RSF Pyrolysis Technology Overview

In contrast to fossil fuels, the use of biomass, waste hydrocarbons, Plastics, etc for energy provides significant environmental advantages. Plant growth needed to generate biomass feed-stocks removes atmospheric carbon dioxide, which offsets the increase in atmospheric carbon dioxide that results from biomass fuel combustion. There is currently no commercially viable way to offset the carbon dioxide added to the atmosphere (and the resultant greenhouse effect) that result from fossil fuel combustion. The climate change effects of carbon dioxide from fossil fuels are now generally recognized as a potential serious environmental problem.

Carbon dioxide is the predominant contributor to the increased concentration of GHGs. The combustion of fossil fuels accounts for two-thirds of global anthropogenic CO_2 emissions, with the balance attributed to land use changes. Although it makes up only about 5% of global population, the United States was responsible for 22% of global anthropogenic CO_2 emissions in 1995. Nearly one-third of the U.S. emissions are attributed to transportation, including motor vehicles, trains, ships, and aircraft. The global share of CO_2 emissions by other countries, particularly China and India, is rapidly rising, even as the CO_2 emissions from the United States increase.

It is imperative that we make use of appropriate technologies for the recovery of resources from non-conventional sources such as waste, in order to ease the energy crisis and to slow environmental degradation which shall, in turn, reduce the percentage of land-filled wastes.

The choice of conversion process depends upon the type and quantity of waste feedstock, the desired form of energy (i.e., end-use requirements), environmental standards, economic conditions and project specific factors. Many biochemical and thermo-chemical processes have been researched for the purpose of waste upgrading. While both methods of processing can be used to produce fuels and chemicals, thermo-chemical processing can be seen as being the easiest to adapt to current energy infrastructures, and to deal with the inherent diversity in some wastes.

Three different thermo-chemical conversion routes are found according to the oxygen content in the process:

- combustion (complete oxidation),
- gasification (partial oxidation) and
- pyrolysis (thermal degradation without oxygen).

Among them, combustion (also called incineration) is the most established route in industry but this is also associated with the generation of carbon oxides, sulphur, nitrogen, chlorine products (dioxins and furans), volatile organic compounds, polycyclic aromatic hydrocarbons, dust, etc. On the contrary, gasification and pyrolysis offer the potential for greater efficiencies in energy production and less pollution. Although pyrolysis is still under development in the waste industry, this process has received special attention, not only as a primary process of combustion and gasification, but also as independent process leading to the production of energy-dense products with numerous uses. This makes the pyrolysis treatment process self-sufficient in terms of energy use, and also significantly reduces operating costs.

The Importance of Energy efficiency

Economic growth is generated either by increased inputs of capital and labour, or by the more efficient use of those inputs. This can come about as a result of new technology, or through better management. Energy is one of the critical inputs in the energy intensive industrial sector, and as growth based on increasing inputs of capital begins to reap diminishing returns, the efficiency with which energy is managed becomes increasingly important.

The need to make changes in the way energy is used and supplied throughout the world represents the greatest challenge to engineers in moving toward sustainability.

Several patterns of energy supply and use currently exist; none of them sustainable. Energy (primarily from fossil fuels) underlies modern industrial development and standards of living. Industrialised countries use vast quantities of energy to run factories, mine and process materials, transport goods and people, and carry out activities of daily life. This energy use is creating both local environmental damage and contributing to changes in global climate.

Reducing the amount of energy we use is widely believed to be the quickest, simplest and most cost-effective way to reduce South Africa's greenhouse gas emissions. Energy efficiency is important for tackling the challenge of climate change, but it's also important for South African businesses to help monitor and cut their own power usage, saving money through delivering effective and sustainable, energy cost reductions.

Companies that not only understand the importance of energy efficiency, but understand how to implement energy efficient practices are key to pushing forward the green building process that is so important to future economic growth and sustainability.

A Carbon Footprint measures the total greenhouse gas emissions caused directly and indirectly by a person, organisation, event or product. Carbon Footprint quantification analysis and reduction are key to preventing this change by, for example, enhancing energy efficiency, mitigating carbon emissions by means of green energy and then compensating for remaining GHG (Greenhouse Gas) emissions by investing in carbon offsets, with a final goal of being carbon neutral. However, it's not about the size of your footprint, but the value generated per unit of carbon processed.

Principles of the pyrolysis process

The term "pyrolysis" is defined as a thermal degradation in the absence of oxygen, which converts a raw material into different reactive intermediate products: solid (char), liquid (heavy molecular weight compounds that condense when cooled down) and gaseous products (light molecular weight gases). The understanding of the pyrolysis process is a complicated one since many factors have to be considered, such as raw material composition and process conditions.

