Comparative energetic sustainability indicators for Paroseni central heating power plant considering its cogeneration and condensing operation

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COMPARATIVE ENERGETIC SUSTAINABILITY INDICATORS FOR PAROSENI CENTRAL HEATING POWER PLANT CONSIDERING ITS COGENERATION AND CONDENSING OPERATION

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Abstract. The main objective of the paper is to highlight the evolution of the energetic and environmental performances of a condensing and cogeneration 150 MW power plant which for different loading levels. The values obtained from the creation of the real hourly thermal-energetic balance were graphically processed highlighting therefore the comparative evolution of the energetic and environmental parameters obtained during the condensing and cogeneration operation. The usefulness of the study is materialised through the expression of the quantitative differences between the values obtained during the cogeneration operation and those obtained during the condensing operation, situation which legally allows for a competitive price for electric energy to be obtained, energy which may be capitalized on the energy market.

Keywords: cogeneration, environmental impact, sustainability indicators, footprint.

AIMS AND BACKGROUND

The role of energy efficiency varies from one country to another, in terms of the remaining potential, energy pricing and other metrics (Ref 1). There is a considerable technical potential for energy efficiency improvements along the entire energy value chain: from extraction of primary energy resources: oil, gas, coal, to their transformation into heat and electricity, transportation and distribution of energy, and ultimately to the final use by appliances, equipment and devices. In coal-fired power generation, for example, efficiencies above 46% are being reached today with the aim to come close to the 50% level in the next few years. Although the state of-the-art technology is at such high levels, the average efficiency of gas and coal fired plant across the world is approximately 41% for gas and 34% for coal. Looking at the coal fired power plant fleet, it becomes obvious that there is a huge efficiency potential.

The total installed capacity of steam power plants in Europe is around 2,300 GW (2011) and 40% of them will be retired in the next two decades. That means roughly 1,000 GW of capacity needs to be replaced. A preview of the net efficiencies of coal fired power plants with steam turbines in different areas of the world compared to a state of the art one is brought forward in Figure 1. Climate and environmental policies focused on reducing greenhouse gas emissions and the change of social attitude in favour of "clean energies" constitute a determining factor which shapes the investing behaviour as well as consumption patterns in the energetic sector. Considering the international conditions which are becoming more and more derogatory using coal with the anticipated increase in the price of CO_2 emissions certificates, its role will decrease in favour of renewable energy production systems.

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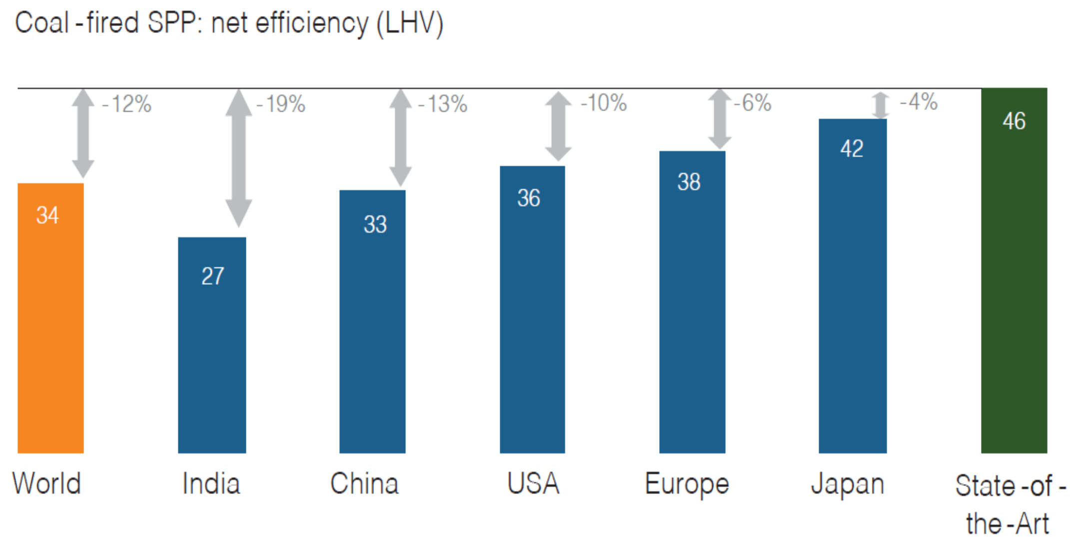

Figure 1. Net efficiencies of coal Steam Power Plants compared to state-of-the-art (2010)[2]

Therefore, the present paper also implies together with an energetic quantification of performance indicators an environmental quantification as well. To sum up, a known evolution scenario for the evolution of the percentage of CO_2 emissions up to the year 2035 may be observed in Figure 2.

