The study of the overall efficiency of a coal thermoelectric power station and its impact on the environment

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THE STUDY OF THE OVERALL EFFICIENCY OF A COAL THERMOELECTRIC POWER STATION AND ITS IMPACT ON THE ENVIRONMENT

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Abstract: The energy transformation, in this paper has two faces: the efficiency of energy transformation in accordance with new discoveries and concepts and the maximal reduction of the negative impact on the environment. Taking into account these two aspects, this paper has in view, besides the traditional efficiency transformation processes, which precede the energy yielding under different forms, the irreversible transformation in the cycles of this installation. The theoretical part is based on the most recent research in the field, adapted to the local condition by using an appropriate mathematical model. This model attempts to print out the basic parameters, which accompany the process, and to provide a methodology for the analyses and interpretation of data. The analysis and interpretation of data is based on their comparison with similar data experimentally obtained during a long operation period in order to draw a conclusion regarding the proposed method and this accuracy. In parallel with the analysis of operation from an economic point of view, the influence of the process on the environment is also assessed. Thus, it is possible to compare the impact obtained through the methodology used with the data obtained by foreign researchers and with European standards.

Keywords: efficiency, environment.

1. INTRODUCTION

In the future, the evolution of the energy system is established by the social and technological development of the country, in correlation with the new domestic standards and those from the European Community. The energy policy has in view to provide the ways of power saving, mainly at the thermoelectric power stations.

Besides the increase of the electrical power demand in the fields of transports and telecommunications service, the thermal power will increase yearly with an

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average rate of about 3 percentage until 2020 (fig. 1). The economic reforms and those from the energetic system should be orientated firmly towards the future trade flows.

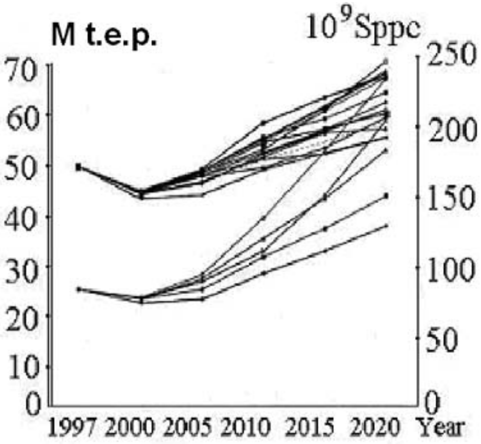

Fig. 1: Power demand increase till 2020

M t.e.p. – Mton equivalent petroleum.

2. THE EXPERIMENTAL PATTERN

The element of a thermoelectric power station to be analyzed is the real Rankine-Hirn cycle. There are three methods to highlight the factors which lead to the improve of the cycle efficiency:

A. of the outputs; B. of the entropy; C. of the exergy. Each of them has to attain the same outcome.

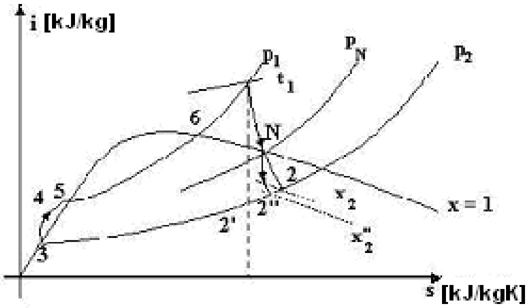

Fig. 2: Real cycle Rankine-Hirn

The real output of the Rankine-Hirn cycle is:

$$\eta_{real} = \eta_g \cdot \eta_{s,i} \cdot \eta_m \cdot \eta_t \tag{1}$$

This output does not take into consideration the power wastes of the pipes, which connect the steam generator to the turbine, then, the different auxiliary equipments without that the cycle is not possible. If we take into consideration the power wastes from the pipes, η_c and the fuel combustion η_a, the overall efficiency of the installation is:

$$\eta_{real} = \eta_g \cdot \eta_{s,i} \cdot \eta_m \cdot \eta_t \cdot \eta_c \cdot \eta_a \tag{2}$$

As the three outputs η_c, η_m, η_g, in principle remain constant, the η_t, $\eta_{s,i}$, η_a outputs still can be discussed over.

