USING BIOMASS-BASED FUELS INCLUDING PYROLYSIS LIQUIDS FOR POWER AND CHP PRODUCTION

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ABSTRACT: The use of biomass-derived liquids (in short: bioliquids) instead of solid biomass can help overcome some of the barriers hindering a wider use of biomass in smaller-scale CHP systems. Relevant bioliquids included biodiesel, vegetable oils as well straight and upgraded pyrolysis oil. In this joint EU-Russian research project Bioliquids-CHP prime movers (engines and turbines) will be developed and modified so that these can run efficiently on bioliquids. At the same time, bioliquids will be upgraded and blended in order to facilitate their use in prime movers. Preliminary results with regard to bioliquid selection, production, and characterisation; the selection and modification of a micro gas turbine; and the development of engines and components are discussed. The research also covers NO_x emission reduction and control and an assessment of the benefits and economics of bioliquids-based CHP systems in EU and Russian markets.
Keywords: Cooperation with Russia in the field of power generation from biomass; combustion, bioliquids, engine, turbine, combined heat and power generation (CHP), cogeneration

1 BACKGROUND

1.1 The challenges of small-scale biomass CHP

The European Commission has set a target to increase the share of combined heat and power (CHP) in the European energy supply to 18% in 2010. In Russia, there is a need for small-sale power production that can serve remote communities, industrial users and commercial users. In both the EU and the Russian market small-scale (50 to 1000 kWe), direct biomass-to-electricity CHP-systems can help fill the need. However, to date the implementation of such bioenergy systems has had relatively limited success. Some of the main reasons for this lack of success include:

- Relatively high investment costs
- High running costs
- Poor reliability and availability
- Low acceptance by end-users

The factors causing these intrinsic problems are manifold, but include:

- The presence of contaminants in the biomass (mainly ash)
- The limited availability of uniform types of biomass
- The non-uniform appearance of biomass
- The low energy density in biomass (especially in terms of GJ/m^3), which requires huge volumes of biomass stocks to be stored near the power production unit and at biomass terminals

The use of biomass-derived liquids (in short: bioliquids) instead of solid biomass can help overcome the main barriers hindering a wider use of biomass in smaller-scale CHP systems. Relevant bioliquids not only include established biofuels like biodiesel and pure vegetable oils (such as sunflower oil), but also straight and upgraded pyrolysis oil.

Upgrading pyrolysis liquids to fuel for power generation and emulating fossil diesel fuel characteristics will allow to:

- Prolong the operation time of generator of diesel-electric power system
- Rise the calorific value of the fuel and thereby the generator capacity
- Simplify the development of the of engine-generating system
- Reduce the level of pollutant emissions due to completely combustion of fuel
- Reduce the requirements to reforming and DeNOx catalysts

This European-Russian research project is based on the joint political decision to strengthen economic and technological cooperation. In the energy field two topics for cooperation were chosen; on the one hand electrical transport networks and on the other hand biomass for CHP generation. The Bioliquids-CHP project was developed early 2008 in response to the FP7-Energy-2008-Russia call, "*Enhancing strategic international cooperation with Russia in the field of power generation from biomass*". It was considered to be the best proposal on the Russian and the EU part and is coordinated by BTG Biomass Technology Group (contract FP7-227303).

The Russian sister project is funded by the Federal Agency of Science and Innovation at the Ministry of Education and Science of the Russian Federation (FASI) as part of the federal programme "*R&D in priority areas of development of Russia's scientific and technological complex for 2007-2012*" (contract 02.257.11.0003). The FASI project is coordinated by Federal State Unitary Enterprise 'Central Scientific Research Automobile and Automotive Engines Institute (NAMI).

2 THE BIOLIQUIDS-CHP PROJECT

2.1 Project objectives

The Bioliquids-CHP project was set up to break down the technical barriers preventing the use of bioliquids in prime movers by following a double approach. On the one hand, the project will develop and modify engines and turbines so that these can run efficiently on bioliquids such as biodiesel, vegetable oil and pyrolysis oil. On the other hand, in the project bioliquids will be upgraded and blended in order to facilitate their use in engines and turbines. Thus, the most economic and reliable engine/turbine-bioliquids combinations will be developed in order to make the system attractive. In addition, the project will develop methods and techniques to control exhaust emissions (NO_x, CO, particulates), which will improve the environmental sustainability of the engine/turbine-bioliquids combinations. Figure 1 illustrates the project philosophy.

