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COMPARATIVE STUDY OF TWO TRIGENERATION SOLUTIONS

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ABSTRACT

The paper provides an analysis of the concept of trigeneration in two variants of the fuel used. The study of the phenomenon is carried out on an external combustion engine operating with natural gas/natural gas and biomass. The technical-economic and energy-ecological efficiency are highlighted in a report of the energy analysis study for each analyzed situation. The results consist of overall efficiency of up to 90% and are achieved by reducing the cost of energy bills up to 60%. The technical and economic impact obtained by using trigeneration is amplified by the use of green fuels in the process.

KEYWORDS: trigeneration, external combustion engine, technical and economic impact, overall efficiency, green energy

1. TRIGENERATION CONCEPT

Currently, there are studies and analyzes regarding the choice of the optimal solution for ensuring comfort in the conditions of achieving a favorable technical-economic and energy-ecological efficiency. This objective is achieved by using the heat produced in some installations that burn fuel both for the process of generating electricity and for technological or domestic hot water heating purposes. The result is called cogeneration. When the installations are coupled refrigeration installations with thermochemical compression, additional thermal energy of low potential is obtained. The process is called trigeneration.

The determination of technical efficiency is made by using a single analysis contour for the simultaneous production of three forms of energy: electricity, heat and cooling by thermochemical compression. The installation consumes conventional gas and/or liquid fuel, which, after combustion, generates combustion gases that settle in a gas turbine. The axis of the turbine is coupled to the axis of a synchronous generator, which generates electricity in the energy system. As a result of the processes that take place during the engine cycle, there is also a quantity of heat stored in the flow of water in the steam turbine, which is used for technological purposes, in district heating or for the supply of domestic hot water.

If we are talking about a trigeneration system, then the heat of the water flow resulting in the back pressure (at the exit of the turbine) is partially used in a reverse cycle installation (heat pump or refrigeration plant) (Fig.1).

The economic efficiency of the solution is increased because on the same fuel consumption, three types of energy are produced simultaneously instead of one, as in the case of thermal or electric power plants.

2. ENERGY ANALYSIS OF A TRIGENERATION PLANT-EXTERNAL COMBUSTION ENGINE OPERATING WITH NATURAL GAS

2.1. Analyzed contour determination

The trigeneration plant has a combustion chamber which is supplied from the gas source. Here, after combustion, a flow of gas occurs which is detented in the gas turbine. The turbine is also connected to an electric generator. The hot gas is then captured in a heat recovery boiler, on the basis of which the space and water in a house are heated and then, steam is also produced, which is relaxed in a steam turbine, producing electricity. Another part of the heat in the boiler is used in a refrigeration plant to cool the air in an enclosure. The comparative energy analysis of this work is made on the basis of classic concept (Fig.1) and real measurements [1].

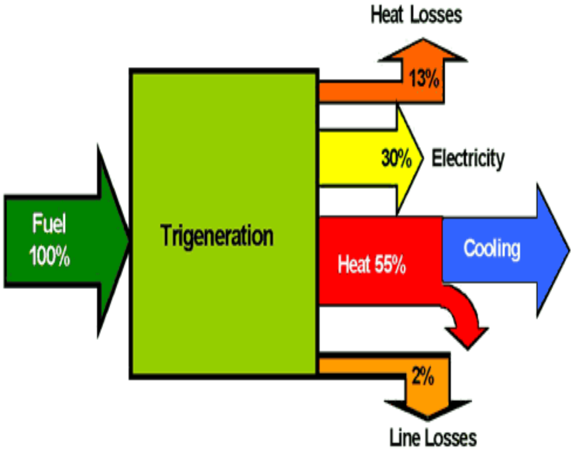


Fig. 1 Trigeneration concept

2.2. Energy analysis of the contour

Following the analysis of the energy balances related to the trigeneration installation, we obtain real measurable conclusions, noted in the technological sheet of the process.

Among the conclusions that can be drawn, we mention those regarding the produced electric power (has values between 950 kW and 1150 kW, that is, an average load of 90%), delivered thermal power (having values between 1050 kW and 1200 kW, that is, a take-over percentage of 72-82%), electric efficiency (values between 40,5% and 41,3%, with an average value of 40,7%), thermal efficiency (values 10% lower than the nominal values, between 37,8% and 33,8%) (Fig.2).

From the process technology sheet, for a period of 18 months, we can conclude features related to: monthly electricity (having values between 720 and 850 MWh/month, and an average value of 800 MWh/month), thermal/monthly energy will have divergence values, thus during winter, it will take values between 500 and 750 Gcal/month and during the warm period of the year, it will reach limit values of 300-350 Gcal/month), average consumption of combustible (falling within the range of values guaranteed by the technical documentation of the trigeneration groups).

