PYROLYSIS TRANSFORMATION OF ORGANIC WASTES – RESULTS OF FULL-SCALE TRIAL DEMONSTRATIONS

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Summary: Pyrolysis gasification of organic wastes has been under development for over 20 years as a method to process organic wastes. The process involves the gasification under vacuum of solid and liquid organic wastes into syngas or oil fuel streams and inorganic residuals. Historically, the technology has struggled to demonstrate technical and financial viability. This paper describes the initial results of full-scale trial demonstrations conducted using the SIMEKEN Inc. pyrolysis technology to process wood wastes and scrap tires. The initial performance of the technology to process these wastes is presented in terms of air emissions quality, energy throughput, and quality of carbon char generated. Finally, a preliminary financial model is presented for a candidate project in Mexico.

1. Introduction

The management of waste continues to represent an important challenge for both developed and developing societies. Developed countries with high population densities are looking for viable alternatives to the land disposal of wastes whereas developing countries struggle to find economical and sanitary solutions to their waste management challenges. As society searches for more sustainable waste management practices, new technologies are emerging as providers of sustainable solutions. One such technology, the pyrolysis transformation of organic wastes, has been under development for over 20 years and offers several advantages. This paper presents the results of large-scale trial demonstrations of a pyrolysis technology. The authors and others have been investigating the need for developing a waste-to-energy project at a closed municipal solid waste dump in the City of Matamoros, Tamaulipas, Mexico. The waste-to-energy project would involve the conversion of wood waste, waste tires and other organic wastes into electrical energy and re-useable by-products via a vacuum pyrolysis technology supplemented by the landfill gas from the dump.

The City has a rapidly growing population of about 600,000 inhabitants, the second largest city in the state, who are drawn to the area by the growing industrial base along the border region with the United States. The cities along the border region struggle to manage the scrap tire generation and historical stockpiles. In addition, there is significant amount of wood waste generated in the area, mainly fromn local Maquilas and local wood pallet manufacturers. Thus, the waste-to-energy project focuses on the potential to:

(i) reduce greenhouse gas emissions;

(ii) use electricity derived from waste and waste-derived materials (LFG, waste tires and wood waste) to replace electricity produced from non-renewable fossil-fuel sources;

(iii) provide a management solution for the large quantities of waste tires in the region which represent a fire hazard and breeding area for vectors;

(iv) provide a potential management solution and make use of significant quantities of organic waste produced in the area such as wood waste and sludge;

(v) provide an important revenue source to the cities from the sale of electricity and carbon char by-products for the implementation of a sustainable and modern solid waste management system (e.g., dump rehabilitation, new landfill development, recycling, household hazardous waste diversion, etc.); and

(vi) provide reliable energy generation for the region.

The trial demonstrations were conducted in Matamaros, Tamaulipas, Mexico and focussed on the processing of waste tires and wood wastes. These waste streams were selected since they present a common management challenge to agencies in Mexico and other jurisdictions around the world. In addition, these waste streams are relatively homogenous thus facilitating their transformation (gasification) in the pyrolysis unit.

Pyrolysis is a process whereby organic compounds are gasified in a near zero oxygen

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environment. There has been limited success in the large-scale application of pyrolysis, in part due to challenges in maintaining the near zero oxygen environment. This paper presents the results of large-scale trial demonstrations of a pyrolysis technology capable of processing 75 tonnes per day of organic wastes during commercial applications. This paper will focus on the results of the wood waste pyrolysis trial.

2. Assessment Of Wood Waste Availabiity For The Matamoros Project

There is no forestry industry around Matamoros, nor in the region. Wood waste material for this project could potentially come from industry, mainly “maquilas”, around the area. There are around 130 maquilas in Matamoros and around 250 in Reynosa. Many of the Maquilas around the area use wood made pallets, and other wood materials for their operations. In many cases these materials are returned to the wood pallet manufacturers, also from the area, and in some other cases are disposed off as refuse in landfills. There are a number of wood pallet manufacturing plants in the region that only serve the local Maquilas. It is estimated that in Matamoros there are 6 main wood pallet manufacturing plants, while in Reynosa, there may be around 9.

In order to calculate the amount of wood waste generated in this region, two main sources of information where assessed. From one hand, the local wood pallet manufacturers were interviewed. On the other hand, the associations of “Maquilas” from Matamoros, Reynosa and Rio Bravo were contacted. A questionnaire was prepared and sent to the Associations and the Maquilas.

