



## **Experimental Study of RDF-Gasification for Power Generation : University's RDF Model**

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### **Abstract**

Waste is the discard matters which is coming out from human activity and needed a proper disposal in order to avoid the harmful to environment. However, there is still the hidden energy inside the throw-away waste and one need to recover that system since it is considered a green and clean renewable energy which can reduce the emission of green house gas and mitigate the global warming effect. In case of community which has the amount of waste less than 100 Tons per day, the prominent Waste-To-Energy technology is the using Refused Derived Fuel (RDF) and Gasification for power generation. Advantage is the only technology that can dispose waste properly, by reducing mass and volume, and at the same time, can generate the green energy in the form of electricity with no harmful to environment. Experimental study has been carried out to study the possibility of using RDF-Gasification technology for power generation by using waste generated within University as Model. Waste has been sorted out of non-combustible materials, as well as recyclable material from source separation. The rest paper and plastic are used to prepare RDF. Gasification by using RDF as feedstock has been performed in a laboratory scale downdraft gasifier which has a capacity of 10 kg/hr. The experimental parameters include the variation of air flow rate that fed into reactor, as well as RDF's compositions. The measured parameters include temperature distribution along the height of reactor, producer gas compositions. The potential of RDF-Gasification for power generation is judged by the cold gas efficiency which is high enough to feed into the engine-generator for electricity generation.

**Keywords:** Refused Derived Fuel, Gasification, Electricity Generation, Waste-To-Energy

### **1. Introduction**

Waste is the discard matter which is coming out from human activities in the diary life and its amount increases with increasing

population. It is inevitable to study and seek for a proper disposal technology. This technology should also include efficient energy recovery from waste without any impacts on environments



for sustainable development and economic sufficiency. Nowadays, the most often technology for waste management in Thailand is landfill which has a low investment cost compared to combustion or composting technology [1]. However, it is realized that waste management by landfill is not the sustainable technology to get rid of waste, because this technology cannot reduce the mass and volume of waste. Using thermal process, mass and volume of waste can be reduced by 70-90% [2]. Furthermore, then energy containing in waste can be converted to heat or electricity which can be used in in-situ plant or connected to electrical grid. Since waste in Thailand is not separated from source, it has high moisture content and low heating value. It is necessary to perform the feasibility study in order to find the proper way for Thailand waste management. Besides waste management problem, Thailand have faced the problem of high oil price, Department of Energy of Thailand has aimed to produce 160 MW electricity from waste in 2022 [3]. To achieve this target, it is necessary to seek for the technology to convert waste to energy.

Typically, thermal technology for power generation from waste is incineration technology and gasification technology. However, the suitable technology for power generation within small community which has the amount of waste less than 100 tons per day is gasification technology, since this technology can produce combustible gases which can directly be used as fuel for internal combustion engine or gas turbine and, consequently, provides higher overall efficiency for small-scale power generation (up to 5 MW<sub>e</sub>) than incineration

technology which generates power from steam cycle. Additionally, Gasification technology provides a cheaper power generation cost than incineration technology. Among several gasifier types, downdraft gasifier can efficiently dispose waste and, at the same time, advantageously generate power for small scale plant, according to [2, 4-8]:

- Variable fuel size (20-100 mm) and wide range of moisture content in fuel (< 20 %),
- Clean producer gas with the lowest tar content among other types of gasifier,
- Suitability for 1 MW electricity,
- Ease for operation and
- Low investment and operating cost

However, it is very crucial to conduct the test of RDF for power generation by using gasification system in order to confirm that the system can be used in the real application, also to get the operating / maintenance information. Therefore, the objective of this research is to test the power generation by RDF gasification in a 10 kg/hr laboratory scale downdraft gasification to study the characteristic of producer gas production to study the optimum point of operating condition.

## **2. Investigation of Waste Generation**

### **In University**

#### **2.1 Amount of waste generation**

As a university campus, the activities taking place in King Mongkut's University of Technology North Bangkok (KNUTNB) can generate substantial amounts of waste. This

waste can be considered to be an alternative fuel for power production. After collection information of waste generation for 6-months, it can be found that the total amount of waste generated in a university from May 2010 to November 2010 was accounted for 855.15 tons or average 4.02 ton/day, as shown in Table 1.

