e-ISSN: 2548-060X

International Journal of Energy Applications and Technologies

journal homepage: https://dergipark.org.tr/en/pub/ijeat

Original Research Article

Production of hydrogen-rich syngas via gasification of refuse derived fuel within the scope of renewable energy

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ARTICLE INFO

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Received March 17, 2022
Accepted November 2, 2022

Published by Editorial Board Members of IJEAT

doi: 10.31593/ijeat.1088741

ABSTRACT

The main challenge facing the globe is the rapid increase in population, energy consumption, and waste production. As a result, gasification might be regarded a favorable, cost-effective, and eco-friendly solution to this issue. In this study was carried out using an updraft fixed bed circulating gasifier transforming refuse derived fuel (RDF) into syngas. It was employed at 700°C, 800°C, and 900°C with a dry air rate of 0.05 l/min. The effect of temperature on syngas, which is the product of gasification, was observed. The maximum heating value of produced syngas was observed about 2900 kcal/m^3 at 900 ˚C. As a result of the gasification process; conducted under optimum conditions, the concentrations of H_2, CH_4, CO were found to be approximately 45, 20, and 20 %, respectively. In conclusion, the gasification process is a suitable method for obtaining high-quality syngas from RDF materials that has a high calorific value.

Keywords: Energy recovery; Gasification; Refuse derived fuel; Waste management

1. Introduction

Population migration and industrial expansion from rural areas to urban areas, together with the increasing population density around the world, cause a large amount of waste production that leads to socio-economic and environmental problems [1]. Although global energy consumption fell by around 5% in 2020 compared to 2019, it is clear that fossil fuel-based energy resources covered the great majority of the world's energy needs. Despite the fact that non-renewable energy usage has been declining in recent years, there is always potential for improvement in the use of renewable energy and waste [2]. Waste-to-energy technologies (WTE-T), which integrate waste management technology with energy systems, are viable ways to handle the rise in population and industry growth in order to utilize waste and transform it into usable commodities. Several applications are being investigated to see how to enhance environmental effect and energy output in order to build a circular economy for sustainable cities [3]. These are known as biological or thermal treatment technologies [4]. Thermal treatment will become more alternative possibilities in the future as the population increases and landfills become an environmental issue [5].

The gasification process has the benefit of producing synthesis gas (syngas) by heating the source material under regulated conditions and partially oxidizing it [6]. As a result, when compared to other energy recovery techniques, it produces lower emissions [7]. Gasification is a suitable method to thermo-chemically transform RDF into syngas which is composed of hydrogen, carbon monoxide, carbon dioxide and methane. As a feedstock, RDF can be used in the gasifier and efficiently converted into syngas and will be produced in the form of ash and tar [8]. The Boudouard reaction, water-gas shift reaction, hydrogasification, methanation process, and stream reforming are the main chemical reactions in gasification [9, 10]. The fundamental equations of gasification process are listed in Table 1.

Table 1. Reactions occurring in the reactor during gasification

Reaction			Reaction number
$C + H_2O \rightarrow CO + H_2$	(ΔH) + 131 kJ/mol	Water- gas shift reaction	R (1)
$C + CO_2 \rightarrow 2CO$	(ΔH) + 172 kJ/mol	Boudouard reaction	R (2)
$C + 2H_2 \rightarrow CH_4$	(ΔH) + 74.8 kJ/mol	Hydrogasification	R (3)
$CO + H_2O \rightarrow H_2 + CO_2$	(ΔH) + 41.2 kJ/mol	Water- gas shift reaction	R (4)
$CH_4 + H_2O \rightarrow CO + 3H_2$	(ΔH) + 206 kJ/mol	Steam Reforming	R (5)
$CH_4 + 2H_2O \rightarrow CO + 4H_2$	(ΔH) + 165 kJ/mol	Steam Reforming	R (6)

