A publication of

The Italian Association
of Chemical Engineering
www.aidic.it/cet

CHEMICAL ENGINEERING TRANSACTIONS

VOL. 45, 2015

Guest Editors: Petar Sabev Varbanov, Jiří Jaromír Klemeš, Sharifah Rafidah Wan Alwi, Jun Yow Yong, Xia Liu

ISBN 978-88-95608-36-5; **ISSN** 2283-9216 DOI: 10.3303/CET1545057

An Argument for Developing Waste-to-Energy Technologies in Saudi Arabia

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Municipal Solid Waste (MSW) management is a chronic environmental problem in most of the developing countries, including the Kingdom of Saudi Arabia (KSA). The concept of Waste-to-Energy (WTE) is known as one of the several technologies capable of benefiting a society, which desires to reduce fossil-fuel addiction. Currently, there is no WTE facility existing in the KSA. The MSW is collected and disposed in landfills untreated. A substantial increase in the population by 3.4 %/y over the last 35 y coupled with urbanization and raised living standards have resulted in high generation rate of MSW. In 2014, about 15.3 Mt of MSW was generated in KSA. The food and plastic waste are the two main waste streams, which covers 70 % of the total MSW. The waste is highly organic (up to 72 %) in nature and food waste covers 50.6 % of it. An estimated electricity potential of 2.99 TWh can be generated annually, if all of the food waste is utilized in anaerobic digestion (AD) facilities. Similarly, 1.03 and 1.55 TWh electricity can be produced annually if all of the plastics and other mixed waste are processed in the pyrolysis and refuse derived fuel (RDF) technologies respectively. The aim of this paper is to review the prospective WTE technologies in Saudi Arabia. However, the real selection of the conversion technologies will be done in conjunction with the fieldwork on waste characterization and laboratory examination of selected technologies and further socio-economic and environmental evaluations.

1. Introduction

The Kingdom of Saudi Arabia (KSA) is the largest crude oil producer in the world. Crude oil revenues have contributed to a large scale socio-economic development over the last four decades (Ouda et al., 2013). This development produced a substantial increase in population (at yearly rate of 3.4 %) and a rapid growth in living standards for the majority of the population. Urbanization has increased due to internal immigration from rural to urban areas and the influx of expatriate workers (Nizami et al., 2015). Consequently, the KSA electricity demand has increased at the rate of 5.8 % from 2006 to 2010 (MEP, 2010). The current peak demand of electricity is 55 GW, which is projected to reach 120 GW in 2032 (KACARE, 2012). Fossil fuels are used solely to meet the energy requirements of the country. The Government has launched a program; King Abdullah City of Atomic and Renewable Energy (KACARE) to establish the renewable energy sources through science, research and industries (Royal Decree, 2010). The plans are to generate 54 GW of energy from various renewable energy sources such as nuclear, wind, solar, waste-to-energy (WTE) etc. facilities (KACARE, 2012).
The generation rate of MSW is 15.3 Mt/y and 1.4 kg/capita/d (Nizami et al., 2015). The MSW is regulated by Ministry of Municipalities and Local Affair and managed by local municipalities, which include the collection and disposal of waste in landfill or dumpsites without material or energy recovery (Ouda et al., 2013) and later (Ouda et al., 2015). The recycling of metals and cardboards from the waste is the only recycling practice, which covers 10 – 15 % of total waste (Khan and Kaneesamkandi, 2013). Most of the landfills are reaching their capacities and the problems of leachate, waste sludge, and methane and odour emissions are occurring. The requirement for landfill is about 28 million m^3 per year (Al-Humoud et al., 2004). The overall waste produced is highly (up to 71.2%) organic in nature and food waste covers 50.6 %

Please cite this article as: Nizami A., Rehan M., Ouda O.K.M., Shahzad K., Sadef Y., Iqbal T., Ismail I.M.I., 2015, An argument for developing waste-to-energy technologies in saudi arabia, Chemical Engineering Transactions, 45, 337-342 DOI:10.3303/CET1545057

of it (Khan and Kaneesamkandi, 2013). This high organic nature waste along with shifting trends of the population towards urban and high energy demand requires the development of WTE facilities in the country.

