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Comparative Energy and Exergy Analysis of Generation Units A2 and A5 of Thermal Power Plant Kosova A

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ABSTRACT: Comparative energy and exergy analysis of the thermal power plants is related with implementation of the first and second law of Thermodynamics. To do such analysis must be considered the fact that the energy as a concept shows the amount between the energy which can be converted into other forms of energy known as exergy, and the rest of energy which cannot be converted into other forms of energy that is closely related to surrounding conditions known as anergy. In our case we have the comparative energy and exergy analysis of the thermal power plant Kosovo A, with A3 generation unit of 200 MW of generation capacity and A5 generation unit with 210 MW of generation capacity. Analysis are associated by energy balances of working cycle which are not concentrated into system losses, and exergy balances of working cycle which identify the losses of generation units processes. The analyze of these units will show the reasons of difference in energy efficiency between generation units and will be focused mainly on the impact of changing thermal parameters, such as surrounding temperature in exergy efficiency where as a result will be compared the efficiencies between these two units while changing this parameter. Exergy efficiency in function of surrounding temperature changes all will be shown graphically.

Keywords: Energy; Exergy; Efficiency; Surrounding; Temperature

I. INTRODUCTION

Based on the second law of thermodynamics, the energy is presented as a sum of exergy and anergy. The technical work which is obtained in case when the final condition of gas that is used as a working fluid reaches surrounding pressure p_0 and surrounding temperature T_0, presents the maximal technical work or exergy (the part of energy which can be transformed in other forms of energy), while anergy presents the part of energy which cannot be transformed in exergy because of the irreversible processes.

In thermal power plants which are categorized with regenerative heating of water feeder, is processed the Rankin cycle where are shown processes starting by evaporation of water from its boiling condition, then vapor reheating, expansion in the steam turbine, condensation in the condenser then ending to the process of pressing the water feeder in respective pumps. Also there are the processes of the steam taken from the turbine which enables the heating of water feeder in heat exchangers. This cycle enables energy and exergy analysis of generation units, defining energy and exergy efficiency.

Energy (thermal) efficiency of a cycle is determined by:

$$\eta_{th} = \frac{Q_{net}}{Q_{in}} \tag{1}$$

whereQ_{net} is the useful heat and Q_{in} is the heat that enters at cycle:

$$Q_{net} = W_{net} + \Delta U \tag{2}$$

W_{net}- useful work (cycle work), ΔU - internal energy change of working fluid. As it is a cycle, where the initial and final conditions are the same, then ΔU=0. So for thermal efficiency is obtained:

$$\eta_{th} = \frac{Q_{net}}{Q_{in}} = \frac{W_{net}}{Q_{in}} \tag{3}$$

Exergy efficiency of the cycle is:

$$\eta_{ex} = \frac{W_T - W_P + Ex_{inSG}}{Ex_{inT}} \tag{4}$$

Where: W_T - turbine work, W_P - pump work, Ex_{inSG}- exergy of water feeder that enters in steam generator, Ex_{inT}- exergy of steam that enters in turbine.

Energy AndExergy Efficiency Of The A2 Unit Generation Of Pp Kosovo A, With 125 Mw Of Generation Capacity

