International Journal of Sustainable and Green Energy
2015; 4(1-1): 44-49
Published online December 31, 2014 (http://www.sciencepublishinggroup.com/j/ijrse)
doi: 10.11648/j.ijrse.s.2015040101.17

Performance analysis of power generation by producer gas from refuse derived fuel-5 (RDF-5)

Natthawut Dutsadee[1, *], Nigran Homdoung[1], Rameshprabu Ramaraj[1], Khamatanh Santisouk[2], Shangphuerk Inthavideth[2]

[1]School of Renewable Energy, Maejo University, Sansai, Chiang Mai-50290, Thailand
[2]Department of Mechanical Engineering, Faculty of Engineering, National University of Laos, Vientiane, Laos

Email address:

natthawu@yahoo.com (Dussadee N.), natthawu@mju.ac.th (Dussadee N.)

To cite this article:

Natthawut Dutsadee, Nigran Homdoung, Rameshprabu Ramaraj, Khamatanh Santisouk, Shangphuerk Inthavideth. Performance Analysis of Power Generation by Producer Gas from Refuse Derived Fuel-5 (RDF-5). *International Journal of Sustainable and Green Energy.* Special Issue: Renewable Energy Applications in the Agricultural Field and Natural Resource Technology. Vol. 4, No. 1-1, 2015, pp. 44-49.
doi: 10.11648/j.ijrse.s.2015040101.17

Abstract: At present, municipal and city corporation governments throughout the world are facing choices about how to manage the unending stream of waste generated by their residents and businesses. In many places landfills and dumpsites are filling up, and all landfills and dumpsites leak into the environment; due to increasing populations, the issue of waste becomes more urgent and more complicated. Many regions are already facing a waste crisis, and drastic measures are needed. In the past, the main approach to waste management operations is the landfill which is causes many environmental pollutions and health hazards. Furthermore, extending the land for land filling is the one of best solutions. This paper demonstrated the performance analysis of power generation producer gas from RDF-5 in Chiang Mai University, Thailand. The efficiency of different ratio waste composition and of RDF-5 was revealed. In addition, the humidity, density and heat capacity of RDF-5 are also focused. In order to analyze the compositions, heat capacity of producer gas, fuel consumption, efficiency of producer gas system, waste water and quantity of ash; RDF-5 have been tested by using producer gas in different ratio of oxygen and fuel. In term of automobile application, the performance of RDF-5 and Diesel-RDF-5 are compared; and the specific factors such as power, specific fuel consumption rate, carbon dioxide, sound level and fuel feeding were included that comparison. Consequently, this paper mainly focused and concerned with the production and properties of refuse derived fuel-5 for use in energy from waste technologies.

Keywords: Municipal Solid Waste, Combustion Engine, Renewable Energy

1. Introduction

Waste management is collection of waste which generated by every person in the society. The majority of the waste consists of household waste, agricultural waste, industrial waste and bio medical waste. They consist of recyclable waste and biodegradable waste. Some of them are hazardous waste and toxic waste which cause health hazardous and environmental pollution. One of the best solutions for waste management is converted waste into renewable energy in the form of thermal energy as well as electrical energy. Refuse Derived Fuel (RDF) is combustible or, in other word, high calorific fraction recovered from Municipal solid waste (MSW). There are other terms used for MSW derived fuel such as Recovered Fuel (REF), Packaging Derived Fuel (PDF), Paper and Plastic Fraction (PPF) and Process Engineered Fuel (PEF) [1, 2].

The refuse-derived fuel (RDF-5) is convenient for transportation and storage, high in calorific value, and low in pollution. The waste composition and physical and chemical characteristics of each waste fraction were determined to evaluate the suitability of the waste for recycling and reuse as RDF-5 [3]. In 2005, the production of RDF-5 waste reached 13 million tons in EU, indicating the rapid development of RDF-5 waste as an alternative energy source. The use of RDF-5 in Asia is gradually becoming popular, e.g., in Japan and Taiwan [4].

RDF-5 is the first alternative fuel which is obtained from municipal solid waste [5]. However, producing RDF-5 does not make household waste and industrial waste disappear.

Presently, in the development of RDF-5 in the form of thermal and electrical energy is only 5 MW [6]. This is due to restriction of laws and regulations and lack of information for decision makers and investors to introduce RDF plant.

