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Influence of Plastic Waste for Refuse-Derived Fuel on Downdraft Gasification

Chatchai Kungkajit[a], Gumpon Prateepchaikul[b], Thaniya Kaosol[a*]

[a]*Environmental Engineering Program, Department of Civil Engineering, Faculty of Engineering, Prince of Songkla University, Songkhla, Thailand*

[b]*Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University, Songkhla, Thailand*

Abstract

The potential of syngas production from used- and unused-plastic-waste Refuse-Derived Fuels (RDFs) by downdraft type fixed bed gasification technology is investigated. The purpose of this study is to investigate the syngas compositions of used- and unused-plastic-waste RDFs in the downdraft type fixed bed gasification system. It is found that used- and unused-plastic-waste RDFs can be successfully converted to generate the syngas consisting of carbon monoxide, carbon dioxide, hydrocarbon, hydrogen sulfide oxygen and water vapor. The performance of the downdraft type fixed bed gasification system is evaluated in terms of the composition of syngas and the rate of carbon monoxide production. The result can be concluded that syngas produced from the used- and unused-plastic-waste RDFs is the same. The HHV (Higher Heating Value) of the syngas from the unused-plastic-waste RDF (781 kJ/Nm^3) is slightly higher than that of the used one (500 kJ/Nm^3). It is also suggested that the gasification of used- and unused-plastic-waste RDFs is a clean alternative to fossil fuels. Moreover, the syngas can be directly used in the internal gas combustion engines.

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Keywords: HHV, plastic waste, gasification, downdraft, syngas, RDF ;

1. Introduction

The major municipal solid waste (MSW) problem in Thailand is plastic waste. The characteristic of plastic waste is its low moisture content by weight. Alternative and sustainable plastic waste disposal

*Corresponding author. Tel.:+6-681-400-6323; fax: +6-674-459-396.
E-mail address: thaniya.k@psu.ac.th.

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methods should be considered in regarding to the environmental and economic awareness. The conversion technologies for utilizing plastic waste can be categorizes into four basic categories: direct combustion processes, thermochemical processes, biochemical processes and agro-chemical processes [1]. A thermal process such as gasification is an existing technology to convert plastic waste into combustible gas and the final disposal from such processes is the residual solid ash. Gasification technology is recognized as one of the possibilities for utilizing plastic waste effectively. A downdraft type gasification system is intended to manage the plastic waste because it produces syngas with less tar [2]. The generated tar under the downdraft type gasification system is lower than that under the updraft type gasification system [3]. Ueki et al. [3] reported that tar can be decomposed during their passing through the lower part of the packed bed, which consists of char grains in the case of downdraft type gasification system. The syngas can be used as a fuel for internal combustion engines. Many researchers have studied downdraft type gasification. Tinaut et al. [4] reported the particle size effect of biomass and air velocity on the gasification characteristics under downdraft conditions experimentally and theoretically. Wander [5] reported the effect of syngas recirculation on a reactor of sawdust biomass gasification under a downdraft packed bed condition. Under a downdraft type gasification system, the volatile as well as tar will be released under high temperature in the pyrolysis zone and will be cracked and oxidized under favor of high temperature and oxygen in the oxidation zone [6].

RDFs cover a wide range of waste materials which have been processed to fulfill guidelines, regulatory or industry specifications to achieve a high calorific value. Possible wastes for syngas production include residues from industrial waste, sewage sludge, biomass waste and MSW recycling. The RDF is thought to have a number of merits such as low construction cost, stable calorific power, low burden on the environment, easy to handling and transport [7].

In this paper, a pilot-scale downdraft type fixed bed gasification system with a tar cleaning system has been studied. This research is aiming to convert plastic waste to a syngas using the proposed gasification system. The characterization of used- and unused-plastic-waste RDFs is important for downdraft type fixed bed gasification system. The most significant properties of any biomass or waste that are known to influence the downdraft type fixed bed gasification system are moisture content, size and shape, bulk density, higher heating value and chemical property (i.e. proximate and ultimate analysis). The temperature at the exit, the gasification zone and the drying zone of the downdraft type fixed bed gasification system is recorded during the experiments in this study.