Table. 1 Amount of waste generated in KMUTNB from May-November 2010

Month	Amount of Waste Generated (ton)	Amount of Waste Generated (ton/day)
May	94.65	3.05
June	136.17	4.54
July	127.58	4.25
August	134.05	4.32
September	119.86	4.00
October	125.08	4.03
November	117.76	3.93
Total	855.15	4.02

With 23,942 registered student and 2,136 personals [9], waste generation rate can approximately be estimated to be 0.14 kg/day capita.

## 2.2 Waste Composition

After gathering information of waste generated in KMUTNB, the determination of physical composition of waste was conducted. Fig. 1 illustrates the physical composition of waste by weight which includes combustible wastes, e.g. food waste, paper, plastic, clothes and leaves or wood waste, as well as incombustible wastes, e.g. glass and other hazardous waste.

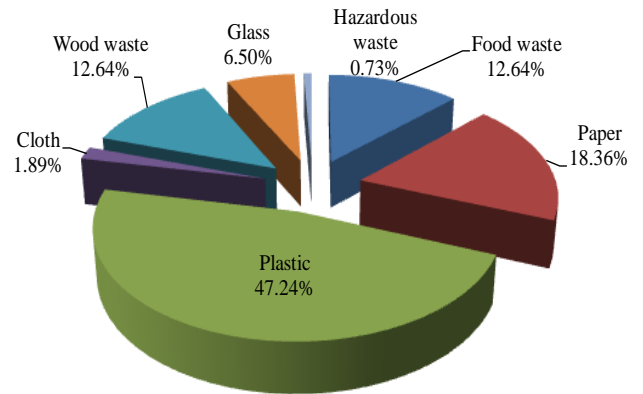


Fig.1 Physical Composition of Mixed Waste (in %-wt.)

From Fig. 1, it can be implied that mixed waste generated in KMUTNB has a high potential to be used as fuel, since it contains 93 % combustible waste. After investigation of mixed waste, the manual separation of dry waste is performed as a first step for RDF preparation in order to reduce moisture content. This RDF from dry waste which consists mainly of paper and plastic as shown in Fig. 2 will further be used as fuel in gasification process.

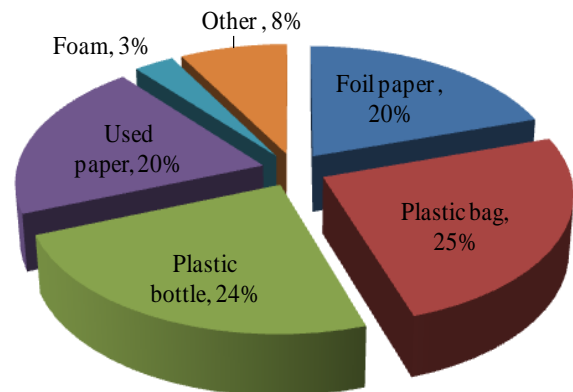


Fig. 2 Physical Composition of Dry Waste (in %-wt.)

## 3. Feedstock and Experimental Set Up

### 3.1 Feedstock

Before using as fuel, dry waste was cut by cutting machine, Fig. 3, in order to reduce size to approximately 2 cm wide and 2 cm long. Fig. 4 shows the dry waste before and after cutting. The properties of dry waste, e.g.

proximate and ultimate analysis as well as other properties were investigated by means of ASTM standard and, thereafter, prepared dry waste was used as RDF feedstock for experiments in a laboratory scale downdraft gasifier.



Fig. 3 Cutting machine



Fig. 4 Dry waste before cutting (left) and after cutting (right)

### 3.2 Experimental set up

In order to study the behaviour and potential of producer gas formation using RDF generated in university, a series of experiments were conducted in a 10 kg/hr laboratory scale downdraft gasifier. A 10 kg/hr laboratory scale downdraft gasifier system consists of a downdraft gasifier with fuel feeding system, air blower, air pre-heater, gas cleaning unit, weighing apparatus and data logger, as shown in Fig. 5. The downdraft gasifier is 2000 mm height and has a diameter of 600 mm. It can be divided into 4 parts as follow: fuel hopper, pyrolysis chamber, reaction chamber and ash chamber. Fig. 6 illustrates a 10 kg/hr downdraft

gasifier in more detail. Normally, the gasification process occurring in a downdraft gasifier can be divided into 4 reaction zones, as followed: drying, pyrolysis, combustion/oxidation and gasification / reduction. The temperature in pyrolysis chamber ranges between 200 and 500 °C, whereas the reaction chamber has the temperature of 500-1200 °C. The temperature in ash chamber can vary from 300 to 1000 °C. The temperature at each position in gasifier is measured by thermo-couples, as shown in Fig. 5.

