Scholar Publishing Group
Academic Journal of Energy
https://doi.org/10.38007/RE.2020.010406
ISSN 2790-2714 Vol. 1, Issue 4: 54-62

The Combined Cycle System of Solar Energy and Biomass Energy Complementary Based on Organic Rankine Cycle

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Keywords: Organic Rankine Cycle, Solar Energy, Biomass Energy, Combined Cycle System

Abstract: Human life is inseparable from energy, but with the progress of economic development and social civilization, energy issues have attracted global attention. In order to produce clean and efficient sustainable energy, this paper designs an internal recuperative organic Rankine cycle(ORC) system, and then based on the operating principle of the ORC system, the heat collection properties of solar energy(SE) and the properties of biomass biogas fermentation are matched, and a CCS is constructed. The power generation system is a power device, which is cooled by power and supplied to the circulation system to generate electricity and refrigeration. In this paper, the performance evaluation experiment of the combined cycle system(CCS) is carried out, and the factors affecting the performance of the CCS are analyzed. The results show that the energy saving(ES) efficiency and emission reduction(ER) rate of the SE CCS are high, which not only saves energy but also protects the environment. If the ambient temperature is too high or too low, the CCS will be affected. If the temperature is too low, the system capacity and efficiency will be reduced. If the temperature is too high, the work of the micro gas turbine(MGT) will be affected. When the ambient temperature remains unchanged, increasing the methane content in the biogas can improve the power generation efficiency(PGE) of the micro-combustion engine.

1. Introduction

As renewable energy, SE and biomass energy have the characteristics of low cost, cleanliness and environmental protection, and play a great role in improving the ecological environment and reducing air pollution, and the energy utilization rate generated is also high, which can meet people's demand for energy. Thereby reducing the use of fossil energy. The CCS can convert the energy efficiency of SE and biomass energy to maximize energy efficiency.

At present, the research on the ORC and the CCS with complementary SE and biomass energy is progressing well. For example, studies have shown that with the increase of(TIO) the evaporation pressure, TIO the working fluid(WF) in the evaporator in the ORC system shows a gradually increasing trend with TIO the evaporation pressure(EP), while TIO the working fluid in the condenser increases with TIO the EP. With TIO evaporating pressure, the change of the loss is very small, which leads to the TIO the available expansion of the expander and TIO the PGE of the system [1-2]. Therefore, when designing the ORC, the appropriate EP should be selected according to the actual situation, and the increase of the EP can improve the circulation efficiency of the system. CCSs are subject to changes in ambient temperature, which have a direct impact on thermal load changes. In addition to the impact on the power generation, the ambient temperature is too high and too low, which has different degrees of impact on the cooling demand and heating demand [3]. The CCS designed by a certain scholar combines the low-carbon, clean and flexible characteristics of SE and biomass energy. The system can reduce the loss of intermediate transmission links and improve energy efficiency [4]. In conclusion, the CCS is an important way to meet energy demand, reduce pollution and carbon emissions, and it is also the development direction of the future energy system.

In this paper, an internal regenerative cycle system is designed to increase the cycle thermoelectric efficiency of the system, aiming at the shortcomings of the ordinary ORC. Then the CCS is constructed, and the process of SE and biomass energy recycling in the CCS is analyzed. Finally, the performance of the CCS and the factors affecting the system performance are experimentally analyzed.

2. Related Systems

2.1. Design of ORC System

The efficiency of the ordinary ORC is generally not high. The temperature of the liquid working medium after condensation in the condenser is low, only about 30℃, which will cause the formation of heat transfer(HT) oil in the evaporator and the circulating working medium. A large heat exchange temperature difference will also cause a large loss of the evaporator. Under the fixed evaporator power, the increased availability of the circulating working medium will decrease, thereby reducing the circulation efficiency of the system [5-6]. Increasing the temperature of the circulating working medium entering the evaporator will reduce this part of the loss, and the same heat in the evaporator can make the circulating working medium gain a greater increase.

When the combined heat and power mode is not used, according to the Carnot cycle principle, the lower the temperature of the cold source, the higher the efficiency of the Rankine cycle. Considering the practical operability and economy, natural water cooling can be adopted for the lowest temperature of the cold source [7]. At this time, if 180℃ is taken as the evaporation temperature and 30℃ , then the temperature at the outlet of the expander is 78.2℃, 30℃ away from the condensation temperature, and there is a temperature difference of 48.2℃, and the WF is still extremely large. Therefore, if the sensible heat of the WF can be fully utilized, the cycle efficiency of the system will be greatly improved, so the internal heat recovery system can be used to increase the system efficiency [8-9]. The cycle diagram of the internal regenerative system is shown in Figure 1.