It is generally accepted that there are two possible steps in any pyrolysis process;

(i) primary pyrolysis, which comprises the de-volatilization of the material where different reaction zones can appear corresponding to the thermal decomposition of the main constituents; and

(ii) secondary pyrolysis, which covers the secondary decomposition reactions in the solid matrix, as well as secondary reactions between the volatiles release (homogeneous reactions), or between the volatiles and the carbonaceous residue (heterogeneous reactions). The first stage mainly involves dehydration, de-hydrogenation, de-carboxylation or de-carbonilation reactions. The second comprises of processes such as cracking (thermal or catalytic), where heavy compounds further break into gases, or char is also converted into gases such as CO, CO_2, CH_4 and H_2 by reactions with gasifying agents, as well as partial oxidation, polymerization and condensation reactions.

Pyrolysis profiles

The diversity in chemical and physical properties of waste materials may imply significant differences between the corresponding pyrolysis profiles, since different levels of interactions between the components may occur. In this sense, an initial characterization of the material is of crucial importance to understand the pyrolysis dynamics, such as initial degradation temperature, conversion time, maximum volatile releasing rate and its corresponding temperature. Along with effective design and operation, each of the aforementioned represent the basic information required for full optimization of the process.

Most of the studies on pyrolysis behaviour have been established for lingo-cellulosic materials, which comprise of a mixture of hemi-cellulose, cellulose, lignin and minor amounts of other organics. It is known that each of these components pyrolyze or degrade at different rates and by different mechanisms and pathways. While cellulose and hemicelluloses form mainly volatile products during pyrolysis due to the thermal cleavage of the sugar units, the lignin mainly forms char since it is not readily cleaved to lower molecular weight fragments. Wood, crops, agricultural and forestry residues, and sewage sludges are some of the main renewable energy resources available and subjected to pyrolysis processes, as are the biodegradable components of municipal solid waste (MSW) and commercial and industrial wastes.

There are different approaches that attempt to establish a correlation between the characteristics of the lingo-cellulosic materials and its final pyrolysis products. The first considers the biomass as a complex mixture of polymers consisting of carbon, hydrogen and oxygen. The second takes into account the functional groups presented, whilst the third is based on the biomass formed from cellulose, hemicelluloses and lignin. However, to date there is no model that predicts yield and composition of the final pyrolysis products, due largely to component interaction and the influence of mineral matter.

Pyrolysis technologies

Not only can raw material composition influence the yield and characteristics of the pyrolysis products, but the pyrolysis conditions can also modify the course of reactions and, therefore, strongly affect the yield and properties of products. Consideration should be taken of temperature, heating rate and residence time of vapours present in the reactor.

Depending on these variables, the pyrolysis process can be divided into three subclasses:

- slow
- fast
- flash pyrolysis

Pyrolysis Technologies	Residence time (s)	Heating rate (K / s)	Temperature (K)
Slow	450-550	0.1-1	550-950
Fast	0.5-10	10-200	850-1250
Flash	<0.5	>1000	1050-1300

Range of the main operating parameters for pyrolysis processes (Elías, 2005) Earlier literature generally equates pyrolysis to carbonization (slow pyrolysis), in which the principal product is a solid char. Today, the term pyrolysis often describes processes in which oils are preferred products flash pyrolysis technologies have been considered as a good solution to convert materials to liquid fuel. Nevertheless, pyrolysis as a means to convert a diversity of waste materials to combustible gas or syngas is receiving the increased attention which it deserves.

Some interventions in the operating parameters may induce and/or alter particular chemical reactions, resulting in different chemical profiles of the volatiles. Generally, increasing the pyrolysis temperature reduces the char yield and increases the gas yield. The liquid yield reaches a maximum value at intermediate temperatures and decreases at higher temperatures due to thermal cracking of heavy compounds. Long residence times of volatiles in reactor and high temperatures decrease tar production but increase char formation as a result of the extension of secondary reactions.

Higher heating rates favour a quick release of volatiles, modifying the solid residue structure with an increased yield of the liquid and gaseous fractions.

Other variables that have to be considered in a pyrolysis process such as the reactor type, mass of feedstock, pressure etc., might also alter the final product distribution. The optimization of each of the final pyrolysis products can also be done by catalytic means. The use of catalysts or additives to improve the yield or quality of pyrolysis gas or liquid fuels is still in its infancy. While there is fundamental work underway, more research is necessary to explore the wide range of conventional and unconventional catalysts. Catalytic pyrolysis has been reported to be a productive means to increase gas yield by decreasing the amount of liquid, as well as positively affecting the quality of the organic composition of the oils – in *situ* upgrading.

Pyrolysis products

Pyrolysis process has the ability to provide three end products: gas, oil and char, which all have the potential to be refined further if required. The concentrations and characteristics of each product can vary considerably according to the feed characteristics and the operating conditions of the pyrolysis process. The main properties and applications of each pyrolysis fraction are presented below:

Solid fraction

Pyrolysis char is a carbonaceous residue mainly composed of elemental carbon originating from thermal decomposition of the organic components, unconverted organic compounds, e.g. solid additives, and even carbon nano-particles produced in the gas phase secondary reactions. This carbonaceous residue plays an important role in the pyrolysis process since it contains the mineral content of the original feed material, relevant to specific catalytic processes. The importance of the char cannot be understated as it

may be involved as a reactive in heterogeneous or catalytic heterogeneous reactions.

