

Reducing the environmental impact of a gas operated cogeneration installation

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Abstract. The paper deals with a case study for carried out in order to justify the installation of a gas cogeneration system fitted with an internal combustion engine, system used to supply electricity and heat to the users of an energy user which exceeds 1000 toe/year. 2 scenarios were therefore compared based on the energetic analysis:

-the actual scenario in which energy is supplied from the National Energetic System.

- the scenario in which a combined heat and power plant is used.

The amount of energy saved yearly, the specific fuel consumption and the environmental impact were determined by the comparative study. The diagrams representing the variation of the performance indicators according to the operation period were also created. The usefulness of the paper consists in the creation of the yearly optimum installation operation time chart.

1 Introduction

Cogeneration defines those processes in which the useful electric energy (or mechanical energy) and the thermal energy are simultaneously produced through fuel burning. Cogeneration systems are efficient alternatives to central heating power plants and traditional central heating plants. Cogeneration is a completely developed technology which has been widely spread and introduced in the industrial sector. For several years now, it has been widely used by the services sector due to its undeniable advantages.

Cogeneration is a potential source used for the efficient generation of electricity as long as they are allowed by the thermal industrial consumption and centralised heating. Nevertheless, cogeneration is the only way of combined production of electricity and heat using fossil fuels considering a general efficiency of over 80%.

Compared to the separate heat production (in central heating plants, CHP) and electricity (in central heating power plants, CHPP), the fuel economy resulted from the combined production of heat and electricity may reach 32-34% (Figure 1).

The fuel economy may be observed in a reduced invoice received by final beneficiaries of heat and electricity. Considering as well the case in which modern cogeneration

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competes with the new and advanced electricity generation technologies (such as, steam-gas combined installations, with efficiencies comprised between 55-58%), the realised economy is comprised between 15-18%. It is estimated that at the present fuel price the proportion of fuel expenses represent 50-80% of the cost of supplied energy, being therefore the most important cost in the proportion of electricity and central heating.

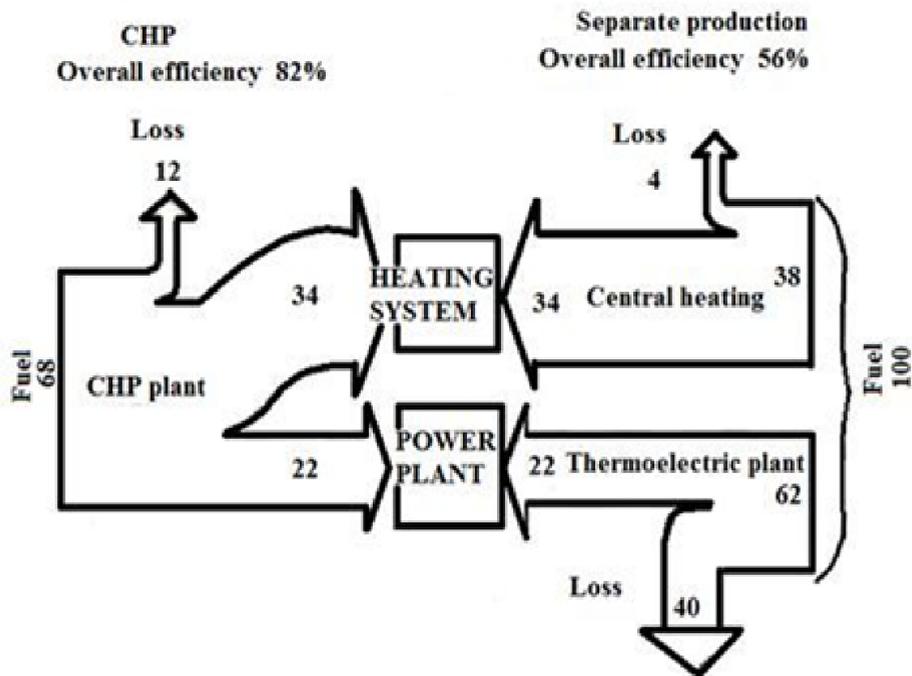


Fig. 1. Comparison between energetic and fuel fluxes considering separate electricity and heat production and respectively cogeneration

The emission of greenhouse gases into the atmosphere represents an important cause of global warming and climate change (especially CO₂), the energetic sector being therefore the main contributor (roughly around 80%). The polluting emissions per useful energetic unit may be significantly reduced through cogeneration, corresponding therefore to the economy of unused fuel, compared to the separate production of heat and electricity.