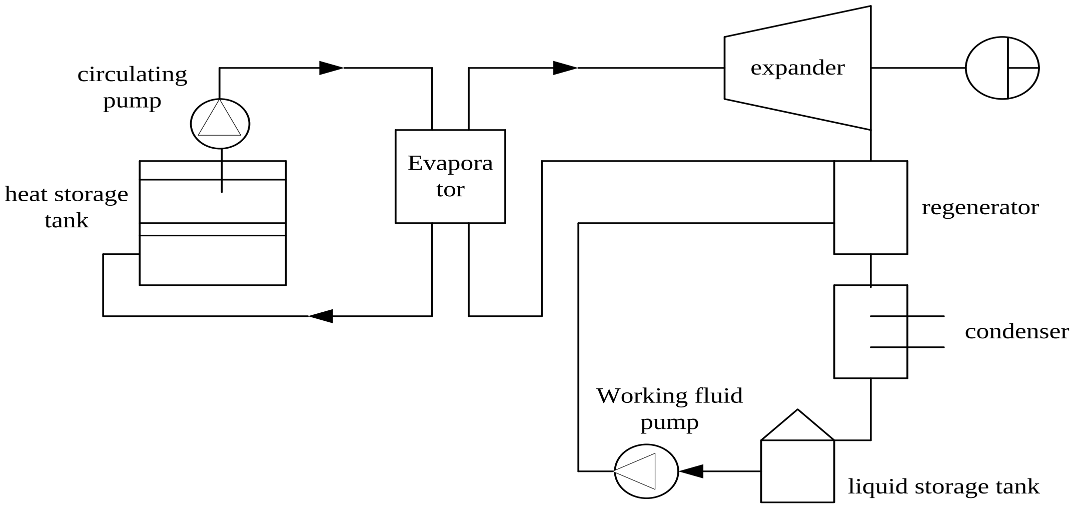

Figure 1. Internal regenerative ORC system

Compared with the basic ORC system, the internal regenerative cycle system adds a regenerator at the outlet of the expander, and the liquid low temperature and high pressure WF after being boosted by the working fluid pump exchanges heat with the superheated low pressure steam at the outlet of the expander. , in order to recover the sensible heat of the exhaust gas and preheat the circulating WF at the same time [10]. Using this system can reduce the condensation loss in the condenser, and increase the temperature of the working medium entering the evaporator, reduce the thermal loss in the evaporator, and thus increase the system cycle thermoelectric efficiency [11].

Considering the system from an economic point of view, adding a regenerator can recover part of the energy and increase the system cycle efficiency, and the more sensible heat recovered, the higher the system efficiency. The coefficient is low, and with the increase of the degree of sensible heat recovery of the exhaust gas, the logarithmic heat exchange temperature difference in the regenerator will also decrease sharply, which will lead to a sharp increase in the volume of the regenerator, resulting in an increase in the initial investment, and the heat recovery. The flow resistance in the device will also increase significantly, making the circulation effect unpredictable [12-13]. Therefore, in the design stage, the factors of efficiency, investment and system resistance should be comprehensively considered, and the size of the regenerator should be reasonably selected to maximize the overall benefit of the system.

2.2. Construction of a CCS that Complements SE and Biomass Energy

The CCS in this paper uses the micro-combustion engine as the power device to generate electricity, in which the micro-combustion engine uses the biogas generated in the solar-heated biogas digester as the fuel, and the exhaust heat is used as the power cooling and is used as the heat source for PGE and refrigeration [14]. The system mainly includes a solar-heated biogas system, a micro-combustion turbine power generation system [15]. The process of the system function is: the hot water provided by the solar collector(SC) heats the biogas thermostatic anaerobic fermentation tank, the biogas generated by the fermentation enters the gas storage tank through the purification and purification process, and is pre-mixed with the air into the combustion chamber, and after combustion, the turbine is driven. Doing work and outputting electric energy, the high-temperature exhaust gas of the micro-combustion turbine can drive the ammonia water absorption power cooling and supply it for circulation, and output electric energy and cooling capacity [16-17].

3. CCS Performance Evaluation Method

3.1. Thermal Performance Evaluation

Since the cogeneration system provides energy with different qualities, there is no definite evaluation index for its thermal performance evaluation.

Energy analysis method: From the perspective of efficient energy utilization(EU), the CCS well follows the energy cascade utilization principle. The biomass biogas generated by the auxiliary heating of low-grade SE is used as the main energy input of the system, and the micro gas turbine burns the biogas to drive the generator to generate High-grade electrical energy [18]. The energy tastes and sources of energy absorbed and consumed by various equipment and devices of the CCS are different, and the overall energy conversion efficiency of the system can be evaluated by the system energy rate.

