin$=0 according to the positions of composite curves in *T-H* diagram. In that case the overall exergy loses can be expressed like:

$$\begin{aligned} Exl_{\Delta T\,\min=0} = {} & T_o \frac{\Delta H_{ExCs}\min}{T_{ExCs}} - 2T_o \frac{\Delta H_{ExHs}\min}{T_{Cs,out} + T_{Cs,HE,out}} + 2T_o \frac{\Delta H_{HE}\max}{T_{Hs,in} + T_{Hs,R,out}} - \\ & - 2T_o \frac{\Delta H_{HE}\max}{T_{Cs,HE,out} + T_{Cs,in}} + 2T_o \frac{\Delta H_{ExCs}\min}{T_{Hs,HE,out} + T_{Hs,out}} - T_o \frac{\Delta H_{ExHs}\min}{T_{ExHs}} \end{aligned} \tag{9}$$

or, according to the (7) and (8), put in the simpler form:

$$Exl_{\Delta T\min=0} = T_o \frac{\Delta H_{ExCs,\min}}{T_{ExCs}} + Exl_{Cs} - Exl_{Hs} - T_o \frac{\Delta H_{ExHs,\min}}{T_{ExHs}} \tag{10}$$

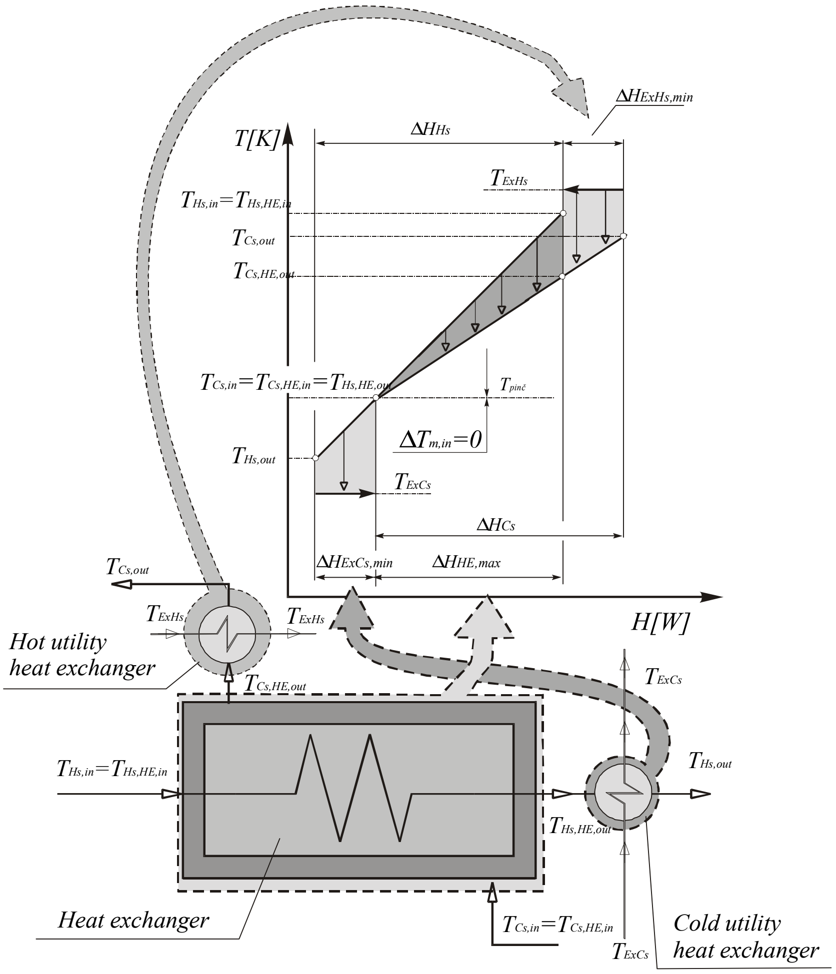

Fig. 3. Composite curve representation of standalone heat exchanger with $\Delta T\text{min} = 0$ in *H-T* diagram

