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An Approach towards Thermal Power Plants Efficiency Analysis by Use of Exergy Method

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Abstract

This paper presents the energetic and exergetic analysis of the working cycles in power plants in particular in power plant Kosovo B. The energetic analysis does not take into account the changed quality of heat and mechanical work and as a result it reflects only one part of the system losses.
The losses cannot be calculated by this balance because of the outside irreversibility of the processes in particular of the working cycle and that's why the thermodynamic analysis according to the energetic balance is necessary but not complete.
The exergetic analysis of the working cycles identifies losses during the processes in the parts of the power plants, in particular, besides the inner losses (inner irreversibility), it also takes into account the outer irreversibility. This is the reason why the analysis of Rankin working cycle analyzes the losses in power plants. This includes the analysis of the exergy of gases in the furnace of the steam generator (heat exergy of the smoke of gases), exergy of the steam produced in the steam generator, the change of exergy in the regulatory parts of power plants, in the turbine, condenser etc. In the plants where are present big losses, there is a need to find ways to reduce them.
The energetic and exergetic analysis of the power plant Kosovo B will be made by different working regimes respectively for different physic and thermal parameters such as temperature and pressure of fresh steam, quantity of the fresh steam, temperature and pressure in the condenser (vacuum change in different regimes), change of parameters of the supplying water and in different points of power plants, quantity of the burning fuel etc.
As a result of this analysis, it is possible to identify where the biggest loss happens during the working cycle, the obtained power in each period of time and the electrical energy production.

Keywords:	Energy; Exergy; Rankin cycle; Steam

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1. Introduction

In relation with the reflection of literature relevant in this field, this paper has given an appropriate contribution, so that, for example, exergy efficiency to EPP Kosovo B is set to change the temperature of the surroundings. This provides a practical approach with regard to optimizing the work of the EPP.

This enables simultaneously deepening the problems concerned in professional and scientific terms.

The optimization of reheat regenerative thermal-power plants has been analysed for the subcritical pressure range. The exergetic analysis and optimization has been done for the supercritical Rankine cycle. Generalized Thermodynamic Analysis of Steam Power Cycle with adequate number of Feed Water Heaters has been analysed.

In addition to the energy analysis, a full-exergy analysis helps to identify components where high inefficiencies occur. Improvements should be done to these components to increase efficiency (exergy yield). The thermodynamic cycle is optimized by minimizing the irreversibilities, so that it is followed to change the temperature of the surroundings (T_0).

Firstly, the steam turbo-aggregate is analysed with two regulated steam makers and then it is given the appropriate analysis of EPP Kosovo B.

2. The exergy analysis for several examples

Amongst various related problems, here are elaborated some concrete cases. Figure 1 presents the regenerative scheme of the heat of the feeding water from the steam taken from turbine.

Thermal efficiency of cycle, Figure 2, with regenerative heating of feeding water is:

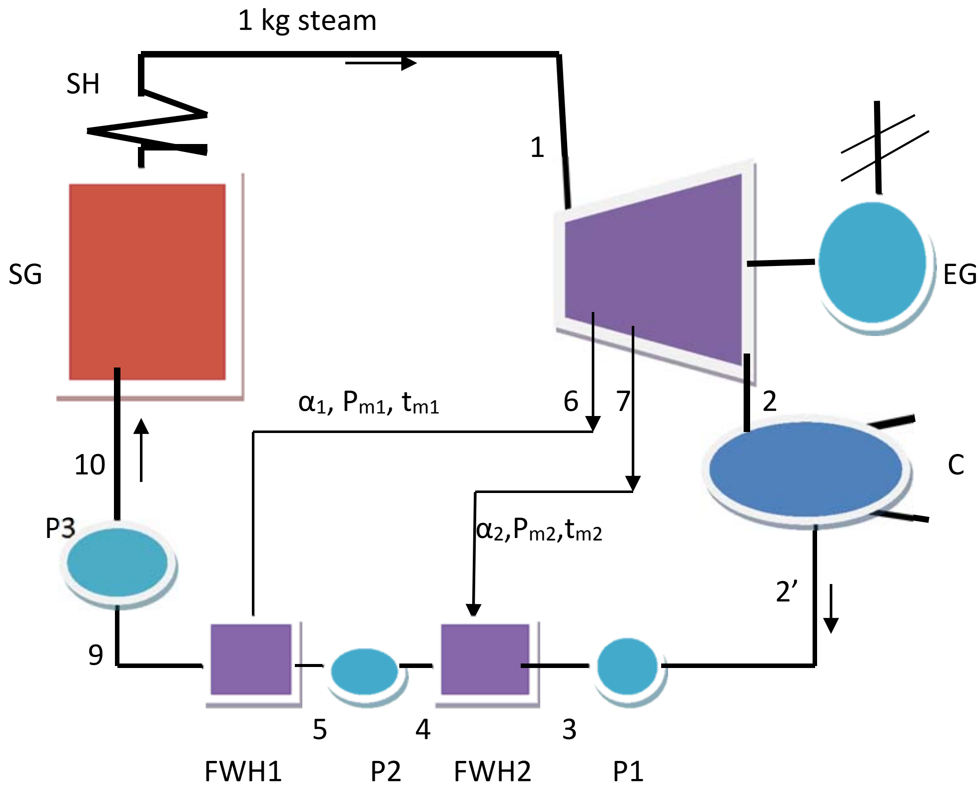

Figure 1: The Scheme of the regenerative heating of the feeding water:
SG-steam generator; SH-superheat; T-turbine; C- condenser; P-pump; FWH-open regenerative feedwater heating;
EG-electrical generator

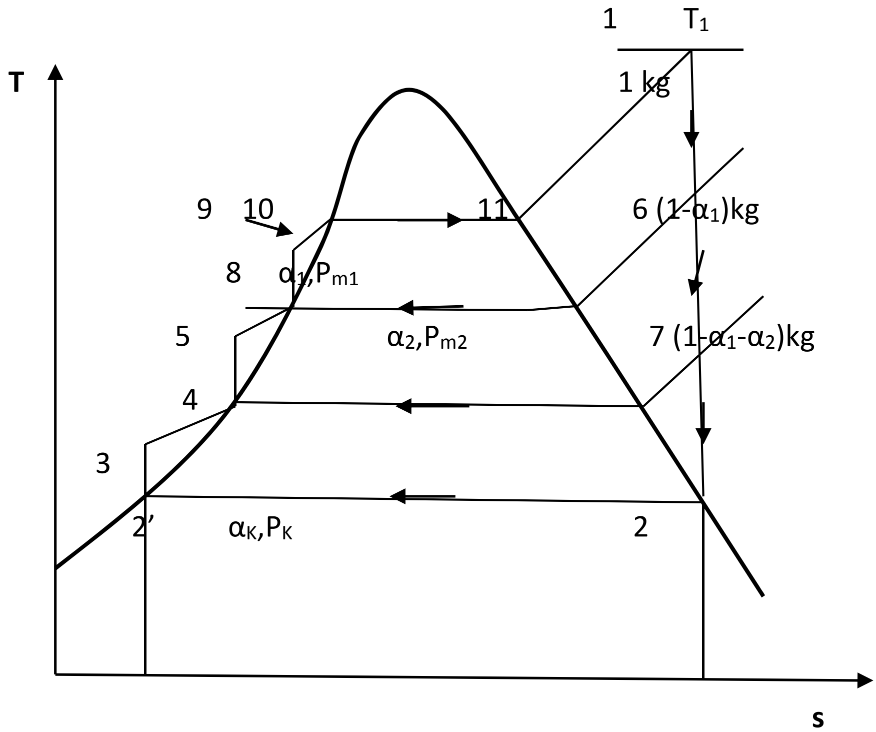

Figure 2: Regenerative heating process diagram (s, T)

$$\eta_t = \frac{l_c}{q_f} = \frac{i_1 - i_6 + (1-\alpha_1)(i_6 - i_7) + (1-\alpha_1-\alpha_2)(i_7 - i_2)}{i_1 - i_{10}} =$$
$$= \frac{i_1 - i_2 - \alpha_1(i_6 - i_2) - \alpha_2(i_7 - i_2)}{i_1 - i_{10}} \tag{1}$$

Under the scheme, it may be noted that at issue is the regenerative heat in two grades, so that the fraction of steam taken off the turbine is the α_1 and α_2.