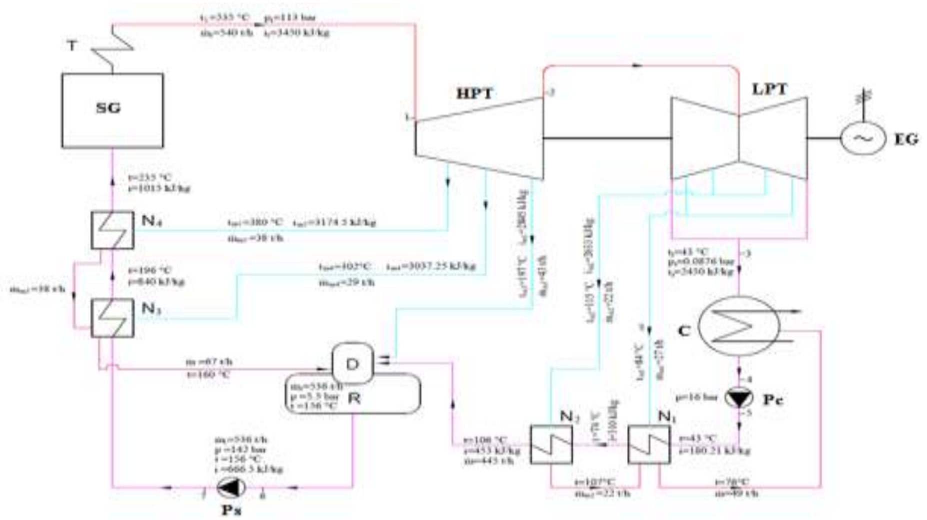

Fig. 1. Thermal scheme of A2 unit of PP Kosovo A: steam generator (SG), high pressure turbine (HPT), low pressure turbine (LPT), electrical generator (EG), condenser (C), condensed fluid pump (P_c), regenerative heaters N_1, N_2, N_3dhe N_4, deaerator, and the supply pump (P_s).

Tab. 1. Thermal parameters of the steam of A2 unit of PP Kosovo A

HPT	*Input*	*Output*
Pressure, *p*	p_1 = 113 bar	P_2 = 5.8 bar
Temperature, *t*	t_1 = 535 ^0C	t_2= 197 ^0C
Enthalpy, *i*	i_1 = 3450 kJ/kg	i_2 = 2845 kJ/kg
Steam flow rate, *m*	m_1=540 t/h	m_2=430 t/h
LPT	*Input*	*Output*
Pressure, *p*	p_2 = 5.8 bar	p_3 = 0.0876 bar
Temperature, *t*	t_2 = 197 ^0C	t_3 = 43 ^0C
Enthalpy, *i*	i_2 = 2845 kJ/kg	i_3 = 2480 kJ/kg
Steam flow rate, *m*	m_2=430 t/h	m_3=381 t/h

Main parameters of the steam in characteristic parts of production unit for the steam that enters and exit from the turbine are presented in tab. 1. And the parameters of regenerative steam takings from turbine are presented in tab. 2.

Tab. 2. Main parameters of the steam in regenerative takings from the turbine of A2 unit of PP Kosovo A

No. of steam takings	Pressure of steam taking	Temperature of steam taking	Enthalpy	Flow rate of steam from takings
5	p_{m5} = 36 bar	t_{m5} = 380 ^0C	i_{m5} = 3174.5 kJ/kg	m_{m5} = 38 t/h

4	p_{m4} = 17 bar	t_{m4} = 302 ^0C	i_{m4} = 3037.25 kJ/kg	m_{m4} = 29 t/h
3	p_{m3} = 5.8 bar	t_{m3} = 197 ^0C	i_{m3} = 2845 kJ/kg	m_{m3} = 43 t/h
2	p_{m2} = 1.7 bar	t_{m2} = 115 ^0C	i_{m2} = 2633 kJ/kg	m_{m2} = 22 t/h
1	p_{m1} = 0.55 bar	t_{m1} = 84 ^0C	i_{m1} = 2535 kJ/kg	m_{m1} = 27 t/h

a) Thermal efficiency:

$$\eta_{th} = \frac{Q_{net}}{Q_{in}} = \frac{W_{net}}{Q_{in}} = \frac{W_{net}}{\dot{m}_1 \left(i_1 - i_4^{out}\right)} \tag{5}$$

To obtain the thermal efficiency from (5) initially is determined the useful work of cycle based on the i-s diagram of thermal scheme:

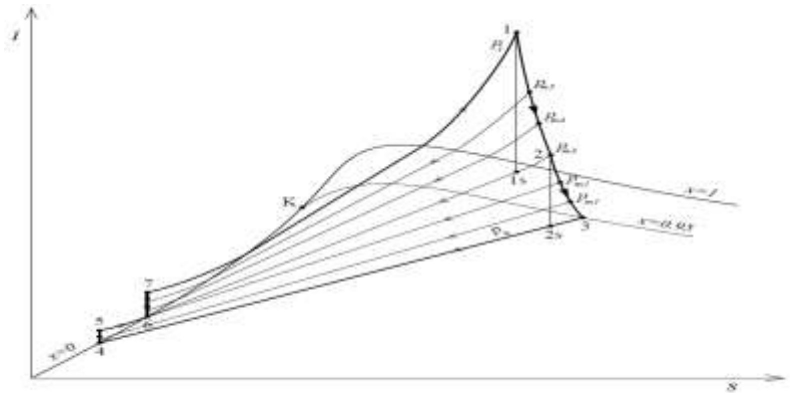

Fig.2. i-s diagram of the thermal scheme of A2 unit of PP Kosovo A

$$\begin{aligned} W_{net} &= W_C = \dot{m}_1 \cdot (i_1 - i_{m5}) + (\dot{m}_1 - \dot{m}_{m5}) \cdot (i_{m5} - i_{m4}) + [\dot{m}_1 - (\dot{m}_{m5} + \dot{m}_{m4})] \cdot (i_{m4} - i_{m3}) + \\ &+ [\dot{m}_1 - (\dot{m}_{m5} + \dot{m}_{m4} + \dot{m}_{m3})] \cdot (i_{m3} - i_{m2}) + [\dot{m}_1 - (\dot{m}_{m5} + \dot{m}_{m4} + \dot{m}_{m3} + \dot{m}_{m2})] \cdot (i_{m2} - i_{m1}) + \\ &+ [\dot{m}_1 - (\dot{m}_{m5} + \dot{m}_{m4} + \dot{m}_{m3} + \dot{m}_{m2} + \dot{m}_{m1})] \cdot (i_{m1} - i_3) = 540 \cdot (3450 - 3174.5) + \\ &+ (540 - 38) \cdot (3174.5 - 3037.25) + [540 - (38 + 29)] \cdot (3037.25 - 2845) + \\ &+ [540 - (38 + 29 + 43)] \cdot (2845 - 2633) + [540 - (38 + 29 + 43 + 22)] \cdot (2633 - 2535) + \\ &+ [540 - (38 + 29 + 43 + 22 + 27)] \cdot (2535 - 2450) = 131 \cdot 10^3 \ kW \end{aligned} \tag{6}$$

So, thermal efficiency is:

$$\eta_{th} = \frac{Q_{net}}{Q_{in}} = \frac{W_{net}}{Q_{in}} = \frac{W_{net}}{\dot{m}_1 \left(i_1 - i_4^{out}\right)} = \frac{131}{0.15 \cdot (3450 - 1015)} = 0.41 \Rightarrow \eta_t = 41\% \tag{7}$$

b) Exergy efficiency

$$\eta_{ex} = \frac{W_T - W_P + Ex_4^{out}}{Ex_1} \tag{8}$$

The pump work is determined as the sum work of all pumps in unit generation:

$$\begin{aligned} W_P &= \dot{m}_1 \cdot (i_7 - i_6) + \dot{m} \cdot (i_5 - i_4) = 540 \cdot (666.5 - 655.88) + 430 \cdot (180.21 - 180.08) = \\ &= 1.61 \cdot 10^3 \ kW \end{aligned} \tag{9}$$

To determine the exergy it must be known the surrounding conditions, for example:

$t_0 = 20^\circ C \Rightarrow T_0 = 293K$ and $p_0 = 1 \ bar \Rightarrow \ s_0 = 0.296 \ kJ/kgK$, $i_0 = 84.2 \ kJ/kg$

$$-i_0 + T_0 \cdot s_0 = -84.2 + 293 \cdot 0.296 = 2.5 \ \ kJ/kg$$

Exergy of water feeder:

$$Ex_4^{out} = \dot{m}_1 \cdot ex_4^{out} = \dot{m}_1 \cdot \left[i_4^{out} - i_0 - T_0 \left(s_4^{out} - s_0 \right) \right] = 540 \cdot \left(1015 - 293 \cdot 2.6561 + 2.5\right) = \\ = 35 \cdot 10^3 \ \ kW \tag{10}$$

