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Application of biomass-powered stirling engines in cogenerative systems

M. Szewczyk, T. Trzepieciński

Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology,
ul. W. Pola 2, 35-959 Rzeszów, Poland, szewmar@prz.edu.pl, tomtrz@prz.edu.pl.

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Abstract. Due to the properties of different kinds of renewable energy as sources of energy for small farms in Podkarpackie province, cogenerative biomass technologies have proved the most suitable for its supplying. Special solutions based on direct combustion boiler coupled with biomass-powered Stirling engine are the most interesting. The characteristics and examples of use of cogenerative system based on Stirling engine are presented.

Key words: biomass use, CHP, cogenerative system, Stirling engine

INTRODUCTION

Limited resources of energy, risks connected with emission of pollutants and greenhouse gas and low efficiency systems of thermal energy transmission lines require exploration of other methods of generation, transmission and consumption of electric and thermal energy. One of the solutions of this problem is the idea of generating electric and thermal energy directly in a house. A special system of combined heat and power for the home (CHPH) is utilized in a single-family home [1, 2]. Application of CHPH improves the degree of thermal energy utilization and eliminates transmission loss of thermal and electric energy. In spite of lower efficiency of electric energy generation, the total efficiency of CHPH is higher than large electrical power systems. Combined heat and power for the home systems raise power engineering safety, reduce power demand and facilitate energy usage from renewable resources. As a source of primary energy a natural gas, liquefied gas, oil derivatives, biogas and biomass may be utilized.

Considering effectiveness of application of renewable energy sources in agricultural tourism farm several assumptions should be made [3, 4]. From the point of view of possibility of RES utilization, the most interesting is the case resulting from location, or ecological assumptions and also the lack of access to traditional direct energy carrier, network energy in particular. It can lead to the necessity of assurance of energy self-sufficiency in respect of electric and thermal energy delivery.

Combined Heat and Power (CHP) is the sequential or simultaneous generation of multiple forms of useful energy (usually mechanical and thermal) in a single, integrated system. Cogenerative systems enable production of thermal and electric energy in association with gas engine, Rankine engine, mictoturbine, Stirling engine and fuel cell. Rankine engine allows for utilization of discard energy with temperature above 100°C and offers power in range from 10kW to a few MW [5]. Cogeneration allows for an increase of total efficiency of system up to 85% in relation to primary energy. Furthermore, this ensures about 35% fuel energy economy in comparison with separable generation of energetic carrier [6]. The additional advantages are minimization of transmission loss in cooperation with distribution network and low emission of greenhouse gases. The reduction of CO_2 decreases by up to 0,5 kg per kWh produced energy. Modular installations enabling to utilize discard energy include, besides Rankine and Stirling engines, steam engine and helical steam engine. Systems utilizing chemical energy of biofuels and biogases for associated production of thermal and electric energy like gas engine, Elsbett engine, Ericsson engine allow for a considerable reduction of the cost of enterprise energy balance and greenhouse gases emmission.

The fundamental issue in using any energy source is its accessibility. In case of some biomass technologies, the natural sources and industrial wastes can be utilized. However, not all technologies tolerate each form of the biomass. Not too much efficiency of photosynthesis in comparison with other technologies of solar radiation processing cause the necessity to establish special plantations of energetic plants.

STIRLING ENGINE

Stirling engine processes heat into mechanical energy without explosive combustion process. The heat is supplied to working medium through the heating of the external wall of a heater. As a result of external heat provision, it is possible to supply the engine's primary energy practically from any source: wood, coal, biomass, oil derivatives. Stirling engine is composed of two cold and warm pistons, regenerative heat exchange and heat exchangers between working medium and external sources (Fig. 1).

The external combustion facilitates monitoring of combustion process and causes that the process is pure and more efficient. The essential part working in circulation is the regenerator that transfers heat from working medium flowed between the heating and cooling space.