The ecologic, social as well as economic advantages of cogeneration are materialised through: flexibility in using fuels, contributing therefore to the stability of the price of heat, the creation of jobs for the local labour market, avoiding transport costs for electricity as cogeneration plants fit perfectly within the modern concept of electricity production and distribution, increasing therefore the safety in supplying electricity locally and reducing the risk of breakdowns which might be caused by a major breakdown of the national electricity supply system. [1].

The international importance of cogeneration has fluctuated during the past years: it has appeared as a practical technology during the 1980s developing rapidly (58% of the electricity generated in the USA by different industries was produced by cogeneration plants) following a decreasing trend around the 1950s (15% of the total generated potential) continuing its course reaching 5% in 1974. The increase of fuel prices, environmental pollution problems, and the focus of energy policies on efficiency determined an increasing trend both on a national as well as on an international scale.

The speciality literature found in the field follows the fluctuations of the technologic trend as nowadays there are papers which deal with theoretical, methodological as well as instrumental aspects regarding its exploitation [2 - 5] as well as papers with an increased applicative character [6 - 8].

The purpose of the present paper consists in creating a basis, focusing on a case study, for to the necessary steps required in order to justify the use of a gas cogeneration installation with a combustion engine destined for the supply with electricity and heat to the users of a certain company. The usefulness of the paper is justified by future financing plans which focus upon the increase of energetic efficiency and the reduction of the environmental impact through cogeneration. The method used consists of comparing the quantity and quality performance parameters for the 2 scenarios, namely the classical thermal energy capitalisation scenario and the cogeneration one. A decision concerning the installation of a cogeneration unit with a gas operated combustion motor may be taken based on the comparison and on the energy usage chronogram. Nevertheless, he should be skilled enough to make the difference between "what is happening?" and what "should happen?" in the work environment [9]. An energy usage chronogram shall be created as in [10].

2 Case study. Presentation

The analysed system makes reference to a company which is supplied with natural gas in order to ensure its demand for technological steam and hot water used for heating and consumption. In order to render the energetic source more efficient, to reduce the expenses as well as the environmental impact, the acquisition and installation of a cogeneration unit with a combustion engine is therefore proposed. (Figure 2).

Arguments for choosing the type of installation: The main component of the installation is a diesel engine which operates an electricity generator. The electric power of the unit is comprised between 25 and 5000 kW, the fuel used being gasoil. 70% of the heat from the burnt exhaust gases (at 500°C) can be recovered by cooling them down to 200°C. The heat of the cooling water and that of the lubrication oil (at approximately 100°C) may be fully recovered. The heat delivered to the consumers consists in hot water and steam.

The main indicators characteristic to the energetic balance of a combustion engine system are presented in Table 1:

Table 1. The characteristic indicators of the energetic balance of a combustion engine system [11]

	Otto	Diesel
Fuel consumption	100%	100%
Electricity production (α_e)	35%	40%
Heat production (α_t)	50%	43%
where: burnt gases	20%	21%
cooling water	30%	22%
Total efficiency	85%	83%
Central heating index -y-(cogeneration), [J_e/J_t], [kW _e /kW _t] [kWh/Gcal]	0.6...0.93 700... 1082	

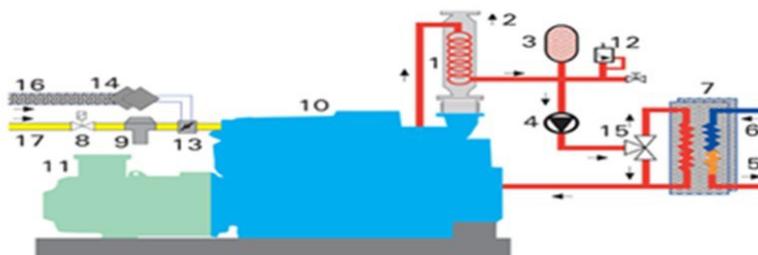


Fig. 2. Basic diagram of the cogeneration installation using an electricity generator group with a combustion engine, 1 – water – burnt gases heat exchanger; 2 – exhaust pipe; 3 – expansion tank; 4 – pump; 5 – hot water outlet; 6 – cold water inlet; 7 – water – water heat exchanger; 8 – closing valve on the gas fuel circuit; 9 – pressure regulator; 10 – internal combustion motor; 11 – electricity generator; 12 – safety valve; 13 – carburettor; 14 – air filter; 15 – thermostat; 16 – combustion air inlet; 17 – gas inlet.