There are primarily six WTE technologies in use worldwide: incineration, pyrolysis or gasification, plasma arc gasification, refuse derived fuel (RDF), anaerobic digestion (AD), and transesterification (Nizami et al., 2015). Each of these technologies and their setup depends on the type of waste, capital and operational cost, technological complexity coupled with labor skill requirements, geographical locations of the plants and above all the efficiency of the utilized technology. A scientific approach to develop WTE facility requires initial examination at laboratory and pilot scale before its commercialization. Therefore, the baseline information and data on waste characterization are critical to select and design a WTE system for a specific or mixed waste. There is very little data available on MSW characterization in KSA. Therefore, the indigenous data generated in local research facilities utilizing local MSW is essential before designing commercial scale WTE plants. The aim of this paper is to review the prospective of WTE facilities in KSA based on the limited available data. The technologies; AD, pyrolysis, transesterification and RDF are selected based on waste type, composition, generation rate and energy contents.

2. Methodology

The year 2013 was considered a baseline year for the forecasting of population and waste generation in KSA. The population has increased from 7 million to 27 million with a yearly rate of 3.4 % over the last 35 years (Ouda et al., 2013). Therefore, this rate (3.4 %) was used to forecast the future population (Table 1). The current waste generation rate of 1.4 kg/capita/d was used to calculate the future waste generation (Table 1). The major ingredients of KSA’s waste are food waste (50.6 %), plastics (17.4 %), paper (11.9 %) and cardboard (6.7 %) (Table 2). The physical and chemical composition of food waste is given in Table 3. WTE takes place using three main conversion processes: thermochemical, biochemical, and physicochemical processes (Nizami et al., 2015). Four technologies; AD, pyrolysis, transesterification and RDF are selected based on the waste type, its composition and generation rates (Table 2-3) and waste energy contents (Table 4).

Table 1: The population and waste generation

Years	Population (million)	Total waste (million tons/year)
2013	30	15.3
2018	35.4	18.1
2023	41.9	21.4
2028	49.5	25.3
2033	58.5	29.9

Table 2: Waste composition

Waste type	Waste composition (Mass %)
Food waste	50.6
Plastic	17.4
Paper	12.0
Cardboard	6.6
Glass	2.9
Wood	2.0
Textile	1.9
Metals	1.9
Aluminium	0.8
Leather	0.1
Other	3.7

Table 3: Physical and chemical composition of food waste (Abu-Qudais and Abu Qdais, 2000)

	Composition (%)	Total amount (million tons/year)
	Physical composition	
Rice	38.72	2.99
Bakery products	18.74	1.45
Meat	25.15	1.95
Fat	13.03	1.01
Bones	2.19	0.17
Fruit and vegetables	2.16	0.17
	Chemical composition	
Moisture	38.4	2.97
Carbohydrates	25.56	1.98
Crude Protein	17.26	1.33
Crude fat	15.27	1.18
Fiber	0.3	0.02
Ash	3.21	0.25

Table 4: Energy contents of MSW (Ouda et al., 2015)

Type of waste	Energy Content (MJ/kg)
Mixed Paper	15.82
Mixed Food Waste	5.58
Mixed Green Yard Waste	6.28
Mixed Plastic	32.57
Rubber	26.06
Leather	18.61
Textiles	18.84
Demolition Softwood	16.98
Waste Hardwood	15.12
Coal	28.61
Fuel, Oil	42.57
Natural Gas	55.14

3. Results and Discussion

In 2013, the total waste generation was 15.3 Mt/y with an average rate of 1.4 kg/capita/d. This waste rate is projected to become almost double with 30 Mt in 2033 (Table 1). The food waste is one of the dominant waste streams (50.6 %) with highest amount of waste (7.7 Mt/y) and generation rate (0.71 kg/capita/day) among the overall collected waste (Table 2). The food waste in three large cities, Riyadh, Jeddah and Dammam is exceeding 6 Mt/y (Kosseva, 2009). During the month of Ramadan in 2014 5,000 t of food was wasted in first three days only in the Makkah municipality (Irfan, 2014). The alarming news is the wastage of 35 – 40 % cooked rice annually with total amount of 3 Mt/y, the worthy of 1.6 billion SR (Saudi Gazette, 2014). Such composition of waste with a high fraction of organic contents (up to 71.2 %), especially the food waste with high moisture content (38.4 %), carbohydrates (25.6 %) and proteins (17.3 %) make it very suitable feedstock for WTE technologies (Table 2-3) especially for AD, fermentation and composting.