2. Material and methods

2.1. Raw materials

Two types of RDFs made of used and unused plastic wastes and palm leaves, were used in the experiments (Figure 1). The palm leaves are used as a binder for RDF compaction. The raw materials were mixed and pressed then extruded to produce cylindrical shape briquettes with a diameter of 50 mm and a height of 60 and 70 mm. The used- and unused-plastic-waste RDFs were evaluated in the downdraft type fixed bed gasification system. The initial moisture contents of used- and unused-plastic-waste RDFs are very low.

(a) (b)

Fig. 1. (a) unused-plastic-waste RDF; (b) used-plastic-waste RDF

2.2. Experimental setup and procedure

Figure 2 presents the downdraft type fixed bed gasification system used in this study. The total height of the downdraft type fixed bed gasification system is 80 cm with a diameter of 12 cm (Fig. 3). Three thermocouples i.e., (T1, T2 and T3) were installed along the height. At the central position of the downdraft type fixed bed gasification system, T1, T2 and T3 were installed at the syngas exit, 10 cm above the grate (combustion zone) and 30 cm above the grate (throat combustion zone), respectively (Fig. 4). The optimum Equivalence Ratio (ER) is 0.38 which is the result from our previous study. Air velocity into the downdraft type fixed bed gasification system is 3.25 m/s.

For each RDF, the primary char bed was created first in the downdraft type fixed bed gasification system to enable a quick start in the subsequent gasification runs. A batch of 1 kg feedstock was loaded into the downdraft type fixed bed gasification system in each experiment. Before starting the ignition, the level of the feedstock was measured in order to calculate the density of the feedstock and the rate of feedstock consumption.

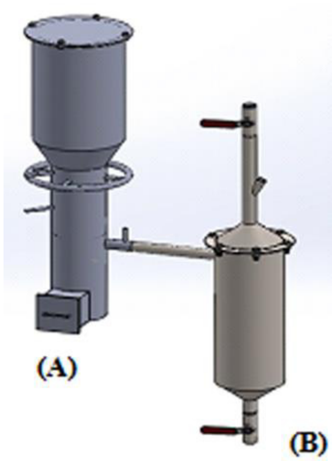
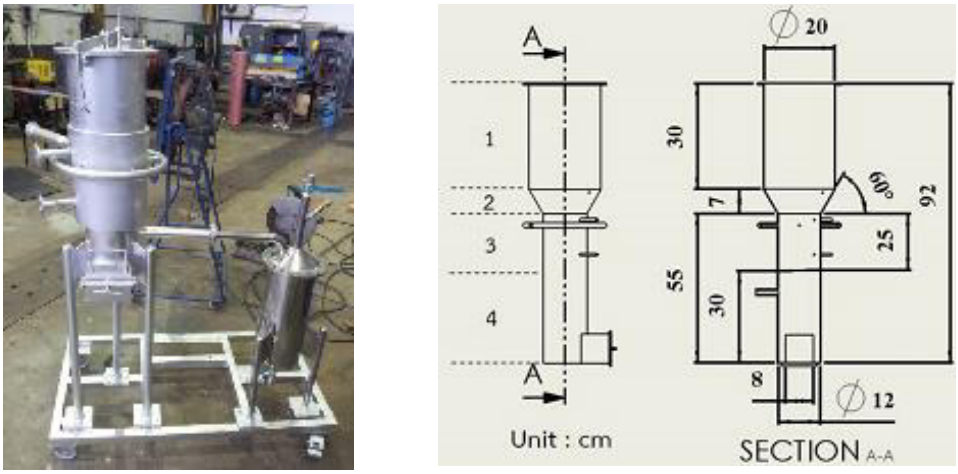


Fig. 2. Schematic of downdraft type fixed bed gasification system: (A) gasification and (B) tar removal tank



(a) (b)

Fig. 3. (a) Downdraft type fixed bed gasification system and (b) schematic of downdraft type fixed bed gasification system

The measurements of temperature and the sampling of syngas are carried out at an interval of two minutes. Each experimental run is carried out for 15 to 20 minutes. At the end of the experiment any leftover char is removed from the downdraft type fixed bed gasification system. The syngas is passed into the tar removal tank cleaned in the water in the tar removal tank which contains water in order to clean the resulting syngas. Passing through the cleaning step, the syngas is also cooled and passed into a gas composition analyzer. The syngas included in the analysis are CO, CO_2, HC, O_2, NH_3, CH_4 and H_2S. The oxygen is possible to be indicated during the security check before each run.