The main economic indicators of different types of installations with cogeneration (internal combustion engine – CE, gas turbine – GT, steam turbine- ST) are presented in Table 2:

Table 2. The main economic indicators of different types of cogeneration installations

	CE	GT	ST
Specific investment, [EURO/kW _e]	1500...400	1200...530	1500...1000
Specific maintenance cost, [EURO/MWh _e]	20...5	7...4	2.3...1.5
Investment recovery period, [years]	2...3	2...3	3.5...4
Life span, [years]	10	15	30

The main principles considered while conceiving the solutions: dimensioning and operating the cogeneration is determined by the thermal criteria, in order to be cost efficient (with energetic economies sufficient enough to compensate the investment effort), they need to be used as more as possible considering as well higher loads (an operation span of over 4000 h/year may be considered as one of the basic rules which need to be respected).

The energetic performances of the gas operated electricity cogeneration group are presented in Table 3:

Table 3. Energetic performances of the gas operated electricity cogeneration group

Measure	Value
Gas thermal power	1446 kW
Gas flow	137 m ³ _N /h
Mechanical power at the shaft of the motor	620 kW
Electric power of the electricity generator	600 kW _e
The available thermal power of the steam generator	348 kW _t
The available thermal power for heating and hot water	320 kW _t
Electric efficiency	41.5 %
Thermal efficiency	46.2 %
Cogeneration efficiency	87.7 %
Cogeneration index	0.898 kW _e /kW _t

The obtained results are brought forward following the realisation of an hourly energetic balance:

- Used energy	1446 kWh – 100 %
- Useful energy	1268 kWh – 87.69 %
- Losses in the electricity generator	20 kWh – 1.383%
- Losses with the exhausted burnt gases	94 kWh – 6.501 %
- Losses with the reduced potential water	41 kWh – 2.835 %
- Radiation losses (engine, generator)	23 kWh – 1.591 %
- Total lost energy	178 kWh – 12.31 %

Calculation data

A. ACTUAL SITUATION

- Natural gas consumption for the thermal generators (steam and hot water) $C_{\text{gas}} = 174 \text{ m}^3_{\text{N}} = 1839 \text{ kWh}_t$;
- Thermic steam flow 930 kWh_t;
- Thermic hot water flow 730 kWh_t;
- Total thermic flow of the thermal generator 1660 kWh_t.

B. THE SCENARIO CONSIDERING THE USE OF A COGENERATION ELECTRICITY GENERATOR GROUP OF 600 kW_e

- Natural gas consumption for the electricity generator $137 \text{ m}^3_{\text{N}} = 1446 \text{ kWh}_t$;
- Electricity 600 kWh_e
- Thermic steam flow 348 kWh_t;
- Thermic hot water flow 320 kWh_t;
- Total thermic flow electricity generator group 668 kWh_t;

Additional calculation data

- The yearly operation period may be estimated within the interval: $\tau_{\text{an}} = 4000 \div 8760$ hours/year
- The price for one kWh of electric energy 0.304 lei/kWh [12]
- The price for one kWh thermal energy with gas 0.128 lei/kWh
- The price of one m³ of gas 1.35 lei/ m³
- The energetic equivalent of one m³ of gas 10.57 kWh
- Tonne of oil equivalent 1 t.e.p. = 11.627907 MWh
- Average value of the factor of CO₂ emissions for gas fuels in Romania $f_{\text{CO}_2} = 0.535 \text{ kg/kWh}$
- Investment cost 2 700 000 lei
- Maintenance cost 30 lei/hour.

3 Results

Based on the herein mentioned results, calculations for different operation periods during a year and for different loading degrees were carried out, obtaining the following performance parameters: the yearly economic actual energy, the yearly effective economy considering the cogeneration scenario, the investment recovery period and the reduction of the environmental impact.