3.1 Anaerobic Digestion (AD)

The AD process converts organic matter into biogas that can be used for heating, generating electricity and as a biofuel (Nizami et al., 2009). There are different types of anaerobic digesters that can carry out this digestion process (Nizami et al., 2011); such digesters are classified based on whether it is a wet or dry process, a batch or continuous process, the number of phases or stages in the digestion, their operating temperature, retention time and organic loading rate (Nizami and Murphy, 2010). The overall efficiency of the AD process is 25 % (MWA, 2013). AD is comparatively cost effective process than other energy conversion technologies. Additionally, AD is used to produce nutrient rich slurry (digestate) besides energy (biogas). The digestate can be used for agricultural purposes as an organic fertilizer (Tchobanoglous et al., 1993). The space requirement is the main disadvantages of the technology. According to Browne and Murphy (2013), the range of biomethane production from food waste is 314 to 529 L CH_4 kg VS^{-1} added depending on the type of reactor (continuous and batch reactor) and source of food waste (domestic and commercial food waste). The canteen and commercial food waste generated 480 - 530 L CH_4 and 535 L CH_4 VS^{-1} added. Zhang et al. (2012) reported 445 - 456 L CH_4 kg VS^{-1} added from domestic source separated food waste. Using different pre-treatment methods, the Davidsson et al. (2007) achieved 300 - 400 L CH_4 kg VS^{-1} added from food waste.

In KSA, AD technology is suitable for organic fraction of municipal solid waste (OFMSW) including food waste due to its high organic contents and the physical and chemical characteristics (Table 3). The produced biogas can generate 2.99 TWh electricity, if all of the food waste (7.7 Mt/y) generated in KSA is utilized in AD facility (Table 5). The demand of electricity for air-conditioning in KSA is extremely high due to ambient weather. In 2012, the electricity production of 45 GW was distributed among residential (52.1 %), industrial (17.9 %), governmental (11.5 %), agricultural (2.2 %) and commercial (12.2 %) sectors. A 30 % of the domestic electricity is only consumed in refrigeration purposes (Khan and Kaneesamkandi, 2013). There is an innovative solution for this high consuming refrigeration sector and that is to use the biogas powered absorption-refrigeration cycle rather conventional vapor compression refrigeration. The biogas will be used as a heat source for regeneration of refrigerant in KSA. Approximately, 0.05 m^3 of biogas is consumed in cooling the 230 KW capacity refrigerators (Khan and Kaneesamkandi, 2013). Moreover, the biogas can be used as a source of electricity, heat and cooking. The digestate of the biogas is used as a source of organic fertilizer, enriched with nutrients of nitrogen, phosphorous and potassium beneficial for plant growth and soil fertility. The applications of digestate are further extended to gardens, landscaping, horticulture and agricultural activities and improving ecosystem in erosion control, reclamation of land and stream, wetland construction and covering landfills.

3.2 Pyrolysis

The waste plastic is the second large municipal waste streams (17.4 % by mass) in KSA (Table 2). In the month of fasting (Ramadan; the 9th month of Islamic lunar calendar) and pilgrimage (Zilhaj; the 12th month of the Islamic lunar calendar), large quantities of plastic waste is produced in KSA due to serving of food and drinks in disposable plastics (Abdul Aziz et al., 2007). Final disposal of such wastes represents operational and environmental overburden to landfills due to slow degradation rates and clogging nature. The conventional mechanical recycling methods such as sorting, grinding, washing and extrusion can recycle only 15 – 20 % of all plastic waste. The pyrolysis technology is being used to convert the plastic or biomass waste into energy in the form of fuel oil and value-added products such as char (Sharma et al., 2014). Pyrolysis is one of the tertiary recycling techniques in which waste plastic is decomposed thermochemically in the absence of air at temperature of up to 500 ^oC and converted into liquid (fuel oil), solid (charcoal) and gaseous fractions. The fuel oil has similar characteristics as of diesel, with lower sulphur and higher cetane value (Sharma et al., 2014). However, pyrolysis of highly contaminated raw materials can affect the yield and quality of produced fuel oil. This is due to the contaminants (sulphur, metal and other materials) that are present in the plastics (Borsodi et al., 2011). A total electricity generation of 1.03 TWh can be achieved, if all of the waste plastic (2.7 Mt/y) generated in KSA is utilized in the pyrolysis process (Table 5).