The turbine. The steam parameters at the entry in the turbine (p_1, T_1) and the pressure p_0 from the condenser improve the efficiency of the Rankine-Hirn cycle, but quantitative differently from case to case. The VK-50-p type steam turbine has the following fundamental parameters:

-the working steam pressure $p_1 = 90$ bar;

-the pressure in condenser 4 kPa;

-the temperature of the working steam $t_1 = 500$ºC;

-steam mass flow rate 204 t/h. The influence of the pressure p_1 is shown in the diagram (i-s):

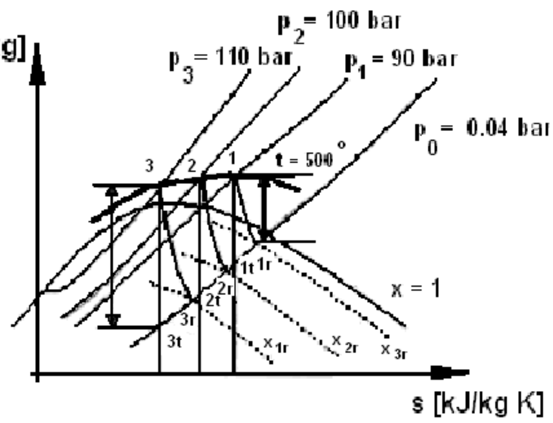

Fig. 3: The pressure influence

The values of the points: 1, 2, 3, 1t, 2t, 3t are obtained from the diagram (i-s) and for the real expansion with entropy increase 1r, 2r, and 3r are calculated starting from the relation:

$$\eta_{s,i} = \frac{H_r}{H_t} = \frac{H_r}{1{,}07 \cdot H_t} = \frac{i_1 - i_{last\ stage\ exit}}{1{,}07 \cdot H_t} \tag{3}$$

H_t and H_r are the theoretical and real heat decrease on the turbine and 1.07 is due to the fact that at the real expansion the steam heats up more than at the isentropic expansion that leads to a mechanic work enhance in which a part of the wasted power is recovered. After the documentation of the machine and the assessment in working, it is adopted $\eta_{s,i} = 0.71$.

From the diagram (i-s) there are got the values of the enthalpies, in kJ/kg: $i_1 = 3386$; $i_2 = 3372$; $i_3 = 3360$; $i_{1t} = 2008$; $i_{2t} = 1968$; $i_{3t} = 1936$ and also the entropies, the moisture content of the steam $s_{1t} = 6.658$ kJ/kg·K; $s_{2t} = 6.6$; $s_{3t} = 6.54$; $x_{1t} = 0.9$; $x_{2t} = 0.768$; $x_{3t} = 0.758$. The values of the heat decreases and the enthalpies at the real expansion are: $H_{1t} = i_1 - i_{1t} = 1376$; $H_{2t} = i_2 - i_{2t} = 1404$; $H_{3t} = i_3 - i_{3t} = 1427$; $i_{1r} = i_1 - \eta_{s,i}\,(i_1 - i_{1t}) = 2409.64$, $i_{2r} = 2375.16$ and $i_{3r} = 2348.96$.

The moisture contents of the real expansion are:

$$x_{1r} = \frac{i_{1r} - i'}{r} = 0.94\,;\ x_{2r} = 0.92\,;\ x_{3r} = 0.91$$

The check of the adopted internal isentrop output:

$$\eta_{s,i}^{(1)} = \frac{i_1 - i_{1r}}{i_1 - i_{1t}} = 0.7126\,;\ \eta_{s,i}^{(2)} = 0.71\,;\ \eta_{s,i}^{(3)} = 0.711$$

Here $r_i = i'' - i'$ is the value for the pressure from the condenser. Using the relation $s = s' + x \cdot (s'' - s')$ the entropy of the steam at the end of the real expansion in turbine is found out. $s_{1r} = 7.77$ kJ/kg·K; $s_{2r} = 6.67$ and $s_{3r} = 7.47$ insignificant. The moisture of the steam after the real expansion does not exceed the accepted limit $x_r = 0.87\ldots0.88$. At the normal working the fuel consumption is of 3.8 kg/Wh [5] at the effective efficiency of the turbine $\eta_e = 0.69$.

For the present case, at the increase of the initial pressure p_1, the fuel consumption becomes:

$$d_e = \frac{3600}{\eta_e \cdot H_{3t}} = \frac{3600}{0.69 \cdot 1424} = 3{,}6 \quad kg/kWh \tag{4}$$

thus, it decreases with 0.2 kg/kWh or 10 t/h at the nominal power of the turbine of 50MWt. Obviously, for decrease of the fuel consumption there are other methods, too, mainly the regenerative heating of the feed water. In the paper [5] is of 2.136 kg/kWh.

