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The gasification efficiency improving by self-steam gasifier using RDF from municipal solid waste

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Abstract. This research aims to improve the efficiency of the gasification by self-steam gasifier stove (SSG) which has been designed to produce steam for using gasification system. The waste heat is generated around the heat exchanger with water for steam production. Then the experiment was conducted to produce syngas from an air gasification and self-steam gasification using Refuse-derived fuels (RDF) from municipal solid waste. The RDF with density of 930 kg/m^3 and feed rate of 10 kg/hr was used as a fuel for gasification. The ER was varied from 0.15-0.50 in order to study the production of the producer gas and evaluate optimum point of heating value and cold gas efficiency for Comparison between air gasification and Self-steam gasification. From the experiment, it was found that The air gasification had optimum ER of 0.35, with maximum syngas heating value of 5.87 MJ/Nm^3 and The Self-steam gasification had optimum ER of 0.30 and steam feed rate of 0.96 kg/hr , with maximum syngas heating value of 6.56 MJ/Nm^3 . The self-steam gasifier shows higher cold-gas efficiency than the conventional gasifier of 13.87%.

1. Introduction

Presently, municipal solid wastes (MSW) have continually increased, bringing with them environmental pollution problems. Municipal solid wastes contain multiple items such as metals, paper, textiles, plastics, wood and food garbage [1], which consist carbon, hydrogen, nitrogen and oxygen [2]. Some of the components in waste can be used to produce energy, i.e., carbon and hydrogen. Gasification is a chemical process that changes the solid organic components of wastes into gases such as O_2 , CO_2 , CO , H_2 , and CH_4 [3]. The important gases affecting the heating value of syngas and cold gas efficiency of gasification are CO , H_2 and CH_4 . There are many types of gasification, for example, fluidized bed and fixed bed, which can be used with down-draft, up-draft, or cross-draft gasifiers [4]. The down-draft gasifier has certain advantages, namely, it is easier to control than the fluidized bed type, and releases less dust and tar than the up-draft and cross-draft gasifiers [5]. Therefore, it has frequently been used for real engineering manufacturing. Moreover, the gasification technology which is installed with a single throat is advantageous since the single throat enables RDF flowing in the combustion zone to compress well and hence making RDF receive thorough heat and burn well. RDF is thus appropriate for utilization as a renewable energy source because of the ease of transportation, low pollution, and small storage space requirement [6]. Municipal solid wastes are therefore popular to be produced and used as renewable energy.

The efficiency of the gasification process can be improved by means of the use of steam and air as the reactant in the gasifier. The resulting combustible gases will contain a high proportion of methane and hydrogen [7], which means an increase of the thermal value of the gases and higher efficiency of the overall system [8]. However, the steam used in the process has to be produced and brought in from an



external source. This increases the cost of fuel gas production. A Self-Steam gasifier (SSG) that can produce its own vapor by the exchange of internal heat with the fixed water coil pipe will reduce the cost since there is no need to import steam.

This article compares the appropriate air feed, fuel components, thermal value of fuel gas and the efficiency of gasification between the conventional gasifier that relies on air and the self-steam gasifier (SSG), which uses air and steam as the reactant. The appropriate temperature of the gasifier was also determined, which will yield steam with the best fuel thermal values and highest gasification efficiency.

2. Materials and Experimental Methodology

2.1. Material of Feed stock

Refuse-derived fuels (RDF) used in the experiment were obtained from municipal wastes that had been separated. Most parts were plastic materials. Then the wastes were shredded into tiny pieces and pressed into small pellet with a diameter of roughly 8 mm, a length of 25 mm and density of 930 kg/m³. The moisture content was not allowed to exceed 4%. Next, an ultimate analysis was performed using Perkin elmer, Series II CHNS/O Analyzer 2400. A proximate analysis was performed with Perkin Elmer instrument, Pyris Diamond TG/DTA model. Heating values were analyzed with Bomb Calorimeter, IKA brand, C5003 control Model. The details of RDF are given in Table 1.

Table 1. The Characteristics of RDF.