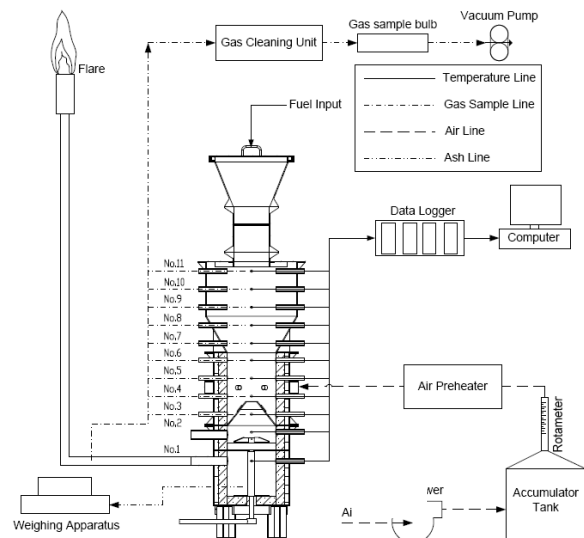


Fig. 5 10 kg/hr laboratory scale downdraft gasification system

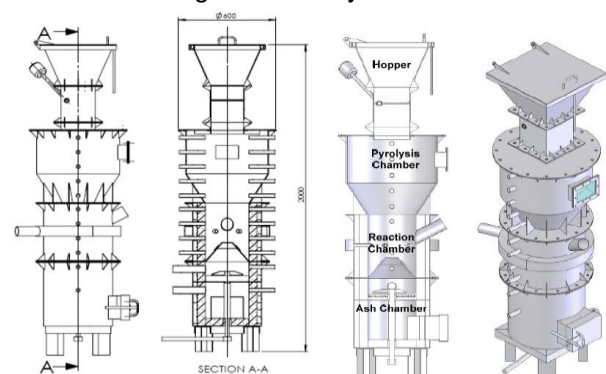


Fig. 6 10 kg/hr Downdraft gasifier

### 3.3 Experimental procedure

In order to facilitate the start up of gasification process in a 10 kg/hr downdraft gasifier, 2 kg of lignite-coal was firstly

introduced into gasifier. After the complete combustion of coal, approximately 5-10 kg/hr of RDF was fed into the gasifier and simultaneously air was supplied into reaction zone of downdraft gasifier as gasification agent at constant flow rate. In this study, air flow rate was set to be 12 Nm<sup>3</sup>/hr, 18 Nm<sup>3</sup>/hr and 24 Nm<sup>3</sup>/hr. RDF was ignited and the gasification process started. During the gasification process, the gasification temperatures at the measuring positions were measured by thermocouples and recorded. When the gasification temperature reached the constant value, it can be implied that the gasification process was completely taken place. The reaction time of gasification process was then recorded. Three sample of producer gas were taken for producer gas analysis during the gasification process. Fig. 7 illustrates the experimental procedure.

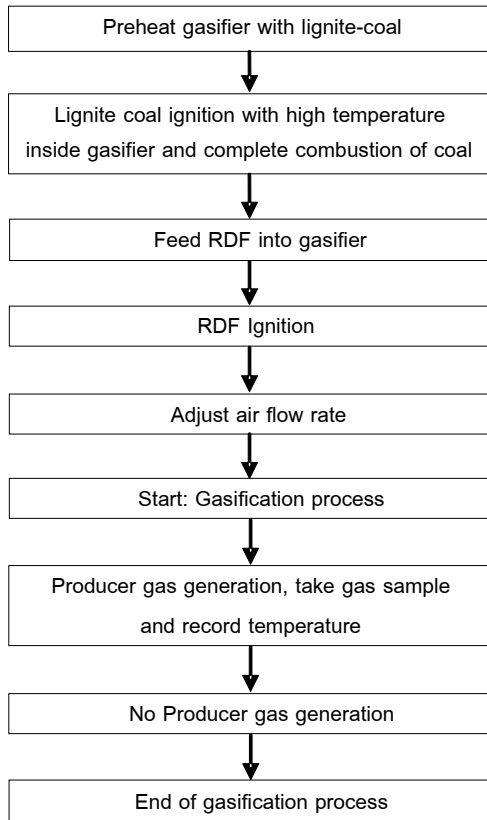


Fig. 7 Experimental procedure step by step

For producer gas analysis, the concentration of CO, CH<sub>4</sub>, H<sub>2</sub> and CO<sub>2</sub> was investigated. Lower heating value of producer gas was also calculated in order to determine the cold gas efficiency. Furthermore, RDF consumption rate and ratio of producer gas yield to RDF consumption rate were investigated.