(a) **(b)**

Fig. 4. Three measuring points inside the gasification; (a) T1 and (b) T2 and T3

3. Results and discussion

3.1. Plastic-waste RDF characterizations

Table 1 reports the ultimate and proximate analyses of the used- and unused-plastic-waste RDFs. The used-plastic-waste RDF characteristic is 4.13% moisture content, 62.99% volatile solids, 7.70% fixed carbon and 25.17% ash. The ultimate analysis of used-plastic-waste RDF contains 41.88% C, 6.50% H, 24.59% O, 0.78% N, 0.06% S and 5,671 kcal of calorific value. The unused-plastic-waste RDF characteristic is 7.18% moisture content, 72.41% volatile solids, 9.24% fixed carbon and 11.16% ash. The ultimate analysis of unused-plastic-waste RDF contains 42.86% C, 6.42% H, 20.49% O, 0.77% N, 0.06% S and 5,725 kcal of calorific value (Table 1). The used- and unused-plastic-waste RDFs show similar ultimate and proximate characteristics. The moisture content effects both the operation of the downdraft type fixed bed gasification system and the quality of the syngas. The moisture content of most biomass varies between 11 and 18%. This range of moisture content is within the range for the gasification system application [8]. In this research, the moisture content of used- and unused-plastic-waste RDFs are range 4.13% and 7.18%. The results are concluded that used- and unused-plastic-waste RDFs is satisfactorily gasified in a downdraft type fixed bed gasification system.

Table 1. Chemical properties of used- and unused-plastic-waste RDFs

Chemical properties	Unused-plastic-waste RDF	Used-plastic-waste RDF
1. Ultimate analysis		
C (% by weight)	42.86	41.88
H (% by weight)	6.42	6.50
O (% by weight)	20.49	24.59
N (% by weight)	0.77	0.78
S (% by weight)	0.06	0.06
2. Proximate analysis		
Volatile solids (% by weight)	72.41	62.99
Fixed carbon (% by weight)	9.24	7.70
Ash (% by weight)	11.16	25.17
Calorific value (kcal)	5,725	5,671

3.2. Gasification operations

In this study, the syngas production potential from used- and unused-plastic-waste RDFs by downdraft type fixed bed gasification system is investigated. The four distinct reaction zones of the downdraft type gasification system are drying, pyrolysis, oxidation and reduction zones [9]. Figure 4 shows the temperature as a function of operation times for used- and unused-plastic-waste RDFs. Temperature is fluctuated in the downdraft type fixed bed gasification system; producing unstable syngas composition at the exit of the downdraft type fixed bed gasification system. The material balance is carried out to examine the reliability of the results generated in the experiment. The total mass input includes the plastic-waste RDFs consumption and air. The total mass output comprises of the ash and syngas product.

In these experiments, the maximum temperature at the syngas exit is determined as 649 °C and 594 °C for the used- and unused-plastic-waste RDFs, respectively (Fig. 5).