Composite curves of the real process in heat exchanger, with respect to its finite area, are presented on Fig. 4. Coupling the (8) and (9) in (11):

$$Exl = Exl_{\Delta T\min=0} + T_o \frac{\Delta H_{ExCs,ad}}{T_{ExCs}} - T_o \frac{\Delta H_{ExHs,\,ad}}{T_{ExHs}} \tag{11}$$

exergy loses of that process could be expressed as the function of $\Delta Tmin$ $Exg = f(\Delta T \min)$. It could be noted $\Delta H_{ExCs,ad} = \Delta H_{ExHs,ad}$, and $T_{ExCs} < T_{ExHs}$.

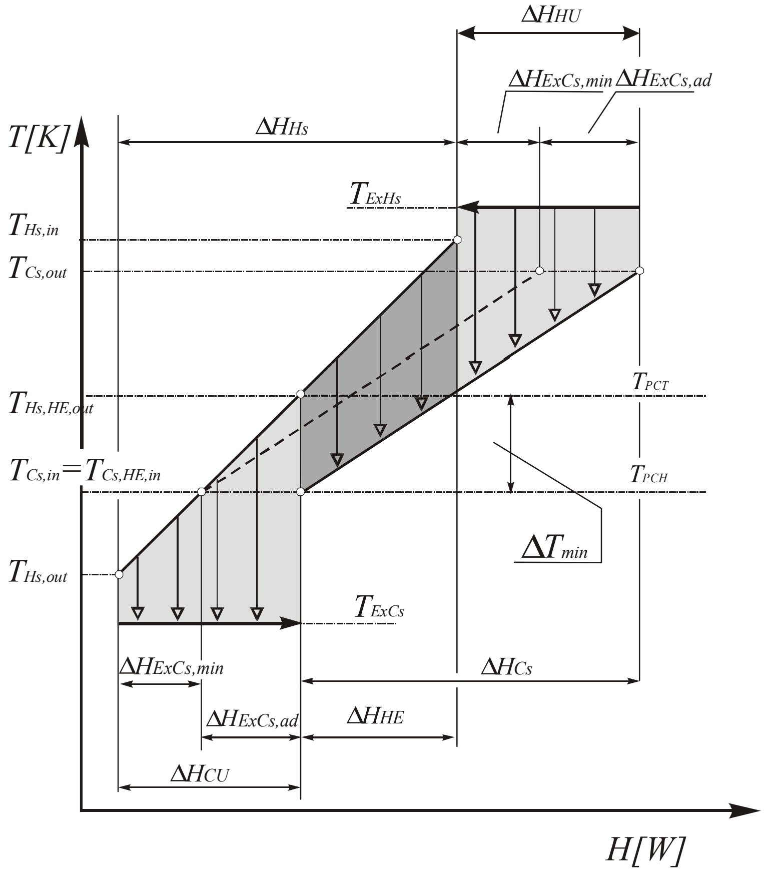

Fig. 4. Composite curve representation of standalone heat exchanger with ΔTmin > 0 in H-T diagram

3. EXERGY CHANGES AND EXERGY LOSSES OF STREAMS IN HEAT EXCHANGER NETWORK

The task of heat exchanger network synthesis is represented in the Fig. 5. As in previous case heating/cooling is carried with only one utility stream of constant temperature level. Exergy loses could be expressed as the sum of exergy loses in hot utility heat exchangers, heat exchangers, and cold utility heat exchangers:

$$Exl_{NW} = \sum Exl_{HU,i} + \sum Exl_{HE,k} + \sum Exl_{CU,j} \tag{12}$$

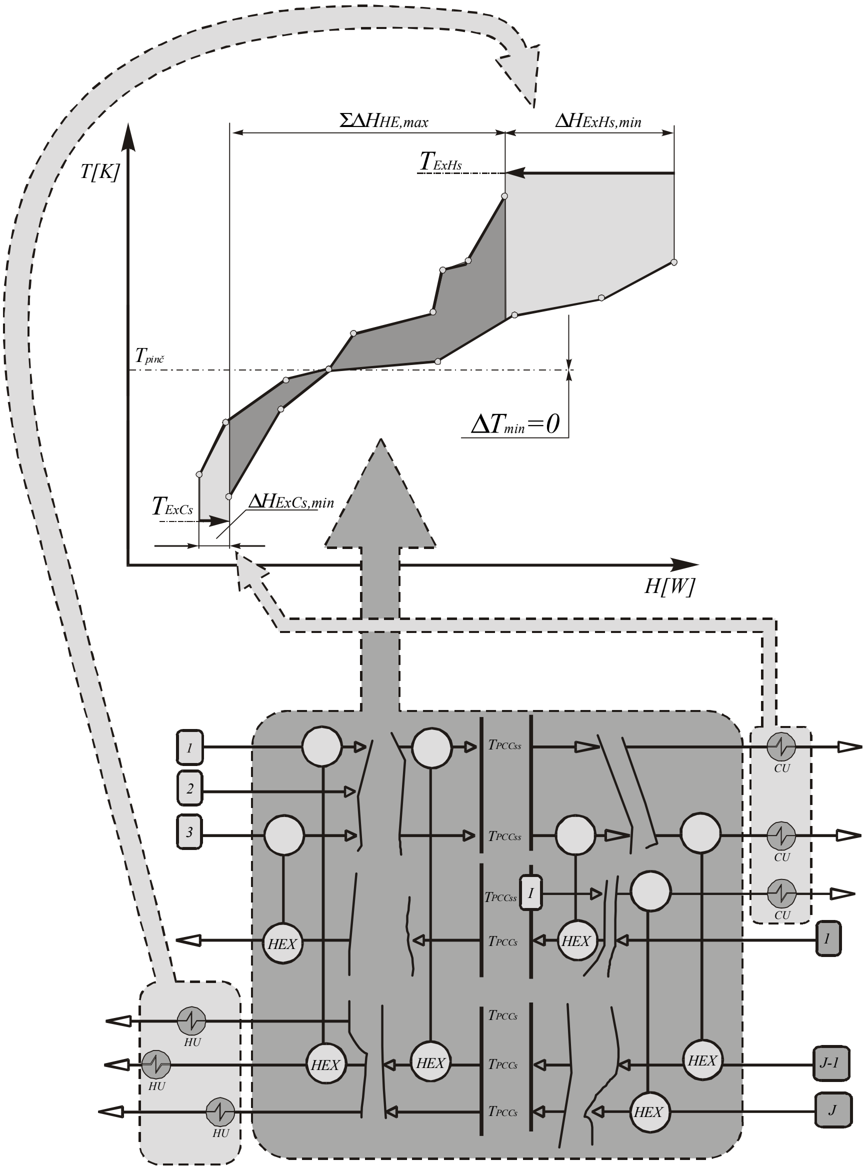

Fig. 5. Composite curves representation of heat exchanger network with ΔTmin = 0 in H-i diagram

First, the energy optimal design with ΔTmin = 0, Fig. 5, was analyzed with respect to (7) and (8), the exergy loses of the network can be as follows:

$$\Delta Exl_{NW,\Delta T\,\min=0} = T_o \frac{\Delta H_{ExCs,\min}}{T_{ExCs}} + \Delta Exl_{Cs} - \Delta Exl_{Hs} - T_o \frac{\Delta H_{ExHs,\min}}{T_{ExHs}} \tag{13}$$