Considering that applies:

$$\alpha_1 = \frac{i_4 + i_8}{i_4 + i_6} \quad ; \quad \alpha_2 = (1-\alpha_1)\frac{i_2^{'} + i_4}{i_2 + i_7} \tag{2}$$

following can be derived:

$$\eta_t = \frac{1}{(i_2+i_7)(i_4+i_6)(i_1-i_{10})}$$
$$(i_1 i_2 i_4 + i_1 i_2 i_6 + i_1 i_4 i_7 + i_1 i_6 i_7 - i_2^2 i_6 - i_2 i_6 i_7 - 2 i_4 i_6 i_7 -$$
$$i_2 i_6 i_8 - i_6 i_7 i_8 + i_2^2 i_8 + i_2 i_7 i_8 - i_{2'} i_6 i_7 + i_{2'} i_2 i_6 -$$
$$i_{2'} i_7 i_8 + i_{2'} i_2 i_8 - i_4 i_7 i_8 + i_2 i_4 i_8) \tag{3}$$

For optimal working regimes:

$$\frac{P_1}{P_{m1}} = \frac{P_{m1}}{P_{m2}} \quad ; \quad \frac{P_{m1}}{P_{m2}} = \frac{P_{m2}}{P_K} \tag{4}$$

Related of (4) is:

$$P_{m1} = \left(P_1^2 P_K\right)^{1/3} \quad ; \quad P_{m2} = \left(P_1^2 P_K\right)^{1/6} \tag{5}$$

Provided deals: P_1 = 80(bar), t_1 = 500(^{0}C), P_K = 0.05(bar), following is obtained:

$$\alpha_1 = 37.17(\%), \alpha_2 = 15.31(\%), \eta_t = 47.57(\%) \tag{6}$$

Considering that the energy characteristics of the cycle can be given as a ratio between thermal efficiency and thermal performance of Carnot cycle, for this case is obtained:

Θ = 78.74(%).

Exergy efficiency per cycle according to Figure 1 and 2 can be determined by:

$$\eta_{ex} = \frac{l_T - l_P + ex_{10}}{ex_1} \tag{7}$$

Where l_T- is useful work which is obtained from turbine, l_P - is work which is lost in the pump, ex_1- is exergy of steam at the entrance of steam turbine, ex_{10} – exergy of the steam at the entrance of the steam generator.

For the case is:

$$\eta_{ex} = \frac{i_1 - i_2 - \alpha_1(i_6 - i_2) - \alpha_2(i_7 - i_2) + i_8 - T_0 s_{10} + 2.5}{i_1 - T_0 s_1 + 2.5} \tag{8}$$

where:

$$-i_0 + T_0 s_0 = -84,2 + 293.0,296 = 2.5(kJ/kg)$$

In Figure 3 is presented graphically the exergy efficiency in function of temperature surroundings. In Figure 4 is a topological diagram where exergy efficiency is given in function of steam intakes off the turbine α_1 and α_2. By analysing the diagram in Figure 4, according to the topological diagram, can be concluded:

- As regards exergetic efficiency as a constant value, by increasing $\alpha_1$intake, the value α_2 is decreased;
- Parametric curves (in this case the parametric directions) separated with a linear trend in the reduction (with a trend in reduction);
- If the value of exergy energy is greater then, parametric direction is limited, namely the number of solutions is less favourable.

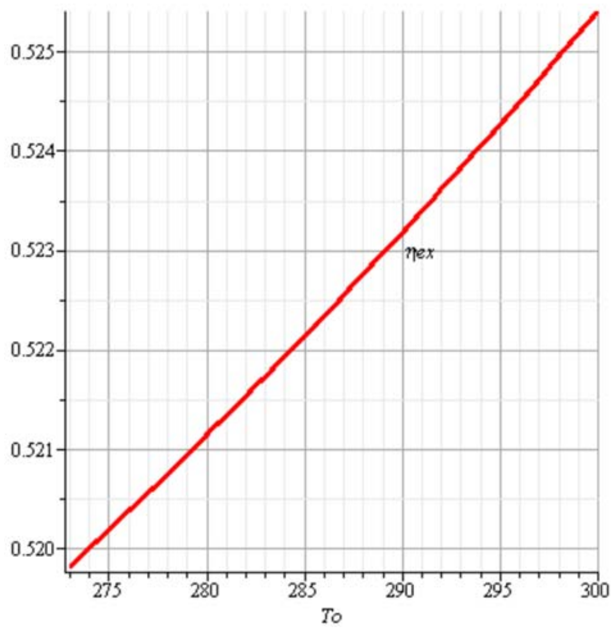

Figure 3: Exergy efficiency η_{ex} in function of temperature T_0 (K) of the surrounding