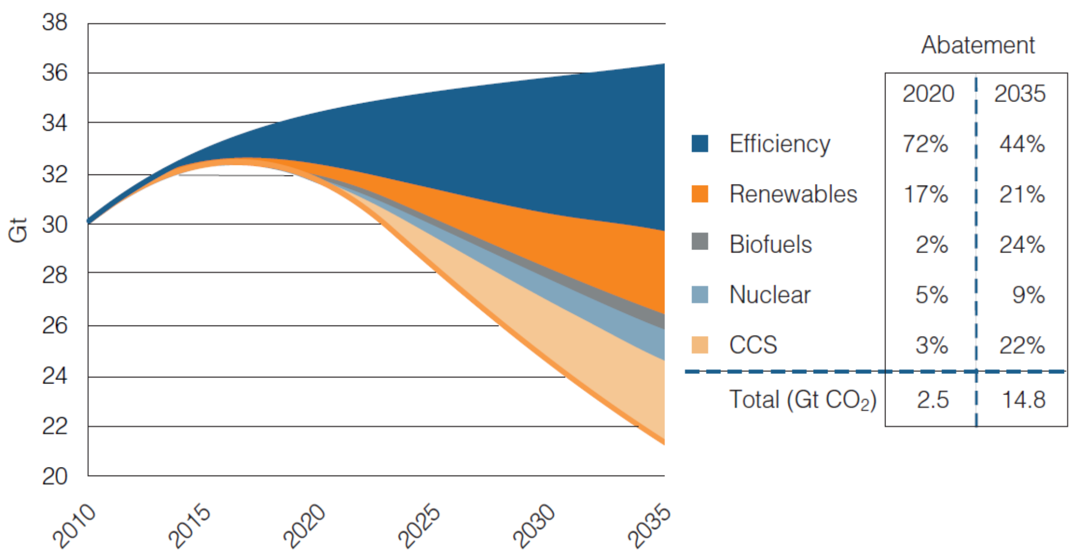

Figure 2. Scenarios for CO_2 emissions [2]

Today fossil fuels account more than 80% of the energy demand: coal (25%), oil (35%), natural gas (21%), nuclear (6.3%), hydro (2.2%), and biomass and waste (10%)[3]. In Romania, in the field of electricity and heat production using coal (brown and black coal) and steam turbines there is an installed power of approximately 4500 MW. The technological process has had important contributions for the decrease of demand through multiple energetic efficiency measures. The labour productivity increase and the changes in the structure of the economy lead to the accentuated disconnection process of the economic increase from the energetic consumption. For example, between 2010-2014, Romania's GDP increased with roughly 20%, while its energetic consumption decreased with approximately 20%[3]. Nevertheless, Romania's energetic intensity is still superior to the EU average.

Energetic efficiency is one of the most important factors for the increase of energetic security and a good way of reducing emissions and greenhouse gases. Therefore, the appointment of the comparative energetic and environmental performances is considered useful for a condensing and cogeneration coal fired power plant. Having developed the real hourly energetic balance for the condensing and cogeneration operation, it may be used as a base for the determination of the energetic performance parameters of the power plant. The paper focuses as well on the environmental effect the reduction of the footprint has considering the difference between cogeneration and condensing.

The usefulness for the comparison of these performance parameters is reflected in the possibility to qualify electricity production in high efficiency cogeneration for Paroseni CHPP, situation which legally allows for a competitive price for electric energy to be obtained, energy which may be capitalized on the energy market.