3. THE ENERGETIC ANALYZE OF THE RANKINE-HIRN CYCLE

3.1. The steam Generator. The Fuel Combustion

The composition of the combustion process is carried out at the PK-10p-type natural circulation boiler with two π form combustion ways, one ascending (the firebox) and the other descending (the connective part) joint by the return chamber. The fundamental parameters are:

- mass rate flow 230 t/h;
- working steam pressure 101 bar;
- working steam temperature 510ºC;
- average year loading *L* = 80%;
- fuel powdered coal and pit gas;
- the heat power of the boiler: 85MWt.

In table 1 there are shown the data on the used fuels and the equivalent one resulted from the mixture.

Table. 1. **The data of the used fuels**

Fuel	**Mass rate flow** ***m*** **[kg/h]**	**Lower heating power** ***Hi*** **[kJ/kg]**	**The elementary composition in percentage**						
			c	h	s	n	o	w	a
Coal	8914	16748	43	3	2	0.6	5	11	33
Gas	3123	35589	54	18	-	-	-	-	-
Mixture	12037	25205	51	9	1	-	4	8.5	25

For the lower heating value of the equivalent fuel H_i^e has been used the relation:

$$H_i^e = \sum H_i \cdot r_i = H_{ic} \cdot r_c + H_{ig} \cdot r_g \qquad (5)$$

where r_i are the shares in the volume of the component parts. The pit gas has the specific mass $h = 0.718$ kg/m^3_N.

The heat balance E (2+7) -70, according to the equation carries out the boiler's efficiency:

$$Q_a^c + Q_f^c + Q_f^{aa} + Q_a^p + Q_f^a = Q_u + Q_g^e + Q_a^i + Q_p^a + Q_r \quad [kJ/h] \qquad (6)$$

The heat output is:

$$\eta_t = \frac{Q_u}{\sum Q_i} = \frac{Q_u}{Q_a^c + Q_f^a + Q_f^{aa} + Q_a^p + Q_f^a} \qquad (7)$$

The analyze of the heat balance of the boiler has been made in three hypotheses: - case A - at average year parameters; - case B - under the conditions of recovery of a part from the heat of the flue gases; - case C - for the optimum working (with waste of minimum power).

The outcomes are shown in table. 2 [4]:

Table 2: **The outcomes of boiler working**

Boiler working	Q_a^c $[kJ/h]$	Q_f^{aa} $[kJ/h]$	Q_u $[kJ/h]$	$Q_u - Q_f^{aa}$ $[kJ/h]$	η_t $[\%]$	$c = \dfrac{Q_a^c}{Q_u - Q_f^{aa}}$
Case A	$24270 \cdot 10^4$	$437.86 \cdot 10^4$	$20928 \cdot 10^4$	$20454 \cdot 10^4$	$84.47 \cdot 10^4$	1.186
Case B	$24270 \cdot 10^4$	$437.86 \cdot 10^4$	$21529 \cdot 10^4$	$21055 \cdot 10^4$	86	1.152
Case C	$24270 \cdot 10^4$	$437.86 \cdot 10^4$	$22474 \cdot 10^4$	$22000 \cdot 10^4$	90.72	1.103

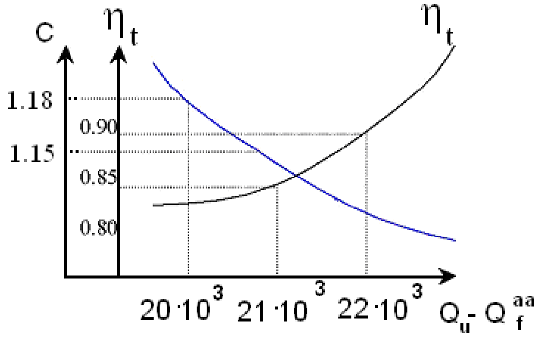

Fig. 4. Depending between specific fuel consumption and heat output

The diagram from figure 4 shows us the heat output increases the specific fuel consumption "*c*" decreases. If a part of the gas heat is recovered in a (calculated) heat exchanger (ΔQ_g^e), the efficiency increases with 1.5%. (table 2). In this case, the fuel saving becomes:

$$\Delta E_c = \frac{\Delta Q_g^e}{H_i^e} = \frac{601{,}1 \cdot 10^4}{25.202} = 238{,}48 \quad kh/h$$

that is not to be neglected.

