Journal of Solid and Fluid Mechanics (JSFM), 13(6): 1-3, 2024

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/jsfm.2024.13577.3790

Manufacturing Engineering of Iran

Thermodynamic and economic analyses of combined generation system based on hybrid prime mover of internal and external combustion engines with natural gas and biomass power sources

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Received: 09/08/2023 Revised: 12/01/2023 Accepted: 02/17/2024

Abstract

In this paper, a combined cooling, heating and power system based on hybrid drive of internal and external combustion engines with biomass power source with a gasification reactor with air gasification agent and of the counter flow type is discussed and the synthesis gas obtained from this equipment is used in a gas-burning internal combustion engine. This proposed system has been compared with a similar cogeneration system with a natural gas power source, and energy and economic perspectives have been used for the system. The results show that the proposed system that uses synthesis gas as input fuel will have a significant advantage from energy and economic viewpoints compared to the case where natural gas is used as the main fuel, where the parameter related to the percentage reduction of primary energy consumption shows that if synthesis gas is used as a fuel in the drive of the internal combustion engine, compared to natural gas, it will save 40.55% in input energy consumption. The proposed system with synthetic gas fuel has a significant advantage from the economic point of view and the percentage of fuel consumption reduction, so that the results show a savings of 83.98% in fuel consumption costs. The results also show that the total price of electricity production in the proposed system with biomass and synthesis gas power source in different rotational speeds of the internal combustion engine will be lower and more economical compared to the cost of electricity production with natural gas fuel.

Keywords: Combined cooling, heating and power system; Renewable energy; Biomass; Gasification

1. Introduction

Combined cooling, heating and power system have significant advantages compared to conventional energy supply systems. These benefits include reducing energy consumption and subsequently reducing the cost of fuel consumption. Today, due to the low efficiency of conventional energy supply systems compared to simultaneous and high production systems, the amount of primary energy consumption and the emission of environmental pollution in this type of system, attention has increased to the provision of new systems that have higher efficiency, produce less environmental pollution and have less dependence on non-renewable energy sources such as fossil fuels. Using renewable energy sources such as biomass sources as a reliable power source is a good choice. Among the advantages of these resources are renewability, environmental adaptability and lack of concentration in a particular place [1]

Among the studies on the use of biomass resources in Combined cooling, heating and power system with various Driver with the help of gasification reactors. Studies conducted by Asghari et al. [2] can be noted. In their studies, they evaluated a Combined cooling, heating and power system based on the main drive of the gas turbine. In their proposed system they used natural gas and synthesis gas produced with the help of biomass sources as a power supply the results show that among the equipment used in the proposed system, the combustion chamber has the greatest exhaust degradation. In another study conducted by Balafkandeh et al. [3], they optimized combined cooling, heating and power system. in their studies, they used synthesis gas produced in a gasification unit with an air gasification agent as a power supply and provided optimal conditions for the operation of their proposed system. Fakhari et al. [4] also went on to optimize a simultaneous power and heat generation system. Their proposed system included the gasification unit, desalination unit, polymer-type fuel cell, and organic Rankine cycle. They used waste heat in the fuel modification process to produce water in their proposed system. They also used genetic algorithms to determine the optimal performance of the proposed system.

2. System description

The proposed systems used gas-fired internal combustion engine actuators and an alpha-type Stirling engine as hybrid actuators. The following is a description of the operation of each system.

- System I

The number one system is a combined cooling, heating and power system based on the hybrid drive of the gas-fired engine and the Stirling engine. The proposed system uses natural gas as a power supply and uses the heat dissipation of the cooling system of the combustion engine to provide the energy needed in the absorption chiller generator and hot gases from the exhaust of the combustion engine in a Stirling engine, and the heat dissipation of this drive is also used in an absorption chiller.

