Increasing the Operational Efficiency of a Heat Engine Plant Through Implementation of Trigeneration

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***Abstract*— This paper discusses how to increase the efficiency of a plant by implementing a trigeneration solution. There have been analyzed two refrigeration technologies: compression and absorption. Since the purpose of the district heating plant is to use the heat engines to produce as much electricity as possible, which will further be sold, and to utilize the available thermal energy, the implementation of an absorption trigeneration solution has been proven to be viable. The analysis of the load duration curves showed a thermal potential of approximately 2.9 MW that could be used in an absorption installation for the production of cold. The resulting amount of cold is about 1.7 MW and will be used in a vegetable and fruit storehouse near the plant to keep the temperature in the range of 4-6 ° C.**

***Index Terms*--CHP, district heating, heat losses, Tri-generation**

I. Introduction

Operating in cogeneration is a method of increasing the overall efficiency of a plant, through total or partial use of residual heat, otherwise lost to the atmosphere.

In this paper, the authors analyze the solutions which can be developed in case of a combined heat and power producer which aims to sell the most possible quantity of the electrical energy produced by the heat engines and at the same time, to make use of the available excess heat occurring as a result of lower demand, through implementing a trigeneration solution. There are various types of consumers who have a cooling demand, such as city halls, hospitals, fruit warehouses [1]-[3].

The combined heat and power plant is equipped with: 1) two heat engines by Rolls-Royce, type B35:40 V16AG2, with 6800 kWel power output and the electrical efficiency of 47.22%; The flow of flue gases at the outlet of the turbocharger is 39500 kg/h, with a temperature of 350 °C. 2) a hot water boiler (CAF 1) of 58 MWt (50 Gcal/h) and a steam boiler (CA 1) of 10 t/h, which produces steam at the pressure of p=10 bar and the temperature of t=176 °C, to cover the internal steam demand and for the preparation of added water for the heating circuit of the plant.

During the summer period, the heat engines operate according to the load curve to cover the heat demand for the domestic hot water preparation and during the winter period, the engines operate at full load, to cover the demand for heating and domestic hot water preparation. Hot water boilers complement the heating load to cover the heat demand in winter.

A problem that the plant faces with is that, although there are periods of time when selling the electricity is profitable, due to the decreasing of heat demand, there is excess heat which appears when operating the engines at nominal parameters. In these circumstances, during the summer time, one of the two heat engines is stopped. A solution to this problem entails the implementation of a trigeneration application in accordance with the available heat potential.

II. Process Description

Description of trigeneration solutions

The overall concept of a trigeneration plant depends on the operating principle of the refrigeration plant. There have been analyzed two refrigeration technologies: compression and absorption.

A. Compression refrigeration system

Fig. 1 shows a simplified diagram of a trigeneration plant which uses a compression refrigeration system to produce the cold.

In a plant as such, the compressor of the refrigeration system can be directly connected to the engine or it can be driven using the electric power produced by the engine. By connecting the compressor directly to the engine, the energy losses afferent to an electric generator will be excluded, however in this case, the refrigeration system will require to operate throughout the operation of the engine [4], [5]. The complete separation of the refrigeration system from the thermal engine has the disadvantage of introducing energy losses in the electric generator. Instead it is completely autonomous and can operate independently.

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This solution has a disadvantage related to the consumption of electricity for the production of cold, but the amount of cooling agent of the refrigeration plant is lower than that of the absorption refrigeration plant and the average cooling coefficient is around 5.

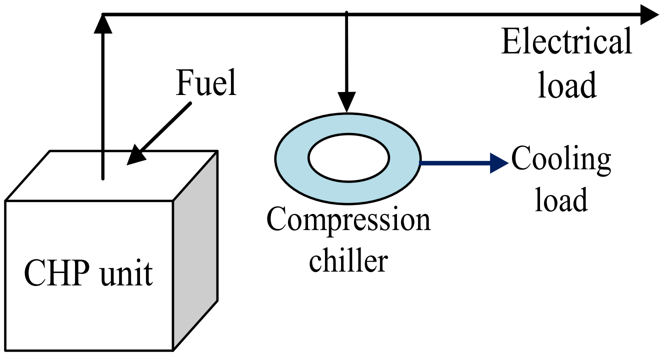

Figure 1. Compression refrigeration system

B. Absorption refrigeration system

Absorption refrigeration systems account for about 10% of all cooling technologies, with a high potential for future development [6]. The main advantage of this technology comes from the fact that any residual heat can become a source of energy for the system, such as heat from cogeneration, waste incineration plants, etc. [7].