EXPERIMENTAL

The paper focuses on the problem for the appointment of the evolution of the energetic /environmental for a condensing and cogeneration power plant. Based on the general diagram presented by the power plant (i.e. Paroseni CHPP) the main values which are required to be determined in order to create the thermal-energetic balance were identified. The electricity produced is supplied to the National Electrical Grid while the thermal energy is capitalised in Jiu Valley (i.e. Petroşani, Vulcan, Lupeni). The power plant of Paroseni CHPP has an installed power of 150 MW being composed of a Japanese Babcock Hitachi steam generator with a mass flow of 540 t/h, which complies with the European norms for emissions, and a Ukrainian Turbo-Atom; a Toshiba electricity generator of 176.5 MVA. In dealing with the proposed objective, the requirements of the beneficiary were always considered, namely the requirements of Paroseni CHPP regarding the indicators necessary to consider the production of electricity as high efficiency cogeneration. Performance tests have been carried out for 3 loading levels (i.e. 150, 130 and 115 MWh), distinctively on the steam generator, the turbine and afterwards on the power plant: a). in cogeneration: at a nominal rate 150 MWh and thermal load 48.64 Gcal/h; electricity at an intermediate rate 130 MWh and thermal rate 48.28 Gcal/h and the minimum of electricity 115 MWh and thermal load 47.75 Gcal/h[4].

b). in pure condensing: at a minimum technical rate 115 MWh; at a nominal rate 150 MWh; at an intermediate rate 130 MWh[4].

Black coal from Jiu Valley is used as fuel which has an inferior calorific value determined in a laboratory, comprised within 15407.42 ÷ 15750.74 kJ/kg and an addition of methane (1.5%)[5].

The balance outline contains the steam generator, the steam turbine, the condenser, the regenerative cycle, the regenerative feed water heaters; feed water and condensate pumps. The Distributed Control System (DCS) of the unit provided most of data in order for the energetic balance of the 2 operation scenarios to be created. Based on the primary data measured by the authors / obtained from the DCS the components of the real hourly thermal-energetic balance were calculated: input energies, useful energies, energies lost at the steam generator and at the plant. These energetic and environmental performance indicators were graphically processed and they correspond to the three loading levels, distinctively for condensing operation and respectively for cogeneration. In order to avoid useless repetition, the paper brings forward only one of the 6 operational sequences, i.e. the simplified thermal diagram of the steam generator – turbine, which corresponds to the cogeneration operation at 130 MW and 47.75 Gcal/h heating load (Figure 3).