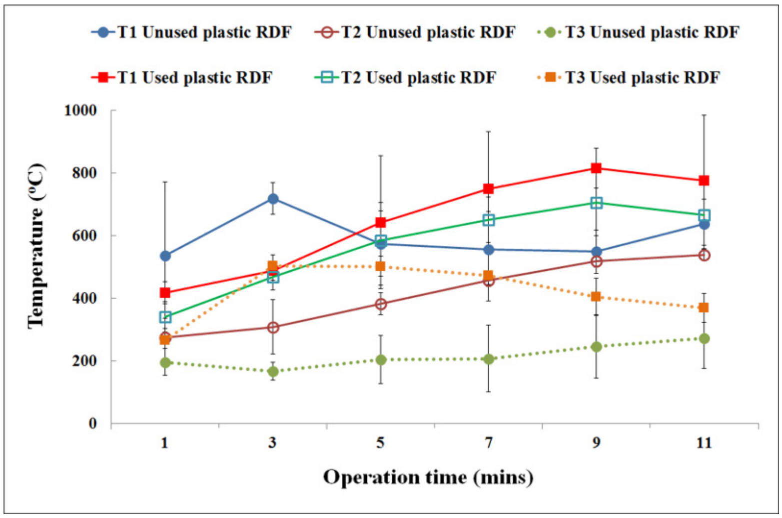


Fig. 5. Temperature as function of operation times for used- and unused-plastic-waste RDFs

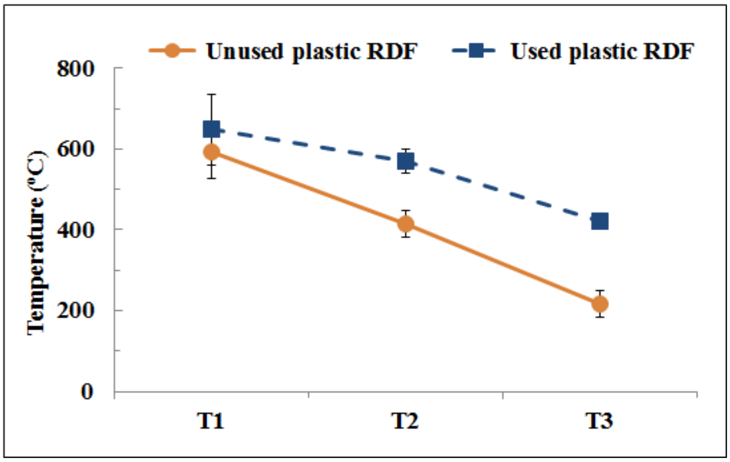


Fig. 6. Temperature as function of three thermocouple positions for used- and unused-plastic-waste RDFs

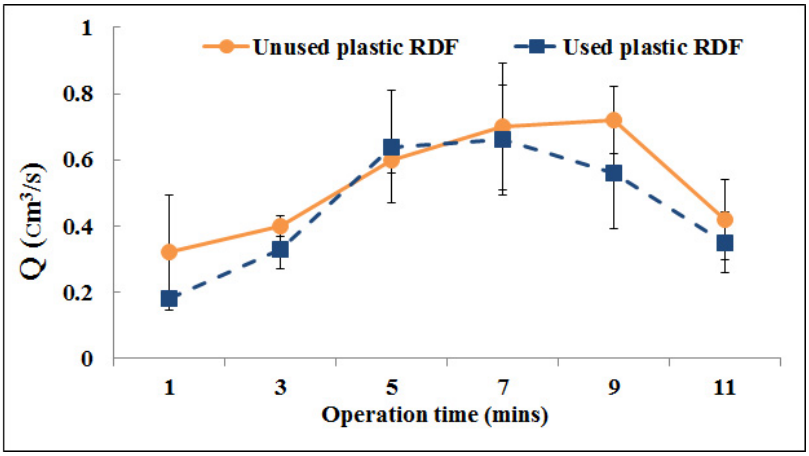


Fig. 7. Syngas flowrate as function of operation times for used- and unused-plastic-waste RDFs

3.3. Performance comparison on used- and unused-plastic-waste RDFs in the downdraft type fixed bed gasification system

The experimental results are compared with those reported in the literatures. Zainal et al. [2] performed experimental study on a downdraft biomass gasification system using wood chips and charcoal. It varied the equivalent ratio (ER) between 0.259 and 0.46 and found that the calorific value increases with ER and it reaches the peak value of 0.388, for which the calorific value is reported to be 5.34 MJ/Nm^3. The optimum ER is 0.38, which is used in our experiments. Both used- and unused-plastic-waste RDFs produce the syngas from gasification system (Table 2 and Figure 6). The Higher Heat Value (HHV) of the syngas from the used- and unused-plastic-waste RDFs is 500 and 781 kJ/Nm^3, respectively. Focusing on the syngas, the unused-plastic-waste RDF produces the highest syngas among all RDFs in this study.