The overall efficiency of pyrolysis technology is reported to be around 17 % (Bridgwater, 2012). The advantages of pyrolysis technology are the high power generation capacity (Tatemoto et al., 1998) in comparison to other WTE technologies such as RDF and Plasma arc gasification with less land requirements (Mekonnen et al., 2014). According to Quaak et al. (1999), the net energy generation from pyrolysis varies between 20 - 26 KW/t of MSW. The overall volume of MSW can be reduced up to 50 – 90 %). The main disadvantage of the technology is the cleaning of byproducts due to produced corrosive nature tar, alkali metals and acidic gases (Quaak et al., 1999). The high initial capital cost in setting up the technology is also a problem (Larson, 1992).

Table 5: Total energy potential and electricity generation of WTE technologies in KSA.

Technologies	Waste stream used	Waste Used (Mt)	Energy Potential (TJ)	Electricity generation (TWh)
AD (biogas)	Food (50.6 %)	7.7	30,760	2.99
Pyrolysis (Fuel oil)	Plastic (17.4 %)	2.7	85,190	1.03
RDF (Combustion)	*Mixture (26.3 %)	4.0	35,008	1.55
Recycling [a]	Glass (2.9 %) + metal (2.7%) = 5.6 %	0.9	44,593	-
Total		15.3	195,551	5.56

*Mixture: Paper (12%)+Cardboard(6.6 %) + Wood(2%) + Textile(1.9%) + Leather(0.1%) + Others(3.7%) = (26.3%)

AD efficiency used for electricity generation = 35 %

Pyrolysis efficiency used for electricity generation = 33 %

RDF efficiency used for electricity generation = 18 %

8.37Mj/kg energy potential used for RDF

[a]Energy conservation concept used for recycling, which means 445,93TJ of energy would be used to produce the same amount of recyclable material (0.9 Mt).

3.3 Rendering and Transesterification

In 2014 Pilgrimage (Hajj) period, more than 2.5 million animals were sold in KSA for slaughtering to perform Hajj rituals (Amtul, 2014). Typically, 12 % waste per body weight is generated in sheep and goat slaughtering, while cattle slaughtering generate 38 % waste (Singh, 2013). This waste includes rumen, blood, stomach, intestine, tallow and fats. There is no such information available on the amount of waste generated by slaughtering during the Hajj and Ramadan periods. However, it is evident that this animal blood and solid waste quantities are huge in KSA and they are disposed in landfills untreated. A rendering process can convert animal waste into lard and tallow (Mekonnen et al., 2014), which can be utilized subsequently in transesterification process to produce biodiesel. A large fraction of the country MSW is also consisted of used-oil from households and restaurants. Transesterification is a process of converting such fats and used-oils into biodiesel by recycling polyesters into individual monomers (Thamsiriroj and Murphy, 2010). It is a chemical reaction by which fats or oils are reacted with short chain alcohols such as methanol or ethanol. Glycerol, soap, excess alcohol are also produced besides biodiesel, which are removed by using different standard methods.

3.4 Refuse Derived Fuel (RDF)

RDF is a combustible or a high caloric fraction recovered from MSW. It is now considering as an alternative fuel of coal for power generation plants (Nabeshima, 1996). The RDF preparation scheme includes the waste reduction size wise, separation, crushing and drying. After drying, the RDF is thoroughly mixed with binders such as calcium hydroxide to increase the calorific values of the RDF. The final products are in the shape of chalk-like or pellet. The waste categories suitable for RDF are cardboard, paper, plastics, glass etc. The overall efficiency of the process is 18 % (MWA, 2013). Throughout the Europe, the RDF is well developed. The advantages of RDF are high calorific value and reduction in landfilling problems. While, the main disadvantage of the process is land acquisition, pre-processing equipments and manpower, which makes the process expensive in comparison to incineration. The estimated potential of RDF in generating electricity in KSA is 1.55 TWh per year, if all the RDF making waste is utilized in RDF facilities (Table 5).

3.5 Sustainability of WTE Technologies and Waste Biorefinery

The WTE technologies will not only reduce the fossil fuel dependence, but also creates economic and environmental benefits including job creation, new businesses and pollution reduction and public health improvement. The environmental value of WTE is tremendous including GHG emission reductions (Ouda et al., 2015), energy saving, landfill area saving, soil and groundwater protection, etc. (Nizami et al., 2015). The GHG emission reductions is primarily due to the thermal conversion of the landfill methane gas to carbon dioxide. Methane (CH_4) is 21 times more detrimental than carbon dioxide (CO_2) from the global warming perspective. The energy reduction is the result of saving energy associated with production, transporting, manufacturing of raw materials and waste disposal. The environmental values of WTE technologies in KSA needs further research. There is a substantial potential for financial revenue through claiming carbon credits from GHG emission reductions.