Various researchers have attempted to assess waste gasification method by evaluating the economic and environmental implications. Panepinto et al. (2015) examine waste gas emissions, energy recovery, and the feasibility of both combustion and pyrolysis/gasification, concluding that gasification is more cost-effective, although direct burning of Municipal Solid Waste (MSW) allows for more power generation [11]. Lee et al. carried out an experiment in which sewage sludge was used as a feedstock for hydrogen-enriched syngas synthesis and a high-temperature steam gasification reactor was used as a thermal treatment system. In addition, the effect on the gasification products was monitored by varying the flow rate of the gasification agent in the reactor. The results show that a high temperature steam gasifier can optimize syngas production from the sewage sludge treatment process, when optimum operating conditions are provided in the reactor [12]. Yasar et al. (2021) investigated the effects of different temperatures and the ratio of steam to biomass on the synthesis gas composition and calorific values by gasification for the conversion of RDF to energy. High temperatures of around 900°C, a steam-to-biomass ratio of about 2.0, and a 3 min residence time were all suitable conditions for skilful gasification. The calorific value of RDF was found to be around 4340 kcal/kg of RDF [13]. The objective of the study is to determine syngas efficiency at different temperature through gasification of RDF. In addition, the influence of temperature on gasification performance was examined, as well as the hydrogen enriched gas potential of RDF using the gasification technique.

2. Material and Methods

Refuse derived fuel (RDF) was used as raw material in the experiments. The samples are in granular form, consisting of approximately 75% dirty raw waste and 25% combustible liquid solvent. Paper, kraft bags, textile products, packaging waste and dye (solid, liquid and powder) are the main components found in the RDF sample. The raw RDF material is shown in the Figure 1. Analyzes such as moisture, ash content and volatile matter for the samples were made according to Standard Methods.

Figure 1. The raw RDF sample.

2.1. Elemental analysis

C, H, N and S concentrations of the samples were carried out with Thermo-Flash 2000 CHN-S elemental analyzer using the ASTM-D5373-16 method [14].

2.2. Calorific (Heating) value analysis

The calorific values of the raw samples were determined by IKA C200 bomb calorimeter using the ASTM D5865-13 [15].

2.3. Gasification experiments

A laboratory scale updraft circulating fixed bed (UCFB) cyclone separator steel reactor was used for refuse derived fuel (RDF) gasification. Fig. 2 and Fig. 3 show the schematic diagram and the lab scale gasification reactor setup used in the laboratory, respectively. 20 g RDF was used as a feedstock. The steel reactor is 50 cm high and 8 cm in diameter and is electrically indirectly heated. Dry air was used as partial oxidizing agent for gasification. The flow rate was set at 0.05 $L.min^{-1}$ with a flowmeter. Gasification process was carried out at 700° C, 800°C and 900 °C temperatures. By keeping the agent flow rate constant; the effects of temperature on experimental processes were observed. H_2, CO and CH_4 were observed in the syngas formed as a result of gasification. The volumetric composition of synthesis gas was recorded instantly with the ABB AO2020 model online gas analyzer. The calorific values of the gasification products were calculated according to their volumetric percentages [16-18]. For calculations, values presented in Table 3 were used (URL 1, 2, 3).

3. Results and Discussion

3.1. RDF Characterization

The proximate and ultimate analyses of RDF were carried out under respective conditions and are shown in tables 1 and 2 respectively. The fixed carbon content was approximately 9 %, the volatile matter content was approximately 74 %, and the moisture level was around 4 %, as determined by the proximate analysis (Table 2).