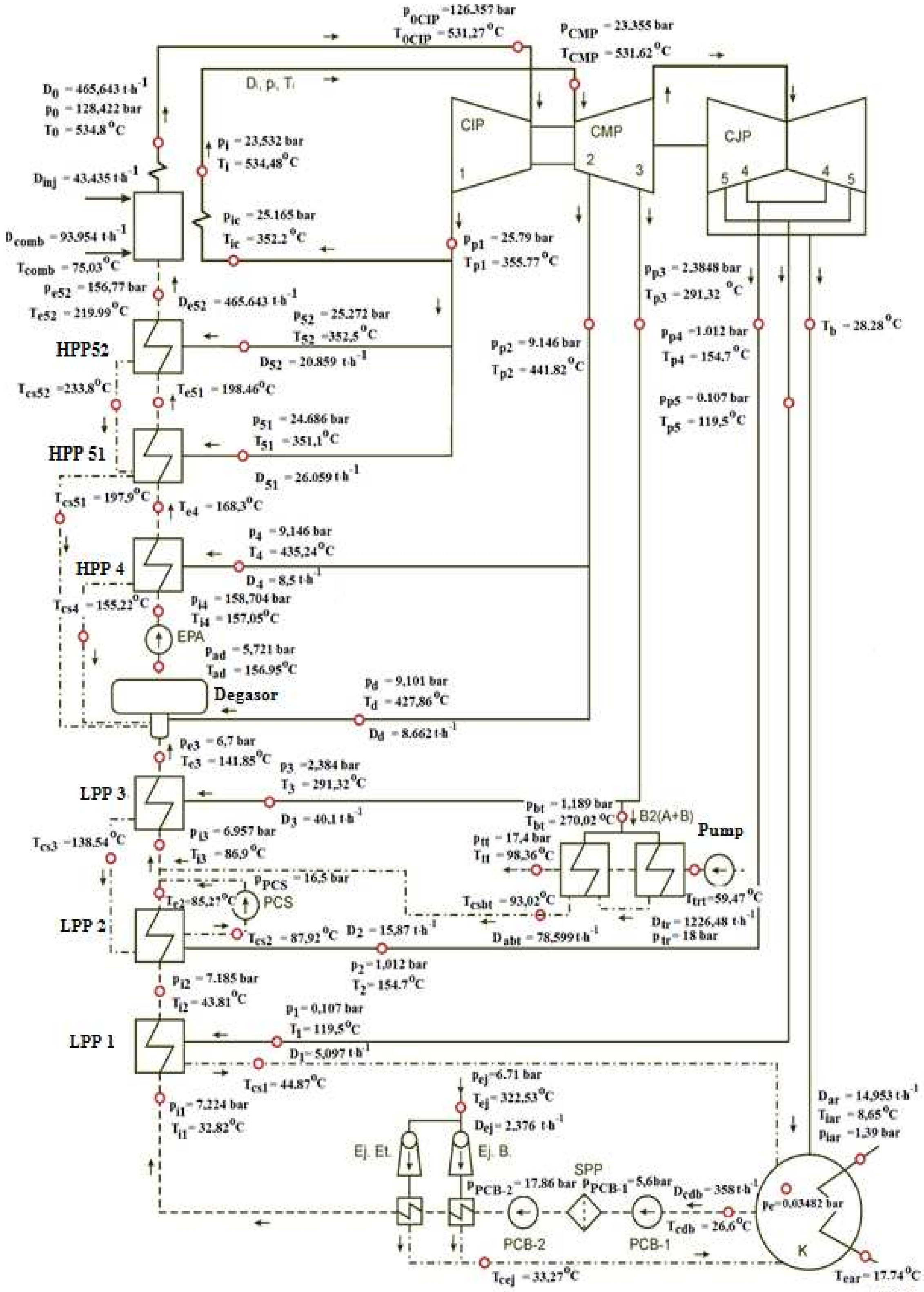

Figure 3. The simplified thermal diagram of the steam generator – turbine 130 MWh, cogeneration, 47,75 Gcal/h[4] heating load, LPP - low pressure preheater; HPP - high pressure preheater; PCB - Condensed base pump; CIP - high pressure body; CMP - medium pressure body; CJP - Low pressure body; SPP - filter separator

Before calculating the significant energetic indicators, numerical calculation programmes had been were created, the experimental measured data, respectively the data from the DCS making reference to: temperatures, pressures, water-steam flows on the renewable circuit, immediate analysis, elementary analysis, flue gases concentrations and flow, chemical analysis of coal samples, cinder and ash, specific enthalpies, specific entropies, specific heats, vapours title, relative humidity, calorific values[4]. From lack of space, these values were not presented in the paper, only the performance parameters were (i.e. energetic and environmental). The values of the performance indicators were established based on the quantity values and percentages of the elements comprised in the thermal-energetic balance which were determined through analytic calculations: gross energetic efficiency, condenser losses, sensible heat losses through flue gases, specific fuel consumption on the power plant, carbon footprint determination. The figure presents the following parameters: pressure, temperature, measured/obtained flow from the DCS, respectively analytically determined on the renewable circuit of the power plant[4].

RESULTS

The values of the components of the thermal-energetic balance and the obtained performance indicators belonging to the 3 loading scenarios for cogeneration and condensing operation were graphically processed allowing the selection of a series of significant dependencies capable of highlighting the energetic and environmental advantages for producing electricity using cogeneration compared to the condensing operation. The results obtained outline the energetic aspect in figure 4–7, while figure 8 represents the environmental impact the reduction of the carbon footprint has. Analysing figure 4 it may be clearly observed that the net efficiency for cogeneration increases within the range 4.89 - 5.83% compared to the net energy efficiency for condensing. Making therefore a comparison between the obtained values and the values presented in figure 1, an accordance with the international values may be observes, the values being with 4% below the European average (for cogeneration).