Exergy analysis method: It can scientifically express the degree of EU, and can correctlyevaluate the EU rate of equipment and devices [19]. The exergy efficiency(EE) expression in this system is as follows:

$$\eta = \frac{Q_1 + Q_2 + Q_3}{Q} \tag{1}$$

In the formula, η is the EE of the system, Q1 is the total power generation, Q2 is the total heat exergy; Q3 is the total cold exergy, and Q is the system fuel input exergy.

3.2. Environmental Benefit Evaluation

CO_2 emissions: CO_2 emissions from the CCS come from biomass, and the calculation formula is as follows:

$$E = e_f E_C * \frac{44}{12} \tag{2}$$

In the formula, E is the CO2 emission of the CCS, e_f is the biomass consumption, and E_C is the biomass carbon content. The CO_2 emissions of conventional systems come from coal-fired(CR) heating and CR CO_2 emissions of thermal power plants. The CO_2 emissions of CR heating are obtained by multiplying the amount of CR by the coal CO_2 emission coefficient. The CO_2 emissions of thermal power plants are based on electricity consumption multiplied by thermal power generation. The plant CO_2 emission factor is obtained. Because conventional systems do not utilize biomass, biomass is wasted in the form of direct incineration, which also produces CO_2.

NOx emissions: Different from the calculation of CO_2 emissions, NOx can not only come from the N contained in the biomass itself, but also from the N in the air, which cannot be calculated by the method of C conservation, so the NOx emission factor is generally calculated [20-21] .

4. Experimental Analysis

4.1. Performance Evaluation Results of CCS

(1) Thermal performance evaluation results

According to Table 1, the total energy consumption(EC) of the co-supply system and the sub-supply system are 217.5kW and 364.2kW respectively when generating the same amount of electricity, heat and cooling. The EE of the joint supply system and the sub-supply system are 48.3% and 32.4% respectively, and the primary ES rate of the system is 36.5%.

Table 1. Thermal performance of co-supply system and sub-supply system

	Joint supply system	Distribution system
System energy input(kW)	217.5	364.2
System energy output(kW)	92.8	90.4
System thermal efficiency(%)	57.6	39.7
System exergy efficiency(%)	48.3	32.4
Primary energy saving rate(%)	36.5	

(2) Evaluation results of ES rate

The primary energy used by the CCS is biomass energy and SE. There are three scenarios: one is that SE is not included in primary energy consumption; the other is that biomass is the only renewable carbon source, which cannot be A large amount of acquisition is included in primary energy consumption; one does not distinguish between energy types, and both SE and biomass energy are included in primary EC. Calculate the primary ES rate of the three scenarios. The traditional energy supply method is compared with the above three scenarios, and the ES rates are 100%, 30.55% and 15.75%, respectively, as shown in Table 2.

Table 2. Energy Saving Rate

	Traditional energy supply	Scenario 1	Scenario 2	Scenario 3
Biomass consumption	None	None	73.52	73.52
Solar radiation	None	None	None	315720
Coal consumption	48.6	None	None	None
Total primary energy consumption	1879635	None	1305446	1583563
Energy saving	None	1879635	574189	296072
Energy saving rate	None	100	30.55	15.75

(3) Environmental benefit assessment results

According to the calculation model of CO_2 and NOx emissions, the environmental benefits of the CCS are obtained as shown in Table 3. Compared with traditional energy supply methods, the CCS can reduce CO_2 and NOx emissions by 84.36 tons and 0.88 tons, respectively, and the ER rates are 33.99% and 85.44%, respectively. The environmental benefits are obvious.

Table 3. Environmental Benefits

	Traditional functional system	CCS
CO_2 emissions	248.21	163.85
CO_2 ER	none	84.36
CO_2 ER rate	none	33.99%
NOx emissions	1.03	0.15
NOx ER	none	0.88
NOx reduction rate	none	85.44%

4.2 Analysis of Influencing Factors of CCS

(1) Influence of ambient temperature(AT) on system performance

The impact of changes in AT on the combined cooling, heating and PGE system complemented by a variety of renewable energy sources is mainly manifested in the following aspects:

When the ambient temperature decreases, the heat loss(HL) of the SC and the anaerobic fermentation tank will increase, and even the fermentation temperature may not reach the set temperature. If the fermentation temperature is not enough, there will be undesirable phenomena such as insufficient gas production and reduced methane content in the biogas. If the ambient temperature is too low, the daily gas production will be insufficient, the power generation time will be limited, and the 24-hour continuous operation requirements cannot be met, and the total system capacity and overall efficiency will inevitably decrease.