## 4. Results and Discussion

### 4.1 Feedstock analysis

Table. 2 shows the proximate and ultimate analysis of RDF feedstock used in this study compared to the proximate and ultimate analysis of mixed waste.

The moisture content of RDF from dry waste and mixed waste is remarkably different. Mixed waste has a very high moisture content of 41.49 %, whereas the moisture content of RDF is only 2.15 %. The difference in moisture content is resulted from waste composition, e.g. mixed waste contains more food waste and water than RDF. Since RDF consists of a higher amount of plastic than mixed waste, the volatile matter in RDF is slightly higher than its value for mixed waste. There are no significant difference in other properties between RDF and mixed waste. Other properties which play an important role on gasification behavior are heating value and density [7]. Due to a very low moisture content of RDF, the higher heating value is accounted for 23.08 MJ/kg and the lower heating value is 20.78 MJ/kg. The bulk density of RDF from dry waste is very low, approximately 65 kg/m<sup>3</sup>.

Table. 2 the proximate and ultimate analysis of RDF from Dry Waste and Mixed Waste

	RDF from Dry Waste	Mixed Waste
<b>Proximate analysis (%-wt.)</b>		
Moisture content <sup>1</sup>	2.15	41.49
Volatile matter <sup>2</sup>	92.26	85.11
Fixed carbon <sup>2</sup>	1.02	7.37
Ash <sup>2</sup>	6.72	7.52
<b>Ultimate analysis<sup>2</sup> (%-wt.)</b>		
C	58.10	56.00
H	8.22	8.56
N	Not detected	0.134
S	0.037	0.066
O(by difference)	33.65	35.25

<sup>1</sup> as received

<sup>2</sup> dry ash free basis

#### 4.2 Temperature distribution in a 10 kg/hr downdraft gasifier

Temperature in each reaction zone in downdraft gasifier can be measured by thermocouples installed at different positions in gasifier, as listed in Table. 3. Fig. 8-10 show temperature distribution inside a downdraft gasifier (without thermocouple no. 1, 7, 8 and 9) at the air flow rate of 12 Nm<sup>3</sup>/hr, 18 Nm<sup>3</sup>/hr and 24 Nm<sup>3</sup>/hr, respectively.

Table. 3 Position of thermocouple for each reaction zone in downdraft gasifier

Reaction zone	Thermocouple No.
Drying	6 Up
Pyrolysis	5, 6
Combustion/oxidation	4
Gasification/reduction	2, 3

The temperature distribution for gasification process of RDF shown in Fig. 8-10 is highly fluctuated, since the gasification process cannot reach its equilibrium for each

air flow rate.