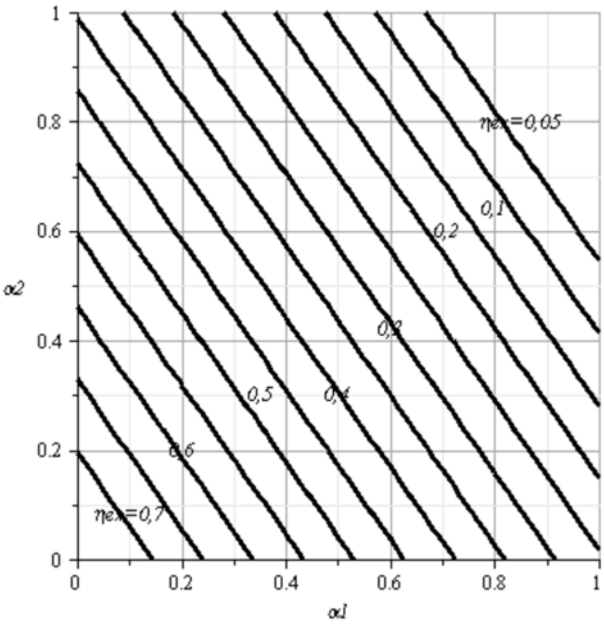

Figure 4: Exergetic efficiency η_{ex} as a function of α_1 and α_2

Let us now discuss the working regime of EPP Kosovo B. The scheme of the steam turbine is shown in Figure 5. In this figure is shown the reheating water vapour after leaving the high pressure turbine.

Thermal parameters of water vapour of turbine in EPP Kosovo B (working parameters) are given in the Table 1, while the number of intakes of EPP Kosovo B is given in Table 2.

High pressure turbine gives this power:

$$N_{HPT} = m_1(i_1 - i_2) \tag{9}$$

From the medium pressure turbine steam enters the medium pressure turbine, and the obtained power:

$$\begin{aligned} N_{MPT} &= (m_1 - m_A)(i_3 - i_B) + (m_1 - m_A - m_B)(i_B - i_C) + \\ &(m_1 - m_A - m_B - m_C)(i_C - i_D) + \\ &(m_1 - m_A - m_B - m_C - m_D)(i_D - i_{EF}) \end{aligned} \tag{10}$$

From low pressure turbine steam passes into low pressure where it is obtained**:**

$$N_{LPT} = m_1(i_4 - i_G) + (m_4 - m_G)(i_G - i_5) \tag{11}$$

General power turbine is:

$$N_T = N_{HPT} + N_{MPT} + N_{LPT} = 90.73 + 141.3 + 91.41 = 323.4 (MW) \tag{12}$$

- Mechanic efficiency, η_m = 0.97 to 0.99;
- Electrical generator efficiency, η_{gj} = 0.98 to 0.99,

and approved values, η_m = 0.987 and η_{gj} = 0.987, then it is obtained:

$$N = N_T \eta_m \eta_{el} = 323.4 \cdot 0.987 \cdot 0.987 = 315.053 (MW) \tag{13}$$

This is the nominal power of one block of EPP Kosovo B.