The characteristic feature of Stirling engine is utilization of heat for heating up of working gas in the cylinder. The heat regeneration occurs under conditions of constant gas volume inside closed working space of the engine. Recovered heat in heat exchanger is used for heating running water and habitats in household. The theoretical cycle of Stirling engine operations is composed of a few thermodynamic processes (Fig. 2). During the Stirling process, the thermodynamic medium being ideal, the gas is subjected to four thermodynamic processes in turn. Stirling cycle is composed by constant volume heating process, isothermal expansion process, constant volume cooling process and isothermal compression process. As a heat source, mainly combustion gases derived from combustion process of fuels are utilized. Cycle efficiency depends on temperature difference between sources (T_H – T_L). Cogenerative systems with using of the Stirling engine are characterized by high electric and thermal

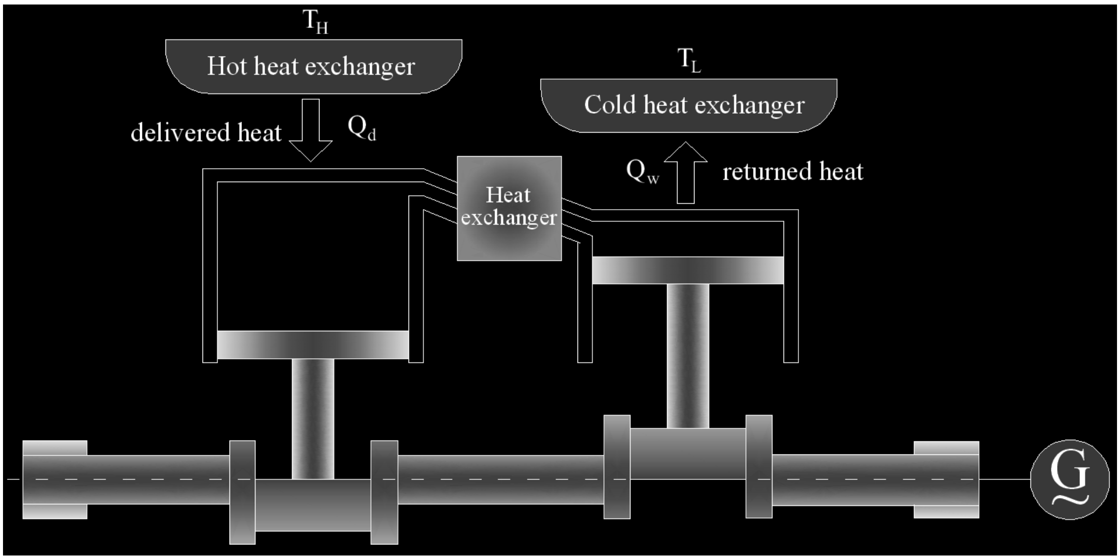

Fig. 1. Scheme of α-type Stirling engine [7]

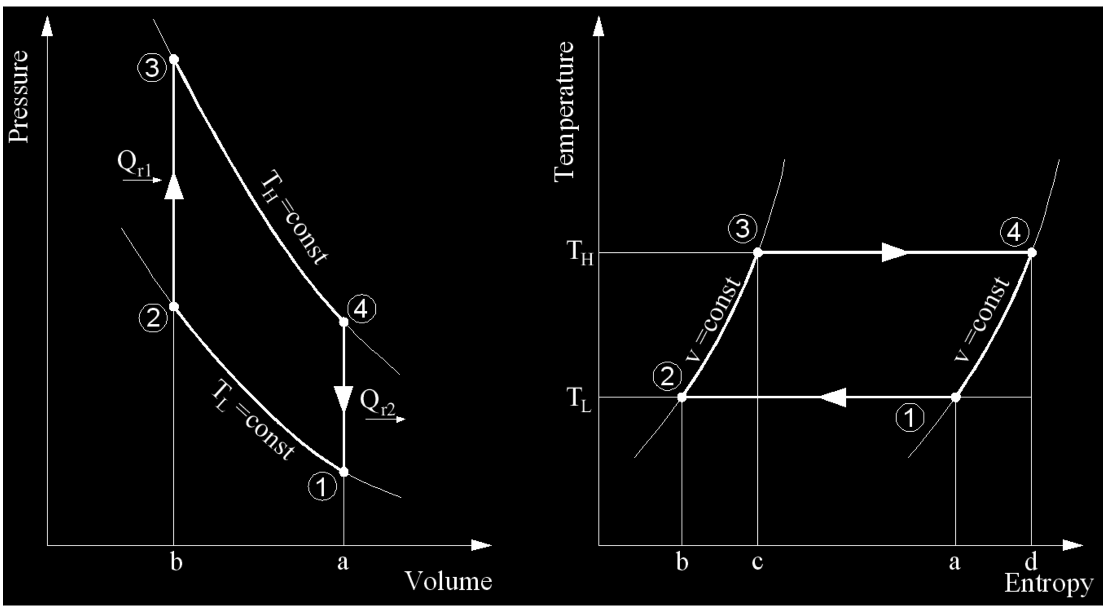

Fig. 2. The theoretical cycle of Stirling engine on pressure-volume (a) and temperature-entropy (b) coordinates

efficiency, adequately about 30% and 70% [8]. Their total efficiency reaches about 90%.