Exergy of steam that enters in the turbine of high pressure (HPT):

$$Ex_1 = \dot{m}_1 \cdot ex_1 = \dot{m}_1 \cdot \left[i_1 - i_0 - T_0 \left(s_1 - s_0 \right) \right] = 540 \cdot \left(3450 - 293 \cdot 6.6426 + 2.5\right) = \\ = 225 \cdot 10^3 \ \ kW \tag{11}$$

As a result, exergy efficiency is:

$$\eta_{ex} = \frac{W_T - W_P + Ex_4^{out}}{Ex_1} = \frac{131 - 1.61 + 35}{225} = 0.73 \Rightarrow \eta_{ex} = 73.00 \ \ \% \tag{12}$$

Energy AndExergy Efficiency Of The A5 Unit Generation Of Pp Kosovo A, With 210 Mw Of Generation Capacity

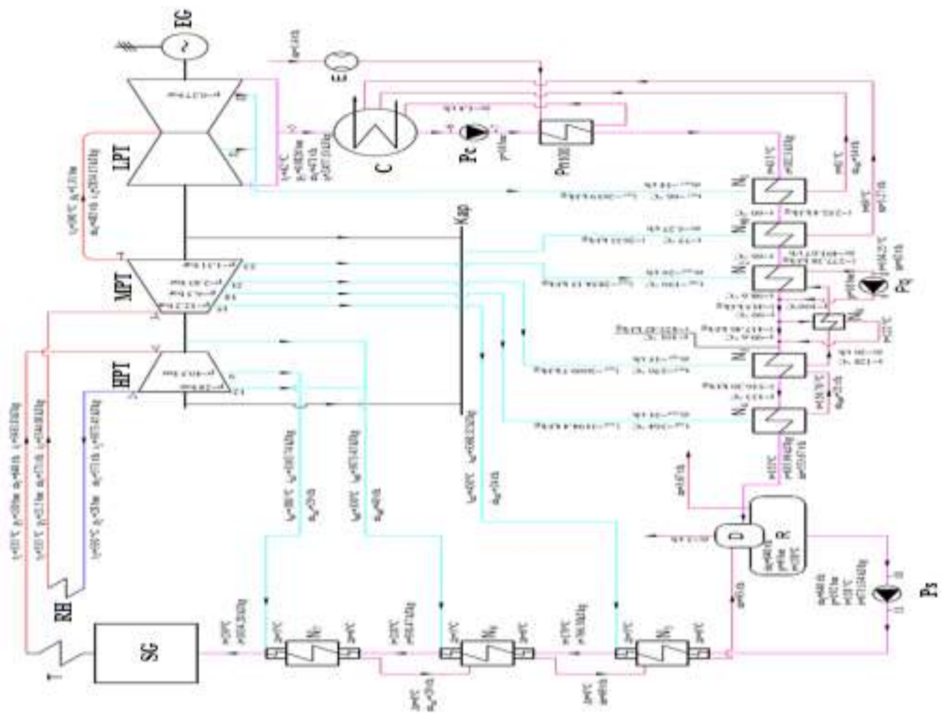

Fig. 3. Thermal scheme of A5 unit of Kosovo A: steam generator (SG), reheater (RH), high pressure turbine (HPT), medium pressure turbine (MPT), low pressure turbine (LPT), electrical generator (EG), condenser (C), condensed fluid pump (P_c), regenerative heaters H_1, H_2, H_3, H_4,H_5, H_6 and H_7, deaerator, and the supply pump (P_s).

Tab. 3. Thermal parameters of the steam of A5 unit of PP Kosovo A

HPT	*Input*	*Output*
Pressure, *p*	p_1 = 130 bar	p_2 = 28 bar
Temperature, *t*	t_1 = 535 ^0C	t_2 = 330 ^0C
Enthalpy, *i*	i_1 = 3431.8 kJ/kg	i_2 = 3073.45 kJ/kg
Steam flow rate, *m*	m_1=640 t/h	m_2=571 t/h
MPT	*Input*	*Output*
Pressure, *p*	p_3 = 21.5 bar	p_4 = 1.31 bar