doi: 10.31593/ijeat.1088741

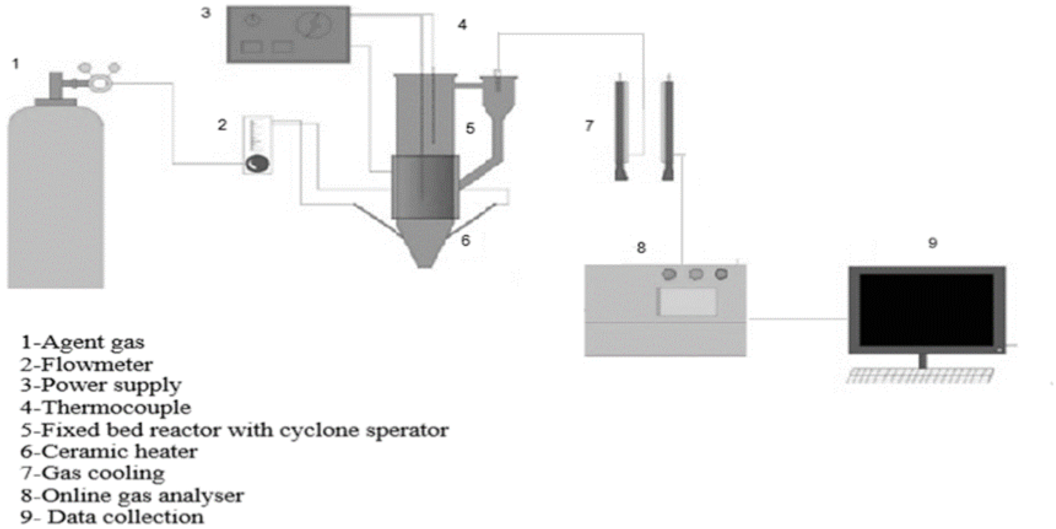

Figure 2. The schematic diagram of gasification reactor

Figure 3. The lab-scale gasification reactor

Table 2. Chemical Analyses of RDF

	Parameter	Method (ASTM)	Test Results
1	Total Moisture Content	D 3173–13 (2021)	3.98 % [19]
2	Volatile matter	D 3175–11	74.36 % [20]
3	Total Ash content	D 3174–11	12.6 % [21]
4	Fixed carbon	D 3172–13 (2021)	9.06 % [22]

The elemental composition of RDF was also studied by conducting the ultimate analysis. It was observed that the highest weight percentage was of carbon 58.2 %, and the concentration of hydrogen 6.4 % (Table 3).

Table 3. Elemental analysis and calorific values of raw RDF

Type of Fuel	Elemental analysis				Calorific Value analysis
	C (%)	H (%)	N (%)	S (%)	Calorific value (MJ/kg)
Raw RDF	58.1	6.5	-	-	17.23

*-: It is could not be detected

3.2. The composition of syngas

Dry air was used as partial oxidizing agent for gasification experiments. The flow rate was set at 0.05 $L.min^{-1}$ with a flow meter. Gasification process was carried out at 700, 800 and 900 °C temperatures and the effects of temperature on experimental processes were observed.

Fig.5 shows the syngas composition produced from the gasification RDF using dry air 700°C. H_2 concentration in syngas increased to 18 %, and CO increased to 12 %, while both CH_4 and CO_2 dropped in the time span between 17 th and 60 th minutes for the RDF gasification. Due to the drying of RDF, a high amount of steam is produced, which enhances the steam methane reforming process in the time interval. Furthermore, due to the endothermic feature of the methane reforming mechanism in R (5) and R (6) CH_4 decrease in the time span between 20^{th} and 83^{rd} minutes [23]. It was observed that the gas composition increased to 32 % by the 24^{th} minute and decreased after the 44^{th} minute.