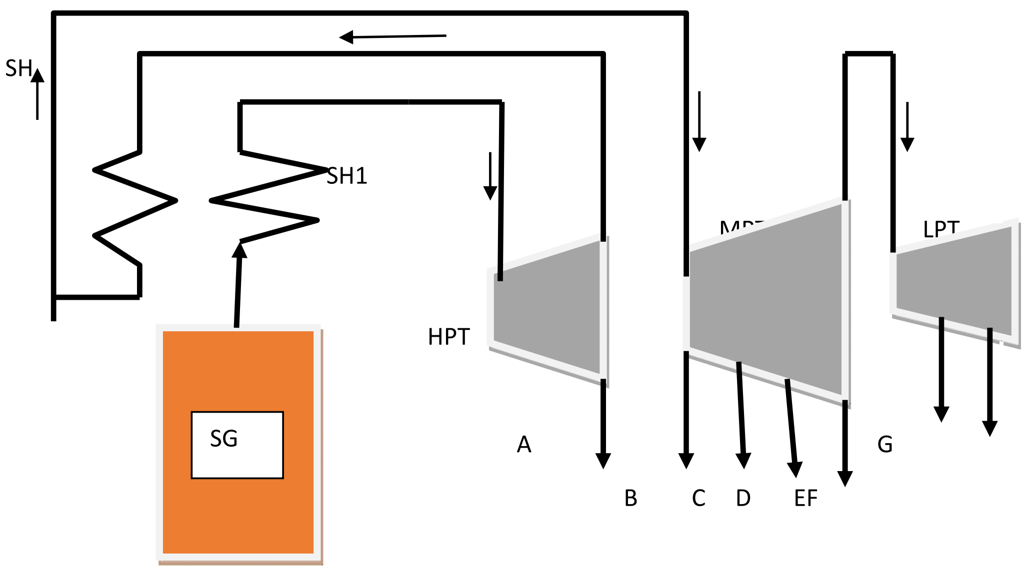

Figure 5: The scheme of the steam turbine for EPP Kosovo B

(SG-steam generator, SH-super heater, SG- steam generator, HPT-high pressure turbine, MPT-medium pressure turbine, LPT- low pressure turbine)

Table 1: Working parameters of EPP Kosovo B

HPT	ENTRY	EXIT
Pressure, P	P_1=177.4 bar	P_2 =41.19 bar
Temperature, t	t_1 = 540^{0}C	t_2 = 326.5^{0}C
Enthalpy, i	i_1 = 3390.7 kJ/kg	i_2 = 3031.5 kJ/kg
Steam flow, m	m_1 = 252.589 kg/s	m_2 = 250.4 kg/s
MPT	**ENTRY**	**EXIT**
Pressure, P	P_3= 37.07	P_4 = 3.04 bar
Temperature, t	t_3 = 540.2^{0}C	t_4 = 214.1^{0}C
Enthalpy, i	i_3 = 3538.7 kJ/kg	i_4 = 2894.9 kJ/kg
Steam flow, m	m_3 = 233.105 kg/s	m_4 = 189.65 kg/s
LPT	**ENTRY**	**EXIT**
Pressure, P	P_4= 3.04	P_5 = 0.0607 bar
Temperature, t	t_4 = 214.1^{0}C	t_5 = 36.6^{0}C
Enthalpy, i	i_4 = 2894.9 kJ/kg	i_5 = 2387.3 kJ/kg
Steam flow, m	m_4 = 189.65 kg/s	M_5 = 173.409 kg/s

Table 2: Number of intakes of EPP Kosovo B

Number of intakes	Pressure of intakes	Temperature of intakes	Enthalpies	Steam flow from takeovers
A	41.19 bar	326.5^{0}C	3031.5 kJ/kg	17.262 kg/s
B	21 bar	456.2^{0}C	3370.2 kJ/kg	13.465 kg/s
C	10.30 bar	356.1^{0}C	3170.8 kJ/kg	8.719 kg/s
D	6.08 bar	290.2^{0}C	3041.6 kJ/kg	9.714 kg/s
EF	3.04 bar	214.1^{0}C	2894.9 kJ/kg	13.233 kg/s
G	0.892 bar	104.1^{0}C	2685.9 kJ/kg	16.247 kg/s

The heat which enters the process is comprised of:

- Heat which is given in the steam generator for water vapour state (225.5 bar pressure and enthalpy of i= 1076.1 kJ / kg);
- Heat which is given in the steam generator for steam superheat from the dry steam to the superheated steam state 1.

$$\begin{aligned}
&Q_{f1} = D_0\left(i_1 - i_{a'}\right) = \\
&252.589(3390.7 - 1065.1) = 587420.98(kW) \\
&Q_{f2} = \left(D_0 - D_A\right)\left(i_A - i_2\right) = \\
&(252.589 - 17.262)(3538.7 - 3031.5) = 119357.854(kW) \\
&Q_f = Q_{f1} + Q_{f2} = \\
&587420.98 + 119357.854 = 706778.83(kW)
\end{aligned} \tag{14}$$

