LOW BOILER EMISSIONS WITH A COST COMPETITIVE LIQUID BIOFUEL

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ABSTRACT: The aim of the project is to verify a new liquid biofuel chain for heat production (proof of a concept), to determine fuel specifications for pyrolysis oil (PO) in different applications and to carry out long-term combustion tests. Scientific objectives include modification of PO composition for improved stability by hot gas filtration and production of emulsions and cleaner combustion by increased understanding of fundamental phenomena through single droplet experiments. Pyrolysis oil has been produced in a pilot plant, and oil has been used in boiler and laboratory tests. Laboratory facilities have been prepared and used to study fundamentals of pyrolysis liquid combustion. Emulsions from PO and light fuel oil have been produced in laboratory to be tested in combustion. An existing process development unit (PDU) has been modified to include a hot vapour filter (HVF). Both emulsion and HVF oils should have improved utilisation properties. Competitiveness of PO production in Finland has initially been assessed.
Keywords: Bio-oil, fast pyrolysis, district heating, heat generation, feasibility studies

1 OBJECTIVES

The aim of the partly EU-funded Combio-project (2003-05) is to verify a new liquid biofuel chain for heat production. Following specific scientific objectives are defined to solve major technical problems and to address the principal economic uncertainties within the proposed scheme:

- Generation of process performance data (proof of a concept) of pilot-scale pyrolysis oil (PO) production,
- Defining three classes of preliminary PO fuel specifications,
- Generation and reporting of performance and emission data of various boilers in long term tests,
- Generation of fundamental PO combustion data to assist in developing higher quality fuels with less emissions,
- Improving PO fuel quality in PDU-scale. Two main technologies are studied: emulsions and hot vapor filtration, and
- Improving economic competitiveness of the bioenergy chain.

2 INTRODUCTION

The pyrolysis process is able to produce high yields of liquid products [1] which can be shipped, stored and utilised more economically than solid fuels in the small to medium size class.

However, up to date there have been no long-term experiences with pyrolysis liquid in this size class due to lack of sufficient quantities of suitable quality fuel. To confirm the concepts proposed and to satisfy future market requirements, the project will generate data and know-how on selected technical and economic aspects related to the whole utilization chain (Figure 1).

A stage-wise approach for R&D work is adopted in this project. The first stage is to verify continuous pilot-scale production of PO (proof of a concept), followed by industrial scale use in a boiler. Initially heavy fuel oil (HFO) will be replaced. Based on earlier short-term tests, this is technically feasible, but longer time experiments are needed to generate performance and emission data and to improve handling procedures of PO. This approach makes it possible to verify and develop the whole utilization chain, which is a necessary step before further R&D on improving product quality.

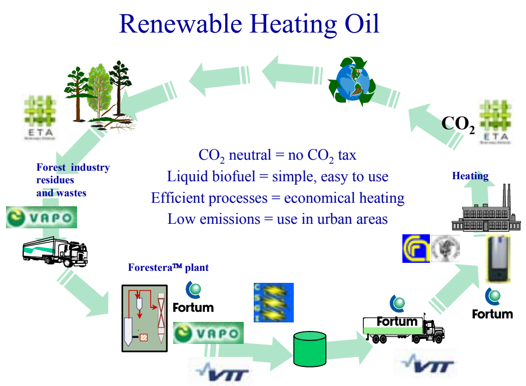

Figure 1. Project structure and the biomass utilization chain studied

Large quantities of PO are produced, long-term utilization tests are carried out, fuel specifications for PO are determined, PO quality is improved, and the whole concept from biomass to PO use is verified from market perspective.

It is envisaged that to be able to enter into heating fuel markets, the new liquid biofuel chain has: 1) To be competitive economically with chips, pellets, and light fuel oil (LFO) in heat production, and 2) To fulfill specifications required by users. The companies involved have plans of producing and using PO. The R&D organizations aim in improving the process and PO quality.

3 TASKS

3.1 Feedstock

Logging residues were selected by Vapo as the raw material in Finland for the pyrolysis pilot plant. The residues consist of the tops and branches of the spruce dominated loggings. The share of the residues is about one third of the total wood biomass. In terms of energy units it is about 100 MWh per hectare. In Italy, an assessment will be carried out by ETA of the potential amount of biomass available in the Tuscany Region for the production of pyrolysis oil. The assessment is based on the utilisation of GIS tools. On the basis of this assessment, statistical data, and previous analysis, an evaluation of the potential feedstock in the whole Italy will be performed.

