THERMOCHEMICAL CONVERSION RESEARCH & DEVELOPMENT ACTIVITIES IN CANADA

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ABSTRACT

An overview of the R & D activities and strategies of the Canadian Biomass Thermochemical Conversion Program, part of the CANMET Energy Technology Centre(CETC) will be presented. The paper will focus on the pyrolysis technology area and examine both the current status of research activities in Canada and the future research directions.

The major objective of this program is the development of cost competitive technologies that convert biomass into gaseous and liquid fuels and chemicals to be used for process heat, electricity, alternate refinery feedstocks and value added products. The program can be divided into the following main project areas: i) assessment of the potential of thermochemical conversion systems to process new biomass and/or waste feedstocks; ii) process development and optimization of thermochemical conversion processes; iii) evaluation of the potential of producing value added chemicals from pyrolysis products and determination of end use industrial applications for these; v) assessment of the commercial utilization of pyrolysis oils for heat and/or electricity production in boilers, diesel engines and gas turbines; and, vi) continued development and optimization of the production of high cetane diesel fuel from plant and vegetable oils.

INTRODUCTION

The objective of the biomass thermochemical conversion program is to develop cost competitive technologies that can thermochemically transform biomass materials into liquid, solid and gaseous fuels which can be converted to process heat, electricity, refinery feedstocks and value added products. Research efforts are focussing on processing, upgrading and utilization issues that will result in an optimal system for energy production. Work will also increasingly focus on the production of value added chemicals from the products of thermochemical conversion and will address the fractionation, isolation, recovery and application issues related to this. This paper will focus on the technology development and commercialization activities associated with pyrolysis technologies.

MAJOR PYROLYSIS RESEARCH AREAS

1. Assessment of the potential of pyrolysis to process new biomass and waste feedstocks, particularly those causing environmental disposal problems.

2. Process development and optimization of thermochemical conversion processes, including oil quality improvement and health and safety related issues.

3. Evaluation of the potential of producing value added chemicals from pyrolysis products and determination of end use industrial applications for these.

4. Assessment of the commercial utilization of pyrolysis oils for heat and/or electricity production in boilers, diesel engines and gas turbines.

5. Continued development and optimization of the production of cetane enhancers from plant and vegetable oils, including process optimization and scale up, co-product upgrading, laboratory engine and emission testing and field trials.

STATUS OF PYROLYSIS DEVELOPMENT

1. Assessment of the Potential of Pyrolysis and other Thermochemical Conversion Systems

In order to assist the fast pyrolysis technology in penetrating new industrial markets, various biomass feedstocks, particularly wastes presenting disposal problems, need to be assessed for their potential concerning oil yields, product characteristics, etc. Waste biomass from a number of forest products companies have been successfully pyrolyzed by various groups involved in fast pyrolysis. Research projects with Ensyn Technologies and Pyrovac Institut to assess whether bark residues could be pyrolyzed have been completed, and the results indicate that industrial softwood and hardwood bark can be processed without operational difficulties. As a result of these tests, a number of forest companies are exploring the application of fast pyrolysis technology in the treatment of their bark wastes. Ensyn recently announced that a RTP^{TM} plant will be built in the Prince George area of British Columbia with Northwood Pulp Timber Ltd. to convert bark residues to both a liquid bio-oil fuel and a natural resin to be used as a replacement for phenol or phenol formaldehyde in wood composite adhesive formulations. Pyrovac Institut is installing a plant in the St. Jonquiere region of Quebec to convert bark residues from forest operations in the area to bio-oil.

A research project is starting up with Kemestrie and Tembec's Chemicals Division to investigate fractionation methods that will result in the removal and recovery of extractives from bark rich residues. The work will identify marketable co-products that can be isolated from the extractives and address the use of the remaining biomass for subsequent fermentation or pyrolysis processing.

In evaluating further feedstock availability, agricultural crops and residues continue to represent a considerable potential. Feedstocks such as grasses and animal wastes are being examined by Ensyn Technologies and Resource Transforms Intl. to determine if pyrolysis could be part of an integrated biomass refining concept to produce a number of value added products, including energy, thereby increasing the overall commercial viability of biomass systems. Another problem associated with agricultural residues is the materials handling costs associated with bringing the biomass into a processing facility and an overall program priority is to examine systems, ie, collection, compaction, that will reduce the input feedstock costs.

Industrial biomass wastes represent another large source of biomass feedstocks that could provide economic opportunity, especially if the material has limited reuse, recycling or disposal options. An example of this is creosote treated railway ties. They continue to be used by railroads, combustion and landfilling are no longer considered as viable disposal methods and there is no alternate recycling program available. Stockpiling of these ties are costly and could pose a number of environmental concerns. As a result of this need to dispose of this ties, work is underway to evaluate wood treated with creosote to determine if they can be converted by pyrolysis to useful products. Ensyn Technologies and Resource Transforms Intl.(RTI) have also successfully processed a number of cellulosic packaging waste streams - corrugated, bleached and waxed cardboard to determine they can be converted to bio-oil with good liquid yields.