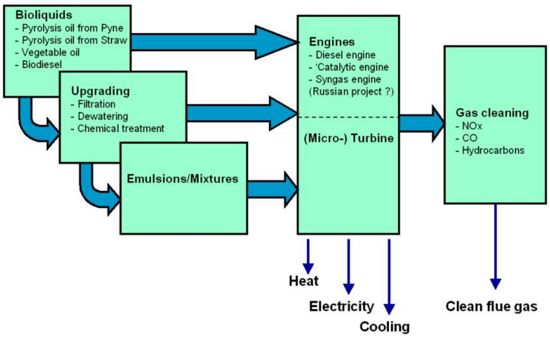

Figure 1: Bioliquids-CHP project

2.2 Research Issues

A fundamental problem of pyrolysis liquid is its rather low heat content and its high ignition temperature. Other problems derive from its corrosive properties and its relatively low repolymerisation temperature (<100°C). Its acidity will corrode conventional engine materials, and it has a low lubricating effect. For these reasons, pyrolysis liquid cannot be used in a high-speed diesel engine without modification to the injection system or the application of a separate ("dual") injection system. It is also not possible to directly use pyrolysis liquid as an additive to conventional diesel, biodiesel or straight vegetable oil since it is not miscible with these liquids. Typical characteristics of pyrolysis oil are presented in the table below.

Table I: Typical characteristics of (pine based) pyrolysis oil

Composition	$C_2H_5O_2$
Density	1150-1250 kg/m^3
Higher heating value	17-20 GJ/m^3
Water content	15-30 wt.%
Viscosity	25-1000 cP
Ash	< 0.1 wt.%
pH	2.5-3

In the past, exploratory tests have been carried out to upgrade pyrolysis liquid for application in a prime mover, e.g. by adding chemicals and mixing with other fuels by means of an advanced process of emulsification. An alternative approach is modifying the diesel engine, in order to permit the use of a higher share (or even neat) pyrolysis liquid in the emulsified mixture.

Nitrogen oxides (NO_x) are amongst the typical pollutants emitted by diesel engines. High NO_x content in the diesel exhaust gases represents an environmental problem. Therefore, research will be carried out to develop catalysts and a system for NO_x removal from diesel engine exhaust gases.

3 PRELIMINARY RESULTS

3.1 Fuel selection, production, and characterisation

Bioliquids used in the research programme include pure plant oil (also known as pure or straight vegetable oil), biodiesel (typically rapeseed or sunflower methyl ester, neat or blended with fossil diesel), and pyrolysis oil (made pinewood or wheat straw; also neat or blended with fossil diesel). Pure plant oil and biodiesel are readily available, whereas in the absence of large production plants pyrolysis oil is only produced in smaller quantities. At BTG two pyrolysis units are available for the production of pyrolysis oil: a mini plant (input capacity 2-3 kg/hr) and a pilot plant unit (input capacity 200 kg/hr; see Figure 2). The default feedstock used in the pyrolysis plant is pine; for this project pyrolysis oil will also be produced form wheat straw. Aston University (UAS) is in the process of commissioning a 5-7 kg/hr pyrolysis oil production plant (see Figure 2).

Figure 2: Pyrolysis Plants at BTG (left) and UAS (right).

BTG led the initial characterisation of bioliquids, and defined which parameters need to be analysed within the project. For pyrolysis oil in prime movers, the viscosity is an important parameter for atomization. The viscosity has been determined for fossil diesel and for different bioliquids, including pyrolysis oil batches with varying water content. In Figure 3 the viscosity of the different bioliquids is plotted as a function of temperature. In Figure 4 the effect of water on viscosity is shown.

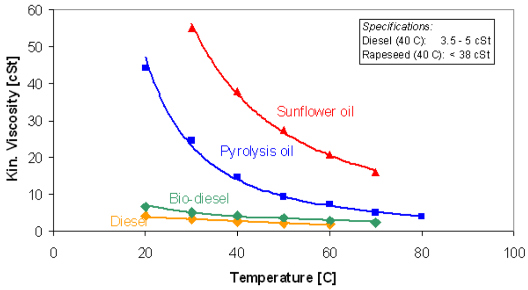

Figure 3: Viscosity of different fuels as a function of temperature

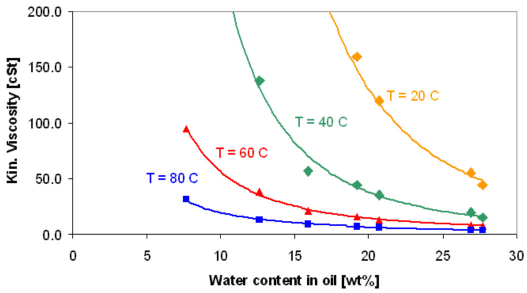

Figure 4: Kinematic viscosity in pyrolysis oil as a function of water content and temperature

For the characterisation of the properties of bioliquids (including blends and emulsions) a Round Robin is being organised for research laboratories to share experiences, practices and results. This is particularly interesting where Russian laboratories can be involved.