Proximate analysis (% wt)		Ultimate analysis (% wt)	
Moisture	4.00	C	58.16
Volatile matter	81.47	H	9.80
Fixed carbon	9.73	N	0.73
Ash	4.80	O	31.31
High heating value (kJ/kg dry basis)	29,410		
Density (kg/m ³)	930		

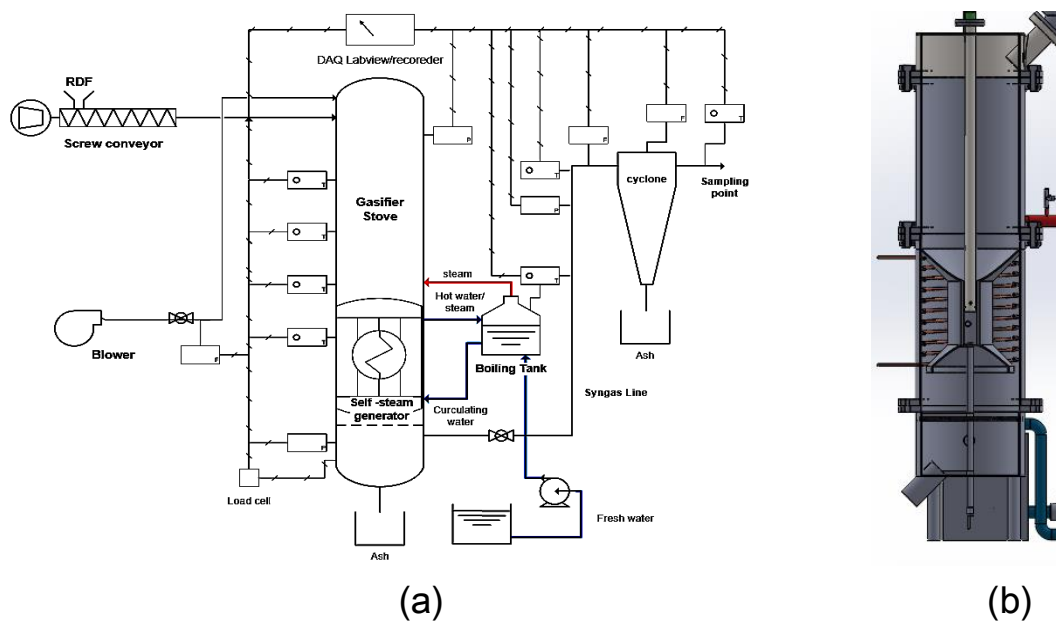


Figure 1. (a) The schematic of Self-Steam gasifier experimental setup, (b) Section View of SSG.

2.2. Experimental setup

The experiment was conducted in the single-throat downdraft gasifier and Self-Steam gasifier (SSG) using RDF. The operation was carried atmospheric air as gasification medium. The experimentation plan started with the design of a single-throat down-draft gasifier with a capacity of 30 kw. The gasifier was 1.70 m high, with a diameter of 0.50 m and the single throat tilting at 45°. Four air ducts were attached to one side of the gasifier. At the bottom, a mesh and hand-stirred to get rid of ash were installed. Water was used to seal the ash exit and prevent gas leakage. The gasification system itself was composed of a gasifier, cyclone, screw conveyer, blower and sensors as illustrated in Figure1. (a)

The experiment started by feeding 10 kg of RDF into the top of the gasifier which was placed over burning charcoal to ignite the system, Then the gasifier cover was closed and the blower opened to draw air in. The blower used was a 1 hp, 3-phase Hitachi blower, VB-007-DN Model, having a maximum capacity of 2.1 m³/min. Air was fed in through the four air pipes at the side of the gasifier. The air flow rates were measured by the Testo 340 and calculated for the air feed rate. Next, the temperatures in the gasifier were monitored using the Thermocouple type k and were measured by the NI-DIQmx temperature sensor. All of the data obtained were stored in the computer.