Table 2. Syngas composition of used- and unused-plastic-waste RDFs under ER = 0.38

Gas composition (%Vol)	Unused-plastic-waste RDF	Used-plastic-waste RDF
CO_2	9.23±2.38	7.63±2.52
O_2	5.67±2.24	6.89±4.39
H_2S	0.16±0.04	0.21±0.09
CO	6.75±1.45	4.32±2.49
HC	0.46±0.18	0.21±0.12

High volatile matter in biomass generally increases tar contents in the syngas. The used- and unused-plastic-waste RDFs have low volatile matter; thus the syngas has low tar content. The tar contents are generated in the gasified operation under downdraft condition. Tar might be generated from the fresh used- and unused-plastic-waste RDFs just after feeding onto the top of the fixed bed. The tar contents in syngas from the downdraft type fixed bed gasification system is low because they can be decomposed when the passage through the char grains section at high temperature.

4. Conclusions

The syngas produced in a pilot-scale downdraft type fixed bed gasification system from used- and unused-plastic-waste RDFs has been characterized to identify the effect of used- and unused-plastic-waste RDFs. The 0.38 of ER is used in all experiments. The tar removal performance of the syngas cleaning system is also investigated. Tar content is low in the downdraft type fixed bed gasification system. Tar can be decomposed when passing through the lower part of the fixed bed, which consists of char grains. The results show that the used- and unused-plastic-waste RDFs can be successfully converted to generate the syngas. The performance of the downdraft type fixed bed gasification system is evaluated in terms of the composition of syngas and the rate of carbon monoxide production. The results can be concluded that the both used- and unused-plastic-waste RDFs can produce similar character and amount of syngas the syngas. However, the higher heating value of the syngas produced from unused-plastic-waste RDF (781 kJ/Nm^3) is higher than that of the syngas produced from the used-plastic-waste RDF (500 kJ/Nm^3).

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References

[1] Babu B.V., Chaurasia A.S. Parametric study of thermal and thermodynamic properites on pyrolysis of biomass in thermally thick regime. *Energy Conversion and Management*, 2004; **45**:53-72.

[2] Zainal ZA, Rifau A, Quadir G.A., Seetharamu KN. Experimental investigation of a downdraft biomass gasifier. *Biomass Bioenergy*, 2002; **23**:281-304.

[3] Ueki Y., Torigoe T., Ono H., Yoshiie R., Kihedu J.H., Naruse I. Gasification characteristics of woody biomass in the packed bed reactor. *Proceedings of the Combustion Institute*, 2011; **33**: 1795-1800.

[4] Tinaut F.V., Melgar A., Pérez J.F., Horrillo A. Effect of biomass particle size and air superficial velocity on the gasification process in a downdraft fixed bed gasifier. *Fuel Processing Technology*, 2008; 89: 1076-1089.

[5] Wander P.R., Altafini C.R., Barreto R.M. Assessment of a small sawdust gasification unit. *Biomass Bioenergy*, 2004; **27**: 467-476.

[6] Phuphuakrat T., Nipattummakul N., Namioka T., Kerdsuwan S., Yoshikawa K. Characterization of tar content in the syngas produced in a downdraft type fixed bed gasification system from dried sewage sludge. *Fuel*, 2010; **89**: 2278-2284.

[7] Nabeshima Y. Technical evaluation of refuse derived fuel. *Waste Manag. Res.*, 1996; **7**: 294-394.

[8] Dogru M. *Fixed-bed gasification of biomass*. PhD Thesis, University of Newcastle, UK, 2000.

[9] Reed TB, Das A. *Handbook of biomass downdraft gasifier engine systems*. Biomass Bioenergy Foundation Press; 1988.