From the local pallet manufacturers we learned that most of the wasted wood pallets from the Maquilas are actually sent back to them. From that, they reuse whatever wood they can, and the rest is sent to off-site refuse disposal. There are 6 main pallet manufacturers in the Matamoros area. In average, 15 tonnes of wood waste is produced weekly by each plant. Thus, a total of about 90 tonnes per week of wood waste is produced weekly (i.e., 4,680 tonnes per year) from the wood pallet plants in Matamoros.

In the case of Reynosa, a similar situation occurs whereby the 9 wood pallet manufacturers would be producing around 135 tonnes of wood waste per week (i.e., 7,020 tonnes per year). In total, from Reynosa and Matamoros, it is estimated that about 11,700 tonnes of wood waste is generated per year. Considering that not all wood waste would be collected for the pyrolysos project, it was deem appropriate to consider a capture rate of 0.8. Therefore, it is estimated that 9,360 tonnes of wood waste per year for the pyrolysis plant.

3. Pyrolysis And Emissions Control Process

The SIMEKEN pyrolysis system includes the following main components:

- Waste Pre-Processing Units (e.g., tire schredder)
- Airlock Knife Gate Valve Feed System (KGV)
- Thermal Converter (with ceramic insulation) and Retort
- Thermal Oxidizer (with ceramic insulation)
- Transition Tube or Steam Boiler (i.e., heat transfer section)
- Steam Turbines, for electrical generation if required
- Wet Scrubber (with blower fan) air emissions control technology

Prior to being fed into the pyrolysis unit wood wastes are reduced in size using a mechanical processing unit. For this trial demonstration, the particle reduction was performed off-site and resulted in particles being no more than 50 millimteres in maximum dimension for the wood. The processed waste was then transferred to the SIMEKEN pyrolysis unit using a conveyor and manual labour.

The SIMEKEN pyrolysis unit is comprised of a Thermal Converter which consists of an outside shell with a stainless steel cylindrical shell called the Retort located inside the Thermal Converter. The Retort is enclosed on both ends with an airlock knife gate valve system consisting of knife gate valves (KGV) that open and close in sequence to prevent oxygen from entering the Retort. A vacuum pump is located inside the chamber enclosed by the KGV system to remove any oxygen that is drawn into the chamber and thereby prevent any possible combustion within the chamber.

The heat required to allow the gasification of the organic wastes is provided by burners that are strategically placed on the side of the unit to allow circulation of the combustible fuel with a spiraling effect. The heat needed to liberate the gases from the organic wastes ranges from about 540 to 1,025 ^{o}C.

Once the Retort is heated to the preferred temperature the KGV system drops the waste material into the Retort. Once inside the Retort, the material is conveyed through the chamber which results in a resonance time for the gasification to occur.

Once the resonance time for gasification is achieved, the remaining carbon char by-product is conveyed out of the Retort by means of a second KGV system. The carbon char contains primarily ash and carbon black. To recover the heat lost on exiting the Retort, a pipe coil containing water is placed amongst the carbon char. The brackish water is turned into superheated steam which is subsequently condensed and passed through carbon filters and recycled. The SIMEKEN pyrolysis unit does not generate any residual oils from the gasification process.

The liberated gases are then drawn by a suction fan located on the top of the wet scrubber. Before entering the wet scrubber the liberated gases are directed to the Thermal Oxidizer which is a long steel cylinder. In the Thermal Oxidizer the liberated gases are combusted at a temperature of 1,100 ^{o}C and greater. The mixture of combusted gases then flow to a waste heat boiler where steam is generated for either direct use or for the generation of electricity by means of a steam turbine (also referred to as the co-generation unit). The potential for energy generation depends on the rate of flow and the energy content of the waste material.

Once the waste heat gas is past the steam boiler, it is then cooled in the Transition Tube using a series of water jet sprays before entering the Wet Scrubber. The cooled gases are treated in the Wet Scrubber using lime (to control SO_X).

The Thermal Oxidizer is designed to thoroughly oxidize the fuel gases leaving the Retort to harmless combustion products. The design incorporates features to achieve robust gas mixing, high temperatures and conservative residence times to ensure complete oxidation and energy release of the retort gases. However, the same combustion management features built into the combustor that are necessary to achieve this goal also unavoidably cause the formation of oxides of nitrogen, which are pollutants. These gases, principally nitrous oxide (NO) and nitrous dioxide NO_2), called NO_X for short, are created in the high temperature environment associated with good combustion processes. They are precursors to the formation of smog, and NO_2 can be a direct concern if elevated ground level concentrations are involved.