Fig. 2 shows a simplified diagram of a trigeneration plant which uses an absorption refrigeration system to produce the cold. In this case, the cold is produced by using a part of the thermal energy produced by the plant. In contrast to the previous solution, this system does not use electricity to produce the cold, but it requires a larger quantity of cooling agent and the average cooling coefficient is around 1.

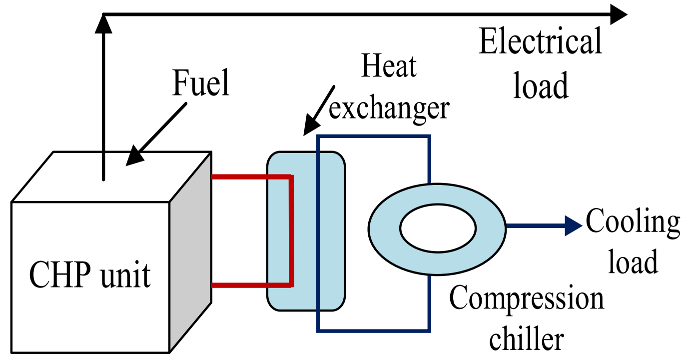

Figure 2. Absorption refrigeration system

III. Results And Discussion

Determination of thermal potential

Following the analysis of the plant operation, the thermal load duration curves were drawn, as can be seen in Fig. 3, showing an important potential for thermal energy that could be used in the trigeneration plant during the summer.