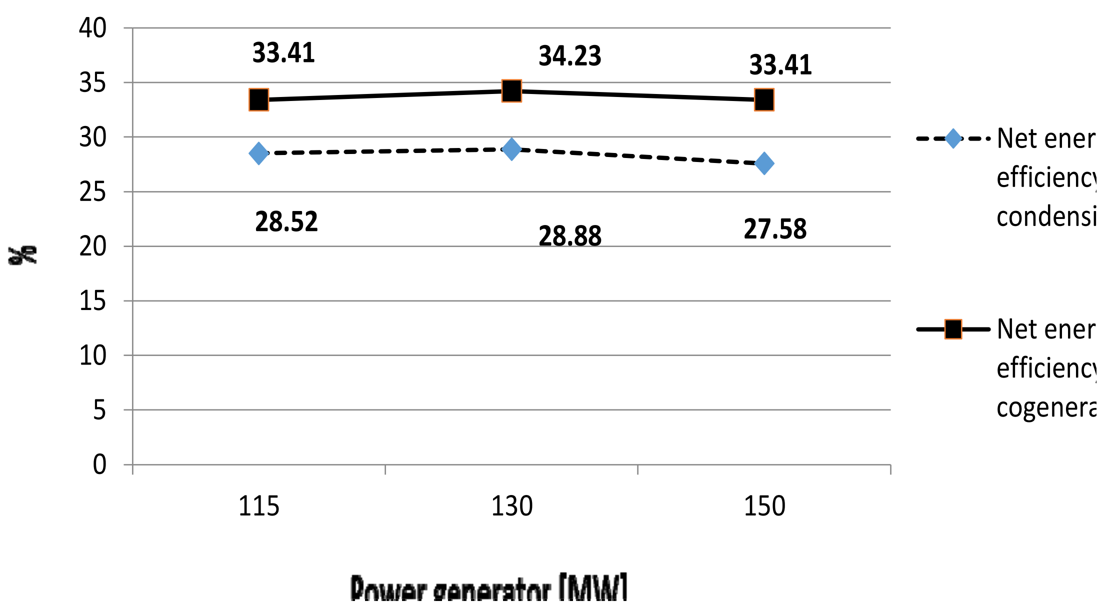

Figure 4. The variation of the energy efficiency depending on the electric load per unit in cogeneration and condensing

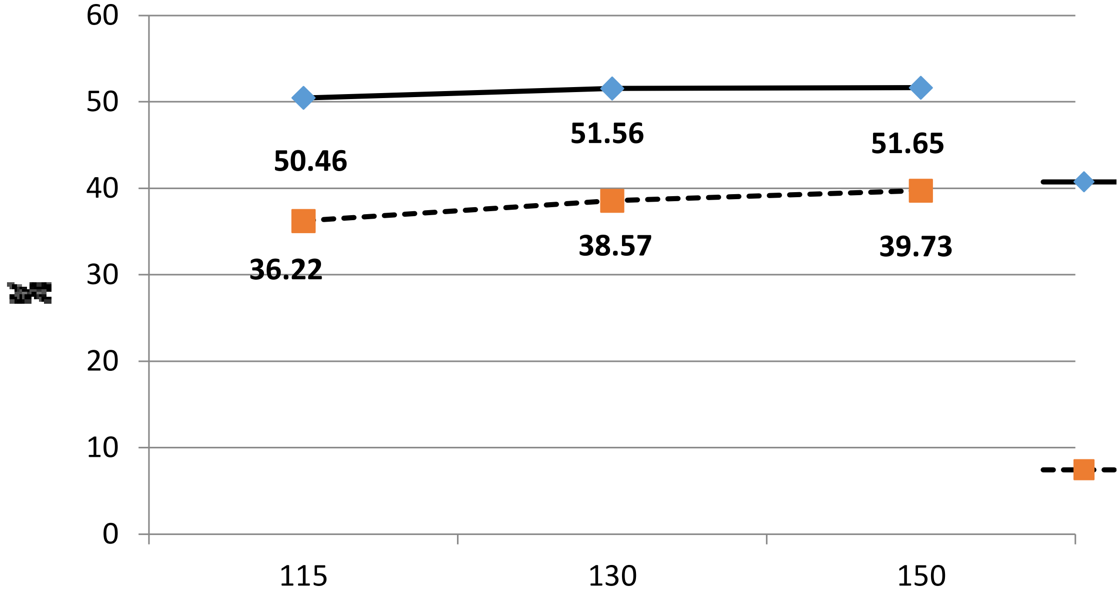

Figure 5. The variation of the losses in the condenser depending on the electric load per unit in condensing and cogeneration

