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Exploitation of low-temperature energy sources from cogeneration gas engines

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ABSTRACT

This paper describes an original and innovative technical solution for exploiting low-temperature energy sources from cogeneration gas reciprocating engines installed within district heating systems. This solution is suitable for those systems in which the heat is generated by the use of reciprocating engines powered by gaseous fuel for combined heat and power production. This new technical solution utilizes low-temperature energy sources from a reciprocating gas engine which is used for a combined production of heat and power. During the operation of the cogeneration system low-temperature heat is released, which can be raised to as much as 85 °C with the use of a high-temperature heat-pump, thus enabling a high-temperature regime for heating commercial buildings, district heating or in industrial processes. In order to demonstrate the efficiency of utilizing low-temperature heat sources in the cogeneration system, an economic calculation is included which proves the effectiveness and rationality of integrating high-temperature heat-pumps into new or existing systems for combined heat and power production with reciprocating gas engines.

1. Introduction

Over recent decades there has been substantial effort across the entire planet Earth for cleaner air and the reduction of greenhouse gas emissions. Various agreements and protocols have been signed relating to environmental issues. Energy consumption control in Europe and greater utilization of energy from renewable sources, together with energy savings and increased energy efficiency, are an important part of the package of measures needed to reduce greenhouse gas emissions and to comply with the Kyoto protocol in accordance with the United Nations framework convention on climate change and the subsequent Community obligations and international commitments to reduce greenhouse emissions after the year 2012. The European Community has pledged that cost-effective renewable sources for heating in Europe have to represent at least 20% of all energy sources used.

With the development of techniques and the growing demand in the world for energy, which is still mainly produced from non-renewable sources, the combustion of which ecologically burdens the environment, in accordance with the guidelines of the EU (European Union) and the adoption of new legislation, greater emphasis is being given today on the exploitation of renewable energy sources [1–3]. Focus is on the rational use of energy and the energetic self-sufficiencies of commercial and public buildings with all kinds of energy (electricity, the heat and the cold).

There are few studies regarding the coupling of high-temperature heat-pumps and cogeneration engines. An experimental study was done in order to enhance the heating capacity of an electric heat pump using heat recovered from a gas engine generator [4]. Mancarella presented an approach for energy and CO_2 emission modeling of cogeneration systems coupled to electric heat pumps [5] Blarke and Dotzauer [6] developed a novel cogeneration concept with a compression heat pump and cold storage using flue gas heat. Similar concepts were presented in Ref. [7], where Blarke compared an electric boiler and heat-pumps in regard to distributed cogeneration in West Denmark. Capunder et al. [8] introduced an optimization model for evaluating the techno-economic and environmental characteristics of different multi-generation options.

The goals of the presented ideas on the exploitation of low-temperature energy sources in cogeneration gas engines in this paper are the following:

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– To determine a new comprehensive technological solution for the efficient and smooth operations of existing conventional CHP plants, including a new technological solution which uses the exploitation of low-temperature energy sources in cogeneration gas engines to produce a greater quantity of usable heat for the needs of high-temperature heating;
– To maximize the overall efficiency of cogeneration gas engines;
– To select a technologically and economically optimal high-temperature heat pump.

The study is based on:

– The need for more efficient energy use in the production of heat for district heating systems, as today's energy efficiency is limited mainly to the insulating of pipes in district heating and efficient energy use by the end-user,
– The need to utilize low-temperature waste heat from a cogeneration gas engine, which is discharged into the environment and is here represented as a low-temperature energy source for the high-temperature heat pump,
– Desire to make a contribution to reducing CO_2 emissions into the environment with parallel substantial economic savings,
– The requirement for satisfying the recommendations and requirements of the EU's efficient use of energy and environmental protection.

2. The conventional cogeneration device and its operating parameters

A cogeneration device allows simultaneous production of useful heat and electricity within one unit. The device converts the chemical energy of fuel by using a steam turbine, gas turbine or internal combustion engine that, with use of a generator, converts energy input via mechanical energy into electricity. A bi-product from this process is also usable heat that is used for high-temperature heating and low-temperature waste heat, which is discharged through the cooling system and the exhaust system into the environment [6,7].

The need for the operation of a cogeneration plant is affected by the time of year, outside temperature and the individual specific requirements of end-users. The mode of operation varies accordingly and is adapted to the current needs for useful heat and electricity output. With regard to the amount of usable heat and electricity, there is also a proportionate share of low-temperature waste heat produced.