Temperature, *t*	t_3 = 535 ^{0}C	t_4 = 190 ^{0}C
Enthalpy, *i*	i_3 = 3544.08 kJ/kg	i_4 = 2854.15 kJ/kg
Steam flow rate, *m*	m_3=571 t/h	m_4=485 t/h
LPT	*Input*	*Output*
Pressure, *p*	p_4 = 1.31 bar	p_5 = 0.0826 bar
Temperature, *t*	t_4 = 190 ^{0}C	t_5 = 42 ^{0}C
Enthalpy, *i*	i_4 = 2854.15 kJ/kg	i_5 = 2457.13 kJ/kg
Steam flow rate, *m*	m_4=485 t/h	m_5=471 t/h

Tab. 4. Main parameters of the steam in regenerative takings from the turbine of A5 unit of PP Kosovo A

No. of steam takings	After scale	Pressure of steam taking	Temperature of steam taking	Enthalpy	Flow rate of steam from takings
7	9	p_{m7} = 40.5 bar	t_{m7} = 380 ^{0}C	i_{m7} = 3165.74 kJ/kg	m_{m7} = 29 t/h
6	12	p_{m6} = 28 bar	t_{m6} = 330 ^{0}C	i_{m6} = 3073.45 kJ/kg	m_{m6} = 40 t/h
5	15	p_{m5} = 12.2 bar	t_{m5} = 450 ^{0}C	i_{m5} = 3368.32 kJ/kg	m_{m5} = 24 t/h
4	18	p_{m4} = 6.5 bar	t_{m4} = 364 ^{0}C	i_{m4} = 3194.4 kJ/kg	m_{m4} = 21 t/h
3	21	p_{m3} = 2.83 bar	t_{m3} = 270 ^{0}C	i_{m3} = 3009.7 kJ/kg	m_{m3} = 15 t/h
2	23	p_{m2} = 1.31 bar	t_{m2} = 190 ^{0}C	i_{m2} = 2854.15 kJ/kg	m_{m2} = 246 t/h
1	25 dhe 29	p_{m1} = 0.27 bar	t_{m1} = 66 ^{0}C	i_{m1} = 2619 kJ/kg	m_{m1} = 14 t/h

a) Thermal efficiency:

$$\eta_{th} = \frac{Q_{net}}{Q_{in}} = \frac{W_{net}}{Q_{in}} = \frac{W_{net}}{\dot{m}_1\left(i_1 - i_7^{out}\right) + \dot{m}_2\left(i_3 - i_2\right)} \tag{13}$$

To obtain the thermal efficiency from (14) initially is determined the useful work of cycle based on the i-s diagram of thermal scheme:

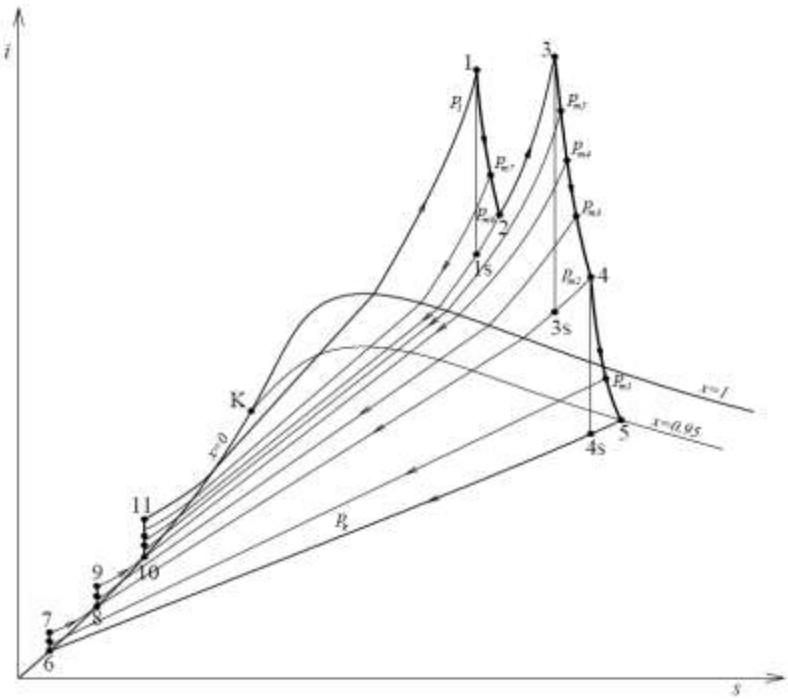

Fig.4. i-s diagram of the thermal scheme of PP Kosovo A5

$$\begin{aligned}
W_{net} &= W_C = \dot{m}_1 \cdot (i_1 - i_{m7}) + (\dot{m}_1 - \dot{m}_{m7}) \cdot (i_{m7} - i_{m6}) + [\dot{m}_1 - (\dot{m}_{m7} + \dot{m}_{m6})] \cdot (i_3 - i_{m5}) + \\
&+ [\dot{m}_1 - (\dot{m}_{m7} + \dot{m}_{m6} + \dot{m}_{m5})] \cdot (i_{m5} - i_{m4}) + [\dot{m}_1 - (\dot{m}_{m7} + \dot{m}_{m6} + \dot{m}_{m5} + \dot{m}_{m4})] \cdot (i_{m4} - i_{m3}) + \\
&+ [\dot{m}_1 - (\dot{m}_{m7} + \dot{m}_{m6} + \dot{m}_{m5} + \dot{m}_{m4} + \dot{m}_{m3})] \cdot (i_{m3} - i_{m2}) + \\
&[\dot{m}_1 - (\dot{m}_{m7} + \dot{m}_{m6} + \dot{m}_{m5} + \dot{m}_{m4} + \dot{m}_{m3} + \dot{m}_{m2})] \cdot (i_{m2} - i_{m1}) + \\
&+ [\dot{m}_1 - (\dot{m}_{m7} + \dot{m}_{m6} + \dot{m}_{m5} + \dot{m}_{m4} + \dot{m}_{m3} + \dot{m}_{m2} + \dot{m}_{m1})] \cdot (i_{m1} - i_5) = \\
&= 640 \cdot (3431.8 - 3165.74) + (640 - 29) \cdot (3165.74 - 3073.45) + \\
&+ [640 - (29 + 40)] \cdot (3544.08 - 3368.32) + [640 - (29 + 40 + 24)] \cdot (3368.32 - 3194.4) + \\
&+ [640 - (29 + 40 + 24 + 21)] \cdot (3194.4 - 3009.7) + [640 - (29 + 40 + 24 + 21 + 15)] \cdot \\
&\cdot (3009.7 - 2854.15) + [640 - (29 + 40 + 24 + 21 + 15 + 26)] \cdot (2854.15 - 2619) + \\
&+ [640 - (29 + 40 + 24 + 21 + 15 + 26 + 14)] \cdot (2619 - 2457.13) = 219 \cdot 10^3 \ kW
\end{aligned} \tag{14}$$

Flow rates and enthalpies of steam and the water feeder are obtained from tables above and from thermal scheme of unit generation. As a result:

$$\begin{aligned}
\eta_{th} &= \frac{Q_{net}}{Q_{in}} = \frac{W_{net}}{Q_{in}} = \frac{W_{net}}{\dot{m}_1 (i_1 - i_7^{out}) + \dot{m}_2 (i_3 - i_2)} = \\
&= \frac{219}{0.18 \cdot (3431.8 - 1034.28) + 0.16 \cdot (3544.08 - 3073.35)} = 0.43
\end{aligned} \tag{15}$$

So, thermal efficiency is $\eta_t = 43\%$.

b) Exergy efficiency

$$\eta_{ex} = \frac{W_T - W_P + Ex_7^{out}}{Ex_1} \tag{16}$$

Pump work is:

$$\begin{aligned}
W_P &= \dot{m}_1 \cdot (i_{11} - i_{10}) + \dot{m} \cdot (i_9 - i_8) + \dot{m} \cdot (i_7 - i_6) = 640 \cdot (673.134 - 666.894) + \\
&+ 62 \cdot (445.528 - 437.044) + 491.67 \cdot (178.12 - 176.39) = 1.49 \cdot 10^3 \ kW
\end{aligned} \tag{17}$$