Analysing figure 5 it results that the effect of the cogeneration is materialised through the reduction of the losses in the condenser, losses comprised within the range 11.92-14.24 %. Nevertheless, the capitalisation of a part of the heating potential of the steam supplied by the turbine reduces the load of the condenser, which is highlighted and materialised through the reduction of losses at the condenser in cogeneration compared to the condensing operation.

From figure 6 it results a logarithmic increase of the losses with the sensible heat of the flue gases in condensing compared to the cogeneration operation.

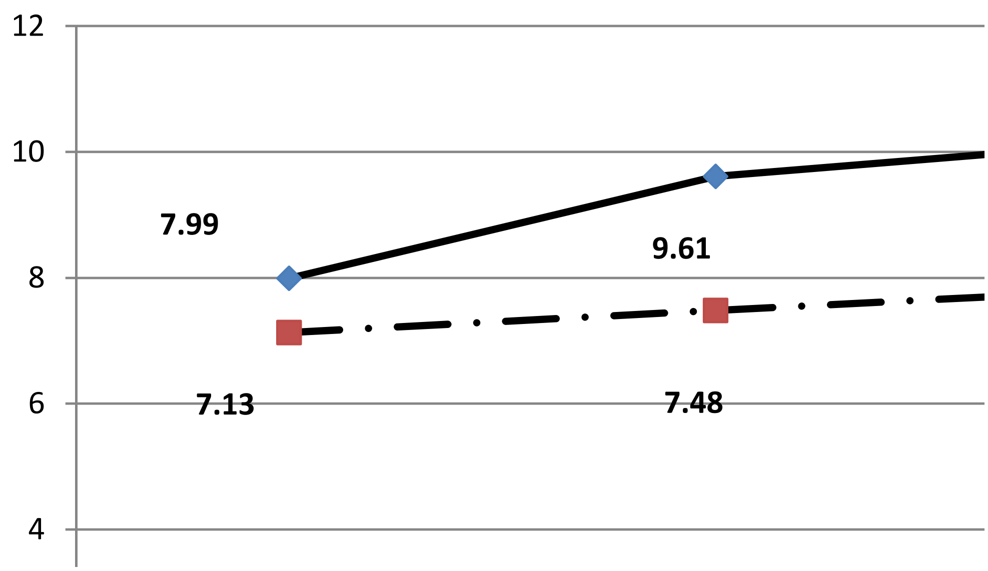

Figure 6. The variation of heat losses through flue gases depending on the electric load per unit in cogeneration and condensing

The drawn curves highlight a rapid increase on the first level belonging to condensing (from 115 to 130 MW), fading out on the final level (from 130 to 150 MW). Figure 6 also highlight the fact that in the case of cogeneration the losses with the sensible heat of the flue gases are reduced to the range 0.86-2.34%, compared to the condensing operation.

The specific fuel consumption per unit is significantly lower during cogeneration compared to condensing (Figure 7).