Moreover, the communities cannot managed the waste as well as it should be and most people do not believe that the technology can be overcome those problems. In 2007 the wastes increased 14.72 million tons or 40332 tons/day which is 14,432 tons/day or 35.8% is treated in the right way [5], show in Table 1. In 2006, the northern of Thailand, the wastes are 2,195 tons/day [6, 8]. It would be useful if this amount of waste is converted into renewable energy, such as thermal and electrical energy as supplementary fuel for industries. Therefore, it could be reduced the amount of import fuel from oversea as well as reduced environment pollution.

Table 1. *Solid waste management in 2007.*

Region	Solid waste (ton/day)		
	Generated	Eliminated	Proportion (%)
Bangkok	8532	8532	21.2
Municipal and Pattaya (1,277 places)	13600	4810	11.9
Outside of Municipal 6,500 places)	18200	1090	2.7
Total	40332	14432	35.8

Currently, there are several technologies to eliminate the municipal solid waste; anaerobic digestion, biogas from waste landfill, producer gas RDF-5, manufacturing of fuel, plasma arc, converted plastic waste into fuel and incinerator. In this paper, producer gas RDF-5 is chosen as eliminate municipal solid waste technology. The steps and advantages of producer gas process are shown in the list below:

1. Preliminary liberation: this step involves separating municipal solid waste into bio-degradable, glass, rags, paper, plastic, leather and rubber, metals and other domestic hazardous, inert.
2. Size screening: size screening involves separating the municipal waste based on the size and shape of the particle. It helps in material handling comfortably.
3. Shredding: destructing the large amount of solid waste into smaller pieces by crushing and cutting for easy handling and transporting.
4. Magnetic separation: separating the metal particles from the crushed particles.

According to the ASTM E-75 standard, producer gas divided into 7 types [4]: RDF (Municipal Solid Waste (MSW)), RDF-2 (Coarse RDF), RDF-3 (Fluff RDF), RDF-4 (Dust RDF), RDF-5 (Densified RDF), RDF-6 (RDF Slurry) and RDF-7 (RDF Syn-gas). Producer gas technologies are included mechanical system and thermal system. In this paper, producer gas Down-Daft Gasified type is used. The system divided into three zones: Distillation zone, Combustion zone and Reduction zone. The chemistry reaction of each zones divided into combustion zone, reduction zone, distillation or pyrolysis zone and drying zone [5,9].

2. Experimental Design

2.1. Experiment Apparatus and Measurement System

Producer gas RDF-5 shown in Figure 1 and Figure 2 illustrated the producer gas system Down Draft type which is used in this research. The system consists of producer gas system, cleaning system and heat exchanger (producer gas cooling), piping and its associated devices. The producer gas has a neck diameter of 16.6 cm. The location of nozzle is 13 cm along the height of producer gas from the neck diameter plane of producer gas. There are 5 nozzles in this system which is 15 cm diameter for each. The gasifier reactor capacity is 35-40 kg for charcoal and 100-110 kg for RDF-5. The top of the reactor is the feedstock hopper which has the capacity 10 kg and 30 kg of charcoal and RDE-5, respectively. The charcoal (biomass) consumption rate is about 5-20 kg/hr. To eliminate the ashes, the filter is installed and there is storage for ash which is contained 70 liters of water. The air input and output controlled by 220 V, 185.5 W fan.

Figure 1. *Producer gas RDF-5 [7].*

Figure 2. *Producer gas Down Draft type.*

The cleaning system was demonstrated in Figure. 3. The system consists of cyclone, wet collectors, filters, and trap tank. For the heat exchange is exhibited in Figure 4. The producer gas is transmitted by the pipe which has 5.08 cm diameter and welded with the cyclone. The 90 liters square steel tank contains the cool water to drop the temperature of producer gas out from 400-500 °C to 200-250 °C. The gas transmitter and air controller are used the 3 phase, 400 W, 50 Hz, 380 V fans as show in Figure 5.

