2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Alternative Energy Derived from Agricultural and Cafeteria Wastes using a Rotary Kiln Gasifier

Paul Amodeo, Ph.D., SUNY Cobleskill, Cobleskill, NY
Douglas Goodale, Ph.D., SUNY Cobleskill, Cobleskill, NY
David Waage, P.E., SUNY Cobleskill, Cobleskill, NY
Robert Rynk, Ph.D., P.E., SUNY Cobleskill, Cobleskill, NY
Renee Comly, W2E USA, Inc., Princeton, NJ

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Abstract. The State University of New York at Cobleskill has launched an alternative energy program that will foster the utilization of agricultural and cafeteria wastes for the production electrical power through the conversion of wastes to clean fuel gas (also known as syngas). The project is being funded by the Department of Defense utilizing a patent pending rotary kiln gasifier developed by W2E USA Inc. The rotary kiln gasification system is uniquely suited for handling a variety of difficult feedstocks with sizes, shapes, moisture levels, and compositions that cannot be used in most gasifiers. The first major initiative is the installation of a 300 kW bench-scale waste to energy test facility that will provide an effective and economical means of developing gasification design data for a variety of wastes. W2E's rotary kiln gasifier has a unique internal arrangement for introducing reactant gases at various locations within the gasification zone allowing for the adjustment of temperature and gas distribution to optimize gasification. Additionally, this permits an increase in temperature at the gasifier outlet to crack tars into smaller hydrocarbon chains to minimize tar production. This unit will be used to develop design criteria for a future 1 megawatt demonstration plant.

Keywords. *Bioenergy, Biofuel, Biowaste, Gasifier, Gasification, Rotary Kiln, Soil Amendment,Syngas, Waste to Energy*

Introduction

The State University of New York College of Agriculture and Technology at Cobleskill (SUNY Cobleskill) is highly respected as a career-oriented institution committed to practical technical education with state-of-the-art animal waste handling facilities and distinguished, caring faculty. SUNY Cobleskill is initiating a Biomass-to-Bioenergy research program to demonstrate a potential means to affect a reduction in US dependency on fossil fuels. An innovative rotary kiln gasification unit at the "emerging technology" phase of development, is the core of the system with the capability of converting energy from a diversified waste stream into electricity and/or liquid fuel.

The rotary kiln gasifier is a patent-pending process developed by W2E USA, Inc. While the gasifier design has been effectively proven by W2E, SUNY Cobleskill will assume the role of running a bench scale pilot unit to develop operational standards for both feed and emission equipment. The work is currently being funded by DOD grants in cooperation with the Benèt Laboratory. Ancillary programs supported by the project include a degree-bearing academic program in alternative energy, certification programs and workforce training, and technical support publications.

Safety Emphasis

Gasification produces carbon monoxide, hydrogen, and methane, which are flammable gases. Under normal conditions, syngas will not leak from the process equipment. If these gases were to leak in the rare event of equipment failure, a fire or explosion may occur. The specific gravity of syngas is almost equal with air, so the leakage of any gas may rise or settle based on the temperature differences. If the leaking syngas is hotter than the surrounding air, the syngas will rise, otherwise it will dwell near the leakage point. Since the gas is a mixture, there is a risk under certain conditions where lighter gases, such as hydrogen, could separate from the rest of the gas mixture and rise. Lighter gases will rise and may accumulate under enclosed areas, such as under roof peaks. It is common practice to avoid the accumulation of gases in enclosed areas using ventilation.

There are numerous codes that address how to operate process and electrical equipment safely in a hazardous environment. Federal, state, and local codes apply. The National Fire Protection Agency (NFPA), National Electric Code (NEC) and the American Petroleum Institute (API) dictate numerous codes that govern the installation and operation of gasification equipment.

Although carbon monoxide is flammable, it is also a well known health risk. Even in small concentrations (<50 ppm), the leakage of carbon monoxide is a serious health concern. Health risks, including death from carbon monoxide exposure occur well before the flammability limit in the surrounding air is reached. As a result, the concentration of carbon monoxide mixed with ambient air in the process area must be monitored using carbon monoxide sensors. These sensors will indicate the leakage of carbon monoxide well before the risk of fire or explosion can occur.

Adequate forced ventilation is commonly used to dilute any leaking gas, to keep the concentration of hazardous gases well below the threshold of health and flammability.