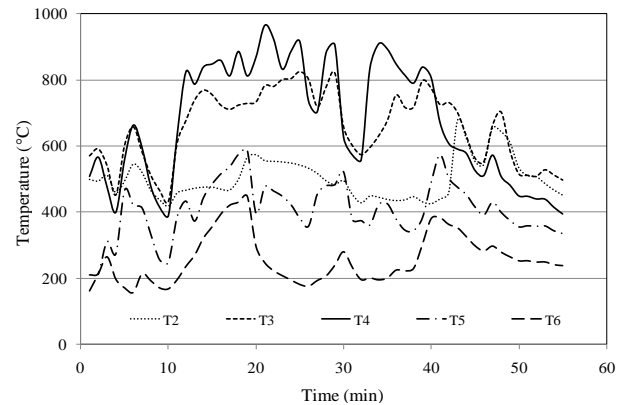


Fig. 8 Temperature distribution at the air flow rate of 12 Nm<sup>3</sup>/hr

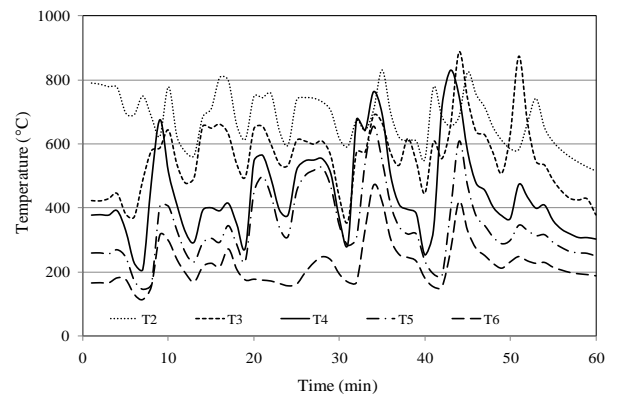


Fig. 9 Temperature distribution at the air flow rate of 18 Nm<sup>3</sup>/hr

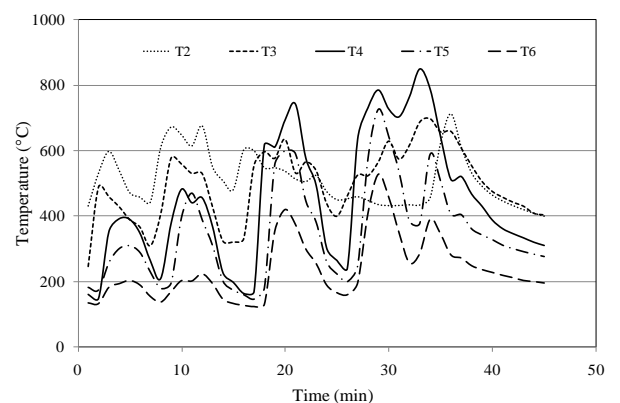


Fig.10 Temperature distribution at the air flow rate of 24 Nm<sup>3</sup>/hr

Such temperature profile is resulted from the fact that the gasification process in the reactor is not stable and cannot reach its equilibrium. Since RDF feedstock used in these experiments is very loose with a bulk density of only 65 kg/m<sup>3</sup>, the whole amount of RDF

cannot be feed into gasifier at the beginning of experiment. Only 1-2 kg was fed each batch and after ignition, this RDF was rapidly gasified at high temperature; new batch of RDF was then introduced into gasifier in order to proceed the gasification process. During feeding RDF, air is leaked into gasifier through feeding door. This led to the temperature drop in gasifier. After RDF was completely fed, the fuel feeding door was closed and exothermal combustion of RDF with additional air occurred. Therefore, the temperature in gasifier increased again to promote gasification process. This step was repeated until the whole amount of RDF fed into gasifier was about 8-10 kg. Almost stable gasification process occurred at the air flow rate of 12 Nm<sup>3</sup>/hr during the time period of 40 minute because the temperatures in gasifier did not extremely fluctuate. From the investigation of temperature distribution in gasifier, it can be implied that loose RDF is not suitable to used as feedstock because it causes unstable and non-equilibrium gasification process.

The reaction zones in gasifier and their temperature can be observed from temperature profile along the height of gasifier, as shown in Fig. 11. The reaction zone for the experiments with different air flow rate is almost identical. Drying zone for moisture removal taking place at the top of gasifier (a height of 70-90 cm) has the temperature of less than 200 °C for all air flow rate. Next reaction is pyrolysis zone, ca. 50-70 cm high, which has the pyrolysis temperature of approximately 200-400 °C for all air flow rate. At the height of 30-50 cm, where air is introduced into gasifier, the temperature for three air flow rates is remarkably different.

The amount of air flow rate affects the combustion process. The more air is supplied, the more exothermal process occurred and therefore higher temperature. From Figure 9, average temperature in combustion zone can reach 700 °C at the air flow rate of 18 Nm<sup>3</sup>/hr, whereas at the lowest air flow rate of 12 Nm<sup>3</sup>/hr, the temperature in combustion zone is only 480 °C. However, the temperature in combustion zone for the air flow rate of 24 Nm<sup>3</sup>/hr cannot be estimated to be 500 °C due to the significant fluctuation in temperature profile. At the bottom of downdraft gasifier (20-30 cm), where the reduction process was taken place, the temperature in the reduction zone is considerable reduced to 440-700 °C depending on the air flow rate.