As a part of the study, data were obtained on the functioning of the real cogeneration device manufactured by Ref. [9]. Fig. 1 shows a cogeneration gas internal combustion engine with the intercooler 1st stage, ICE (the oil and crankcase cooler), G (the generator), HE1 (the flue gas heat exchanger), CT (the cooling tower) for the cooling of the intercooler 2nd stage (HE2) and optionally the lube oil cooler 2nd stage.

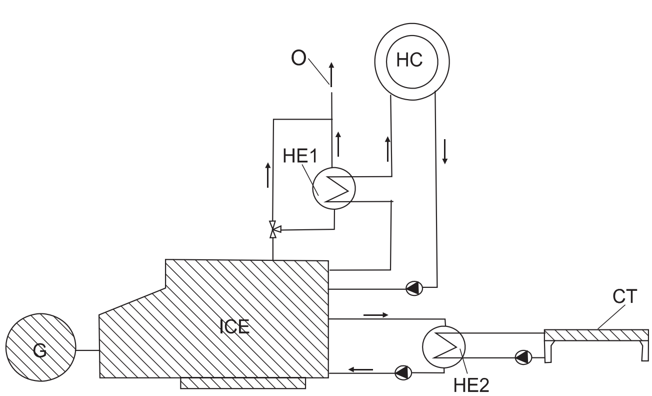

Fig. 1. Cogeneration plant integrated within a high-temperature heating system.

The whole system regarding exploitation of the high-temperature heat flow of the cogeneration plant [9] and the low-temperature cooling system, is shown in Fig. 2.

The rated power of the cogeneration plant [9] and other data are provided in Table 1. The estimated operating time of the cogeneration plant depends on the needs of heat consumers, which in this case amounts to ca. 4000 h/annum. The operation mode of the district heating network or a HC (heat consumer) during winter is 90/60 °C, and during summer 90/55 °C.

2.1. Waste heat from the gas engine of the cogeneration plant

Waste low-temperature heat from the gas engine of the cogeneration plant is unused and discharged into the environment in several different ways, the more common of which are the following:

– Flue gas heat with a temperature of 120 °C, which is discharged through the exhaust system of the cogeneration unit into the environment. During the operation of the cogeneration gas engine, hot flue gas with a temperature of about 365 °C is discharged into the heat exchanger HE1 (Fig. 1), where it is cooled to a temperature of 120 °C and then discharged into the environment. Flue gas with a temperature of 120 °C, which is discharged into the environment, represents significant low-temperature energy potential.
– The heat of the external cooling system (CT) of the cogeneration gas engine. The cooling system is used for cooling compressed air during the intercooler 2nd stage. During this the intercooler 2nd stage transfers the compressed air heat to a mixture of water and glycol, which is heated to 45 °C and is led to an air cooling system CT, where it is cooled to 40 °C. The heat flux of the cooling system (CT), which is discharged into the environment as a waste low-temperature heat, is 197 kW.

In order to be able to exploit the low-temperature heat of the exhaust gas with a temperature of 120 °C, it is a requirement to install the condenser heat exchanger HE3 (Fig. 6) into the exhaust system of the gas engine, where the flue gasses are expected to be cooled to a temperature of 25 °C. For this purpose, a computer simulation of the cooling exhaust gases was made using the Aspen plus software, the results of which are shown in Figs. 3 and 4.

The diagram in Fig. 3 represents the heat flux obtained with an additional cooling of the flue gasses from the cogeneration device, the specifications of which are presented in Table 1, where the flue gasses are first cooled from a temperature of 120 °C to a temperature of 46 °C, at which the water starts condensing from the flue gasses within the condenser heat exchanger HE3 (Fig. 6). Fig. 4 presents the mass flow of the condensed water from flue gas depending on the temperatures of the flue gasses.

3. High-temperature heat pump

A pilot project for developing a high-temperature heat pump with a rated power of 500 kW_{th} was implemented within the framework of the Laboratory of Thermo-energetics at the Faculty of Chemistry and Chemical Engineering, University of Maribor, together with the manufacturer of compressors [10], for the needs of the geothermal district heating in Lendava. The high-temperature heat pump is now a serial product [10]and can reach