In order to give an example, the operation period was set within the following range 4000-8660 hours / year, while the required load by the users considered 3 situations: 100% (668 kWh), 80% (534.4) kWh and 50% (334 kWh).

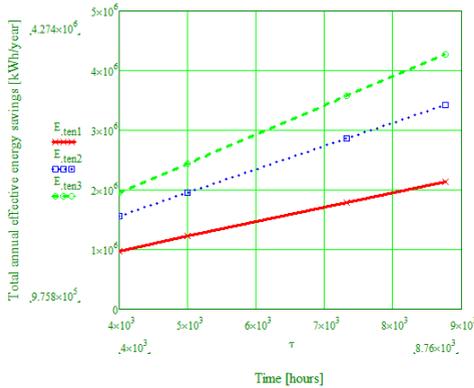


Fig. 3. The scenario in which the yearly actual economy depends on the yearly operation period, corresponding to the loads: 100%, (668 kWh), corresponding to the loads 100% (668 kWh), 80% (534.4) kWh and 50% (334 kWh)

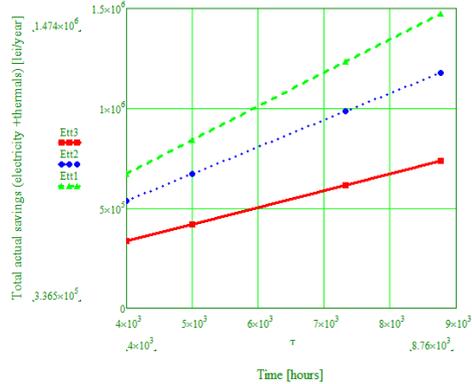


Fig. 4. The variation of the total actual electric and thermal energy economies depending on the yearly operation period

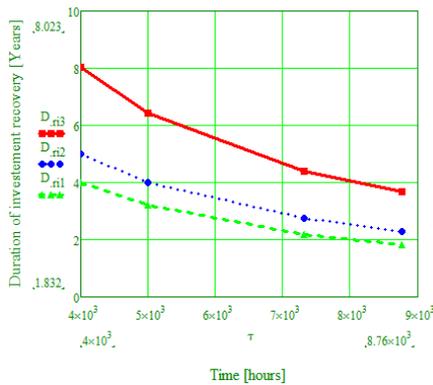


Fig. 5. The variation of the investment recovery period depending on the yearly operation period corresponding to the loads 100% (668 kWh), 80% (534.4) kWh and 50% (334 kWh)

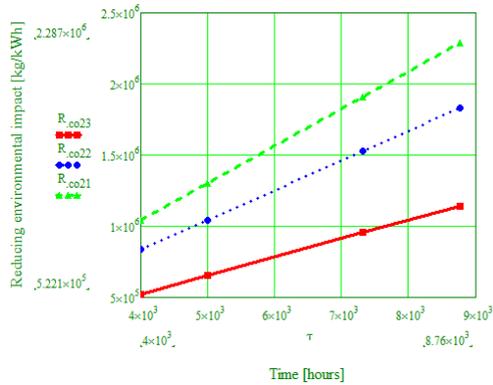


Fig. 6. Environmental impact reduction depending on the yearly operation period corresponding to the loads 100% (668 kWh), 80% (534.4) kWh and 50% (334 kWh)

The previously presented diagrams highlight the energetic, economic and environmental performances depending on the yearly operation period and the loading demand of the final beneficiaries, namely the users.

Figures 3-6, highlight the fact that the optimum performances are obtained for larger operation periods. Considering Figures 3, 4 respectively 6, the values obtained for an 80% load may be increased considering the increase in efficiency for the said load.

Considering Figure 5, a correction may be introduced according to which, towards the maximum limit of the operation period, the investment recovery might become more favourable due to the increase of the loading efficiency, namely that of 80%.