- System II

System Number Two is a combined cooling, heating and power system based on a hybrid drive of a gas-fired engine and a Stirling engine with a biomass power supply. The biomass used in this system is wood. In this system, synthesis gas is produced with the help of gasification reactor with air gasification agent and the gas fuel produced is used as a fuel consumption. The potential of hot exhaust gases from the gasification reactor is used to provide heating load and the waste heat is used in hot exhaust gases from the exhaust gas engine to provide the energy needed in the Stirling engine heater. The heat dissipation in the cooling system of the combustion gas engine and the heat dissipation in the Stirling engine were also used to supply the cooling load.

3. Results

- **Energy results**

The energy consumption is reduced compared to the conventional energy supply system due to the recovery of waste heat with the help of thermal recycling systems including Stirling engine and Absorption chiller. On the other hand, the percentage decrease in primary energy consumption in the proposed systems will increase with the increase in internal combustion engine speed due to the increase in production power and the increase in waste heat in the cooling system used in the chiller generator and the waste heat of hot gases exhausted from the exhaust of the internal combustion engine used in the Stirling engine heater. If biomass power supply is used, the combustion engine has a more favorable performance at high rounds, except in the lower round of the combustion engine, where the coefficient of the absorption chiller and the cooling load produced is a small amount.

- Economic results

With the increase in the internal combustion engine speed due to the increase in production power and recyclable waste heat by the hybrid actuator, as well as the increase in the performance coefficient of the absorption chiller, The percentage decrease in fuel consumption costs also increases, in fact, the proposed systems will perform much better compared to conventional systems. On the other hand, given that the price of biomass is lower compared to natural gas, it is expected that the system that uses a biomass power supply will perform more favorably than the other system.

The proposed system that uses biomass resources as incoming fuel, although it has less electricity generated within one year compared to the other system, on the other hand, due to the rate of production power and less waste heat, it has less investment cost and maintenance service compared to the other system. On the other hand, the system will also have a lower power generation cost due to the lower cost of purchasing consumable fuel compared to natural gas fuel, the cost of generating electricity in all internal combustion engine rounds exceeds the average price of electricity, which is about $0.13^{\$}/_{kWh}$. Therefore, using these types of systems alone and only in order to produce power is not cost-effective. The cost of generating electricity in the number two hybrid system that uses synthesis gas as a power supply is also lower than the average price of electricity in the grid at 3000 rpm and above, so the use of this system along with the use of waste heat in sectors such as Stirling engine and Absorption chillers will be very attractive.

4. Conclusions

- The results show that Combined cooling, heating and power system have a significant advantage compared to conventional systems due to the recovery and use of waste heat in subsystems such as Stirling engine and absorption chillers that are capable of using waste heat to generate power and supply heating and cooling loads. On the other hand, as stated in the previous section, system Number Two, which uses biomass power supply as incoming fuel, has a more favorable performance from an energy point of view and saves primary energy consumption compared to System number one, so that in the 3000 rpm internal combustion engine, the percentage decrease in primary energy consumption in System number one is 40.55%, while in this situation, the percentage decrease in primary energy in system Number Two is 39.75%.
- The review of the proposed systems from an economic perspective and the parameter related to the percentage reduction in fuel consumption also shows that due to the decrease in the percentage of incoming energy consumption in system Number Two, which works with synthetic gas fuel, and on

the other hand, due to the low price of biomass compared to natural gas, the percentage reduction in fuel consumption in this system will be significantly desirable, so that in the 3000rpm round the percentage reduction in fuel consumption in systems one and two, which use natural gas and synthetic gas as incoming fuel, respectively, equals 12.87% and 83.98%.

- By examining the cost of electricity generation in the proposed systems compared to the Combined cooling, heating and power system, it can be concluded that the strength of using Combined cooling, heating and power system is the use of waste heat in equipment that can use this heat. The results show that the cost of generating electricity in system Number Two, which uses synthesis gas as fuel for consumption, is affordable at medium and high internal combustion engine rpm (3000rpm and above) compared to the purchase of electricity from the grid.

5. References

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