Possibilities of utilization of waste heat of synthesis gas

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Abstract

The paper discusses possibilities of energetic utilization of waste heat from synthesis gas, which worsens possibilities of its further utilization. In this case, it is the recovery of synthesis gas with a high proportion of hydrogen produced by the thermal recovery of municipal waste by means of a plasma reactor. High temperatures deteriorate its recovery potential by separating hydrogen from the gas mixture and its subsequent use in fuel cells. Hydrogen separation takes place in the plant using metal hydride materials.
Keywords: synthesis gas; waste heat; plasma reactor; hydrogen;

1. Introduction

In view of the increasing need to improve the efficiency and energy use of all materials, to reduce the environmental burden and reduce the carbon footprint, there is a need to use all kinds of energy released during processing and to discharge it inefficiently into the environment. Due to the increasing amount of waste produced, there is also a need for efficient recovery, recycling and other recovery options.

Since it is not possible to carry out 100% recycling of municipal waste with current technology, it is necessary to improve its recovery. Landfill or incineration of municipal waste generates hazardous gases that cause soil pollution, acid rain and promote global warming.

Plasma reactors may represent a significant change in waste treatment. They can relatively cleanly dispose of most hazardous wastes, with the resulting product being synthesis gas and slag. During the gasification process, complex carbon chains decompose into primarily simple hydrocarbons, carbon monoxide, carbon dioxide and hydrogen. Nitrogen, argon and other gases are also present in the gas, either entering the system either in the material being processed or in the air that serves as the oxidant.

2. Amount of waste heat of the investigated gas

Synthesis gas produced by RDF waste was obtained for the experiment and was obtained by separating the combustible components from municipal waste. The treatment of the waste in a plasma reactor resulted in synthesis gas having the composition of Tab. 1.

Table 1. Proportion of individual components of synthesis gas [1]

COMPONENT	PERCENTAGE (%)	SPECIFIC HEAT CAPACITY c_p (kJ·kg^{-1}·K^{-1})	DENSITY ρ (kg·m^{-3})
CH_4	0.26	2.17	0.676

H_2	50.9	14.05	0.0899
O_2	0.03	0.91	1.429
N_2	4.25	1.04	1.234
CO_2	1.1	0.83	1.951
CO	43.5	1.09	1.234

Processing was carried out on a 10 kVA plasma reactor. Feeding of waste into the reactor is effected by means of a spiral feeder, the rate of feed being regulated by changing the speed. The decomposition of the waste to the basic elements is carried out by means of an electric arc of 1300° C.

Figure 1. Plasma reactor.

In order to determine the amount of heat to be removed from the gas, it is necessary to determine the operating conditions such as inlet and outlet temperature, the heat capacity c_p of the gas mixture and the gas flow through the exchanger. The operating conditions necessary to determine the amount of heat to be removed from the gas mixture are shown in Tab. 2. The gas outlet temperature is selected based on the requirement for further processing of the synthesis gas.

Table 2. Boundary conditions [1]

Inlet temperature t_1 (°C)	750
Outlet temperature t_2 (°C)	300
Amount of waste delivered Q_m (kg·min^{-1})	0.12
Amount of gas produced Q_V (m^3·kg^{-1})	1.803

The calculation of the heat (Q) of the individual components of the synthesis gas is performed only around because of the continuously varying proportion of the individual components, which is significantly dependent on the type of waste treated and even if the same proportion of individual components is maintained, the individual components are uneven.

$$Q = c_p \cdot m \cdot (t_1 - t_2) \quad (W) \qquad (1)$$

Where c_p is specific heat capacity; m – mass; t_1 - inlet temperature; t_2 - outlet temperature.

The total amount of heat to be removed from the synthesis gas can be determined by Equation (1). To determine the amount of heat it is necessary to determine the mass of the gas passing through the device. From Tab. 2 it is possible to determine the gas flow in $m^3 \cdot min^{-1}$. Gas flow rate $Q_{Vs} = 0.21636\ m^3 \cdot min^{-1}$. In Tab. 3, the heat values that must be removed from the individual components of the synthesis gas and subsequently the total value are determined.

Table 3. Heat quantity [1]

Component	The proportion of individual ingredients in syngas Q_{Vs} ($m^3 \cdot min^{-1}$)	The proportion of individual ingredients in syngas Q_{ms} ($kg \cdot min^{-1}$)	Q (W)
CH_4	0.000563	0.000380	6.2
H_2	0.110127	0.009900	1043
O_2	0.000065	0.000093	0.63
N_2	0.009195	0.011347	88.5
CO_2	0.002380	0.004643	29
CO	0.094117	0.116140	949
		together	2116

3. Possibilities of heat removal from synthesis gas

In most cases, the gas is cooled either by the using cooling water which is injected into the gas to purify it from solid contaminants, or in heat exchangers where the water is heated for further technological use. Another possibility is to dissipate heat into the surrounding environment by means of an exchanger.