3.2. The Environment Pollution

The Division of Economic Development and Strategy (DEDS) establishes the operative assessment methodology of the polluting emissions, in thorough concordance with the standards in force. The precise establish of the polluting emissions are got on the basis of the measurements with special equipments. (Laser and IR spectroscopy) or through calculus, after the relation:

$$E = B \cdot H_i^i \cdot e \quad [kg/h] \tag{8}$$

where B is the hourly fuel consumption, in kg/h; H_i^i -the fuel lower heating value, initially, in kJ/kg E -the emission factor, in kg/kJ

The SO_2 polluting agent is established, thus:

$$e_{S02} = \frac{\frac{M_{SO2}}{M_S} \cdot \frac{s}{100}}{H_i^i} \cdot (1 - r) \tag{9}$$

M_{SO2}, M_s- the gram-molecular weight; $r = 0.2$ the degree of the sulphur content in ashes. The NO_x polluting agent for the load of 100% of the boiler is obtained in table 3, or, for a load x > 50%, with the correlation:

$$e_x^{NOx} = e_{100}^{NOx} \cdot \left[a + (1 - a) \cdot \frac{L - 50}{50} \right] \tag{10}$$

Table 3: **NOx polluting agent**

Fuel	e_{100}^{NOx}		
	Heat power of the boiler [MWt]		
	50-100	100-300	>300
Lignite	0.2	0.22	0.26
Pit coal	0.38	0.42	0.45
Burning oil	0.19	0.21	0.28
Natural gases	0.13	0.15	0.17

$a = 0.5$ coefficient for powdered coal and natural gases. The powdered coal polluting agent is determined with the relation:

$$e_{ashes} = \frac{a \cdot (1 - X) \cdot (1 - Y)}{H_i^i} \tag{11}$$

$a = 33.7$ ashes content in fuel, in percentage; $X = 0.15$ degree of ashes content in firebox, in mass percentage; $Y = 0.97$-the storage efficiency of the dust (filter) in percentage.

The CO2 polluting agent has the emission factor depending on the character of the fuel. For coal $e_{CO2} = 98 \cdot 10^{-7}$ and for natural gas e_{CO2} is $50 \cdot 10^{-7}$, or it can be calculated with the relation [3]:

$$e_{C02} = \frac{\frac{M_{CO2}}{M_C} \cdot \frac{c}{100}}{H_i^i} \qquad (12)$$

The table no. 4 contains the calculus of the polluting agents produced by the boiler PK-10p, at an average loading of 80%.

Table 4: **The calculus of the polluting agents**

Polluting agent	**Fuel**	**B** [kg/h]	**H_i** [kJ/kg]	**e** [kg/ kJ]	**E** [kg/h]	**E_{tot}** [kg/h]	**E_{tot}** [t/day]
SO_2	Coal	8914	16748	$1.8 \cdot 10^6$	270.2	270.2	6.48
	Natural gas	-	-	-	-		
NOx	Coal	8914	16748	$1.76 \cdot 10^{-7}$	26.27	39.6	0.661
	Natural gas	3123	35589	$1.2 \cdot 10^{-7}$	13.33		
Ashes powder	Coal	8914	16748	$0.5 \cdot 10^{-6}$	74.64	74.64	1.79
CO_2	Coal	8914	16748	$98 \cdot 10^{-7}$	1463	2018.78	48.45
	Natural gas	3123	35589	$50 \cdot 10^{-7}$	555.7		

4. CONCLUSION

1.The electric power producing in the industrial plants is obtained at an efficiency of 20-40%.
2. The reduction of the fuel consumption from 3.8 kg/kWh to 2.136 kg/ kWh has been obtained by the method of the regenerative heating.
3.The energy balance of the boiler highlights a fuel saving of 172 t/month recovering a part of the heat of the roast gases. 4. By increasing initial pressure there is got a reduction of the fuel consumption with 10 t/h.

BIBLIOGRAPHY

[1] **Houberechts A**. *Thermodinamique*, *Technique* Tome II, Dunoid Paris 1962.
[2] **Kirillin V.** a.o. *Termoyinamique*, *Tehnique* Edition Mir Moscow 1976
[3] **Ionel I.** a.o *Temoenergetics and Environment,* Technical Publishing House 1996.
[4] **Petrilean D.C.** *The Working Regime Study of the PK-10p Boiler from the Electric Power Plant from Paroseni* Graduation Project, University of Petrosani 2000.
[5] **Petrilean I., Maierean V**. *The Analyze of the Functional Parameters for the VK-50-1.* Graduation Project, University of Petrosani 2001.