4. Trial Demonstration

An important technical consideration of the pyrolysis plant is whether the anticipated emissions would meet Mexican regulatory criteria. A key consideration herein are the initial results of the detailed air emissions sampling and laboratory test results from the trial demonstration conducted in Matamoros from October 2004 to August 2005. The pyrolysis plant was shipped to Matamoros in the fall of 2004 and setup as a temporary facility under an approved permit issued by the Mexican federal environmental agency (SEMARNAT) for the purpose of conducting trial demonstrations. Several months of short trials and equipment modifications led to the undertaking of long-duration test trials in June and August 2005.

One component of the trial demonstration was to monitor and measure the quantity and quality of air emissions out of the wet scrubber stack. The air emissions monitoring program consisted of two (2) components: (1) on-going measurement of temperature, and carbon dioxide (CO_2), nitrous oxide (NO_X) and sulphur dioxide (SO_2) concentrations during the trials using a hand-held instrumentation package; and (2) a specific source testing program for the waste trials developed by ABC Laboratories of Mexico City.

The applicable air emissions regulation in Mexico is NOM-098-SEMARNAT-2002. This regulation governs point source emissions and specifically covers technologies that involve the thermal processing of wastes. Specific to the pyrolysis plant technology plant being proposed, the regulation outlines the maximum permissible emission limits which are summarized in Table 1.

5. Wood Waste Trial Results

The wood waste final pyrolysis trial was conducted on May 25, 2005 in Matamoros, Tamaulipas, Mexico. Following the warm up period, the plant processed about 8 tonnes of wood waste over an eight (8) hour period at an average rate of about 1.0 tonne per hour. The Retort gasified the waste at temperatures ranging form 805 to 860 ^{o}C. Over the duration of the trial, the plant produced about 1.6 tonnes of carbon char (i.e., 20% of the initial wood waste mass). The Retort consumed about 2 to 3 million BTU per hour of liquid propane fuel to gasify the wood waste.

The operating temperature in the Thermal Oxidizer ranged from 650 to 750 ^{o}C. The Thermal Oxidizer used an additional 12 BTU per hour of liquid propane to combust the syngas retrieved from the Retort. Overall, the Thermal Oxidizer generated about 22 to 25 million BTU per hour with the syngas fuel.

During the entire trial, including the warm up period, the plant consumed about 500 litres of liquid propane fuel. In addition, the plant used some electricity supplied by a 0.5MW diesel generator. During the trial, the electrical load used for the plant ranged from 25 to 33 percent of the generator's peak capacity.

The results from the air emissions sampling and laboratory analysis are summarized in Table 2. These emissions results meet the Mexican regulatory requirements and are consistent, albeit at higher concentrations, than the results obtained from the hand-held instrumentation package.

Following the trial samples of the carbon char were retrieved and submitted for laboratory analyses. The results indicate that the wood waste char had a carbon content of 97.6 percent with the remaining ash being primarily comprised of calcium as carbonate (1.97 percent) and magnesium as carbonate (0.33 percent). The carbon tetrachloride activity of the wood char was 3.1 percent per ASTM D3467.

Table 1 – Maximum permissible emission limits per NOM-098-SEMARNAT-2002

Parameter	Test Method	Units	Max. Permissible Limit
Sulphur Dioxide (SO_2)	NMX-AA-55	mg/m^3	80
Carbon Monoxide (CO)	USEPA-10-1996	mg/m^3	63
Nitrous Oxides (NOx)	USEPA-7E-1990	mg/m^3	300
Particulates (PSTs)	NMX-AA-010/2001	mg/m^3	50
Hydrogen Chloride (HCl)	NMX-AA-70-1980	mg/m^3	15
Metals I: As, Se, Co, Ni, Mn, Sn	USEPA-29-A-1996	mg/m^3	0.7
Metals II: Pb, Cr, Cu, Zn	USEPA-29-A-1996	mg/m^3	0.07
Cadmium (Cd)	USEPA-29-A-1996	mg/m^3	0.7
Mercury (Hg)	USEPA-29-A-1996	mg/m^3	0.07
Dioxins and Furans	USEPA-23	ng EQT/m^3	0.5

Metals I: Arsenic (As), Selenium (Se), Cobalt (Co), Nickel (Ni), Manganese (Mn), Tin (Sn).