Injection of water into the system is not suitable for our use because of the excessive increase in moisture in the gas, which would lead to significant and rapid corrosion in the subsequent separation of hydrogen through the metal hydride materials, causing damage to the equipment. In this case, it is possible to use a small amount of water spraying to remove the solid contaminants, merely to stick the particles into larger agglomerates and then remove them in a cyclone trap.

Since the device in question is intended to operate independently and independently of the environment, the dissipation of heat through the exchanger would only lead to its transfer to the environment, which would in no way improve the overall energy efficiency of the device. On the contrary, it would be necessary to cool the device if it is placed in a closed complex due to the overheating of individual, especially electronic components.

The use of stirlig engines for converting the thermal energy contained in the gas into mechanical and then by means of an electricity generator, which could to some extent be used to meet the energy needs of other parts of the plant, thus increasing energy efficiency, seems to be an interesting option.

Referring to Fig. 1, it can be determined that, for a given device, the efficiency of a stirling engine to dissipate thermal energy from syngas is at a level of 20%, since the remaining heat is discharged to the cooler used for heating metal hydride alloys to allow better desorption of hydrogen. According to the graph, it can be determined that the efficiency of stirling engines will increase proportionally with increasing power, so it would be advisable to increase the production and possibly the temperature of the gas coming out of the reactor so that the efficiency of stirling engines could increase.

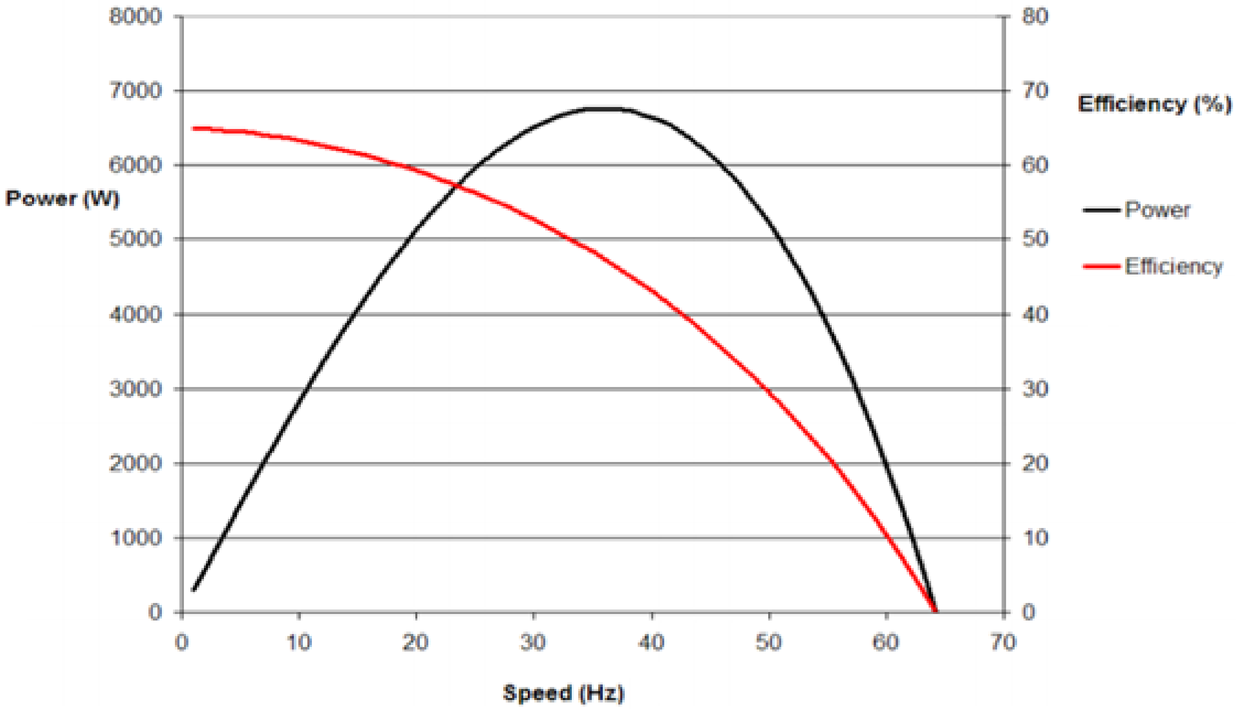

Figure 2. Dependence of efficiency on power and speed [5].

After removing 20% of the thermal energy by means of stirling motors, approximately 1700 W remains for heating the heat transfer medium. This energy can then be reduced to about 700-800 W in a further heat exchanger using another series of stirling motors, which is a sufficient level for heating the metal-hydroxide containers. By utilizing the cascade arrangement of stirling engines, it is possible to significantly reduce the temperature of the synthesis gas, whereby part of the energy is converted to mechanical and subsequently to electrical, thereby increasing the overall efficiency of the device.

3. Conclusion

Due to the use of the first set of stirling engines in a cascaded configuration, it is possible to obtain approximately 425W of mechanical energy from the synthesis gas in our case, which will then be used to generate electricity in the generator. The use of waste heat to generate electricity increases the efficiency of the plant and reduces the total operating costs of its operation.

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