3.2 Pilot plant operation

The construction of the pilot plant at the Fortum Porvoo Refinery Technology Centre took about one year. It was mechanically ready in early 2002. Investment costs were approximately 3,5 M€ (Figure 2).

Figure 2. Product storage area of the pilot plant

The pilot plant has undergone thorough and extensive commissioning during the spring of 2002 and early fall of 2002 and consisted of testing of unit operations, warranty runs of purchased equipment, verification of safety systems and plant automation. During 2003 all of the liquids for the Combio-project have been produced corresponding to more than 33 m^3, which is equivalent to about 40 tonnes. Initially most of the liquids have been produced from white wood chips as these gave the highest yields and the best quality product. In addition more than 70 cubic meters of forestry residues have been processed.

Very low levels of solids in PL were produced in the pilot-plant, typically 0.05 wt% ±0.02 wt%. The pilot was operated in continuous 3-shift mode.

3.3 Laboratory combustion experiments

A drop tube furnace (DTF) and a single droplet combustion chamber (SDCC) experimental system were developed at IM. Combustion tests were carried out in the SDCC on pure pyrolysis oil and on emulsions.

Figure 3 below shows the temperature of droplets of pure PO and emulsion having almost the same diameter. Both the curves start to increase when the heating is switched on. After the increase both the curves present a plateau around T=130°C. This corresponds to vaporization of lighter compounds, mainly water present in the PO. The plateau ends with droplets ignition [2, 3]. The ignition temperature is much higher for PO, T = 580 °C, compared to that of emulsion, T = 420 °C.

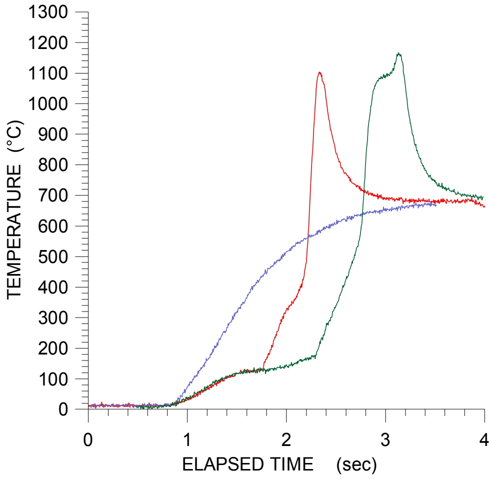

Figure 3. Temperature of PO (green on right) and emulsion (red on left) in droplet combustion test. Blue (smooth) correlation shows the reference temperature.

There is a large difference in the duration of the high temperature "bell shape" part of the curve that starts at a droplet temperature higher than 500°C. This part of the curve corresponds to the burning of cenosphere, i.e., the carbonaceous particles formed by liquid phase pyrolysis [2, 3]. Thus, the width of the bell curve corresponds to the quantity of solid carbonaceous residual that is formed. Light oils have a very low tendency to form carbonaceous residuals, less than 1% in wt. Heavy fuels like PO, however, are prone to form carbonaceous residuals [2, 3, 4]. Thus, the narrow high temperature peak, experienced by drops of emulsion, means a small formation of residual and it is in agreement with the limited content of oil in the emulsion. The large high temperature peak observed in oil drop combustion corresponds to the formation of large residual.

3.4 Use of PO in boilers

Using of PO in three size classes is developed: large boilers for district heating and industry (2-10 MW_{th}), medium size boilers for heating of larger buildings (0.2 - 1 MW_{th}), and small boilers for residential heating (20-30 kW_{th}). In large boilers, heavy fuel oil is replaced, and in medium and small scale light fuel oil is replaced. No modifications for the existing equipment are assumed in the small scale, and emulsions are considered.

Fortum Oil & Gas has been developing combustion related equipment for the past several years together with Oilon Oy of Finland. The equipment developed by Oilon is used in the current Combio-project. The main modifications to existing equipment have been in the area of the burner retention head, but also in the control systems and in the pumping.

Typical combustion tests are shown in Table 1 below. During combustion various gases were monitored on-line continuously. Very clean combustion could be obtained in the modified test boiler using the prototype burner developed in co-operation with Oilon of Finland. This can be seen from the very low carbon monoxide (CO) and unburned hydrocarbons (C_xH_y) emissions. The main emissions are derived from the non-combustible matter from the fuel namely the process bed material and the ash from the micro char. Once sand present in fuel was removed, also dust emissions were very low, and the emissions were on the same level of heating oils.

Overall more than 12 m^3 were used in over 1500 cycles in the combustion field trial. The combustion system was fully automated, and the tests proved the technical feasibility of the concept.