2. Process Development and Optimization of Thermochemical Conversion Processes

As thermochemical processes progress to commercialization, new technical problems that were not apparent previously concerning various aspects of the processes need to be addressed. Improved efficiencies of process components such as filtration methods or char separation systems are being proposed based on experience derived experimental pyrolysis runs. Current research projects are examining the technical viability of these methods as means of improving the efficiencies of the fast pyrolysis systems.

RTI Ltd. has recently developed a new fluidized bed pyrolyzer based on some concepts arising from a recently completed contract with CETC. Some principal features of this design include: blown through mode of char removal; bed temperatures between 360-490°C; residence times that can be greater than 2 seconds; indirect heating; deep fluidized bed with a height to width ratio greater than one; a mass ratio of recirculated non-oxidizing gas to biomass that is less than 2; biomass particles that are less than 3mm; and char that is thermally gasified in situ.

In another project related to health and safety issues, RTI Ltd. has performed a preliminary study on measuring the biodegradability of bio-oil using respirometry methods. The project results indicate that bio-oils are biodegradable in aquatic and soil environments; the biodegradability of bio-oil is substantially higher as compared to diesel fuel; and the neutralization of the bio-oil enhances their biodegradation in water. Additional studies using this respirometric approach will be required in order to develop an acceptable standard methodology.

3. Production of Value Added Chemicals from Pyrolysis

The production of co-product, value added chemicals, will improve the overall economics of biomass pyrolysis processes. This integrated recovery of fuels and chemicals from pyrolysis oils is in the preliminary stages of development but will provide considerable impetus to the commercial implementation of pyrolysis processes if the existing technical and market barriers can be addressed.

Pyrolysis oil products in the early stages of development include: i) the development by Resource Transforms Intl. of a slow release fertilizer using pyrolysis oil as the binder/carrier; ii) the evaluation by Pyrovac Institut and Ensyn Technologies of the potential of using pyrolysis oil to produce a 'green resin' to replace phenol formaldehyde resins currently used in the production of waferboard, and; iii) the production of calcium salts by Dynamotive Corp. which when injected into coal fired burners may provide an effective means of reducing SOx and NOx emissions.

Various techniques are also being examined for the fractionation, isolation and recovery of pyrolysis oil components including pyrolytic lignin, levoglucosan and aldehydes. Lignin for example could be depolymerized to oxyaromatic monomers that could be upgraded to a variety of end products, ie, oxycyclic compounds, hydroxylated aromatics and Kemestrie Inc. is performing a feasibility study to evaluate this approach.

Another research focus in this area has been to examine the upgrading of the char produced from fast pyrolysis. A series of devolitization and activation test runs and pelletizing/briquetting evaluations have been performed by pyrolysis industry groups to determine the potential commercial production of activated charcoal from the pyrolytic char and initial results look promising. In another char utilization project, the University of Saskatchewan is examining the characterization and steam gasification of high ash content pyrolysis chars. Preliminary work has found that the conversion (only of the combustible material, not counting the ash) ranges from 59% wt. For a Danish wheat straw sample to 93% for rice straw. The conversion appears to be a function of the source of the char (the type of feed material) and its history (residence time in the reactor and temperature) rather than the ash content of the char.

4. Assessment of Commercial Utilization of Pyrolysis Oils for Electricity and Heat Production

Boilers

A significant barrier to the commercialization of pyrolysis technology relates to the market acceptance of a novel fuel having different characteristics from traditional fossil derived fuels. Bio-oil has been fired in combustion boilers in a number of tests in Canada, the US and Europe. These tests have demonstrated that only minor boiler retrofitting is required, and combustion is clean and self-sustaining with no adverse change in emission levels. As a result, the use of pyrolysis oils in large industrial units (those greater than 1MWe) can now considered to be commercially viable. For example, at the Manitowoc Public Utilities, Wisconsin, USA, bio-oil was co-fired at a rate of about 11 million BTU/hr. in a coal-fired stoker boiler. This represented about 5% of the fuel input, or about 1Mwe of the 20 Mwe output of the was terminated when this bio-oil surplus supply was re-directed for internal boiler use at the Red Arrow Products facility where the bio-oil was produced. It should be noted that bio-oil has been commercially fired in a 20 MBTU/h West Waste Fuel Burner at the Red Arrow facility since 1989.

The remaining objective of this segment of the program is to work with burner manufacturers and end users to increase the applications of bio-oils in the area of small boiler and burners. As part of an international assessment of the feasibility of utilizing these oils as an energy source, the program will continue to provide technical support and oil samples to a number of industry and research groups, such as Neste Oy, Coen and VTT- Energy, who have projects underway in this area. Information from these groups on oil characteristics, combustion efficiencies, emissions, etc., will be made available to the pyrolysis community and accelerate the commercial acceptance of the technology.