Efficiency of Rankin cycle to EPP is:

$$\eta_t = \frac{N_T}{Q_f} = \frac{323.4}{706.8} = 0.458 \tag{15}$$

Exergy efficiency for Electrical Power Plants (EPP) Kosovo B is determined by:

$$\begin{aligned}
\eta_{ex} = &\frac{1}{D_0(i_1 - T_0 s_1 + 2.5)}[D_0(i_1 - i_2) + (i_A - i_B)(D_0 - D_A) + (i_B - i_C)(D_0 - D_A - D_B) + \\
&+ (i_C - i_D)(D_0 - D_A - D_B - D_C) + (i_D - i_{EF})(D_0 - D_A - D_B - D_C - D_D) + (i_{EF} - \\
&- i_G)(D_0 - D_A - D_B - D_C - D_D - D_{EF}) + (i_G - i_K)(D_0 - D_A - D_B - D_C - D_D - \\
&- D_{EF} - D_G) - D_0(i_{1'} - i_{a'}) + D_0(i_{1'} - T_0 s_{1'} + 2.5)]
\end{aligned} \tag{16}$$

Taking everything into account, the values tabulated by Tables 1 and 2 are presented in the Figure 6, where

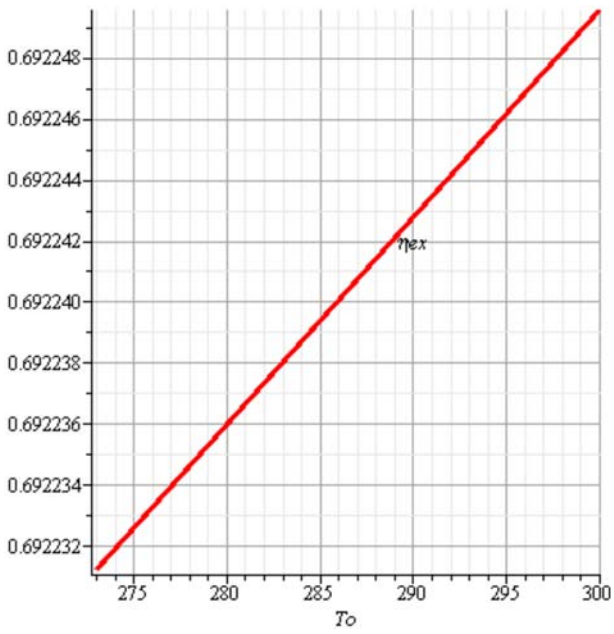

Figure 6: Exergy efficiency η_{ex} to EPP Kosovo B in function of temperature T_0 (K) of the surrounding

exergy efficiency of Electrical Power Plants Kosovo B is given in function of temperature T_0 of surroundings.

3. Conclusions

The exergy analysis of the steam power plants presents a qualitative overview of exergy losses against any energy process and offers the possibility of defining the losses into question. Such analysis is essential not only, specifically, in a theoretical research, but also in relation to the design of thermal-energy devices, as well as for the provision of the possibility of deepening the analysis in terms of professional and scientific research.

The rapid and quick industry, livestock, communication, and human growth based on contemporary standards makes a great impact on the development of energy. Nowadays, it cannot be imagined the planning of the development of any industrial branch, and that this mostly because of the implication in the problem of exploitation and energy production. Therefore, out of the large number of energy wells which are available to contemporary man, only a small number of wells into question can be used in a comprehensive manner and can be reasonably economical. For this reason, the contemporary man is bound to define its activities in the so-called classical field with respect to the benefits of energy and requires efficient technological principles regarding their utilization. Understandably, the energy analysis and thermal-energy devices are based on exergy and they are closely related to the first and the second law of thermodynamics.

It is important to note that instead of classic diagram to Grassmann (diagram of exergy flows), this paper proposes a chart where respective exergy losses (in the elements of the aggregate), as the exergy efficiency can be given to the effect of temperature environment (T_0). So is the complete analysis, dynamic and depth in professional and scientific terms. Additionally thus offered the opportunity to optimize the issues in question even using linear and nonlinear programming.

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