Figure 3. *Cleaning system.*

Figure 4. *Heat exchanger and producer gas transmitter system.*

Figure 5. *producer gas engine and load (heater).*

Table 2. *Environmental and algal biomass measurements*

Gasifier System Specification	
Type of Gasifier	Downdraft
Feeding	Manual/batch feeding
Biomass consumption	5-20 kg/h
Hopper capacity	Charcoal: 35-40 kg, RDF-5: 100-110 kg
Producer gas cooling	Water
Producer gas flow rate	80 m^3/h (maximum)
Biomass size	10 mm (minimum)-50 mm(maximum)
Producer gas cleaning	Ventury Scrubber/Pack bed Scrubber Biomass filter/Fubrics filter/Paper filter

For the producer gas engine, the ignition engine NISSAN Z16, 4 cylinders, 4 strokes, 1595 cc, maximum power 61.74 kW is used, as shown in Figure 5. The compression ratio have modified from 8.8:1 to 10.5:1 as more details refer to table 2 and 3.

Table 3. *Performance testing parameters of producer gas engine.*

SI producer gas engine specification	
Engine make & model	NISSAN/Z16
Cylinder/alignment/cycle	4/Inline/4stroke
Compression ratio	8.8:1 (10.5)
Bore x Stroke (mm)	83 x 73.7
Cylinder capacity	1595 cc
Gross engine power	61.74 kW
Ignition system	Battery-based distributor type with ignition advance
Total oil capacity	ELECKING 1 phases 50 Hertz 220 V 2kVA
Load	Electrical heater

2.2. Experimentation and Implementation

The experiment setup and measurement system is illustrated in Figure 6. The angle velocity of the engine is measured by a Tacho meter at the pulley of the engine while exhaust emission analysis is installed at the exhaust emission.

Performance testing of producer gas engine is started by measured the temperature, pressure at the atmosphere pressure. The average pressure and temperature are 0.92 kPa and 32 ± 3°C, respectively, air density is 1.1 kg/m3. In order before run the test, RDF-5 should be weigh first to obtain feeding capacity. After that, the gas generator is started to ignition about 20 min, the gas quality is checked by ignition at the gas check point (1) as shown in Figure 7; when observe that the gas is balance, the valve is opened to allow the producer gas flow into the cleaning system and flow throughout the heat exchanger and then check the quality of producer gas again at check point (2). If the producer gas is balance, the valve is opened to allow the producer gas flow and mix with the air in the appropriated composition and then enter to the producer gas engine. In the case of the amount of gas in the storage is exceed the other valve will open to release it to the environment.

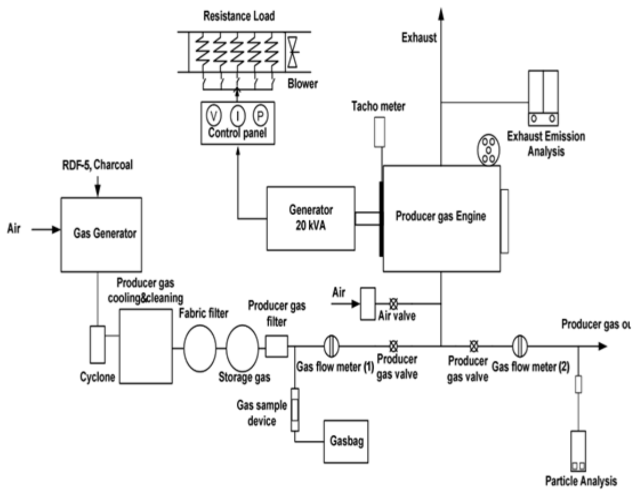

Figure 6. *Overall schematic diagram of experiment apparatus and instruments setup.*

Figure 7. *Checking quality of producer gas and running generator.*

The test are divided into 6 cases of load; 1.5 kW, 3 kW, 4.5 kW, 6 kW, 7.5 kW and 9 kW and in the case of unloading. The consumption of RDF-5, producer gas flow rate, angle velocity of engine, ignition angle, emissions of engine and sound of engine are recorded 3 times for each case.

3. Results and Discussion

The result illustrates that the maximum efficiency of producer gas is 62.4%. The substances obtained from producer gas RDF-5 are 8.35% CO, 10.23% H_2, 3.52% CH4, 17.70% CO_2, 8.11% O_2 and 52.10% N_2, respectively. The average of heat capacity of producer gas is about 3,434.45 kJ/Nm^3. For the engine power systems, producer gas RDF-5 produced maximum electric power 9 kW at 1500 rpm, combustion located at 25°C, minimum specific fuel consumption 1.53kg/kWh at the load of 7.5 kW and obtained maximum 3.21% of CO and 74.5 ppm of hydrocarbon. The minimum of CO and hydrocarbon occurred at the load 1.5 kW are 0.26% and 42 ppm, respectively.