Importance to Agriculture

The agricultural community is in a paradox relative to its waste stream. There is more biowaste than solutions of what to do safely (in this case environmental) with this waste stream. Current technology has animal and plant waste spread on the land to build the organic matter content and nutrient level of the receiving soil. The dilemma is a growing amount of waste in a decreasing amount of land mass upon which to spread the excrements. This inference is not that land is less available but that the animals per owner-acres are in a narrowing ratio. Current environmental regulations cap nutrient loading per acre per annum to levels below the supply for many farmers. Producers need an alternative plan; and what better way than convert "the excess" into energy capable of substituting for fossil fuels. It is hoped that this process proves to be an affordable substitute to the purchase of energy for agriculture and agricultural operations, and in some cases, may provide energy generation as a secondary product for the agricultural community.

The Waste Stream

SUNY Cobleskill is uniquely suited for this project due to its position as a college where the supply of a diversified biomass "test-feed" is abundant. This biomass includes paper, green, animal and cafeteria wastes, and organic municipal solid wastes, which are not efficiently degradable by conventional technologies. There are 2500 on-campus students, 350 faculty and staff, a sizable proportion of which create institutional cafeteria waste on campus.

In addition, the nearly 400 animals on the College farm contribute to this diverse waste stream. SUNY Cobleskill recently completed a state-of-the-art equestrian center and a new 200 free-stall cow barn, which, outside of Cornell University, is the largest bovine teaching and research facility in New York State.

In addition to the energy derived, positive benefits of the process include the reduction of landfill waste, deleterious run-off into water, fossil fuel conversion pollutant emissions, waste removal expense.

Using New York State as an example of landfill contribution, the average per capita landfill contribution in 2005 approached one ton. Redirecting this waste stream has been estimated to potentially reduce New York’s dependency on crude oil by 2.9 billion barrels, valued at $174 million based on the comparative (waste to oil) heat units. A unique goal of this project is to create an affordable technology with the ability to exchange the current cost of waste disposal for positive and sustainable financial, energy, and environmental benefits. It is hoped that this goal may be realized through the production of, as close as possible, zero waste. The investigation is to focus on recycle methods with emphasis on reuse of materials for agricultural uses. An example would be the development of methods to use resultant ash in soil amendments or as a fertilizer.

The Gasification Process

Gasification is a thermal process that uses heat and steam, sometimes under pressure, to convert materials directly into a gas termed syngas. Literature demonstrates that the predominant gas species will vary depending upon the operating temperatures (Skoulou V., et al., 2009 and Maoyun He, et al, 2009). At higher temperatures (approximately 1000 deg C), syngas composition consists primarily of carbon monoxide and hydrogen (more than 85% by volume) and smaller quantities of carbon dioxide and methane. Methane and carbon dioxide are favored at lower gasification temperatures. The process can take place at between 800 and 1000 deg. C and between 0 and 30 atm. pressure (Boyle, G., 2004).

Gasification technologies differ in many aspects but rely on four key engineering factors:

- Reactor design;
- Gasification reactor atmosphere (level of oxygen or air content);
- Internal and external heating; and
- Operating temperature.

Reactors may be oriented horizontally but most often as vertical columns and include various fixed bed or fluidized systems. Typical bed designs include fluidized bed, entrained bed, downdraft gasifier, and updraft gasifier. All of these configurations require, to varying degrees, that feedstock material be of relatively small particle size, reasonably homogeneous, and low moisture content.

The reactor atmosphere can be air or oxygen in combination with steam. To a point, the water present takes part in a positive manner toward the formation of desired syngas end products.

Gasifiers may be heated external to the vessel or may be heated internally by combustion of some of the product gases or through the application of auxiliary heat. External heating is reminiscent of predominately pyrolytic processes where the intent is shifted from the production of syngas to production of an energy rich char.

As stated above, operating temperatures can be varied depending upon the desired composition of the syngas. Tar and ash production are favored at lower operating temperatures as are larger particulate sizes (Rapagna, S., 1997). Tar production tends to decrease at higher temperatures, probably due to extended thermal cracking and steam reforming reactions (Skoulou V., et al., 2009).

Gasification of carbonaceous fuels undergoes three processes:

- Pyrolysis (or devolatilization): As carbonaceous fuels are heated volatiles are released and char is produced.
- Combustion: Volatiles and char react with oxygen to form carbon dioxide and carbon monoxide. The heat produced promotes subsequent gasification reactions.
- Gasification: Char reacts with carbon dioxide and steam to produce syngas.