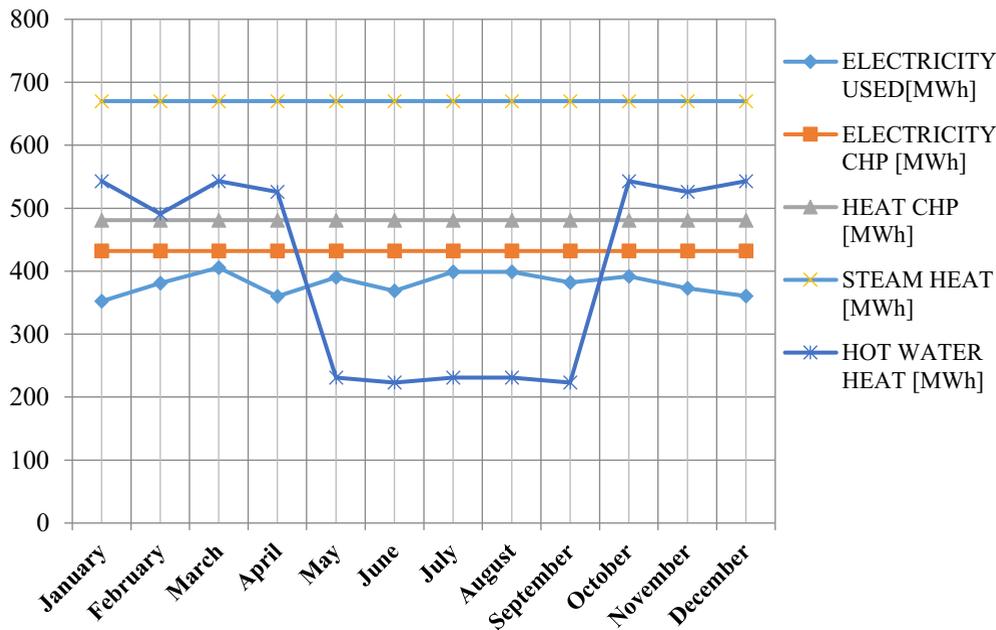


Fig. 7. Energy usage chronogram

4 Conclusions

The energy usage chronogram for the case dealt within Figure 7 highlights the following:

- the available electricity at the cogeneration installation fully covers the demand of the company;
- during the cold season, the thermal energy available at the cogeneration installation fully covers the hot water demand, the steam demand being covered by the steam generator existent within the company;
- during the warm season there is a thermal energy surplus which can be capitalised through the water supplying the steam generators or through the use of a recovery steam generator.

The solutions mentioned capitalise the cogeneration advantages determined by the quasi-continuous yearly operation.

The solution used to render the cogeneration group more efficient is proposed considering the energy usage chronogram.

References

1. A. Leca, C. Cremenescu, *Serviciul public de încălzire centralizată. Propuneri de eficientizare*, (AGIR Publishing, 2008)
2. V. Athanasovici, *Tratat de inginerie termică-Alimentări cu căldură - Cogenerare* (AGIR Publishing, 2010)
3. B. Kolanowski, *Small-scale Cogeneration handbook* (Lulu Press, Inc, 2013)
4. J. Orlando, *Cogeneration Design Guide* (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1996)
5. T. Lipper, H. Setetter, P. Krzyslak, Proceedings of the Xth Int. Conf. "Steam and Gas Turbines for Power and Cogeneration Plants", Karlovy Vary, Czech Republic, 178, 1 (1994)
6. *** *Studiu de fezabilitate pentru centrala termică de cogenerare pe bază de biomasă lemnoasă* (National Research Institute for the Development of Electric Engineering ICPE-CA, 2010)

7. *** http://www.sistemecogenerare.ro/continut/tehnologii-cogenerare_ Accessed 14.03.2017
8. *** *Cogenerarea de mica si medie capacitate OPET* (Organization for the Promotion of Energy Technologies, 2002).
9. R. I. Moraru, G. B., Babut, L. I. Cioca, *Environmental Engineering and Management J.*, **13**, 6 (2014).
10. D.C. Petrilean, S.I. Irimie, *J. of Environmental Protection and Ecology*, **16**, 3 (2015).
11. D. C. Petrilean, S. I. Irimie, *J. of Environmental Protection and Ecology*, **17**, 4 (2016).
12. V. Pasculescu, S. M. Radu, D. Pasculescu, T. Niculescu, *Proceedings of the 13th SGEM GeoConference on Science and Technologies in Geology, Exploration and Mining, Albena, Bulgaria*, 417, **1** (2013).