There are certain limitations associated with each WTE technology based on process efficiency, commercializing, feedstock, infrastructure requirements and end use applications. It is difficult for an individual technology to achieve zero waste concept and competes with other renewable-energy sources like wind, solar, etc. The technological solution to these limitations is to select the conversion technologies based on waste composition and characterization and integrate them in a waste biorefinery. A biorefinery is a cluster of conversion technologies producing chemicals, fuels, power, products, and materials from different feedstock at one platform. A waste biorefinery will treat different fractions of MSW in different processes yielding different products.

4. Conclusion

A review of the prospective of WTE technologies in KSA is carried out based on the limited available data. However, the real selection of the conversion technologies will be done in conjunction with the fieldwork on waste characterization and laboratory analysis of selected technologies. The food and plastic waste are the two main waste streams with total production of 7.7 and 2.7 Mt/y with generation rate of 0.7 and 0.3 kg/capita/day respectively. The overall waste produced is 71.2 % organic in nature and food waste covers 50.6 % of it with a high composition of carbohydrates (25.6 %), proteins (17.3 %) and fats (15.3 %). An estimated electricity potential of 2.99 TWh can be produced annually, if all of the food waste is utilized in anaerobic digestion (AD) facilities. Similarly, a total electricity of 1.03 and 1.55 TWh can be produced annually if all of the plastics and other mixed waste are processed in the pyrolysis and refuse derived fuel (RDF) technologies. The economic, environmental values and future perspectives for adapting WTE technologies in KSA are promising. Further investigations are highly recommended to evaluate the perspectives of WTE in the Kingdom towards successful development and utilization.

References

Abdul Aziz H., Isa M., Kadir O., Nordin N., Daud W., Alsebaei A., Abu-Rizaiza A., 2007, Study of baseline data regarding solid waste management in the holy city of Makkah during Hajj 1427. In: National Seminar on Hajj Best Practices through Advances in Science and Technology, Centre for Education, Training and Research in Renewable Energy and Energy Efficiency (CETREE), Universiti Sains Malaysia, Penang, Malaysia, May, 2007, Penang, Malaysia.

Abu-Qudais M., Abu-Qdais H.A., 2000, Energy content of municipal solid waste in Jordan and its potential utilization, Energy conversion and Management, 4, 983-991.

Al-Humoud J.M., Al-Ghusain I., Al-Hasawi H., 2004, Management of recycling in the Gulf Co-operation Council states, Waste Management, 24, 551-562.

Amtul S., 2014, Kingdom: 2.5m animals sold in Saudi Arabia during hajj. Saudi Gazette. <www.saudigazette.com.sa/index.cfm/myfiles/Images/2011/11/04/index.cfm?method=home.regcon&contentid=20141012220920> accessed 04.07.2015.

Borsodi N., Miskolczi N., Angyal A., Bartha L., Kohán J., Lengyel A., 2011, Hydrocarbons obtained by pyrolysis of contaminated waste plastics. 45th International Petroleum Conference, June 13, 2011, Bratislava, Slovak Republic. Catalyst. International Journal of Renewable Energy Technology Research (IJRETR).

Bridgwater A.V., 2002, The future for biomass pyrolysis and gasification: status, opportunities and policies for Europe, <ec.europa.eu/energy/renewables/studies/doc/bioenergy/2002_report_p536.pdf> accessed 01.08.2015.

Browne J.D., Murphy J.D., 2013, Assessment of the resource associated with biomethane from food waste, Appl. Energy, 104,170–177.

Cheng H., Hu Y., 2010, Review Municipal solid waste (MSW) as a renewable source of energy: Current and future practices in China, Bioresource Technology, 101, 3816-3824.

Davidsson A., Gruvberger C., Christensen T.H., Hansen T.L., Jansen J.I.C., 2007, Methane yield in source-sorted organic fraction of municipal solid waste, Waste Manage, 27(3), 406–414.

Irfan M., 2014, Massive wastage 'unacceptable', <www.arabnews.com/news/596446>, accessed 04.07.2014.

KACARE, 2012, Renewable Energy-Waste to Energy. A pillar of the sustainable energy kingdom. In: First international environment conference, Yanbu Al Sinaiyah, KSA: King Fahd Civic Centre 20–21.

Khan M.S.M., Kaneesamkandi Z., 2013, Biodegradable waste to biogas: renewable energy option for the Kingdom of Saudi Arabia, International Journal of Innovation and Applied Studies, 4(1), 101-113.