doi: 10.31593/ijeat.1088741

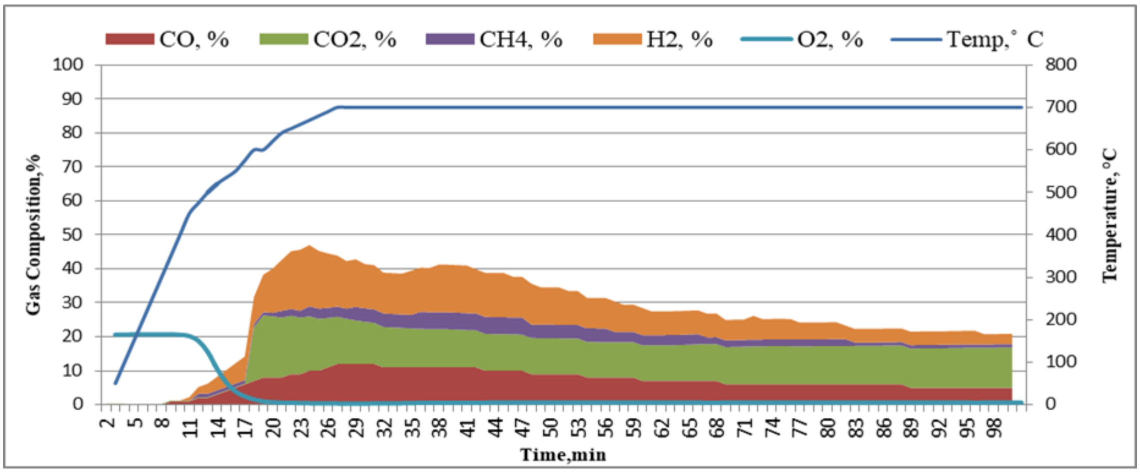

Figure 4. The syngas composition by RDF gasification at 800°C

The syngas composition produced from the gasification RDF using dry air at 800 °C is shown in Fig. 5. For CO, CO_2, CH_4, and H_2, the maximum volumetric syngas composition derived from RDF gasification reached to 14%, 19 %, 15 %, 28% respectively. H_2 content in syngas grew from 18 % to 28 % in the time interval between 19th and 30th minutes. The gas composition grew to 54 % in the 28th min and then decreased after the 33rd min, according to the data. Compared to the 700 °C temperature results, a higher H_2 gas ratio was observed at 800 ˚C.

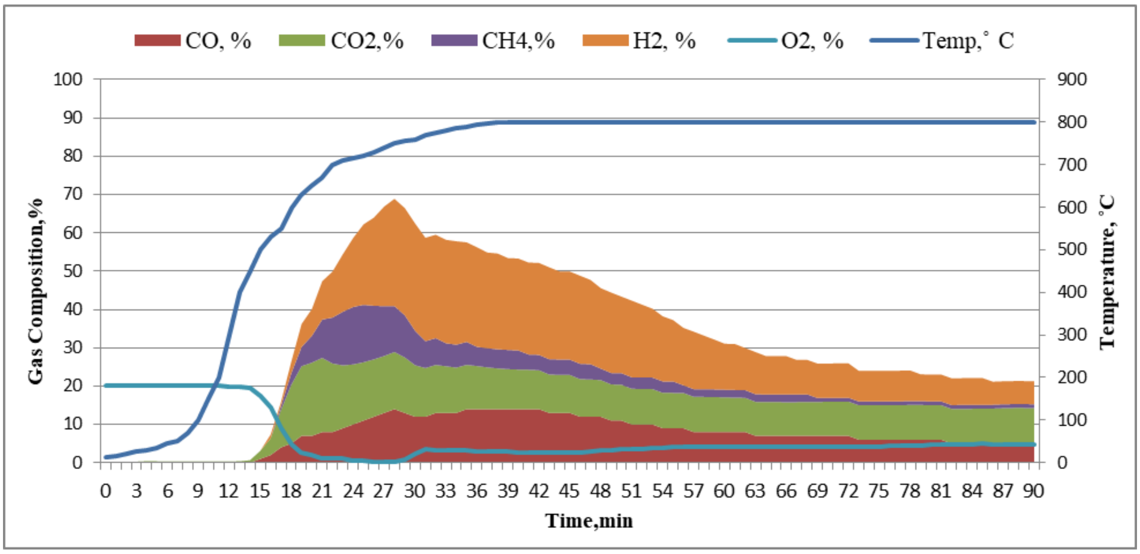

Figure 5. The syngas composition by RDF gasification at 800°C

It was observed that as the temperature increases the rate of gasification also increases which was maximum at 900°C in Fig. 6. At this temperature, the less tar content was achieved along with the good quality of syngas. The moisture in the gasifier, as well as the moisture in RDF, converts to steam as the temperature rises, and the ratio of steam-to-biomass rises as well, improving the gasification system [24]. At 900°C, the H_2 level increased up to 45%, which was seen as the best result among the gasification experiments. It is seen that the total gas composition reaches around 70 %.