There are a number of gasification reactions. However, the most important are [Souza, 2004]:

- Carbonaceous solid and water. $C + H_2O \rightarrow CO + H_2$
- Carbonaceous solid and carbon dioxide. $C + CO_2 \rightarrow 2\ CO$
- Carbonaceous solid and hydrogen. $C + 2\ H_2 \rightarrow CH_4$

In general, gasification reactions are endothermic. As a result, there is a need for some source of energy. Ideally, heat comes from the combustion of the volatiles released by the pyrolytic reaction. However, many processes require the use of an external source such as natural gas.

Typical raw materials used in gasification are coal, petroleum-based or organic materials. The feedstock is prepared and fed, in either dry or slurried form, to a sealed reactor chamber called a gasifier. The feedstock is subjected to high heat, pressure, and either an oxygen-rich or oxygen-starved environment within the gasifier. Most commercial gasification technologies do not use oxygen, but use air instead. All require an energy source to generate heat and begin processing.

There are three primary products from gasification:

- Flammable gases (also called syngas);

- Hydrocarbon liquids (oils), and;
- Char (carbon black and ash)

An ideal gasification system will emphasize the production of gas and minimize the production of liquids and char. Byproducts from the process have a constituency that is useful for some other purpose such as the use of ash as a soil amendment.

Gasification emissions depend upon

- the type of material being gasified
- the particular gasification system
- how optimally the system is operating

All carbonaceous materials, including wastes, contain energy, and man has learned to harness and utilize this energy for his everyday use. Due to relative low costs, convenience and adequate supply, historical carbonaceous energy sources have included natural gas, coal, wood, coke and various petroleum products. Energy has been derived by direct combustion for heating, steam, or electricity generation. In recent years, waste has been given attention for energy generation. In most cases, wastes have contained large quantities of water that decreases the net energy potential unless moisture is removed. Prior to now, these wastes were committed to landfill or incinerated at the cost of added fuel to remove the additional moisture. Gasification of wastes was feasible. However, the conventional processes were prone to reliability problems which improved when the moisture content was below 20% (McKendry P, 2002b).

Wastes specific to agriculture can include wood waste, manure, crop wastes of which manure represents a substantial energy source due to its high volatility (Fowlera , P. 2009). Manure can approach the energy content of popular western coals used for electrical generation in the United States. Characteristics of biomass that are of greatest interest in any degradation process are (McKendry P, 2002a):

- moisture content;
- heating value;
- fixed carbon and volatile mater proportions;
- ash content;
- alkali metal content;
- cellulose and lignin ratio

While cellulose and lignin content are critical for natural degradation processes, they pose relatively little concern for thermal processes.

The gasification of dry wastes such as waste wood, waste tires, waste oils, etc., pose few issues in balancing energy for the process and producing residual energy for use. However, energy considerations for water-laden wastes require technical knowledge to make the most use of the water available in these wastes in a cost effective manner. For most thermal processes, the energy associated with the removal of excess water has to be supplied to the process. Drying and combustion processes generally utilize natural gas or some other auxiliary fuel. Considering the heat required to evaporate water and for sustaining endothermic gasification reactions between water and carbon, the minimum heat required to gasify 1 lb of waste is approximately 2000 BTU/lb. Some of this heat can be recovered for useful purposes. The amount available depends on how the syngas is cooled in the process.

Generally, emissions or byproducts, if not managed appropriately, can cause some environmental impact that includes:

- mineral matter and particulates in the form of ash;
- nitrogenous products such as ammonia and NOx;
- Volatile organic emissions (VOCs) in the form of tars and oils (from a system that is not working optimally).

Inorganic material in the feedstock is often converted to slag, which is inert and has a variety of uses in the construction and building industries.

Syngas can be used as a fuel to generate electricity or steam, or as a basic chemical building block for a multitude of uses. When mixed with air, syngas can be used in modified gasoline or diesel engines.

Process Description

What differentiates this project from other gasification technologies is an innovative rotary kiln, the W2E TURNW2E^{tm} Gasification Technology, which is the heart of the gasification process. Other gasifier designs include various fluidized and fixed bed reactors which are generally oriented as vertical columns. These designs lack agitation in the reaction zone resulting in numerous technical issues to include a significant need for control of feedstock size and potential dead zones. The rotary kiln is contrasted to these designs with a horizontally oriented reaction vessel placed on a slight slope. Its natural rotation provides agitation of feedstock at high temperatures, allowing for a complete conversion of the material to gas. This natural agitation and the lack of a definable contacting bed allow the kiln to accept a wide variety of feedstock shapes and sizes.

The rotary kiln design lends itself well to the process of gasification in that it provides utility for all three steps of the gasification process. The pyrolytic phase occurs immediately upon entry of the feedstock into one end of the kiln. The resulting solids composed of char drops to the bed while the released volatiles are combusted. Subsequent gasification of the char ensues as it is moved down the length of the bed through the bed's rotation and exposed to air/oxygen and steam as it is turned-over and agitated. Residence time of the material can be effected by variation of the rotation speed of the kiln.

