Perspectives on Waste-to-Energy Technologies

Zoltan Kish, *Ph.D.*
Quasar ScienceTech
Burlington, Ontario, Canada
Email: kishz@quasarsciencetech.com

March 2016

Introduction

Reducing the emission of carbon dioxide and other greenhouse gases is one of the greatest environmental challenges of our time. Growing population, increased urbanization rates and economic growth could lead to a doubling in the volume of municipal solid waste (MSW) created annually by 2025, according to new research conducted by the World Watch Institute [1]. The doubling of waste would bring the volume of MSW from today's 1.3 billion tonnes per year to 2.6 billion tonnes, challenging environmental and public health management in municipalities worldwide. Typically, the waste is sent to landfills and the energy in waste is essentially lost, creating mountains of trash, emitting harmful pollutants into our air, water and soil. In a landfill the biodegradable components of waste decompose and emit methane, which is a greenhouse gas and 21 times more harmful than carbon dioxide. In addition, landfill fires, earth movements, and groundwater flows contribute to landfill leachate, which eventually leaks and contaminate nearby ecosystems. In response to global environmental challenges, there has been a requirement towards Waste-to-Energy technologies to produce alternative/ clean energy from waste feedstocks, such as MSW, industrial waste, biomass waste, sewage sludge, used tires, etc. The primary challenge of these technologies is the heterogeneous nature of MSW, which creates a widely varying chemical constituency of the energy products generated from these processes. A solution for waste disposal and clean energy production is an effective Waste-to-Energy technology application. The global market of Waste-to-Energy has significantly increased. Waste feedstock can be converted to higher value products by the physico-chemical (including biochemical) interactions, such as thermo-chemical and/or biological processes without or with additional reactants (e.g., water, oxygen, air, etc.). The produced product type depends on the types of feedstock and reactants, and the applied physico-chemical interaction conditions in the system [2]. The higher value products created from waste can be transformed into various forms of clean energy correspondingly to the application/ market requirements.

Waste-to-Energy technologies

The Waste-to-Energy technologies can be classified in the following major types.

Conventional

- *Incineration*
- *Gasification & Plasma Enhanced Gasification*
- *Pyrolysis*
- *Anaerobic Digestion*

Unconventional

- *Steam Reformation*

Incineration

The most common technology for treating waste is incineration, which is a thermo-chemical process wherein the combustible components of a solid waste stream are oxidized to produce heat energy, which can be used to create steam to generate electrical power using a steam turbine, for industrial processes, or for district heating. Incineration is the combustion of waste using an excess of oxygen (air) to ensure complete combustion at temperature above 850°C. Therefore, the products (flue gas) of the waste combustion are significantly diluted and increased in volume by the nitrogen content of the excess air use. In addition to thermal energy, products of the incineration process include bottom ash, fly ash, and flue gas, in which are found a number of regulated pollutants (e.g., mercury, lead, cadmium, etc.). The common gaseous pollutants in the flue gas are carbon dioxide, nitrogen oxides, sulfur oxides. Combustion of waste is a major source of furans and dioxins, which are highly toxic and carcinogenic pollutants. Incineration can be identified as a baseline competitor technology. However, incineration is a wasteful use of resources – providing low energy conversion efficiency.

Gasification and Plasma Enhanced Gasification

Gasification and Plasma Enhanced Gasification are thermo-chemical processes and are based on partial oxidation of the waste to convert carbonaceous materials into syngas (synthesis gas). Usually, the gasification is performed at temperature above 700°C. Pure oxygen has limited use for the partial oxidation processes as a result of high costs. Hydrogen and carbon monoxide are predominating gas products in the syngas, along with water vapor, methane, carbon dioxide, nitrogen (if air is used), and other hydrocarbons. As a result of the oxidation/ incineration component of the gasification systems that use oxidation, they will generate noxious oxides (e.g. nitrogen oxides, sulfur oxides). In addition, produced syngas is contaminated by tar, acid gases, ammonia, and particulate matter. Plasma arc gasification is a waste treatment technology that uses an electric arc to produce high temperatures (up to 7000°C) within the reactor to convert carbonaceous materials into syngas and melt the residual inorganic materials. Plasma is the fourth state of matter containing ionized gases. The content and consistency of the waste have a direct impact on performance of the plasma enhanced gasification. The tar cleaning is not efficient as a result of the inconsistency of the heat distribution produced by the plasma arc. Large amounts of inorganic materials such as poorly sorted construction waste, metals, and glass, result in increased slag production and decreased syngas production. The heat energy that is required to melt these materials is lost since the molten slag does not contribute to syngas production. The use of the plasma arc significantly increases parasitic electricity consumption and operating and capital costs of the gasification process. In addition, gasification of waste typically requires extensive and expensive waste feedstock pre-treatment and the produced syngas will be significantly diluted by the oxidation process which includes the nitrogen content of air. Therefore, the heating value of syngas produced from the partial oxidation gasification process is significantly reduced. The lower quality syngas fuel generated from partial oxidation gasification can be run in reciprocating engines, but generally cannot be used as a fuel for cleaner burning and more efficient gas turbines, due to its relatively low heating value.

