JIT Journal of Innovation and Technology
e-ISSN: 2721-8562; p-ISSN: 2721-8570
Vol.4, No.2, October 2023. Page: 57 – 61

Simulation Study of Small-Scale Electricity Generation Plant Utilizing Flue Gas of Solid Garbage Waste Incineration as Energy Source

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Article history
Received: 07.04.2023
Revised: 22.08.2023
Accepted: 27.09.2023

DOI:10.31629/jit.vxix.1234

Abstract
This study aims to get an overview of the operational parameters of a small-scale electrical generation plant that utilizes thermal energy included in the flue gases of garbage waste incineration. The organic Rankine cycle (ORC) thermodynamic system was performed to evaluate this system. The organic fluid was used as a heat transfer medium instead of water because it has a low boiling point so it does not require a lot of thermal energy to generate small-scale electric power. Hexane was used as the working fluid and Aspen Hysys was used as a tool to perform simulations. The plant is optimized through the operating temperature, working fluid flow rate, and pressure to obtain electrical output power that can be obtained. The simulation results show that flue gas at a temperature range of 300 to 350 ^{0}C can produce electric power in the ranges of 7.84 to 128.6 kW at working pressure ranges of 2.5 to 7.5 bar, and working fluid flow rate of 3.600 to 10.100 kg/h

Keywords: Garbage waste, Incineration, Thermal energy, ORC

1. Introduction

Energy needs will continue to increase along with the increase in world population and in fact, there is also an increase in carbon emissions [1]. Currently, the world's main energy sources still rely on fossils, especially liquid fuels, and coal. The adverse effects of the use of fossil-based fuels are, of course, extreme weather and climate change. This is due to the pollution and emissions produced when using such fuels [2]. Underworld agreement that individual countries must reduce emissions from fossil fuel use, they must therefore consider other potential energy sources that are low carbon dioxide or zero carbon dioxide. In Indonesia itself, the potential for bioenergy utilization is very high to support the energy mix in 2050 [3].

In addition to dealing with global warming, the world is also currently dealing with adverse effects caused by the abundance of garbage waste. The most harmful impacts are leachate [4] and soil pollution by heavy metals [5] in addition to pollution caused by particulate matter, acidic gasses, and dioxins. From day to day, the amount of garbage waste is getting out of control, even though if processed properly, garbage waste can be a source of thermal energy [6] or an alternative liquid fuel source [7].

One of the efforts being developed is to use garbage waste as a source of thermal energy in boilers, then converted it into electrical energy using turbines. In 2006, two units of garbage waste power plants with a capacity of 46.2 million kWh of electrical energy were operated, but due to low LHV, the garbage waste was mixed with coal [8]. In Indonesia, the use of garbage waste as a source of electrical energy is also very potent. By taking garbage samples from landfills, Baskoro et al. (2019), and Hanson et al. (2022) succeeded in simulating and predicting the electrical power that can be obtained from garbage incineration [9, 10].

Utilization of thermal energy from combustion gases can be performed utilizing boilers, but combustion gas cleaning systems are very important to ensure the environmental air is free from pollution [11]. To reduce pollution that arises, the combustion chamber of a combustor is important to improve its performance. Air distribution is the main key to producing high combustion chamber temperatures [12, 13]. In fact, the combustion gases of solid waste of biomass type leaving the chimney still have a temperature of about 390 ºC [14]. This temperature needs to be reduced before being put into the cleaning device or gas cleaning system (GCC) and released into the environment. For this reason, a combustion gas temperature-lowering device is needed, namely a heat exchanger. In reducing the temperature of combustion gases, working fluids such as water and organic fluid can be used that can absorb heat energy and send it to thermal energy storage devices [15], then can be used for other purposes including electrical energy generation [16, 17]. Another way is to use hot combustion gases directly to evaporate a working fluid in the evaporator.

It has been known for a long time that the organic Rankine cycle is capable of extracting thermal energy even at low levels. Usually, the working fluid used has a low boiling point even far below the boiling point of water. As many as 31 types of working fluids can be used in an ORC [18] with several thermal energy sources to be used. Currently, not many power generation systems using ORC are implemented in the field. Research is still in the development stage and testing is mostly through simulations. There are also many sources of thermal energy used, including hot gas from burning fuels other than solar and geothermal energy.