Since higher temperature favours an endothermic reaction, higher temperature leads to higher H_2, CO while lower CO_2 and CH_4 contents. The water-gas shift and oxidation reactions which mainly produce CO_2, only take place at low-temperature ranges. Boudouard reactions R(2) consume CO_2 and take place mostly at higher temperature ranges [25]. Another study results showed that a higher temperature promotes thermal dissolution of carbon-carbon bonds, leading to water-gas-shift and methane reforming processes, enhancing H_2 synthesis in the gasification process [26, 27]. The composition of the synthesis gases produced by the gasification mechanism in our investigation is similar trend to that reported in other studies.

Temperature was the most critical factor impacting the energy recovery potential of gasification. At the high temperature, more energy was recovered as compared to less temperature (Fig. 6). The heating value given in Fig. 7 was seen as 2844 kcal/m^3, 2423 kcal/m^3 and 1815 kcal/m^3,

doi: 10.31593/ijeat.1088741

respectively. The high temperature allows for a higher conversion of RDF to energy while producing less ash and tar. RDF has a high calorific value due to the organic component in the waste. Furthermore, it was environmentally friendly in terms of emissions and recovered the maximum amount of energy from waste [28].

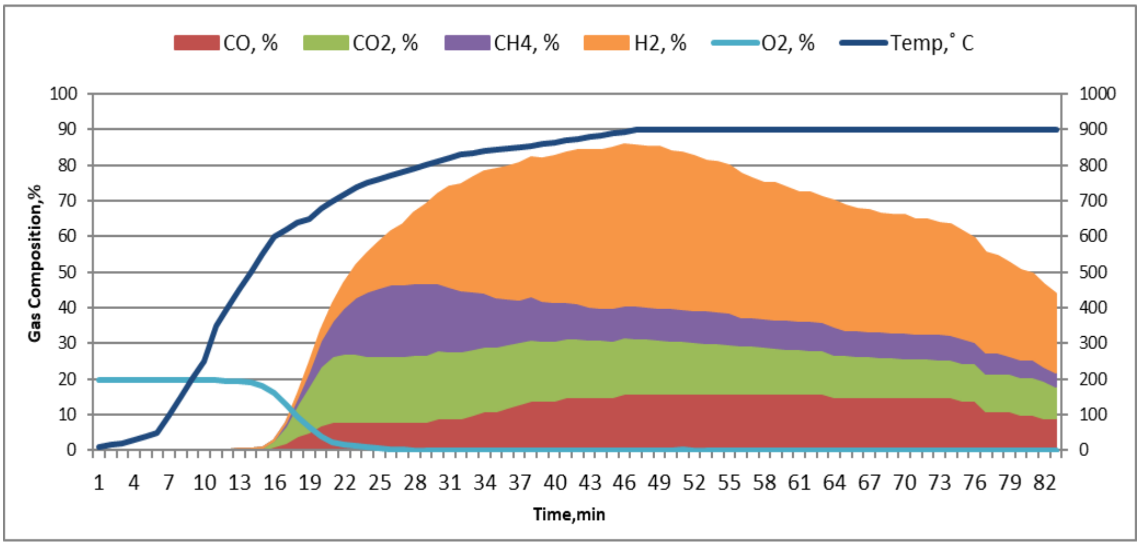

Figure 6. The syngas composition by RDF gasification at 900°C

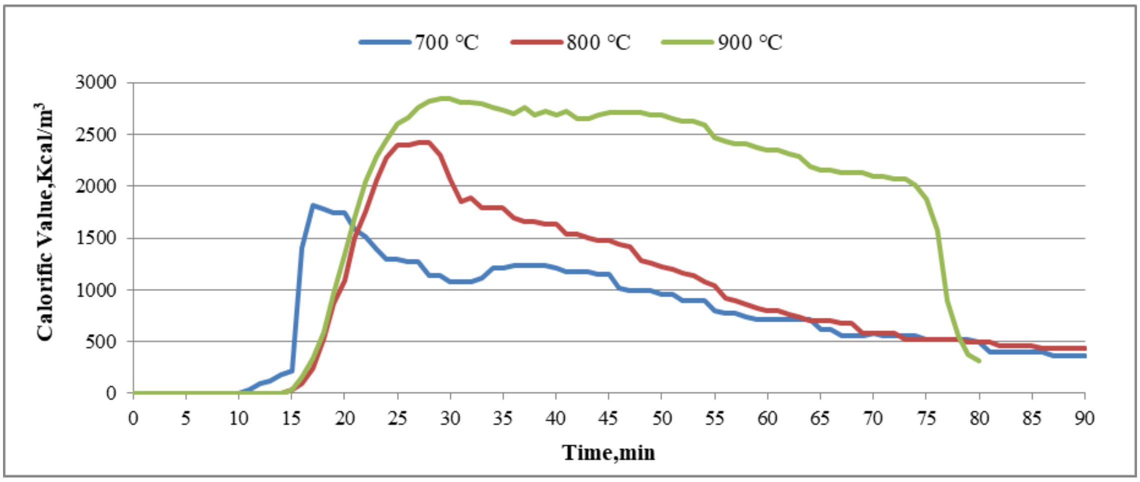

Figure 7. Calorific values of producer gas via gasification of varying temperature

Table 4. Higher Heating Value (HHV) for some common fuels (URL 1, 2, 3)

Fuels	Density	MJ m^{-3}	kcal m^{-3}
Hydrogen	0.090	12.7	3050
Methane	0.716	39.8	9530
Carbonmonoxide	1.140	12.6	3014
In this study	-	**11.9**	**2844**

4. Conclusion