In the ideal cycle, heat is rejected and work is done on the working fluid during the isothermal compression process 1-2. For a fixed mass of working fluid, the amount of total work required for this process is represented by the area 1-2-b-a on the pressure-volume *(p-v)* diagram (Fig. 2a) and the amount of heat transferred from the working fluid, by area 1-2-b-a on the temperature-entropy *(T- s)* diagram (Fig. 2b). During process 2–3, heating at constant volume occurs, where the temperature is raised from T_L to T_H and the pressure increases. Area 2-3-c-b (Fig. 2b) represents heat addition. Next, the constant-temperature expansion process is done 3-4 where work is done by the working medium as heat is added. Area b-3-4-a (Fig. 2a) represents work and area c-3-4-d (Fig 2b) represents heat addition. The last process 4-1 represents constant-volume heat rejection process where no work is done and the rejected heat is represented by area a-1-4-d (Fig. 2b). Because more work is done by expanding gas at high temperature than it is required to compress the same amount of gas at a low temperature, the Stirling cycle produces a net amount of work. The net work is represented by area 1-2-3-4 (Fig. 2a). By the first law of thermodynamics, this is also the net amount of heat that must be added to the cycle to produce this work. This net amount of heat is represented by the area 1-2-3-4 (Fig. 2b).

During isochoric process heat delivered Q_{r1} and heat returned Q_{r2} are equal. Thanks to this, a constructional possibility exists to alternate delivering and returning the same quantity of heat from gas without using external heat sources. This task is realized by using regenerator, that accumulates heat during process 1-4. During the process 2-3 the same quantity of the heat is transferred back to gas.

Types, design, principles of work and state-of-the-art of Stirling engines are described in greater detail in literature [2, 9].

APPLICATION OF STIRLING ENGINE

Actually, Stirling engines are not very popular although they have a dominant position in the renewable energy technology. They are used as a power unit in solar dish collectors and convert solar energy with efficiency higher then photovoltaic. The most innovative Stirling engines at solar power technology are line β-type engines with no rotating parts, line generator, no bearings and lubrication system and very long maintenance-free time [10].

Other typical but still not very popular application of Stirling engine is CHP biomass combustion plant (Fig. 3). In Stirling engine over internal combustion engines the