It is appreciated that, from this point of view, the trigeneration plant is operated under optimal conditions. Due to monthly variations in thermal energy, the average overall efficiency reaches about 73%, over than 13% less than the nominal load equivalent value (Fig. 2).

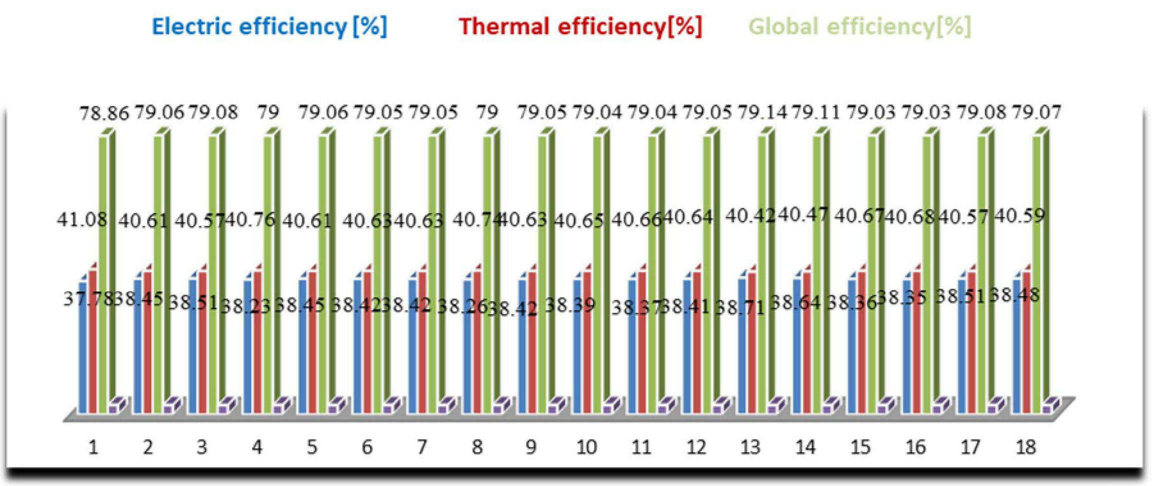


Fig. 2 Monthly variations of efficiency/consumption

3. SOLUTIONS TO INCREASE THE ENERGY EFFICIENCY OF THE TRIGENERING INSTALLATION WITH FOSSIL FUEL (GAS)

The increase in energy efficiency is achieved by: over fueling the engine, by increasing the volume of the combustion boiler, by the most advanced recovery of the residual heat.

- Overfeeding is the process of increasing the inlet pressure of the turbine blades by increasing the specific mass of steam/gas or fuel mixture in the combustion boiler. The oversupply, which may be either total throughout the intake phase, or partial over a fraction of it, is due to the increase in inlet pressure, by means of turbochargers, centrifugal, axial, volumetric compressors. The thermodynamic efficiency of the turbine and implicitly the electric one by driving a generator reaches values of 42-44%.

- The increase in the volume of the combustion boiler is achieved by modifying the architecture of the combustion chamber and the turbines in order to leave space necessary for the formation and circulation of gas or steam.

- The waste heat is recovered from the cooling systems of the heat recovery boiler, and the judicious use of the heat of the flue gases discharged from the combustion boiler leads to the increase of the efficiency of the thermodynamic cycle. The highest efficiencies are obtained in the case of installations where the entire amount of heat in the form of hot water is recovered (at a temperature level of 70-90 ^{o}C). In case of separation of heat recovery (from the turbine cooling water and from the flue gas in a steam-processing recovery boiler), the thermal level of the flue gas is discharged into the atmosphere, and it increases significantly (the temperature of the flue gas can reach 150-180^{o}C). In this case, the degree of heat recovery and implicitly the thermal efficiency of the installation is reduced (60-68% compared to 95% obtained by heat recovery).

In the second situation, the use of the rated powers and the times of use of the trigeneration at a higher level than the previous one, leads to the increase of the annual global efficiency, that is, to reduce the recovery time of the initial investment [2]. Some of the practical technical methods used are to reduce the physical heat of the flue-gases before discharging into the atmosphere, to recover the physical heat of the cooling water of the engine sub-assemblies, to reduce the cost price of the thermal energy, far below the delivery of the centralized heat supply system.