Further catalytic treatment of the pyrolysis oil is carried out by Boreskov Institute of Catalysis (BIC), and the resulting oil is tested at the Scientific Autotractor Institute (NAMI). Additionally blends of 5-10% biodiesel in pyrolysis oil will be prepared for testing.

Emulsions of biodiesel in pyrolysis oil may improve the ignition properties of the latter. UFL prepared a state-of-the-art literature review to serve as theoretical basis for the production of emulsions and for their testing in prime movers. Based on this review it was decided to try making emulsions of 5% biodiesel and 95% pyrolysis oil.

3.2 Prime movers: micro gas turbine

Project partner University of Florence (UFL) carried out a survey on available micro gas turbines (MGT), comparing technical characteristics towards needed modifications. The MGT architecture was carefully examined, as the possibility to implement minor modifications largely depends on the type of MGT: issues such as combustion–chamber type, injector characteristics, fuel line, and control system, were the driving factor for comparing the various options. The Garrett GTP 30-67 was finally selected and procured. This is a small-size gas turbine, single-stage centrifugal compressor, radial inward-flow turbine wheel. Main components are the fuel control unit, the fuel solenoid valve and the fuel atomizer (see Figure 5). A test bench for the MGT was designed and constructed (see Figure 6). The MGT normally runs on fossil diesel and will be modified to allow the combustion of bioliquids including plant oils, biodiesel, (upgraded) pyrolysis oils and mixtures or emulsions. Only minor modifications will be considered, and to help determine what modifications are needed UFL carried out a review of the combustion behaviour of a pyrolysis oil droplet. Furthermore UFL developed a three-dimensional Computational Fluid Dynamics (CFD) model of the combustion chamber, to study the aerodynamics of the combustor and predict the droplet's paths when the fuelling will be switched to bioliquids.

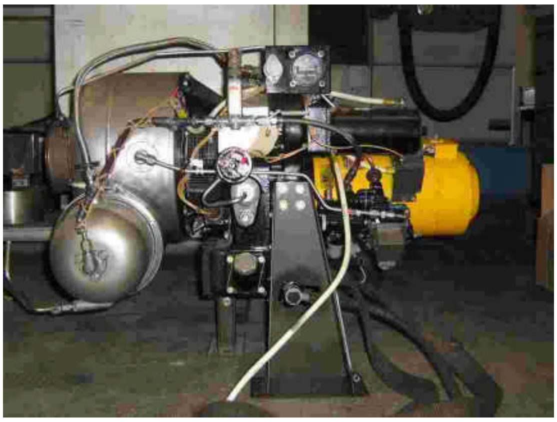

Figure 5: Micro gas turbine

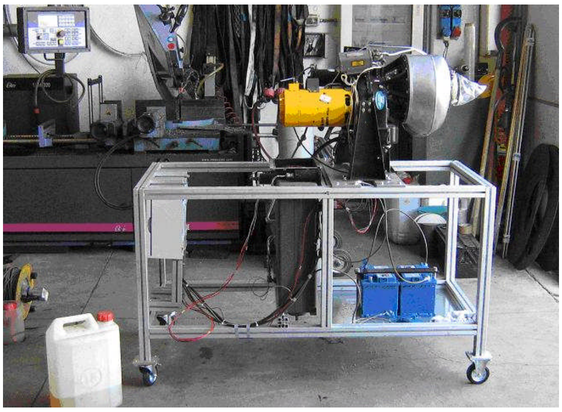

Figure 6: Micro gas turbine (grey) and alternator (yellow) mounted on a skid

3.3 Prime movers: engines and component development

With regard to engines, the main objective is to develop engine components that are tolerant towards the (upgraded) bio-liquids, including pyrolysis oils, or mixtures of bioliquids and fossil diesel. Project partner EnConTech (ECT) elaborated a relevant research strategy. The approach adopted involves the construction of experimental facilities, lab-scale experiments, engine modifications and engine testing and emission measurement. ECT, BTG and NAMI follow three parallel research tracks respectively.

ECT has initiated the development of a radically new external combustion single-piston engine, and built a thermodynamic model of the engine (new thermal cycle), a detailed mathematical model of the engine and a numerical programme for engine performance simulation. It also prepared construction drawings for the engine that is currently being built.

BTG will use a small diesel engine (5-20 kW_e) for combustion of various bio-liquids (pure and mixtures) while focusing on improving the feeding and injection system. Potential fuel injector construction materials are being tested on resistance against corrosive and abrasive wear. From four metal blends - selected in close consultation with metalworking specialists- each of these materials, simple samples (circular disc with a hole in the centre) were made, for initial screening tests of corrosion and abrasive wear.

Material resistance to corrosion is screened by keeping the test discs submerged in pyrolysis oil for some days. Weight loss is both measured and visually inspected under microscope.