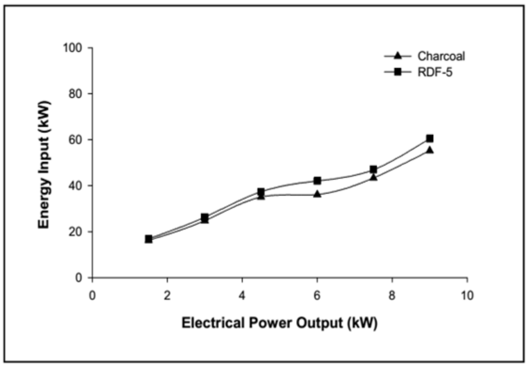

Figure 8. *Power of producer gas engine form RDF-5.*

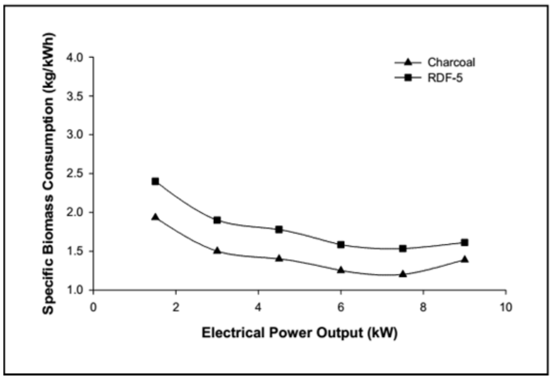

Figure 9. *Specific fuel consumption rate of producer gas engine*

The power generated by producer gas engine is increased gradually by increased energy or producer gas flow rate as show in Figure 8. The producer gas engine generated maximum electrical power 9 kW and minimum 1.5 kW at producer gas flow rate 63.35 m3/hr and 17.7 m3/hr, respectively. The producer gas RDF-5 is better than charcoal 4-14 % in terms of energy input for the engine as show in Figure 9. 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. The specific fuel consumption rate of producer gas engine is the rate of solid wastes or charcoal input compare with electrical power output.

The results show that at the load 2-6 kW the specific fuel consumption rate of producer gas engine trended reduce and increase at the load 8-9 kW. These are occurred both RDF-5 and charcoal as illustrate in Figure 10. The minimum of specific fuel consumption rate of producer gas engine occurred at 7.5 kW of load, the rate of fuel consumption is 1.53 kg/kWh for RDF-5 and 1.2 kg/kWh for charcoal. The maximum of specific fuel consumption rate of producer gas engine occurred at 1.5 kW of load, the rate of fuel consumption is 2.4 kg/kWh for RDF-5 and 1.93 kg/kWh for charcoal.

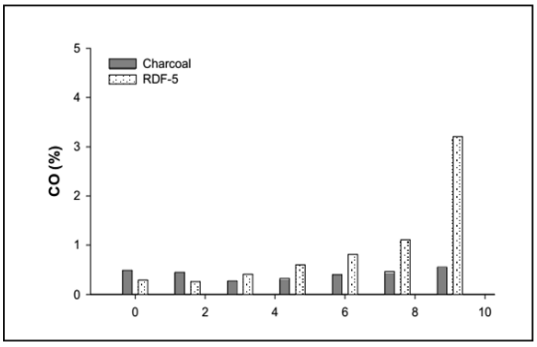

Figure 10. *Carbon monoxide emission of producer gas engine.*

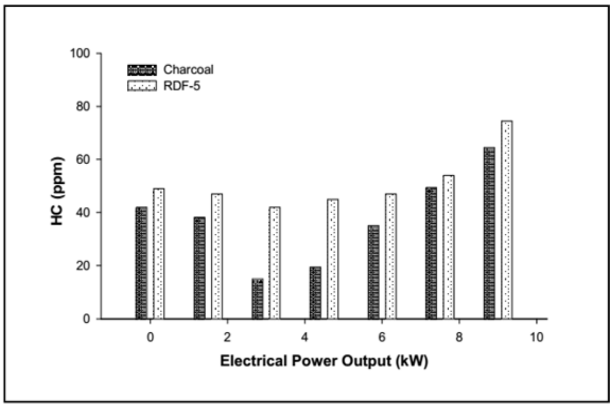

Figure 11. *Hydrocarbon emissions of producer gas engine.*

The quantity of carbon monoxide (CO) from RDF-5 and charcoal increased when the load is lightly and heavily as show in Fig. 10. At the middle load to maximum load CO from RDF-5 is 89% greater than charcoal because of the combustion of the engine trend to be in-combustion [5]. The maximum and minimum of CO from RDF-5 is 3.21 % and 0.26 % at 9 kW and 1.5 kW, respectively. The maximum and minimum of CO from charcoal is 0.55 % and 0.27 % at 9 kW and 3 kW, respectively. At the load of 7.5 kW CO from RDF-5 is lower than carbon monoxide emission standard 26%.