Exergy of water feeder is:

$$\begin{aligned}
Ex_7^{out} &= \dot{m}_1 \cdot ex_7^{out} = \dot{m}_1 \cdot [i_7^{out} - i_0 - T_0 (s_7^{out} - s_0)] = 640 \cdot (1034.28 - 293 \cdot 2.692 + 2.5) = \\
&= 44 \cdot 10^3 \ kW
\end{aligned} \tag{18}$$

Exergy of steam that enters in the turbine of high pressure (HPT):

$$\begin{aligned}
Ex_1 &= \dot{m}_1 \cdot ex_1 = \dot{m}_1 \cdot [i_1 - i_0 - T_0 (s_1 - s_0)] = 640 \cdot (3431.8 - 293 \cdot 6.5602 + 2.5) = \\
&= 269 \cdot 10^3 \ kW
\end{aligned} \tag{19}$$

The obtained exergy efficiency is:

$$\eta_{ex} = \frac{W_T - W_P + Ex_7^{out}}{Ex_1} = \frac{219 - 1.49 + 44}{269} = 0.97 \Rightarrow \eta_{ex} = 97.00\ \% \qquad (20)$$

II. COMPARATIVE ENERGY ANALYSIS

After calculations of the energy efficiency of A2 and A5 generation units of PP Kosovo A, is enable to make the comparisons in relation with the factors that affect the increase or decrease of te efficiency in these units. The main reasons which indicates that the energy efficiency of unit A5 to be higher than the unit A2 are:

- Increase of initial parameter as the pressure of water steam which enters in HPT (high pressure turbine;
- Reheat of the steam water after the expand in the HPT;
- Expand of steam water in MPT (medium pressure turbine);
- Larger number of steam takings from turbine for regenerative heating, etc.

III. COMPARATIVE EXERGY ANALYSIS

Through the graph which is obtained from equation (4) for determining of exergy efficiency is possible to note the difference of exergy efficiency depending on the surrounding temperature in both of units.

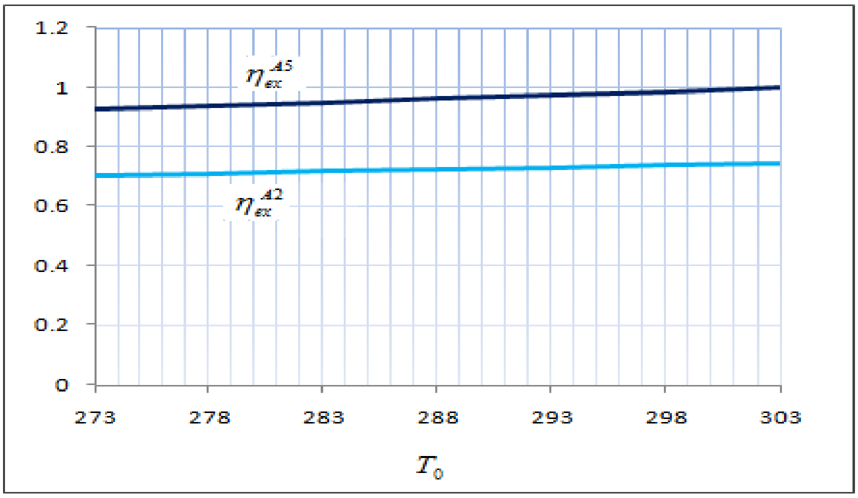

Fig. 5. The depending of exergy efficiency from different surrounding temperature

In diagram can be shown that exergy efficiency increases at unit generations, depending on increases of the surrounding temperature. The A5 unit exergy efficiency is higher than that of A2 unit because the useful work and exergy of the steam that enters in turbine of A5 unit is greater than the unit A2, which affects the efficiency.

IV. CONCLUSION

The paper elaborates the energy and exergy analysis in generation units of power plant Kosova A.
It explains especially the reasons of changing the energy efficiency in these units of generation with different of generation capacity and how the changing of surrounding temperature influences exergy efficiency not only within units but also in comparison between them.

At the beginning it shows the energy and exergy efficiencies of the units after calculations where the value of parameters are taken from relevant tables and are placed in necessary equations to obtain the values of efficiencies and continuing with the analysis of the differences between them and their graphical presentation.

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