The self-steam gasifier has been designed to produce steam at 1.5 kg/hr. Water will flow in 23 copper coils of 8mm diameter placed in the space between the bottleneck and gasifier wall. Water enters from the bottom of the copper coils and flows out from the top for another heat exchange. The steam produced is used in the gasification and the hot water is fed into the copper coil, again for heat exchange. Steam is produced 15 minutes after the system starts to operate. The temperature of the gasifier is between 850-750 °C, which results in the transfer of heat to the coils and steam is produced at 108-100 °C. At this point, the valve is closed in order for the steam to be fed into the gasifier. show in figure 1(b)

The experiment was performed to determine the suitable air feed rate for the conventional gasifier and self-steam gasifier. Controls were made over the fuel feed rate of 10 kg/hr, steam feed rate, steam temperatures, and gasifier temperature. The variables for the fuel feed rate)ER(were set within the range 0.1-0.5 to compare the efficiency and thermal values between the conventional gasifier and self-steam gasifier.

2.3. Self-Steam gasifier stove design

The self-steam gasifier has been designed to produce steam Water will flow in copper coils placed in the space between the bottleneck and gasifier wall the Temperature inside the copper wall is calculated by (1) [9]

$$T_4 = T_1 + Q \left(\frac{\ln(\frac{r_2}{r_1})}{2\pi K_a L} + \frac{1}{h_a A} + \frac{\ln(\frac{r_4}{r_3})}{2\pi K_b L} \right) \quad (1)$$

where T_1 is temperature inside SSG stove (°C) r_1, r_2, r_3 and r_4 are distance from the center of the Stove (m) K_a and K_b are thermal conductivity (w/m².k) h_a is Heat transfer coefficient of air (w/m.k) L is The length of the SSG stove wall (m) and A is area of heat convection (m²)

Temperature of steam is calculate by (2) and (3)

$$T_b = (T_i - T_w) \exp\left(-\frac{hA}{mc_p}\right) + T_w \quad (2)$$

$$m = \rho VA \quad (3)$$

where T_i and T_w are temperature of water inlet and temperature inside the cooler wall (°C) h is heat transfer coefficient of water (w/m.k) A is area of copper tube (m²) m is mass of water (kg) c_p is specific heat capacity of water (J/kg.c) ρ is density of water (kg/m³) and V is velocity of steam (m/s)

2.4. Cold gas efficiency

The air flow rate was effects the quality of syngas production. The air flow rate (M_{fa} ; kg/hr) is calculate by (4) [10]

$$M_{fa} = \left(\frac{32 \cdot C}{12} + 8 \times H + S - O \right) \times ER \times M_{fRDF} \quad (4)$$

where C H N S and O are mass fraction of Carbon, Hydrogen, Nitrogen, Sulfur and Oxygen, respectively by ultimate analysis, ER is equivalent ratio and M_{fRDF} is RDF feed rate (kg/hr).

The Volumetric composition of the production gas affect to lower heating value (LHV) and quality of syngas. The lower heating value of syngas (LHV_{sg} ; kcal/Nm³) is calculated by (5)

$$LHV_{sg} = (h_{co} \times x_{co}) + (h_{H_2} \times x_{H_2}) + (h_{CH_4} \times x_{CH_4}) \quad (5)$$

where h_{CO} , h_{H_2} and h_{CH_4} are lower heating value (kcal/Nm³) of Carbon monoxide, Hydrogen and Methane and x_{co} , x_{H_2} and x_{CH_4} are Volumetric composition of Carbon monoxide, Hydrogen and Methane, respectively.

The cold gas efficiency (η_{cg}) is the energy input over the potential energy output that is calculated by (6) [11]

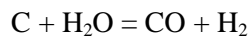
$$\eta_{cg} = \frac{Q_{sg} \times LHV_{sg}}{M_{fRDF} \times LHV_{fRDF}} \times 100 \quad (6)$$

where Q_{sg} (Nm³/hr) is Volumetric of syngas and LHV_{fRDF} is lower heating value of RDF.