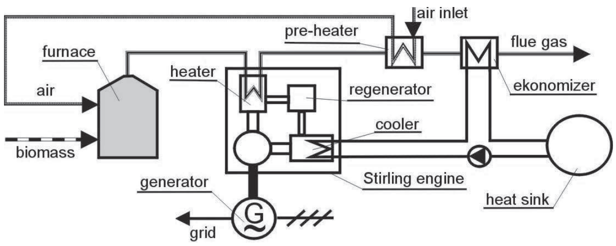

Fig. 3. CHP biomass combustion plant with Stirling engine

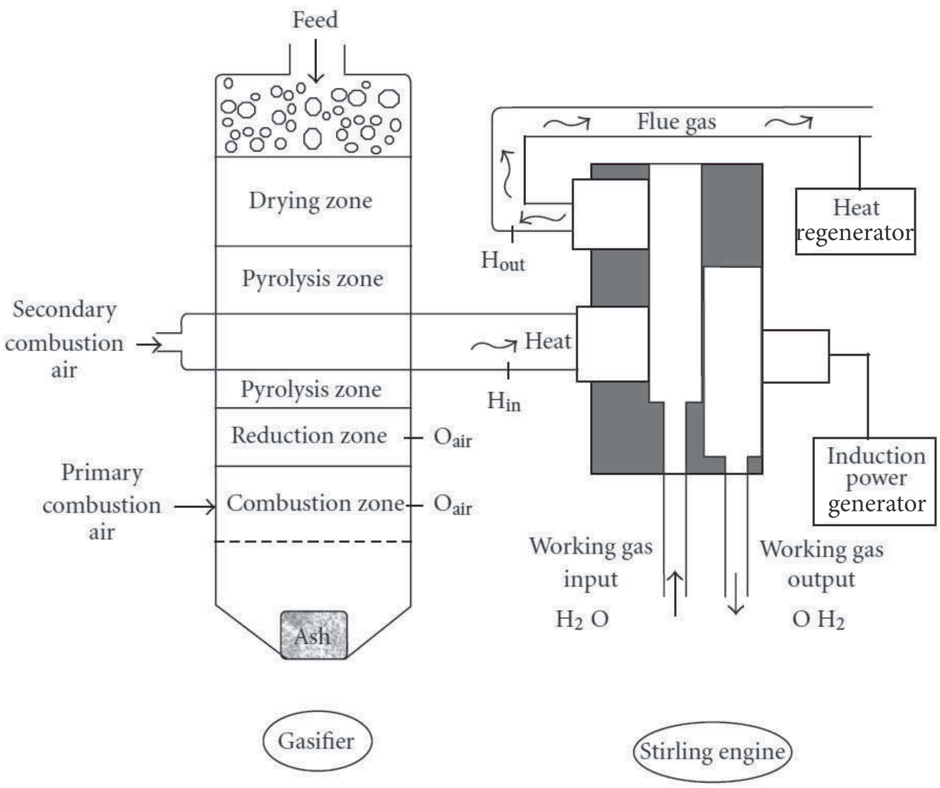

Fig. 4. Direct coupling of the updraft gasifier with a Stirling engine [12]

heat is not supplied to the cycle by combustion of the fuel inside the cylinder, but transferred from the outside through a heat exchanger. Consequently, the combustion system for a Stirling engine can be based on proven furnace technology, thus reducing combustion related problems typical of solid biomass fuels. The heat input from fuel combustion is transferred to the working gas through a hot heat exchanger at a high temperature typically between 680 °C and 780 °C [6, 11]. The temperature of the cooling water in a cold heat exchanger is (25–75) °C.

The more competitive than a large stand-alone plant are the small- scale direct integration of updraft gasifier with Stirling engine combustion system (Fig. 4). The flue gas produced by the synthetic gas combustion is piped directly to the heater head. The engine then will extract and convert the heat contained in the flue gas into electricity automatically. The heat input is proportional to the flow rate and temperature of the flue gas. The proposed technology allows for the use of solid biomass and generation of electric power of 25 kW.

CONCLUSIONS

A biomass-fuelled Stirling plant is an installation which converts biomass, in solid, gaseous or liquid form, into carbon neutral power and heat. The biomass-fuelled Stirling plant has many advantages. The modern cogenerative systems with Stirling engines are fully automated. The use of external combustion causes that the CHP systems engine plants are able to use a variety of low-value fuels, such as wood chips, low-methane biogas or sewage gas. A one-engine plant has a nominal capacity of 1 - 35 kW and 140 kW in multi-engine plant and up to four engines can be combined in individual unit [11]. For every ten units of energy presented in the fuel source, two units are converted into electricity and seven units are converted into heat. This enables close to 90% energy utilization, equal to primary energy savings of over 40% relative to using a heat-only boiler and power from the grid.

Especially interesting for undertakings connected with biomass processing are solutions based on the direct combustion furnace with the Stirling engine supplied with pellets or wood chips. So the implementation of the Stirling machine has been proposed in order to meet the demand of energy small farms. This task demands making specialized investigations of technical solutions applied in the Stirling engine and equipments for production and processing of the biomass.

Endorsement of the presented solution of biomass utilization in order to satisfy energetic needs of a small farm demands doing special research on the technical solutions applied in machines for production and transformation of wood-biomass. Technical solutions of machines for biomass processing were worked out and patented in Rzeszow University of Technology, and they are to be widely tested together with the biomass CHP system with the Stirling engine in cooperation with Lvov State Agricultural University within the framework of „The Program of the Transborder Cooperation Poland - Byelorussia - Ukraine 2007 - 2013" in the project entitled „Bioenergetics". For several years the Rzeszow University of Technology has presented constructional solutions of the machines for cultivation, production and processing of the biomass and technologies of utilization of municipal waste deposits as manure in established plantations.

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