If the ambient temperature is too high, the density of the air will become smaller. Under the premise of a constant suction flow, the micro gas turbine compressor will inhale more air, resulting in an increase in the compression power consumption, and the working capacity of the micro gas turbine will be affected. limit. However, an increase in AT can improve the function of SCs and biomass-based anaerobic fermenters. The reason is that when the ambient temperature rises, the heat loss of the SC and the biogas anaerobic fermentation tank will be reduced, and the working state of the anaerobic fermentation tank at the set temperature can be easily maintained, which is beneficial to the system energy. The increase in utilization has helped to some extent.

(2) Influence of methane content on system performance

Under the condition of constant ambient temperature, the performance of the micro gas turbine was simulated by taking the volume content of methane in the biogas as the input condition. Figure 2 shows the simulation results of the compressor, turbine, output power and power generation efficiency of the MGT under different methane content. As shown in the figure, since the compressor is in a stable working condition during the working process of the MGT, no matter how the methane content changes, the power consumption of the compressor remains unchanged at 38%. The turbine power(TP), the output power(OP) of the MGT, the The PGE of the gas turbine increases with the increase of the methane content in the biogas. When the methane content in the biogas is 50%, the TP is 34kW, the OP of the MGT is 9kW, and the PGE of the MGT is 3%. When the methane content in the biogas increases to 75%, the TP is 64kW, the OP of the MGT is 23kW, and the PGE of the MGT is 17%. At this time, the TP increases by 30kW, and the OP of the MGT increases. 14kW, the PGE of the MGT has increased by 14%. When the methane content in the fuel increases to 100%, the TP is 80kW, the OP of the MGT is 36kW, and the PGE of the MGT is 27%. At this time, the TP increases by 46kW, and the OP of the MGT increases. 27kW, the PGE of the MGT has increased by 24%.

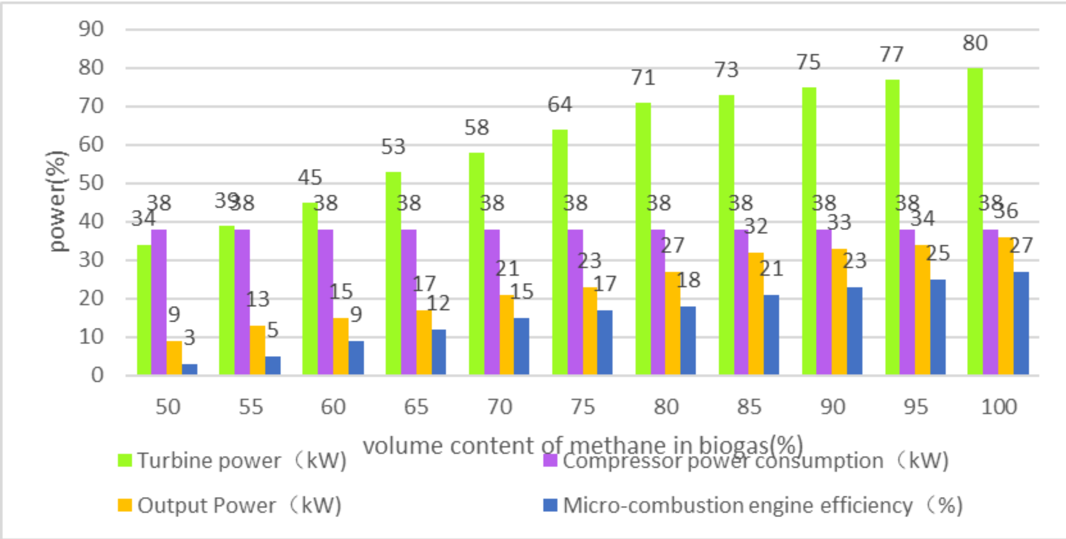

Figure 2. Turbine output power, micro-turbine output power, and power generation efficiency as a function of methane content

5. Conclusion

The organic Rankine-based CCS proposed in this paper generates electricity through a micro gas turbine, and uses SE to heat to generate biomass biogas as the system energy input. Complementary. The experimental analysis of the performance of the system shows that the use of this system to generate electricity and refrigeration can reduce environmental pollution and achieve the purpose of ES and ER. To maximize the power utility of the system, it is necessary to control the AT, and increase the PGE and OP of the MGT by increasing the methane content of the biogas.

Funding

This article is not supported by any foundation.

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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