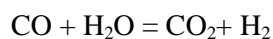
3. Result and Discussion

3.1. The effect of the Equivalent ratio (ER) on syngas concentration

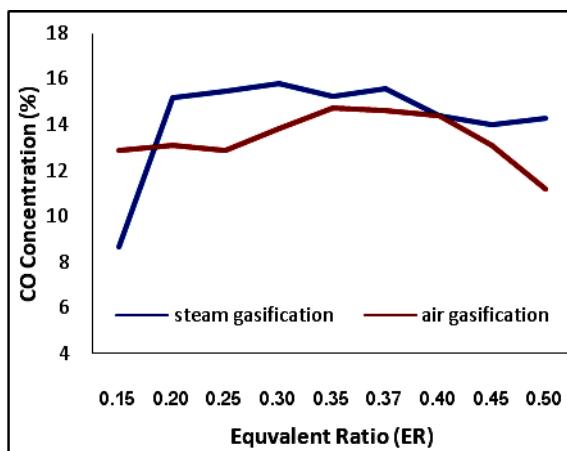
The experiment revealed the control of air for the reaction in the self-steam gasifier (SSG) as follows: CH₄ 9.52% at ER 0.25, CO 15.80 % at ER0.30 and H₂ 11.96% at ER 0.25. This is higher than the air gasifier (single-throat downdraft gasifier) which had the following results: CH₄ 8.76% at 0.25, CO 14.72 at ER 0.35 and H₂ 8.82% at ER 0.25. The results are consistent with the reaction:



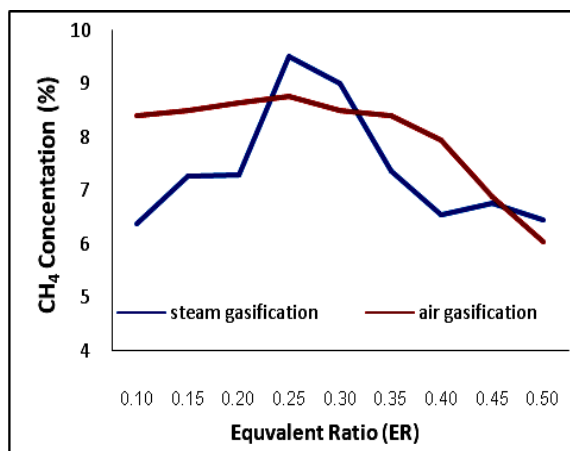
water gas reactor



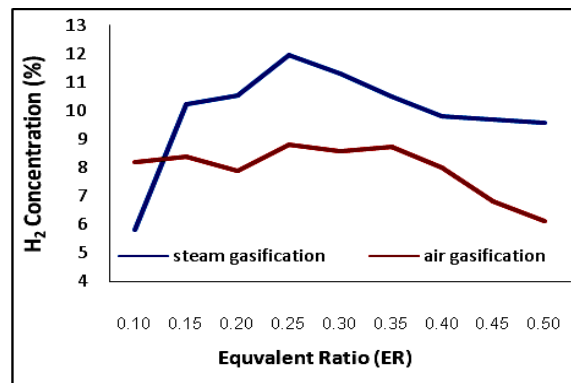
water gas shift reaction



(a)



(b)



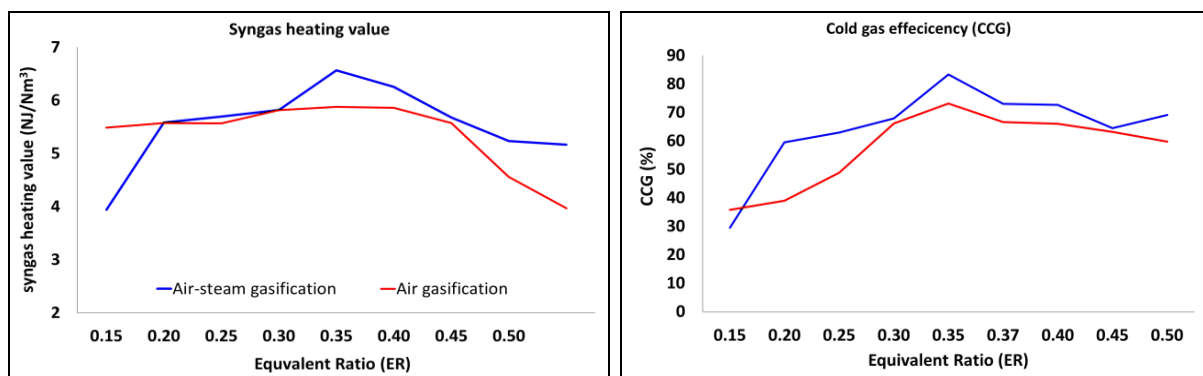
(c)