The purpose of writing this article is to explain the design of a small-scale power generation system by utilizing thermal energy from garbage waste combustion units. Thermal energy is obtained from the hot combustion gas cooling unit before being delivered to the gas cleaning unit and is suitable for release into the atmosphere. The organic Rankine cycle is used as a thermodynamic system of power plants and its performance is reviewed based on the characteristics of the working fluid using Aspen Hysys simulations. For system optimization, several related operational parameters are simulated to obtain the most optimal performance.

Small-scale power plants utilize medium to low levels of thermal energy using a thermodynamic cycle called the organic Rankine cycle (ORC) [19]. **Figure 1** shows a diagram of an integrated power plant with a boiler unit and the flue gas cleaning unit utilizing thermal energy from garbage waste incineration. Flue gas should also not be released into the atmosphere at high temperatures. Therefore, it must be cooled first using a heat exchanger using working fluids with a high heat capacity such as water, oil, or organic fluid. Then the thermal energy in the working fluid is extracted using the Rankine organic cycle with working fluids such as Hexane. This working fluid is considered very suitable at a temperature source between 150-350 ^{0}C.

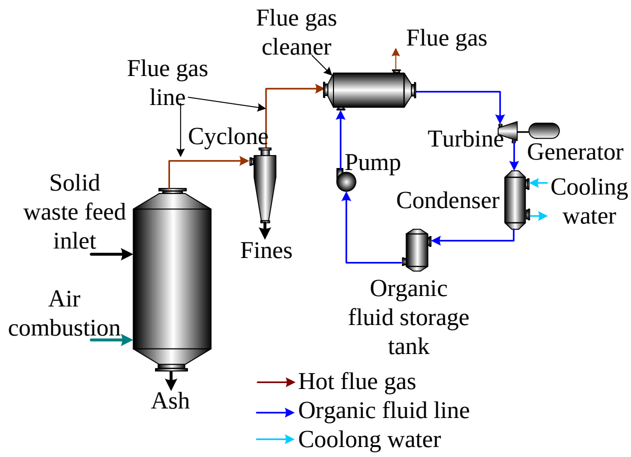

Figure 1. A simple ORC electricity generation plant diagram coupled with a solid waste incineration facility

2. Materials and Methods

2.1 Materials

Hexane is a hydrocarbon compound with the chemical formula C_6H_{14} used as a working fluid in this investigation. Hexane has a molecular weight of 86.178 (g/mol), a boiling point of 68.71 ºC, a critical temperature of 234.40 ºC, critical pressure of 30.28 bar. Under standard circumstances, this material is liquid and colorless and has a character similar to water, so it is relatively easy to handle and use. In addition, Hexane has high energetic efficiency and energetic efficiency [20]. **Table 1** shows the operational parameters used in this simulation study.

Table 1. Parameter used on the simulation

Parameter	Set Value
Flue gas (ºC)	300-350
Flue gas mass flow rate (kg/h)	40000-70000
Refrigerant	Hexane

DOI: DOI:10.31629/jit.vxix.1234

Refrigerant mass flow rate (kg/h)	3600-10100
Outlet pump pressure (bar)	2-7.5
Phase fraction at the pump outlet	0
Phase fraction at the turbine inlet	1
Outlet turbine pressure (bar)	2-8
Cooling water mass flow rate (kg/h)	50000
Cooling water inlet temperature (°C)	27
Turbine efficiency (%)	75
Pump efficiency (%)	75

2.2 Diagram of system simulation

The simulation diagram is shown in **Figure 2**. Hexane working fluid at atmospheric conditions (1) is compressed using a pump (P-100) until the working pressure increases (1a). The working fluid is then fed into the economy (E-101) to increase the working temperature (1b) with the intention of reducing the heating load in the heat exchanger (E-100). The working fluid is then further heated in the heat exchanger by absorbing thermal energy from the flue gas into high-temperature and high-pressure saturated steam (2). The thermal energy in the working fluid is then extracted using a turbine (K-100). The working fluid out of the turbine (3) with saturated steam conditions is put into the economy to heat the working fluid before entering the heat exchanger. The working fluid from economical (4) is then cooled using a condenser (E-102) to convert it back into a liquid state (5).