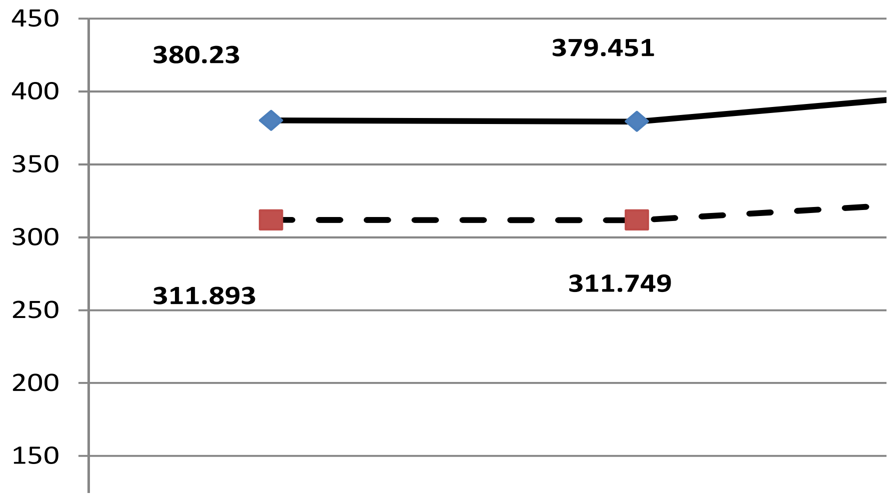

Figure 7. The variation of the specific fuel consumption per unit depending on the electric load of the unit in cogeneration and condensing (g.c.c. – grams conventional combustible)

The values with which the specific fuel consumption per unit is reduced in cogeneration compared to condensing are comprised within the interval 68.337-74.757%.

The environmental impact for the reduction of the carbon footprint in cogeneration compared to condensing is presented in Figure 8. The average value of CO_2 emissions in Romania is assessed at 547 kg CO_2/MWh[6]. In order to obtain comparable values for similar energies considering their transformation ability, the thermal energy has been transformed into exergy with the help of Carnot's factor ($f_C = 0.224$), considering the temperature at which the heating agent is supplied ($T = 371$ K, $T_0 = 288$ K) (figure 8).

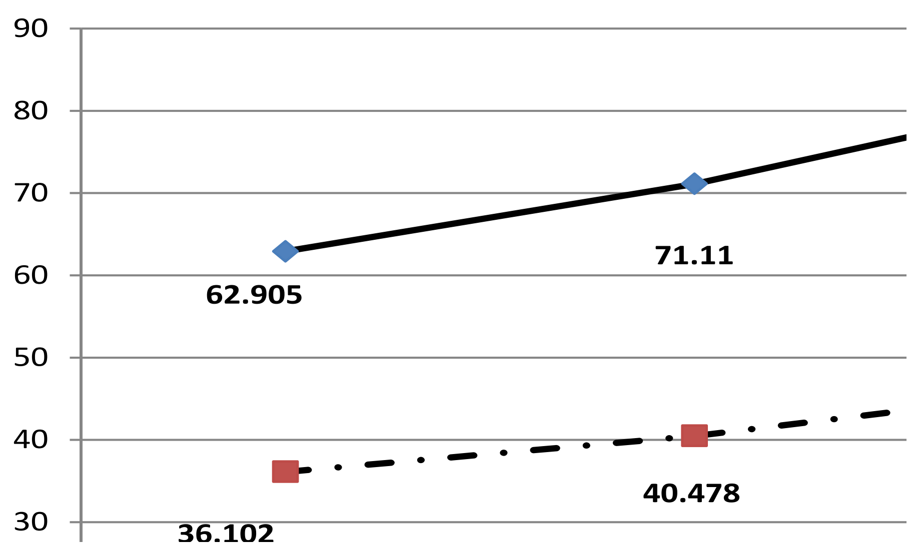

Figure 8. The variation of the carbon footprint in cogeneration and condensing

It results therefore from figure 8 that the cogeneration operation is characterised through a considerably reduced carbon footprint than in condensation. The calculation of the carbon footprint for cogeneration was carried out considering the reduction of the CO_2 emission value in condensation of the value of the thermal energetic exergy supplied in the heating network. It is therefore observed a reduction of the carbon footprint in cogeneration than in condensing within the range 26.803-35.555%.

CONCLUSIONS

Analysing the experimental data and the analytically obtained values expressing therefore the indicators based on the said information, indicators which are necessary to qualify the highly efficient electricity production, the following conclusions may be drawn:
- corresponding to the load per energetic unit the production of electricity in cogeneration brings forward energetic and environmental advantage answering the challenges brought by the sustainable development of the energetic systems;
- the performances recorded at the level of the energetic and environmental indicators are comprised toward the superior side of the values comprised by the Romanian and European norms concerning the energetic efficiency of large burning installations foreseen with steam turbines;

The experimental determinations and the calculations carried out have highlighted a sensible increase of the parameters explored in cogeneration compared to condensing operation. The values obtained are comprised within the interval mentioned in BAT (best available technology), for Central Heating Power Plants fitted with a steam turbine.

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