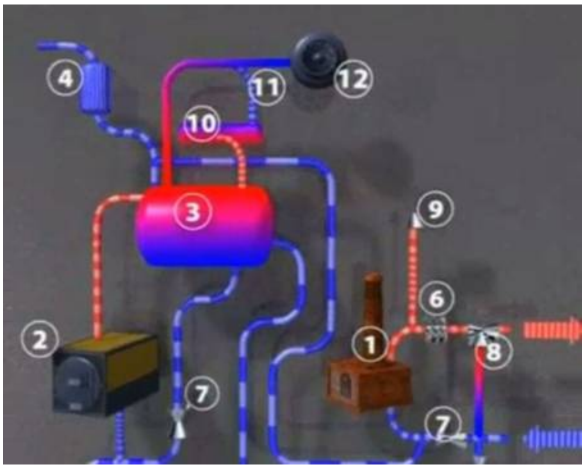
This leads both to the normal operation of the installation and to increasing the trigeneration degree.

4. THE ENERGY IMPACT OF BURNING A MIXTURE OF FOSSIL FUEL AND BIOMASS

A particularly important aspect of energy production under its various forms is the one related to environmental protection. Under current conditions, the aim is to combine economic and environmental benefits [3].

In this regard, trigeneration plants are developed in which conventional fuel consumption is reduced by supplementing it with green fuel such as biomass. The previous study carried out on an external combustion engine operating in a trigeneration regime, located within a company, opened the way for a discussion about the possibility of burning a fuel, gas-biomass mixture, as in figure 3.

The proposed installation is an alternative to the one on which the research was conducted. Figure 3 shows that the feeding water is directed to the steam boiler supplied with natural gas. From the boiler, the superheated steam is pumped into the turbine, connected to a synchronous generator. On the return circuit, after expands into the turbine, the feed water is preheated based on the heat obtained by burning biomass, in boiler 2, with the opening of the valve 7. Pre-heating of the feed water leads to the improvement of the efficiency of the installation and implicitly of its economic efficiency. The recovery of heat on the turbine counterpressure is done as in the case of the previous installation, for technological purposes, in district heating or for the supply of domestic hot water and also partially used in a reverse cycle installation (heat pump or refrigeration plant) [4].



No.	Equipment
1	Boiler (gaz)
2	Boiler (biomass)
3	Water tank
4	Expansion tank
5	Pressure regulator
6	Pomps
7	Valve on/off
8	Valve out
9	Drain valve
10	Hot water tank
11	Relief valve
12	Fan

Fig. 3 Trigeneration plant gas-biomass

Biomass resources can be diverse: agricultural residues (straw), wood waste from forestry and industry, residues from food and paper industry, solid clean municipal waste, dedicated energy crops and old oak wood.

5. CONCLUSIONS

It has been proven that from a technical, economic, energy and environmental point of view, trigeneration brings considerable advantages. But both the efficiency of the cogeneration and trigeneration concepts can be improved by integrating renewable energy into the system, which leads to reduction of carbon emissions but also to increasing the efficiency of installations. Trigeneration allows 75-80% to 90% of the most efficient fuels to be converted into useful energy.

Unlike these concepts, simple generation leads to a global efficiency of only 35-37%.

Even the latest technologies could not exceed the 45% threshold.

Trigeneration, using both fossil and renewable fuels, enables additional benefits to be obtained over the separate production of electric and thermal energies. These benefits include reducing emissions of carbon dioxide and other pollutants, increasing energy security by reducing imported fuel, cost savings for the energy consumer, reducing the transmission network, and making good use of local energy resources (especially through the use of waste, biomass).

The conclusion of the comparative technical-economic study of the processes of trigeneration with fossil fuel and the fossil and biomass mixture, is that the operating principles of the concepts are respected over time and the improvement of the qualitative characteristics of the elements makes each alternative find an efficient and perfectible solution. In other words, biomass is an additional way of increasing the amount of energy, but it is not always qualitatively equivalent to the energy obtained by using fossil fuels (the pressure is lower, the temperature of the heated enclosure is lower).

REFERENCES

[1] **Diaconescu, I., Patrascu, R., Tutica, D., Ionescu, C., Minciuc, E.**, *Influence of technical and economic factors in the assessment of energy efficiency projects in industry,* International Conference on ENERGY and ENVIRONMENT (CIEM), IEEE, Timisoara, October, 2019.

[2] **Costinas, S., Diaconescu, I., Ioana Fagarasanu, I.,** *Wind power plant condition monitoring* , Proceedings of the 3rd WSEAS International Conference on Energy Planning, Energy Saving, Environmental Education (EPESE'09), Canary Islands, Spain, 2009.

[3] **Pătraşcu, R., Bădicu, A., Minciuc, E., Diaconescu, I., Necula H.,** *Integration of renewable energy sources for industrial consumer,* U.P.B. Sci. Bull., Series C, Vol. 79, Iss. 3, 2017.

[4] **Diaconescu, I.,** *Analysis of Irreversible Thermodynamic Processes from Control Valves*, Proceedings of the 3rd WSEAS International Conference on Energy Planning, Energy Saving, Environmental Education (EPESE'09), Canary Islands, Spain, 2009.