Test disks were also exposed to different test liquids including water, acidic water (pH=2.8), water that contains solids (diamond particles, 2-20 µm) and pyrolysis oil at pressure varying between 0 bar and 250 bar. Injecting water that contains dissolved diamond powder clearly showed abrasive wear (see Figure 7).

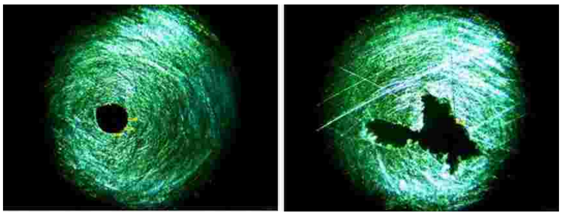

Figure 7: Preliminary tests on abrasive wear

NAMI completed laboratory tests to determine modifications required to run a diesel engine on (synthetic) biofuels, prepared technical designs and manufactured engine components requiring modification (fuel supply and gas-exchange systems), and bench tested these engine components. Figure 8 shows NAMI’s power plant.

Figure 8: NAMI power plant

3.4 NO_x emission reduction and control

BIC screened and tested catalysts for (i) synthesis gas production from diesel, biodiesel and model biofuel and (ii) selective NOx removal & emission reduction using this synthesis gas. Figure 9 shows an diagram of the SCR reactor block

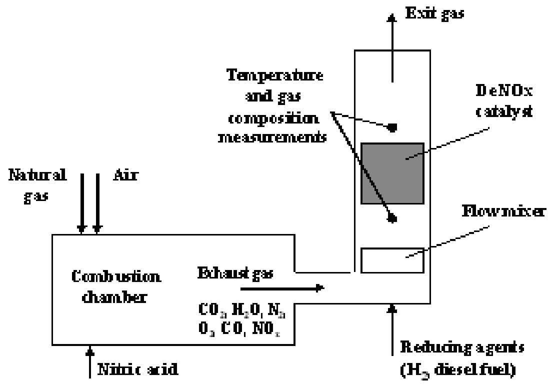

Figure 9 : Schematic diagram of nitrogen oxides SCR reactor block

The system has been tested at laboratory scale at BIC and will now be connected to the NAMI engine for integrated testing in NAMI’s engine laboratory

3.5 Techno-economic assesments and market opportunities

The last project task covers an assessment of (financial and non-financial) benefits of bioliquids-based cogeneration (CHP), based on the results of the technical research and the power demands of the target groups. Issues to be assessed include the state of art of biomass CHP markets and technologies, their techno-economic performance and market potential, sustainability considerations and implementation barriers.

For the state of the art review, carried out by UAS, information on current use of small engines and gas turbines in biomass-based CHP generation is being updated. Future work includes an assessment of the technical and environmental performance, an economic assessment of bioliquids-CHP plants in different markets, and an identification of market opportunities in Europe in general and the partner countries (Italy, The Netherlands, United Kingdom and Russia) in particular.

For the Russian market, the potential usage of bioliquids-based power plants in three target markets will be studied:

- Remote users
- Industrial users: factories, data centres, telecom networks
- Commercial and civilian users: hospitals, schools, restaurants, business centres

The assessment of the Russian market will look at the potential market volume, the potential sales volumes as a function of the sales price, and a risk identification of risks.

4 CONCLUSIONS

The research project is in its second year and the different test facilities required are in place. Production, characterization and upgrading of pyrolysis oil has started. A micro gas turbine has been installed and its characterization is ongoing. A study on the mechanical adaptations required for biofuels feeding has began, and a test bench has been engineered aimed at testing different bioliquids, including pyrolysis oil. A research strategy has been elaborated for the development of engines and components tolerant towards (upgraded) bioliquids.

After a slow start, the collaboration between European and Russian partners is starting to bear fruit. EU expertise on pyrolysis oils and other bioliquids research is combined with engine and catalysis expertise in Russia. Russian partners are strongly committed to force a breakthrough in the development of the combustion of bioliquids and especially pyrolysis oils in engines.

5 ACKNOWLEDGMENT

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In total seven partners (four from EU countries and three from Russia) collaborate. The project partners include:

- BTG Biomass Technology Group BV (Enschede, The Netherlands) / Coordinator
- EnConTech BV (Enschede, The Netherlands)
- University of Florence, CREAR (Italy)
- Boreskov Institute of Catalysis, Siberian Branch of Russian Academy of Sciences (Moscow, Russia)
- Federal State Unitary Enterprise 'Central Scientific Research Automobile and Automotive Engines Institute (Moscow, Russia)
- Aston University (Birmingham, United Kingdom)
- The Likhachev Plant (AMO ZIL) (Moscow, Russia)

Figure 10: Bioliquids-CHP team

For the latest information on the project visit the website www.bioliquids-chp.eu or contact the project coordinator.