Diesel Engines

The use of bio oils for power generation via diesel engines showed promise in preliminary tests performed in Finland. As a result, an industrial consortium from both Canada and Finland was formed to carry out a project to demonstrate the cost effective production of bio-oils from biomass feedstocks and to develop and warrantee a commercial diesel engine that would burn these bio oils in small to medium sized electrical generation systems. The consortium members from Finland included Wartsila Diesel, one of the world's largest suppliers of diesel engines for power applications; VAPO, a company involved in the sale of power and power generation equipment; and VTT-Energy, a government research agency involved in the development of bioenergy technologies. Ensyn Technologies and NRCan were the Canadian industrial member of this consortium. This project has been successfully completed and it is expected that diesel engine manufacturers will be ready to provide performance warranties for bio-oil utilization in pyrolysis oil power production plants.

Gas Turbines

Orenda Aerospace has successfully completed a Phase 1 project to evaluate the concept of utilizing a biomass derived liquid fuel in a gas turbine, optimize the application of this concept and perform endurance testing of the gas turbine. Orenda was able to successfully operate the turbine over the full power range using 100% bio-oil. Performance tests were completed with detailed data acquisition at steady state operating points. Emission results were positive, with the bio-oil having lower levels of SO_2 and NOx relative to diesel. As a result of the findings in this phase of the project, a Phase II project is planned to perform component and fuel system durability testing and a lomg term endurance test which will allow the turbine to be guaranteed for pyrolysis oil.

Microemulsions

Bio-oils have a number of technical problems including acidity, a calorific value half that of petroleum fuels, poor ignitability and high char and ash content. One of the ways to circumvent these problems would be to use the bio-oil as a diesel supplement by dispersing 10-30% of bio-oil in diesel. However, bio-oils are highly polar, retaining about 25% water and are immiscible with diesel. If a stable bio-oil in diesel microemulsion could be formed, it is likely that a conventional power generation systems could be run without major modifications. BDP has initiated a project in collaboration with the Processing and Environmental Catalysis Group, CETC which has shown that stable, combustible microemulsions can be produced from mixtures of bio-oil/diesel ranging from 5% - 40%. A 5 litre/hr. continuous unit has been built to demonstrate economic and technical viability at a larger scale and to produce larger samples for analysis and combustion tests. As a result of this work a follow project is being planned, which will include technical co-operation with VTT - Energy and the European Commission JOULE Programme under the Canada/EU Science & Technology Agreement. The objectives of this project are to optimize the microemulsion process and unit, including improved mixing and feeding systems, examining other surfactants, etc., testing pyrolysis oils derived from other biomass feedstocks, further combustion and emissions testing and the provision of samples to various groups for testing.

5. Development of Cetane Enhancer Technology

Arbokem Inc., in collaboration with BC Chemicals, was awarded the rights to this technology by the CANMET Energy Technology Centre(CETC) in 1991. As a result of successful pilot testing of the process and a positive independent study of the potential diesel market in North America, an industrial consortium was formed to commercialize the technology using tall oil derived from the pulping of softwoods as the input feedstock. The consortium successfully completed an research program to carry out scale up testing and production of a cetane fuel product (cetane numbers vary between 65 from tall oil feedstock to 90 for animal fats), laboratory vehicle emissions tests and field testing of the biodiesel fuel. The technology is now ready for commercialization and a number of implementation strategies are now being evaluated to determine which approach to take. In the interim, the IEA Alternative Motor Fuels has a project underway - "Annex XIII. Emissions Performance of Selected Biodiesel Fuels", and cetane fuel will be provided to these tests in order to further assess the emission characteristics of this fuel.

In the cetane enhancer process, conventional hydrotreating technology is used to convert tall oil and other biomass oils to a high cetane fuel through the addition of hydrogen. In addition to the middle distillate cetane enhancer fuel, heavy and light bio-naphtha fractions are produced as co-products. As part of a follow on project to improve the commercial opportunities of this process, a contract has recently been given to Kemestrie Inc to investigate the upgrading of these products. As part of their research on another project examining MSW gasification, Kemestrie developed a highly efficient catalyst that can generate hydrogen from the synthesis gas produced in biomass gasification processes. It was felt that this catalyst could produce similar results with the heavy bio-naphtha fraction from the cetane process. In recently completed tests, Kemestrie has shown that their catalyst can convert this fraction to hydrogen and that this hydrogen is of sufficient quality and quantity to more than provide all the infeed hydrogen required for the process(5 times the amount of hydrogen needed is produced), reducing the production costs of the cetane enhancer technology. It is esimated that the production of the hydrogen required from the heavy fraction could reduce treatment costs from approximately $170/tonne to about $150/tonne for a 25,000 tonne/year tall oil processing plant

Work is continuing to develop additional value added products from the light and remaining heavy bio-naphtha fractions.

International Activities

The Biomass Thermochemical Conversion R & D Program remains committed to maintaining good research links with the international biomass pyrolysis industry and research communities. In this regard it wilI continue to be active in Annexes of the International Energy Agency - Bioenergy Agreement and will join the Pyrolysis Network for Europe(PyNE) for its next triennium period.