The utilization of the char can vary considerably according to its characteristics. The main industrial uses of char can be summarized as follows:

(i) as solid fuel for boilers which can be directly converted to pellets or mixed with other materials such as biomass, carbon, etc., to form the same.

(ii) as feedstock for the production of activated carbon,

(iii) as feedstock for making carbon nano-filaments,

(iv) as feedstock for the gasification process to obtain hydrogen rich gas,

(v) as feedstock for producing high surface area catalysts to be used in electrochemical capacitors, etc.

Liquid fraction

Pyrolysis oil is a complex mixture of several organic compounds which may be accompanied by inorganic species. In the case of biomass, the liquid or oil fraction (bio-oils) is found to be highly oxygenated and complex, chemically unstable and less miscible in conventional fuels. Thus, the liquid products still need to be upgraded by lowering the oxygen content and removing residues.

The oil obtained from pyrolysis can have the following industrial uses:

(i) combustion fuel,

(ii) used for power generation,

(iv) production of chemicals and resins,

(v) transportation fuel,

(vi) production of anhydro-sugars like levoglucosan,

(vii) as binder for pelletizing and briquetting combustible organic waste materials,

(viii) bio-oil can be used as preservatives, e.g., wood preservatives,

(ix) a suitable blend of a pyrolysis liquid with the diesel oil may be used as diesel engine fuels,

(x) bio-oils can be used in making adhesives, etc. Moreover, the oil may be stored and transported, and hence need not be used at the production site.

Gas fraction

The gas produced in a pyrolysis process is mainly composed of combustible gases, such as H_2, CO, C_2H_2, CH_4, C_2H_4, C_2H_6, etc. Other gases, such as CO_2 and pollutants (SO_2, NO_x), can also appear, although in lower concentrations.

The gas produced from pyrolysis can be used directly as a fuel in various energy applications, such as:

(i) direct firing in boilers without the need for flue gas treatment, and

(ii) in gas turbines/engines associated with electricity generation. Pyrolysis gas containing significant amounts of hydrogen and carbon monoxide might be utilized in syngas applications. It is known that synthesis gas (H_2 + CO) having different H_2/CO molar ratios is suitable for different applications. For example, synthesis gas having a high H_2/CO molar ratio is desirable for producing hydrogen for ammonia synthesis. This ratio is increased further during the water-gas shift reaction for the removal of CO.

The RSF Technology is capable of treating solid/oily sludge waste streams contaminated with high concentrations of a wide range of volatile and non-volatile compounds from Mining, Refineries and various Industrial operations. The resource recovery range includes:

- Light/Heavy oils (Hydrocarbons) and Fuel oils,
- Solvents, and
- Precious metals.

Examples of Waste Streams Amenable to RSF Treatment

- Oil Sludge from: Oil/water separators, trenches, hard surface areas, tank bottoms, steel production and oil contaminated soil,
- Spent grease and/or off-spec grease from various industrial operations,
- Oil filters, drilling mud's, refinery sludge/tar and spent catalysts,
- Sludge from chemicals, paint and other industrial operations, and
- Spent filter clay for lubricating oil and plant oil refineries.
- Wood
- Paper
- Biomas
- Plastics

Reduced Energy Consumption

The uniquely energy-efficient RSF process converts up to 98% of the energy expended into useful heat; traditionally heated pyrolysis reactors are generally only 45% energy-efficient. And since induction requires no warm-up or cool-down cycle, stand-by heat losses are reduced to a bare minimum. The repeatability and consistency of the induction process make it highly compatible with energy-efficient automated systems.

Environmentally Sound

Induction heating systems do not burn traditional fossil fuels; induction is a clean, non-polluting process which will help protect the environment. An induction system improves working conditions for your employees by eliminating smoke, waste heat, noxious emissions and loud noise. Heating is safe and efficient with no open flame to endanger the operator or obscure the process. Non-conductive materials are not affected and can be located in close proximity to the heating zone without damage.

Maximized Productivity

Production rates can be maximized because induction works so quickly; heat is developed directly and instantly (>800°C. in < 5 min). Startup is virtually instantaneous; no warm up cycle is required.

Optimized Consistency

Induction heating eliminates the inconsistencies and quality issues associated with traditional heating methods. Once the system is properly calibrated and set up, there is no guess work or variation; the heating pattern is repeatable and consistent. With modern solid state systems, precise temperature control provides uniform results; power can be instantly turned on or shut off. With closed loop temperature control, advanced induction heating systems have the capability to measure the temperature of each individual pyrolysis reactors. Specific ramp up, hold and ramp down rates can be established & data can be recorded for each reactor that is run.

The standard RSF system can process circa three tonnes per day, however it is both scalable and modular and so lends itself to larger volumes if required. Advanced resources separation and recovery technology developed by OSS, reduces the reliance on landfill, creating products with value whilst simultaneously reducing the potential future Environmental liabilities.

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