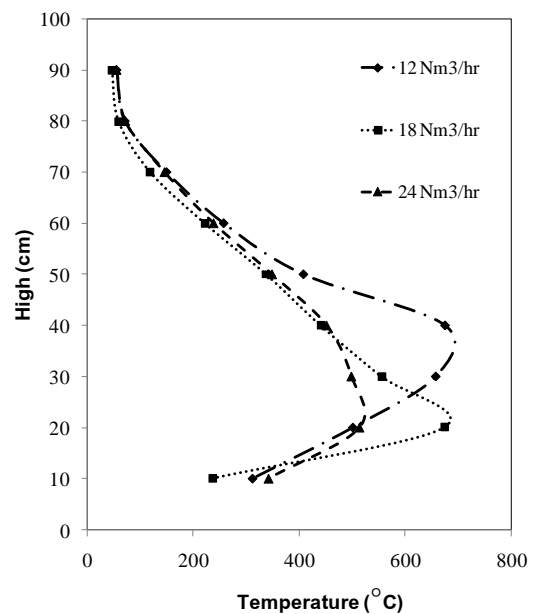


Fig. 11 Reaction temperature as a function of gasifier height

### 4.3 Producer gas composition

To study the characteristic of producer gas, the composition of producer gas from RDF gasification with different air flow rates was



investigated. Table 4 shows the producer gas composition at different air flow rates.

Table. 4 Producer gas composition at different air flow rates

Air flow rate	Producer gas composition (%-vol.)				Lower heating value
	Nm <sup>3</sup> /hr	CO	CH <sub>4</sub>	H <sub>2</sub>	
12	6.41	2.23	9.55	10.59	2.67
18	6.36	1.77	5.10	10.48	1.98
24	7.14	1.93	5.05	10.07	2.12

It was observed that CO had concentration between 6.36-7.14 %-vol., CH<sub>4</sub> of 1.77-2.23 %-vol. where the concentration of H<sub>2</sub> and CO<sub>2</sub> were decreased when increasing air flow rate. At 12 Nm<sup>3</sup>/hr of air flow rate, the concentration of H<sub>2</sub> and CO<sub>2</sub> were 9.55 %-vol. and 10.59 %-vol. and at 24 Nm<sup>3</sup>/hr, they were 5.05 %-vol. and 10.07 %-vol., respectively.

Since the combustible gas compositions are used to determine the producer gas's heating value, at air flow rate of 12 Nm<sup>3</sup>/hr gave more concentration of Methane and Hydrogen gas, consequently, the producer gas heating value at this operating condition was 2.67 MJ/Nm<sup>3</sup>.

#### 4.4 Optimum operating condition for gasification of RDF from old waste

Table 5 shows the overall operating condition and results of the experiments with different air flow rates in term of amount of RDF dosage for each experiment, producer gas yield, fuel consumption rate, ratio of producer gas yield to fuel consumption rate and cold gas efficiency which defines the ratio of energy output to energy input.

It was observed that, while increasing

air flow rate, the producer gas yield was also increased as well as fuel consumption rate. This is due to the acceleration of gasification reaction inside the reactor. It was found that at air flow rate of 24 Nm<sup>3</sup>/hr gave maximum producer gas yield, however, the maximum cold gas efficiency of 65.83% was found at air flow rate of 12 Nm<sup>3</sup>/hr. Therefore, this is the optimum operating point of this gasifier which gave the producer gas yield of 30.72 Nm<sup>3</sup>/hr and gas yield ratio of 5.12.

Table. 5 Overall operating condition and results of the experiments

Air flow rate (Nm <sup>3</sup> /hr)	Producer gas yield (Nm <sup>3</sup> /hr)	RDF consumption rate (kg/hr)	Gas yield: (Nm <sup>3</sup> /kg.RDF)	Cold gas efficiency (%)
12	30.72	6.00	5.12	65.83
18	39.92	8.28	4.82	45.87
24	63.47	13.20	4.81	49.05

## 5. Conclusion and Outlook

From this study, it can be conclude that the waste generated within the university campus has the potential to be converted into high heating value gaseous fuel via gasification process. The optimum operating condition for the gasification process of RDF collected from King Mongkut's University of Technology North Bangkok is at the air flow rate of 12 Nm<sup>3</sup>/hr. The producer gas has the heating value of 2.67 MJ/Nm<sup>3</sup>. This heating value is not high enough to be used as fuel for electricity production in engine-generator which requires fuel with heating value of more than 4 MJ/Nm<sup>3</sup>. Furthermore, the cold



gas efficiency is only 65.83 % and the gasification temperature is much fluctuated according to the unstable gasification process and the reactions cannot reach their equilibriums. It is necessary to improve the heating value of producer gas and, consequently, cold gas efficiency by densification of RDF which will further be carried out in next step.

### 6. Acknowledgement

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