Metals II: Lead (Pb), Chromium (Cr), Copper (Cu), Zinc (Zn)

Table 2 – Wood waste air emissions laboratory analysis results

Parameter	Units	Measured Value	Max. Permissible Limit
Sulphur Dioxide (SO_2)	mg/m^3	<35.3	80
Carbon Monoxide (CO)	mg/m^3	7.1	63
Nitrous Oxides (NOx)	mg/m^3	77.3	300
PSTs	mg/m^3	19.7	50
Hydrogen Chloride (HCl)	mg/m^3	7.1	15
Metals I: As, Se, Co, Ni, Mn, Sn	mg/m^3	<0.0437	0.7
Metals II: Pb, Cr, Cu, Zn	mg/m^3	0.00144	0.07
Cadmium (Cd)	mg/m^3	0.250	0.7
Mercury (Hg)	mg/m^3	<0.00007	0.07
Dioxins and Furans	ng EQT/m^3	0.043	0.5

Metals I: Arsenic (As), Selenium (Se), Cobalt (Co), Nickel (Ni), Manganese (Mn), Tin (Sn).

Metals II: Lead (Pb), Chromium (Cr), Copper (Cu), Zinc (Zn)

6. Preliminary Financial Model

The following presents a preliminary financial model developed for a 75 tonne per day wood waste pyrolysis plant operating in the City of Matamoros. The data contained herein should not be extrapolated to other candidate projects without due consideration of the site-specific conditions for each project.

Based on the results from the trial demonstration, such a wood waste pyrolysis plant would be able to generate about 2.36 megawatts (MW) of peak energy at a 92 percent load factor. In addition, the laboratory analyses presented above indicate that the carbon char generated (20 percent by weight) can also provide a substantial additional income stream to the project. It is also assumed that a disposal fee of $ 10.00 dollars per tonne of wood waste can be charged. With a total capital cost of about $11.33 million (2005 US dollars), an annual revenue stream of about $4.17 million, and annual operating and maintenance costs of about $1.94 million, the project would have a pay back period of about 4 to 5 years. Some of the details from the financial model are presented in Tables 4 and 5.

Table 4 – Wood Waste Pyrolysis Plant - Cost details from the financial model

Capital and Operating Annual Costs ($US 2005)	
Capital Costs	
SIMEKEN System Cost	5,000,000
Co-generation Unit	6,000,000
Additional Equipment	330,000
Total System Capital Costs	11,33,000
Facility Life (years)	15
Operation Costs (annual)	
Labor	630,000
Chemicals	15,000
Natural Gas (40% provided by LFG)	165,000
Electricity (Parasitic)	152,000
Water/Sewer	5,000
General Maintenance	340,000

Rent/Lease Land	180,000
Average Finance Cost (8%)	453,200
Total Annual Costs	1,940,200
Cost/Tonne Processed ($/tonne)	77.04

Table 5 – Wood Waste Pyrolysis Plant - Revenue details from the financial model

Annual Revenue Detail ($US 2005)	
Char Output	
Fraction Char (%)	20
Char Output (tonnes/year)	5,037
Char Price ($/tonne)	400
Total Char Revenue	2,014,800
Wood Waste Disposal Cost	
Wood Waste ($/tonne)	10.00
Total Wood Waste Revenue	251,850
Power Generation	2,358 KWh
Load Factor (%)	0.92
Price for Electricity	0.10
Total Electricity Revenue	1,900,296
Total Annual Revenue	4,166,946
Revenue/Tonne Processed ($/tonne)	165.45

7. Conclusions

The results presented herein demonstrate the large-scale viability of using the SIMEKEN pyrolysis technology as an effective tool in transforming wood wastes into a combustible gas fuel stream while creating useful by-products. In particular, the potential to generate moderate to high levels of heat energy through the combustion of the fuel gas is particularly attractive. Finally, the quality of the end products indicates that not only is a significant volume reduction achieved with a non-hazardous residue, but the by-products have a market value that provides an additional revenue stream.

The ability to take these waste materials through a complete life-cycle terminating with the complete capture of useful resources from their transformation is indicative of the sustainable qualities of this technology. Preliminary financial analyses are provided to indicate that this technology can provide not only a self-sustaining, but in some cases a revenue generating, solution to today's waste management challenges.

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