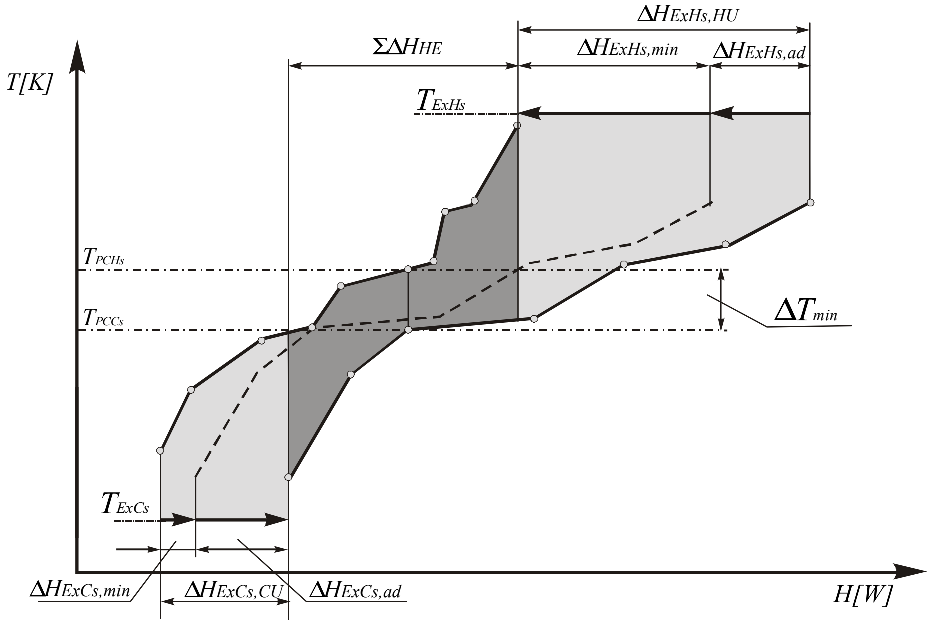

Fig. 6. Composite curves representation of heat exchanger network with ΔTmin > 0 in H-T diagram

Like in the case for only one exchanger, the overall region could be divided in the three sub regions, so (11) for the heat exchangers network get the next form:

$$\Delta Exl_{NW} = \Delta Exg_{MR,min} + T_o \frac{\Delta H_{ExCs,ad}}{T_{ExCs}} - T_o \frac{\Delta H_{ExHs,ad}}{T_{ExHs}} \tag{14}$$

As $\Delta H_{ExCs,ad} = \Delta H_{ExHs,ad}$, and $T_{ExCs} < T_{ExHs}$ last equation clearly proved that the heat exchangers network, generated by pinch design rules and plus/minus principle, is the solution with best performance according to minimum exergy loses.

4. CONCLUSION

The question we asked in the introduction, we tried to answer through the theoretical and mathematical background in this paper. In its origin, Pinch design method was based on the second low statement, but that fact is often neglected, and put in the background position. Normally that conclusion made a lot of misunderstandings [5], especially from the scientific circle which work is based on exergy analyses as a primal method for the process integration. We hope that this work will be a little contribution in prevailing this misunderstanding.

Glossary

T [K]	- temperature
H [W]	- enthalpy (enthalpy flow)
S [W/K]	- entropy (entropy flow)
Ex [W]	- exergy (exergy flow)
$\dot{m}$	- mass flow.

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HE	-heat exchangers
Hs	-hot stream
Cs	-cold stream
HU	-hot utility
CU	-cold utility
Ex	-external
NW	-network

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INTEGRACIJA PROCESA – EXERGIJSKI GUBICI MREŽE RAZMENJIVAČA TOPLOTE

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U radu je data analiza eksergijskih gubitaka mreže razmenjivača toplote koja se generiše upotrebom Pinč metode. Analitičkim putem definisani su eksergijski gubici strujnih tokova kako u izolovanom razmenjivaču toplote, tako i u mreži razmenjivača toplote. Rezultat rada je činjenica da je mreža razmenjivača toplote generisana putem pinč metode ujedno i mreža sa minimalnim eksergijskim gubicima

Ključne reči: Pinč metoda, mreža razmenjivača toplote, eksergijski gubici