The potential for energy recovery from various waste streams such as organic, textile, wood, craft paper and plastic waste existing in the form of RDF is multiplied by gasification. The study's objectives have been achieved, and a high calorific value of around 2900 kcal/m^3 was obtained. Furthermore, an excellent syngas composition was attained, with H_2 concentrations of about 45 %, CO concentrations of approximately 20 % and CH_4 concentrations of approximately 20 %. High temperatures of around 900 °C, was suitable condition for effective gasification. Hydrogen and carbon monoxide production increased with increasing gasification temperature as expected. The optimal gasification temperature for RDF gasification is 900 °C in order to obtain high calorific syngas. When looking at H_2, CO, and CH_4, approximately 70% of the produced synthesis gas was composed of these three gases with energy content at the best condition.

In this study only conducted a few experiments with a few different parameters to see if gasification might be utilized as an RDF management option. Even in such case, economically valuable syngas might be produced.

As a result, high-temperature gasification is an environmentally beneficial method for producing syngas with lower gaseous emissions and energy recovery.

doi: 10.31593/ijeat.1088741

Acknowledgments

This study was supported by the project (ID 34827) from Istanbul University-Cerrahpaşa, Scientific Research Projects Unit. The authors express their thanks to them.
The author took part in the Council of Higher Education YÖK 100/2000 Project as a doctoral scholar. The authors express their thanks to them.

Authorship contribution statement for Contributor Roles Taxonomy

Şeyma Mercan: Writing - original draft, Investigation, Visualization.
Atakan Öngen: Methodology, Supervision, Writing – review & editing.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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doi: 10.31593/ijeat.1088741