Kosseva M.R., 2009, Processing of food wastes, Chapter 3 in: Taylor S.L. (Ed.), 2009, Advances in food and nutrition research, 58, 57-136, DOI:10.1016/S1043-4526 (09) 58003-5.

Larson E.D., 1992, Biomass-gasifier/gas turbine cogeneration in the pulp and paper industry, J Eng Gas Turbines Power, 114, 665–674.

Mekonnen T., Mussone P., Bressler D., 2014, Valorization of rendering industry wastes and co-products for industrial chemicals, materials and energy: review. Crit Rev Biotechnol., doi: 10.3109/07388551.2014.928812

MEP (Ministry of Economy and Planning), 2010, The Nine Development Plan 2010–2014. Ministry of Economy and Planning Documents, Riyadh, KSA.

MWA (Metro Waste Authority), 2013, Alternate Disposal Feasibility, Report prepared by Metro Waste Authority

Nabeshima Y., 1996, Technical Evaluation of Refuse Derived Fuel (RDF), Waste Manag. Res., 7, 294-304.

Nizami A.S., Korres N.E., Murphy J.D., 2009. Review of the integrated process for the production of grass biomethane, Environmental Science and Technology, 43 (22), 8496–8508.

Nizami A.S., Murphy J.D., 2010, What type of digester configurations should be employed to produce biomethane from grass silage? Renewable and Sustainable Energy Reviews, 14, 1558–1568.

Nizami A.S., Ouda O.K.M., Rehan M., El-Maghraby A.M.O., Gardy J., Hassanpour A., Kumar S., Ismail I.M.I., 2015, The Potential of Saudi Arabian Natural Zeolites in Waste-to-Energy Technologies, Energy.

Nizami A.S., Singh A., Murphy J.D., 2011, Design, commissioning, and start-up of a sequentially fed leach bed reactor complete with an upflow anaerobic sludge blanket digesting grass silage. Energy and Fuels, 25 (2), 823–834.

Ouda O.K.M., Cekirge H.M., Raza S.A., 2013, An assessment of the potential contribution from waste-to-energy facilities to electricity demand in Saudi Arabia, Energy Conversion and Management, 75, 402-406.

Ouda O.K.M., Raza S.A., Al-Waked R., Al-Asad J.F., Nizami A.-S., 2015. Waste-to-energy potential in the Western Province of Saudi Arabia, Journal of King Saud University - Engineering Sciences, doi: 10.1016/j.jksues.2015.02.002.

Quaak P., Knoef H., Stassen H., 1999, Energy from biomass: a review of combustion and gasification technologies, World Bank technical paper no. 422, <wwwwds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2000/07/08/000094946_99033105581764/Rendered/PDF/multi_page.pdf> accessed 01.03.2013

Royal Decree, 2010, Establishing King Abdullah City for Atomic and Renewable, No. A 35, 17, <www.energy.gov.sa/_pdf/KACARE%20Royal%20Decree%20english.pdf>, accessed 20.-08.-2015.

Saudi Gazette, 2014, Saudis throw away 440 tons of rice annually. <www.saudigazette.com.sa/index.cfm?method=home.regcon&contentid=20140704210410> accessed, 02.08.2015.

Sharma B.K., Moser B.R., Vermillion K.E., Doll K.M., Rajagopalan N., 2014, Production, characterization and fuel properties of alternative diesel fuel from pyrolysis of waste plastic grocery bags. Fuel Processing Technology, 122, 79-90.

Singh A., 2013, Organic wastes for biomethane production. Chapter in 'Bioenergy Production by Anaerobic Digestion Using Agricultural Biomass and Organic Waste'. Publisher: Routledge, Taylor and Francis, USA, 139-152.

Tatemoto Y., Bando Y., Yasuda K., Nakamura M., Azegami M., 1998, Rotting Prevention by Added CaO in RDF Production, J. Chem. Eng. Japan, 5, 846-847.

Tchobanoglous G., Theisen H., Vigil S.A., 1993, Integrated Solid Waste Management, Engineering Principles and Management Issues, McGraw Hill, Singapore.

Thamsiriroj T., Murphy J.D., 2010, How much of the target for biofuels can be met by biodiesel generated from residues in Ireland? Fuel, 89, 3579-3589.

Zhang Y., Banks C.J., Heaven S., 2012, Anaerobic digestion of two biodegradable municipal waste streams, J. Environ. Manage., 104, 166–174.