Pyrolysis

Another competing Waste-to-Energy technology is pyrolysis. Pyrolysis is a thermo-chemical conversion of waste feedstock without the participation of oxygen or air at elevated temperatures (400°C – 600°C). The main products of the pyrolysis process are char, pyrolysis oil and a mixture of gases. The products are produced in different ratios depending on the reaction types, residence time, temperature, feedstock composition and size. The pyrolysis processes can be classified as slow and fast pyrolysis. The residence time for the slow pyrolysis is in the range of hours and the product yield is approximately 35% of char, 30% of pyrolysis oil, and 35% of syngas. The fast pyrolysis process is performed during very short time (~1 second) and the main product is pyrolytic oil; the product produced ratio is in the range of 12% of char, 75% of oil and 13% of gas. The slow pyrolysis is suitable for charcoal production from biomass. However, the use of the pyrolysis oil is problematic because the produced oil is very acidic, unstable, and contains significant amount of water. For electricity generation, pyrolysis systems typically cannot cool or clean the syngas before burning these mixed products (which then must include both particulate and volatilized contaminants) in a steam boiler combustion unit; otherwise they will lose the energy benefit of the condensable oils and tars. The end result is then not a lot different from simply burning contaminated wastes as during incineration. The energy recovery is then very analogous to incineration, i.e. low energy efficiency plus the additional challenge of developing a cleaning plant which must be very similar to that for incineration, in order to meet environmental emission limits.

Anaerobic Digestion

Anaerobic Digestion is a biochemical conversion of the biodegradable organic portion of waste feedstock in the absence of oxygen into biogas and remaining non-biodegradable material - digestate. Biogas comprises mainly of methane and carbon dioxide and trace amount of hydrogen, sulfur gases (e.g. hydrogen sulfide, methyl mercaptan), siloxanes, halogenated hydrocarbons, and ammonia. Usually the mixed gas is saturated with water vapour and may contain dust particles. Digestate consists of a mix of microbial biomass and undigested material (e.g. lignin, cellulose), which contains organic matter and essential plant nutrients required for plant growth. However, digestate (especially, from sewage sludge and MSW) may also contain contaminants such as heavy metals, industrial chemicals, pharmaceuticals, nano-particles, infectious pathogens, etc. The produced product content is depending on the effectiveness of the treatment process and the contamination levels of the feedstock. Depending on the operational temperature level, anaerobic digestion processes can be classified into three main types: psychrophylic (15°C - 25°C), mesophilic (30°C - 40°C), and thermophilic (50°C - 60°C). The anaerobic process is slow in comparison with thermo-chemical processes, as a result of low temperature operation. it takes many days to convert the biodegradable content of waste feedstock into biogas. The anaerobic digestion technology is best suited to the treatment of wet organic feedstocks, such as high moisture agricultural biomass, food waste, and animal wastes including manure, domestic sewage, and biodegradable components of MSW. The biogas can be used as a source of renewable energy, as a fuel in combined heat and power gas engines. During combustion, siloxanes are converted to silicon dioxide, which is a solid compound and will remain in the engine and cause considerable damage. The produced digestate can be used as a fertilizer if contaminants are not above the application specification limits. Land application of biologically treated waste is regulated in most countries to protect human health, the environment and soil functionality from detrimental impacts associated with potential contaminants.