Similar to carbon monoxide case, the quantity of hydrocarbon from RDF-5 and charcoal increased when the load is lightly and heavily as show in Figure 11. The maximum and minimum of hydrocarbon from RDF-5 is 74.5 ppm 42 ppm at 9 kW and 3 kW, respectively. The maximum and minimum of hydrocarbon from charcoal is 64.5 ppm and 15 ppm at 9 kW and 3 kW, respectively. The results also illustrated that hydrocarbon from RDF-5 is lower than hydrocarbon emissions standard 62.7%.

The maximum sound intensity level from RDF-5 of producer gas engine is 96.4 dB at the maximum load while the maximum sound intensity level from charcoal is 94.4 dB at the same condition of load. The sound intensity is increased gradually along with increasing the loads as show in Figure 12. Fortunately, the sound intensity level from RDF-5 and charcoal are lower than the standard sound intensity level 100 dB. The exhaust temperature of the producer gas engine depends on the load, if the load is increased the exhaust temperature also increased as show in Figure 13. The exhaust temperature from RDF-5 of producer gas engine is lower than the exhaust temperature from charcoal. At the maximum load the exhaust temperature of RDF-5 and charcoal is 339°C and 342°C, respectively. At present, bio-energy refers to useable energy (such as electricity and heat) that is converted from biomass. Similar to wind and solar energy, bio-energy is an excellent energy recycling technology, but it has the most prospects, given its ability to turn refuse into bio-energy [9]. Several technological processes are available to convert this waste into usable energy resources and products, such as ethanol, biodiesel, electric power, and plastics. For example, biomass can be converted to provide an electric power source for automobiles [10]. As such, refuse-derived fuel (RDF) technology has in recent years become the refuse processing technology adopted by advanced nations [11,12].

The American Society for Testing and Materials (ASTM, 2006) divides RDF into seven main categories. The most common type of refuse-derived fuel comes from sewage sludge (RDF-5), where the sewage sludge is made into solid pellet-shaped fuel after going through various processes [13]. Sewage sludge contains a significant amount of organic matter which is predominantly proteins and carbohydrates. These account for approximately 90% of the volatile suspended solids after the sludge is concentrated by settling at 4 °C for 24 h [14, 15, 16]. The main characteristics of RDF-5 lie in its size, its high and constant heating value (3000–6000 kcal/kg), the differing amounts due to the source of waste material, but is usually two-thirds that of coal), its low level of pollution, and that it does not emit a foul smell. In addition, as it is reduced to one-tenth of its original size after processing, it can be easily transported or stored. It is also convenient in use as it can be stored under normal temperatures for 6–12 months without decaying. The fuel can also be used directly in the fired boiler as the main combustible or when mixed with other fuels [15–17]. (Alter, 1996, Raili and Marttl, 1996 and Weber et al., 2009).

Accordingly, the main advantage of RDF-5 is conversion of waste into energy which helps in effective handling of Municipal Waste. The other advantage includes the problem associated with solid waste management and fossil fuels are eliminated. RDF-5 is one of the alternative and renewable resources of fuelwhich is derived from municipal waste. Production and utilization of RDF leads to green environment.

4. Conclusions

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-5 collected from Chiang Mai University, Thailand. The essential characteristics of a refuse-derived fuel-5 (RDF-5) and the combustion behaviors were performed in this study. The test data demonstrate good results for the development of energy recovery technology of organic sludge or waste. The ash deposit formation propensity has been based on pretreatment, temperature and the ratio of organic sludge to sawdust. The usage of organic sludge and waste as an alternative fuel is cost effective and has environmental benefits.

References

[1] United Nations Environment Programme (UNEP), “Solid Waste Management”, Volume I, 2005.