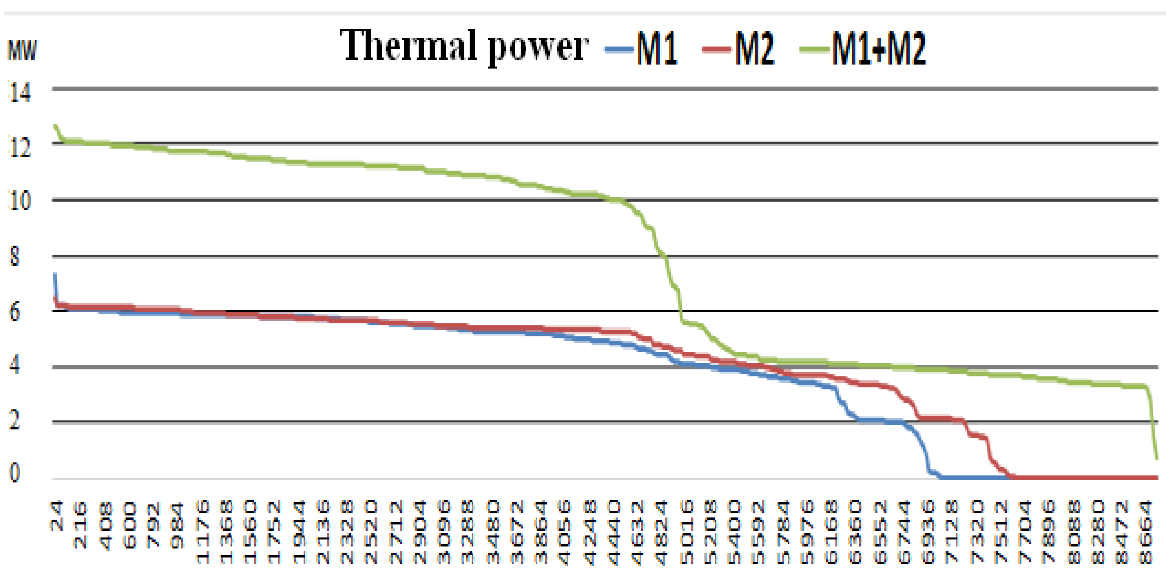

Figure 3. Thermal load duration curves

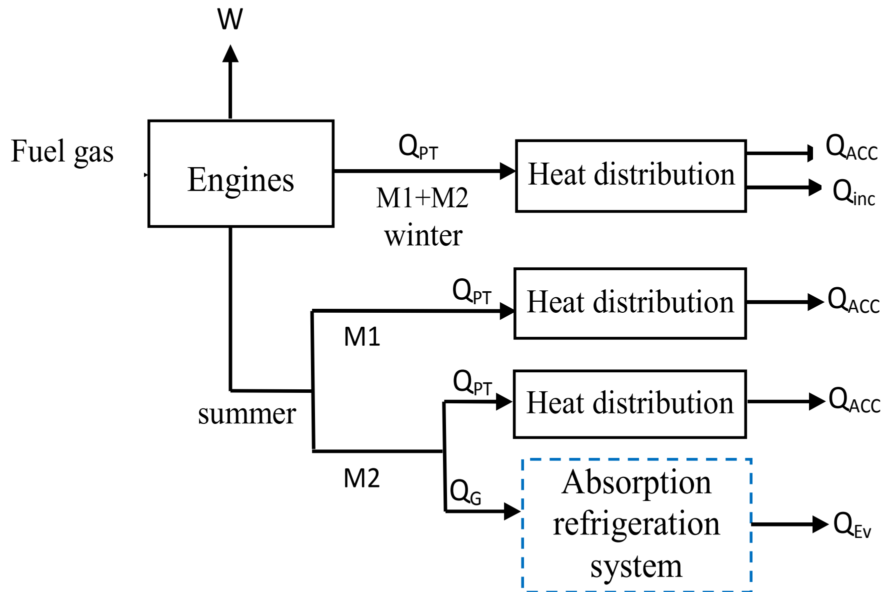

Figure 4. Integrated diagram of the system

Operating the absorption cooling system implies the thermochemical compression of the refrigerant, by using a binary mixture, which requires heat consumption [8], [9]. The proposed solution is to integrate an absorption cooling system, which uses the heat potential of the flue gases, as can be seen in Fig. 4.

Where: W - electrical energy;

Q_{PT} - heat for the heating substation;

Q_G - heat for a cooling system;

Q_{inc} - heat for the heating water circuit;

Q_{ACC} - heat for the domestic warm water circuit;

Q_{Ev} - cold produced.

In Fig. 4, the electrical energy production is noted as W, while the heat production is noted as Q_{th-rec}, as seen in equation 1. The heat recovered from the engines during winter time Q_{PT} is transported to a heating substation for the preparation of the heating agent and the domestic warm water. During summer, Q_G is transported towards the generator of an, where Q_{EV} cooling is produced.

$$Q_{th-rec} = Q_{PT} + Q_{EV} \tag{1}$$

In case of the trigeneration solution, there has been determined the amount of cold Q_{EV} which can be produced, considering the available heat potential Q_G, the energy consumption for pumping P and the coefficient of performance COP of the absorption cooling system, as shown in equation 2.

$$COP = \frac{Q_{Ev}}{Q_G + P} \tag{2}$$

The trigeneration solution entails that one of the engines, which is otherwise off due to low heat consumption, will be operating during the summer. The thermal potential which could be used in an absorption cooling system is approx. 2.9 MW. This potential was calculated from the data measured and presented in Table 1, considering a COP of the absorption refrigeration installation of 0.6.

TABLE I. THE CHARACTERISTICS OF ENGINE

Temperature of flue gases	**350 °C**	**100°C**
Volumetric flow	28000	m^3N/h
Density	0.5672	kg/m^3
Mass flow	10.97	kg/s
Specific heat	1.0724	kJ/kgK
Power	2941.65	kW
COP	0.6	-
Cold	1764.99	kW

If the coefficient of performance of the cold production plant increases from 0.2 to 1.2, a significant amount of cold production can be achieved, from 0.5 MW to 3.5 MW, as shown in Fig. 5.

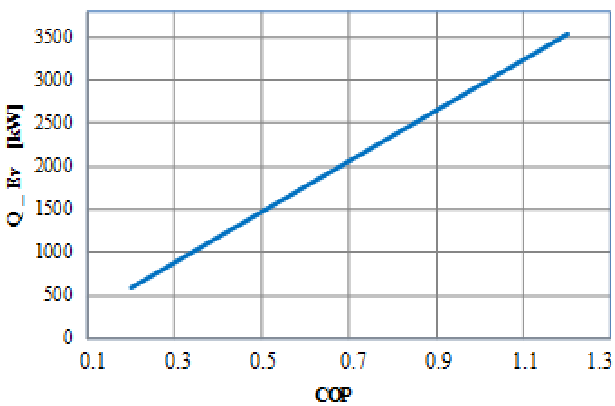

Figure 5. Variation of cold depending on COP

In this case, there will be analyzed the possibility of producing the cold close by the plant by supplying it to a warehouse/storage facility for fruits and vegetables. A remote consumer would imply analyzing the transport system, which would allow the circulation of the high temperature agent.

The optimal trigeneration solution is based on Lithium Bromide, since it does not require specific technological equipment, the latent heat of vaporization of water is high, the agent is not toxic, and the pressure in the system is low. As a disadvantage, the system requires special seals, to maintain the pressure.

IV. CONCLUSIONS

The proposed trigeneration solution allows for the plant to operate both engines during summer, thus producing electricity in a profitable way and making use of the heat potential by harnessing it in an absorption equipment to produce a significant amount of cold (approx. 1.7 MW), to be consumed. Considering this aspect regarding the operation of the district heating plant, the optimal solution for providing the cold was chosen to be the absorption refrigeration system, which uses the thermal energy recovered from the engine, supplying electricity to the national power grid.

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