Steam Reformation

Steam Reformation is a thermo-chemical process and is based on carbonaceous materials reaction with steam without the participation of oxygen or air at elevated temperatures above 700°C. The waste steam reformation is the waste feedstock gasification. The main product of the reactions is a syngas containing mostly hydrogen and carbon monoxide, and a smaller amount of methane, carbon dioxide, water vapour, and other hydrocarbons. Usually, the steam reformation process is used for production of hydrogen from natural gas. The steam reformation technology represents a potential alternative for the traditional waste treatments to produce higher heating content syngas, which contains no noxious oxides and higher hydrogen concentration than products produced by gasification. The chemistry is different due to the high concentration of steam as a reactant and the total exclusion of air and, therefore, oxygen from the steam reformation process. Contaminates (e.g., tar, acid gases, ammonia, and particulate matter) are easier to remove from the syngas because its is not diluted by excess air or nitrogen and products of combustion. Utilizing an indirectly heated kiln, the waste steam reformation technology is a novel and unconventional Waste-to-Energy technology, which allows for robust operation of various heterogeneous feedstocks (e.g., MSW, industrial waste, sewage sludge, waste biomass, used tires and medical waste) with high moisture content and significantly reduces the requirements for pre-processing feedstock [3]. The high quality of the produced syngas and residual waste heat can be used to power combined cycle gas turbines, reciprocating gas engines or potentially fuel cells for the generation of electricity and “green” hydrogen. In addition, because of high hydrogen to carbon monoxide ratio of the syngas, the technology can be coupled with a Gas-to-Liquids technology (e.g., Fischer - Tropsch process) to produce higher value liquid synthetic fuels, such as synthetic diesel, methanol, and “green” chemicals. A combination of the Waste Steam reformation as a Waste-to-Gas technology with a Gas-to-Liquids technology can, potentially, become an economic and environmentally viable method of the clean energy production.

Conclusion

The Waste-to-Energy technologies produce pollutants and, therefore, appropriate and effective scrubbing/ cleaning systems should be applied to remove contaminants from the usable fuel products in order to produce clean renewable energy and protect land, water and air. Depending on the applied processes and processed waste feedstocks, in addition to inorganic materials, the produced solid residue may contain carbonaceous materials (e.g., carbon, tar, digestate). Despite that, all conversion methods, especially, thermo-chemical processes significantly reduce the volume of the original waste feedstock converting carbonaceous materials into usable energy products. The steam gasification reformation technology eliminates the formation of dioxins, furans and nitrous and sulfur oxides within the conversion process. In addition, the waste steam reformation technology has a number of advantages over traditional Waste-to-Energy technologies, including a significant increase of the produced syngas quality, and reduction of the process gas and residual waste volumes. The steam reformation of waste is more efficient than other thermo-chemical and bio-chemical technologies and able to convert both biodegradable and also non-biodegradable carbonaceous waste contents into higher value clean/renewable energy products. Therefore, the steam reforming can be combined with anaerobic digestion to convert digestate into fuels. The Waste-to-Energy technologies can be optimized by analyzing interactions in material systems and modifying physico-chemical (including biochemical) interactions, chemical bonds and reactants to produce new products having clean usable energy content. The goal is to separate the contaminations from the produced energy products to produce clean energy and segregate the toxic components (e.g., heavy metal compounds) in the smaller volume of the produced solid residue. If contaminants are not above the application specification limits, the main part of produced solid residue can be utilized. For examples, the residual inorganic materials can potentially be used as a construction aggregate material and digestate can be used as a fertilizer. The physical-chemical interactions of waste feedstock with steam as a reactant is one of the most promising pathways of energy production as a thermo-chemical conversion of waste feedstock into clean and renewable energy. The waste steam reformation technology can convert various heterogeneous feedstocks and divert waste materials from landfills producing clean energy and significantly reduce environmental impacts versus other waste disposal and waste conversion methods.

References

1. http://www.worldwatch.org/global-municipal-solid-waste-continues-grow

2. Z. Kish, Novel Concept for New Materials and Technology Developments, Quasar ScienceTech, February 2016, pp.3 https://www.researchgate.net/publication/294261339_Novel_Concept_for_New_Materials_and_Technology_Developments & https://www.linkedin.com/pulse/novel-concept-new-materials-technology-developments-kish-ph-d-?trk=mp-author-card

3. E. Dueck, Z. Kish, and D. Kirk, Pure Steam Reforming of Municipal Solid Waste, The International Solid Waste Association World Congress 2013, Vienna, 7th – 11th October 2013, pp.9. https://www.researchgate.net/publication/264861433_Pure_Steam_Reforming_of_Municipal_Solid_Waste