[2] A. Gendebien, A. Leavens, K. Blackmore, A. Godley, K. Lewin, K.J. Whiting, R. Davis, J. Giegrich, H. Fehrenbach and U. Gromke, N. del Bufalo, D. Hogg, “Refuse Derived Fuel, Current Practice and Perspectives- Final Report, European Commission, Report No: CO 5087-4, 2003.

[3] W. Punin, S. Maneewan, C. Punlek, “The feasibility of converting solid waste into refuse-derived fuel 5 via mechanical biological treatment process”, Journal of Material Cycles and Waste Management, 2014, 16: 753–762.

[4] F. C. Wu, P. H. Wu, R. L. Tseng, R. S. Juang, “Use of refuse-derived fuel waste for the adsorption of 4-chlorophenol and dyes from aqueous solution: Equilibrium and kinetics”, Journal of the Taiwan Institute of Chemical Engineers, 2014, 4: 2628–2639.[

[5] Ministry of Energy, “Renewable Energy Development Plan (REDP)”, Available from <http://www.eppo.go.th/ccep/energy_3-5.html> [Accessed 1 August 2014], 2014.

[6] MNRE, “Ministry of Natural Resources and Environment Digital Library”, Available from <http://lib.mnre.go.th/index.php/> [Accessed 1 August 2014], 2014.

[7] K. Sombatsompop, “Wastewater treatment by sequencing batch reactor system”, The Journal of KMUTNB, 2010, 18: 96–103.

[8] Pollution Control Department, “Reports of pollution in Thailand in 2012”, http://infofile.pcd. go.th/mgt/DraftPol, 2013.

[9] P. Nutongkaew, J. Waewsak, T. Chaichana, Y. Gagnon, “Greenhouse gases emission of refuse derived fuel-5 production from municipal waste and palm kernel” Energy Procedia, 2014, 52: 362– 370.

[10] Report2555_25560214.pdf? CFID =13119758& CFTOKEN=22373626. Retrieved 1 Apr 2013. N. B. Chang, Y. H. Chang, W. C. Chen, “Evaluation of heat value and its prediction for refuse-derived fuel”, Science of the Total Environment, 1997, 197:139–148.

[11] W. S. Chen, F. C. Chang, Y. H. Shen, M. S. Tsai, “The characteristics of organic sludge/sawdust derived fuel”, Bioresource Technology, 2011, 102: 5406–5410.

[12] Z. M. Fu, X. R. Li, H. Koseki, “Heat generation of refuse derived fuel with water”, Journal of Loss Prevention in the Process Industries, 2005, 18: 27–33.

[13] T. Kupka, M. Mancini, M. Irmer, R. Weber, “Investigation of ash deposit formation during co-firing of coal with sewage sludge, saw-dust and refuse derived fuel”, Fuel, 2008, 87: 2824–2837.

[14] American Society for Testing and Materials (ASTM), “Standard Definitions of Terms and Abbreviations Relating to Physical and Chemical Characteristics of Refuse Derived Fuel”, Volume 11.04 Waste Management, Annual Book of ASTM Standards 2006. ASTM International, West Conshohocken. 2006.

[15] C. Ryu, “Potential of Municipal Solid Waste for Renewable Energy Production and Reduction of Greenhouse Gas Emissions in South Korea”, Journal of Air & Waste Management Association, 2010, 60: 176–183.

[16] J. Nithikul, “Potential of Refuse Derived Fuel Production from Bangkok Municipal Solid Waste”. A thesis for the degree of Master of Engineering in Environmental Engineering and Management, Asian Institute of Technology School of Environment, Resources and Development, Thailand, 2007.

[17] H. Yuan, Y. Chen, H. Zhang, J. Su, Q. Zhou, G. Gu, “Improved bioproduction of short-chain fatty acids (SCFAs) from excess sludge under alkaline conditions”, Environment Science Technology, 2006, 40: 2025–2029.

[18] H. Alter, “The recycling of densified refuse-derived fuel”, Waste Management and Research, 1996, 14: 311–317.

[19] V. Raili, F. Marttl, “Organic emissions from co-combustion of RDF with wood chips and milled peat in a bubbling fluidized bed boiler”, Chemosphere, 1996, 32: 681–689.

[20] R. Weber, T. Kupka, K. Zajac, “Jet flames of a refuse derived fuel”, Combustion and Flame, 2009, 156: 922–927.