Figure 2. (a) The effect of ER on CO concentration , (b) The effect of ER on CO concentration CH₄ concentration and (c) The effect of ER on CO concentration H₂ concentration.

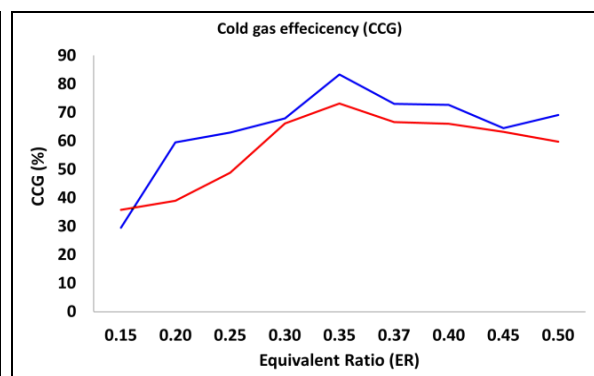
Both equations demonstrate that steam underwent reaction until CO and H₂ increased, as shown in Figure 2. (a-c). In the steam control, the valve was opened when the temperature in the boiler reached 100 °C. The air fed into the gasifier was controlled with the appropriate ER for self-steam gasifier being 0.25-0.35 or an amount of 25.60-18.28 m³/hr of 10 kg of RDF and the steam feed rate of 0.95 kg/hr.

3.2. The effect of the Equivalent ratio (ER) on efficiency

The efficiency of gasification in the self-steam gasifier is higher than the conventional gasifier both in terms of system efficiency and the thermal value of the fuel gas. The trend of the graph is increasing at the range of ER 0.15-0.35 and decreasing at the range of ER 0.50-0.35. This is consistent with the graph showing the gas components in Figure 2. Higher ER means the system approaches complete combustion, making the syngas concentration less dense with less efficiency. In Figure 3(a) and (b), the self-steam gasifier at ER 0.35 will yield the maximum thermal values of fuel gas at 6.56 MJ/Nm³ and the maximum efficiency of 83.22%. The self-steam gasifier shows higher cold-gas efficiency than the conventional gasifier of 13.87% at ER 0.35. This is due to the fact that the self-steam gasifier uses the heat produced to the fullest extent by means of the heat exchange with the water coils to produce steam instead of wasting the heat. The steam produced also increase the density of hydrogen and carbon monoxide, which are the fuel gases and hence the overall efficiency of the system becomes high.



(a)



(b)

Figure 3. (a) The effect of ER on syngas heating value and (b) The effect of ER on syngas heating value

4. Conclusion

The study shows that the self-steam gasifier designed in this study can increase the efficiency of the gasification system to 83.22%, which is 13.87% higher than the conventional gasifier that uses only air. This study used the compact refuse RDF as the fuel with the feed rate of 10 kg/hr. The air feed rate and the fuel feed rate (ER) were between 0.10-0.50. The system could produce steam too at the temperatures between 100-105 °C with the steam feed rate of 0.96 kg/hr. The experiment shows that the self-steam gasifier can produce fuel gas with a higher density of CO, CH₄ and H₂ than the conventional air gasifier. The appropriate ER values are in the range of 0.30-0.35 and the biomass gases obtained show the syngas heating value of 6.56 MJ/Nm³, which is 11.68% higher than the conventional air gasifier. The self-steam gasifier shows higher cold-gas efficiency than the conventional gasifier of 13.87% at ER 0.35

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