Rotary kilns have an over 100-year history of use in the production of cement and lime at temperatures higher than required for clean gasification. A bane of the industry is a natural tendency of the rotary kiln to gravitate toward the unwanted production of a synthetic gas if the flow of combustion air is not adequate. While this creates difficulties when processing cement and lime, for the gasification of organic materials, this is a desirable result. This project capitalizes on allowing the rotary kiln to gravitate towards its typical operating conditions. Specifically, it is the intent of the biowaste to bioenergy project to produce clean synthetic gas. This synthetic gas will subsequently be used in the production of electricity, hydrogen, liquid fuels, soil amendments, and steam for heating and cooling purposes.

The W2E gasification system is a patent pending rotary kiln gasifier with a unique internal arrangement for introducing reactant gases at various locations within the gasification zone. This unique feature optimizes the gasification of waste by allowing the adjustment of temperature and of gas distribution at these locations. As a consequence of this control, an increase in temperature is permitted at the gasifier outlet to crack tars into smaller hydrocarbon chains. As a result, the overall content of the tar in the gas is minimized or even eliminated.

In contrast to other gasification devices such as the fluidized bed, entrained bed, downdraft gasifier, and updraft gasifier, the nature of the kiln gasifier places no feed restrictions with respect to the particle size distribution or the density of the waste. Since the waste bed surface is constantly turning over and fresh material is being exposed at the surface, water content is less of an issue with theoretical acceptance of wastes up to 50% moisture. This method represents an advantage over conventional methods since the additional moisture can be used as a benefit in the gasification process and the need for expensive drying is mitigated. In addition, the above stated history has established that the use of a kiln vessel provides of over 99 percent availability in daily and extended use.

SUNY Cobleskill will be utilizing a bench-scale gasification unit provided by W2E for the purposes of testing a variety of feedstock configurations and mixtures and to develop design data for the conversion of waste-to-energy through the production of clean fuel gas (syngas). SUNY Cobleskill will be responsible for supplementing the unit with appropriate support equipment and instrumentation to meet varying test requirements. The variation of shapes, sizes, composition and moisture content of agricultural wastes requires the flexibility of this gasification system design for optimum success.

Advantages of Rotary Kiln Gasifier

The project's waste-to-energy technology incorporates a unique and highly flexible rotary kiln-type gasification system for the conversion of all types of wastes into energy as electricity and/or steam. Since the nature of rotary kilns are particularly suited for variable feed compositions they are amenable for processing MSW, sludge, biomass, and industrial wastes singly or in combination. The rotary kiln is an established technology with a lengthy track record for reliability when used in similar processing applications, and has a record of availability of greater than 99 percent with minimum maintenance requirements.

Mass burn systems for wastes are notorious for having issues related to the emissions of carcinogenic compounds such as dioxins and furans. The waste incineration permit process can be tedious, often due to local public concerns regarding emissions. By contrast, waste gasification first converts material into fuel gas and then utilizes this fuel gas to produce steam or electricity. The intermediate gasification step between waste and the combustion of fuel gas makes it possible to remove all of the precursors of the compounds of concern that contribute to the formation of carcinogenic compounds. Removing the precursors prevents the formation of these compounds.

The elimination of these precursors simplifies the permitting process. The gasification process is presented as an intermediate step to produce clean fuel with combustion properties similar to those of natural gas. Permitting efforts can be shifted to the power generation or steam generation processes, which are routine applications.

When compared with other gasification technologies such as fluidized bed gasification, entrained bed gasification, downdraft gasification, and fixed bed gasification, the project's gasification system distinguishes itself from others in six unique process and operational areas. These are:

1. The reliable gasification of non-homogenous waste;
2. Sufficient turndown capacity to process varied quantities of waste
3. The production of consistent gas quality to meet the client's requirements;
4. The ability to process difficult wastes (such as plastics and tires);
5. Producing syngas with tar content less than 10 ppm; and

6. A simple and reliable system most suited for operation by relatively unskilled operators

Some of the additional features and advantages that make the project technology a unique system for gasification include the following:

- The system has automated controls and operations to minimize human resource requirements.
- It is rugged and low-maintenance to minimize operational costs; and has few consumables, which minimize logistical requirements.
- In order to meet the objective of maximizing the energy recovery from the waste stream, the feed preparation and reactor designs
    - minimizes parasitic losses;
    - minimizes electrical requirements; and,
    - makes maximum use of waste heat from the conversion process wherever possible.
- The system objective is to consume less than 30% of the gross energy content of the waste stream through these losses (further gains are expected).
- The feed preparation section design is all-purpose rather than specific to a certain waste stream composition. It is flexible for varying waste streams or subsets thereof (e.g., packaging wastes only). The feed preparation section produces a relatively homogeneous product that is suitable for short-term storage and automatic transportation and feeding into the gasifier.
- To facilitate the gasification of water-laden waste (eg. sewage sludge containing 75% water), the material can be easily gasified by mixing with relatively dry material with significantly greater energy content than the wet material. Wet sewage sludge renders little energy (1315 BTU/lb on wet basis), but when supplemented with higher calorific value wastes, can achieve an overall heating value of greater than 5500 BTU/lb. Higher calorific value wastes applicable and readily available include wastewater screenings, chopped wood waste, chopped plastic wastes, chopped used tires, and waste oils. All of these wastes can be gasified in combination to produce syngas.

Process Investigation at SUNY Cobleskill

The research at SUNY Cobleskill will evaluate the advantages of the rotary kiln gasifier system and endeavor to optimize operations procedures and provide operational guidance. Initial research will focus on areas outlined below.

Feedstock Development

The rotary kiln gasifier has the ability to accept a non-homogeneous feedstock. In addition, moisture content of the feedstock should be less critical than it is for incineration and other gasification processes. SUNY Cobleskill will verify preconditioning needs for various feedstocks singly and in combination. Combinations of feedstocks with different moisture (eg. a high and a low) content should complement each other.

Feedstock Densification

Feedstocks for other types of gasifiers need to be readily fluidized or of a uniform size. The rotary kiln gasifier has the capability to accept varying sizes of material. Even so, under certain conditions, clumping of a material or mixtures of material could be an issue. Specifications for optimal sizing of material will be evaluated.

Ash Analysis

Although anticipated to be small, the chemical composition of the ash will vary with the material being processed as well as with temperature and residence time. Mixtures of materials may produce a different ash composition than the summation of their individual single feeds. Specifications for ash production volume and composition will be evaluated.

Scrubbing Demineralization

While it is anticipated, due to low operational pressures, that the system will generate low quantities of particulate in the effluent gas, what particulate exists will be removed using a conventional high efficiency cyclone and a venturi scrubber. Scrub material will be analyzed and technologies for removal of mineral content will be evaluated. The primary focus of the removal technologies will be to produce useful product, especially those beneficial for agricultural purposes, and to eliminate the incidence of a true “waste” product.

Scrub Water

Scrub water will be evaluated for suitability for use as an amended plant irrigation source. Where possible, pretreatment will be avoided; however, technologies will be evaluated that will allow scrub waters to be modified so that dissolved minerals are in a form that is directly and beneficially useful for plant growth.

Conclusions

Bioenergy Center at Cobleskill

The SUNY Cobleskill Bioenergy Center is the site for conducting research and demonstrating new technologies for the production of alternative energy. Our premier project will employ a technology that consists of a unique gasification system, built on a rotary kiln design. In this first project, organic materials – target feedstocks- are converted into syngas. Future projects will then produce electricity, hydrogen or liquid fuel, from this syngas. This "green energy"-producing model can assist the United States in achieving its mandates and goals for fossil fuel reduction through biowaste conversion, using a material that would otherwise be spread on the land or transported to a landfill, into electrical power and liquid fuels.

The rotary kiln design is historically proven to be reliable, robust and by its nature, suitable for the gasification of carbonaceous material. As such, it lacks many of the shortcomings of conventional processes to include the need for extensive feed preparation for size, homogeneity and moisture content, consistent gas production, clumping of material, and tar and ash production. The project system, supplied by W2E, has the ability to accept varied and mixed wastes of various sizes. The ability to accept mixtures allows for moisture content averaging, increasing its ability to accept wastes with high moisture content. Control over process temperatures and air/oxygen and steam injection through the length of the reactor allows for maximum process control and optimum production of desirable clean syngas as product while minimizing tar and ash production. Finally, the syngas produced will be demonstrated to be convertible to alternate energy uses to include the production of liquid fuel, electricity, and hydrogen for fuel cells.

Training and Academic Programs

The Bioenergy Center will also serve as an education and training site for SUNY Cobleskill students and agricultural community members, alternative energy technology equipment designers and operators. As an Agriculture and Technology College with active animal production and student body, SUNY Cobleskill is well suited to conduct research on a diverse stream of waste.

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