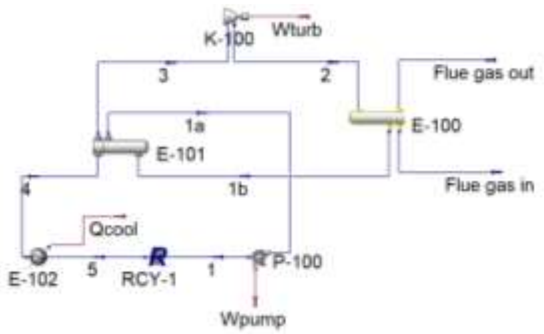

Figure 2. Aspen Hysys flow diagram of the simulation study

3. Results and Discussion

The results of the investigation through simulation were obtained by optimizing operational parameters, of flow rate, pressure, and temperature of the working fluid of the system.

3.1 The effect of working pressure on electrical power output

To obtain a high working fluid temperature, the working pressure must be increased using a pump (P-100). Due to pump pressure, the saturation temperature of the working fluid will also increase accompanied by an increase in enthalpy of working fluid entering the turbine (2). This causes an increase in turbine work output ($\dot{W}_{turb}$). From the graph in **Figure 3** it can be seen that the higher the working pressure, the resulting turbine work also tends to increase. The results of this simulation are in accordance with the results of the analysis carried out using thermodynamic relationships [17].

However, although the working pressure can increase the output power of the turbine, this system cannot be forced until it reaches the critical pressure of the working fluid. The system will be more difficult to operate if the working pressure is too high. It takes extra energy to evaporate the working fluid, while the energy source used is low levels of flue gas. From the graph, it can also be seen that the turbine output is also very sensitive to the rate flow of the working fluid, where the higher working fluid rate will be accompanied by an increase in turbine output.

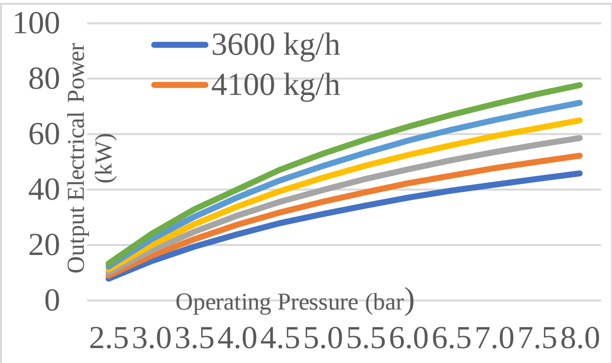

Figure 3. Power output as the pressure dependence

3.2 The effect of working temperature on electrical output power

As explained earlier, the increase in working pressure will increase the saturation temperature of the working fluid. For sufficient thermal energy sources, the saturation temperature will be reached and will increase the enthalpy of the working fluid which has implications for increasing turbine power output as shown in the **Figure 4**. This result is consistent with the results of the analysis using thermodynamic relationships [17]. An increasing the flow rate and temperature of the working fluid will increase the output power of the turbine.

DOI: DOI:10.31629/jit.vxix.1234

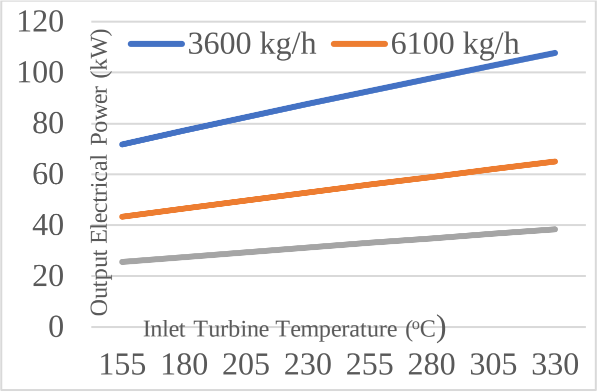

Figure 4. Power output as inlet turbine temperature

4. Conclusion

An investigation into the possibility of developing a small-scale power plant by utilizing solid waste combustion flue gas as an energy source has been carried out. The thermal energy that is still contained in exhaust gases that are considered to have no value can still be used for power generation. The simulation results show that the potential of thermal energy in garbage waste combustion exhaust gas can still be utilized to generate electrical energy on a small scale. By using Hexane working fluid, the thermal energy potential in exhaust gases at a temperature range of 300-350 °C can be used to generate electrical power.

Acknowledgment

The authors thank Universitas Negeri Medan for providing financial support under Contract Number 023.17.1.690523/2022 from the DIPA Directorate of Research, Technology, and Community Service, Directorate General of Higher Education, Research and Technology, Ministry of Education, Culture, Research, and Technology. The authors gratefully recognize two final project students and the members of the mechanical engineering workshop for their involvement in and contributions to this project.

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