Table 1. Example from combustion emissions

Time	O2 ppm	CO ppm	NOx ppm	CxHy ppm
09:30	4.7	15	103	0
09:40	4.7	10	100	0
10:10	4.4	9	101	1
10:20	4.4	7	100	1
10:30	4.3	6	102	0
10:40	4.3	6	102	0
10:50	4.3	6	103	0
Average	4.4	8.4	102	~ 0

Fortum Värme carried out combustion tests in a 10 MW_{th} district heat boiler in April 2004. The tests was quite successful, and analysis of results is underway.

3.5 Production of emulsions

After the preliminary tests, CSGI has determined the formulation of Diesel oil based emulsions with both VTT and Fortum oils. Emulsions were earlier used in small diesel engines for short term tests [5, 6]. Several classes of surfactants and various emulsification methodologies were tested. Emulsions were characterized. Various PO/Diesel Oil weight ratios were investigated (30/70, 25/75,20/80, 15/85, 10/90, 5/95). Once the proper surfactant was identified, the surfactant amount was reduced to 1.0% by weight of PO. This permits the reduction of the costs of the emulsion and the environmental pollution. It was proven that stable emulsions may be produced from oils produced in large scale.

3.6 Hot vapor filtration (HVF)

HVF is developed to remove solids from product liquid, and to improve its fuel characteristics. A HVF was installed in the VTT PDU. The first tests with the filter will be carried out in April 2004.

3.7 Pyrolysis performance

Plant mass and energy balances are currently based on experimental data from PDU-scale of operation. Therefore they will need to be verified in larger scale. Two case studies will eventually be presented: a Finnish case, where PO is used in boilers as such, and an Italian case, where PO emulsion is used in small boilers.

The critical yield data, which has been employed in estimating the industrial plant performance, is given in Figure 4 below [7]. Yields from four distinct wood fuels are shown: pine (corresponding to stem soft wood), hardwood, and two different forest residue qualities. These differ mainly in the storage time applied, where "brown" refers to a fuel which has been stored about 6 to 12 months in the forest before use. For this case study, green forest residues have been selected as fuel.

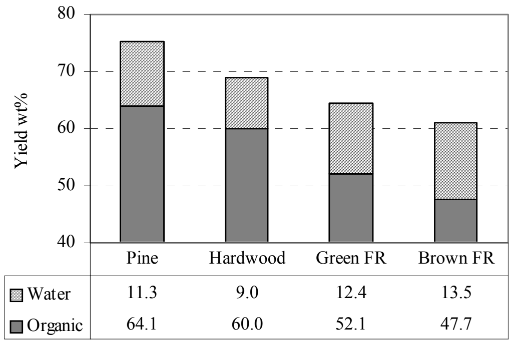

Figure 4. Liquid yields for different wood fuels, FR = forestry residues.

A summary of various investment cost estimates are compared in Figure 5. These estimates are from several independent sources. The specific investment costs shown are calculated based on product liquid chemical energy (mass flow kg/s * product LHV MJ/kg). All the estimates are corrected with the Chemical Engineering Plant Cost Index (CEPI) to 2003 US dollars. Dollars are employed because all the earlier estimates were done using this currency. No other corrections have been made to the original numbers. It is seen that the general correlation is as expected. However, from about 40 to 60 MW_{th} the correlation is not acceptable. It is probable that different specifications used in assessments explain much of the variation in this range. Very little industrial data is available to verify the published data.

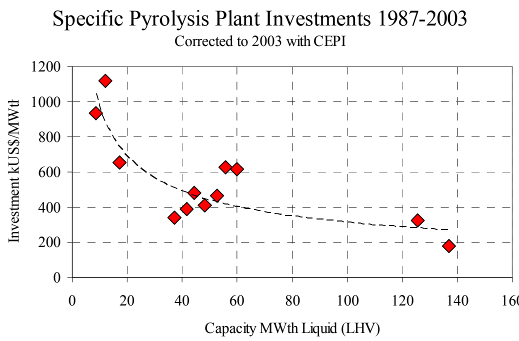

Figure 5. Pyrolysis plant investments

In the Finnish case study, an integrated production facility is selected. Pyrolysis plant is integrated to an existing combined heat & power (CHP) power plant. The power plant is based on fluidized-bed boiler. In principle power plant main fuel could be either bio- or fossil fuel.

Consumer prices during the past 5 years for heavy and light fuel oil have varied between 6 and 12 €/GJ in Finland. Using 8 €/GJ as a value for the liquid biofuel, an internal rate of return of 10 % is calculated (pre-tax). IRR as a function of product price is presented in Figure 6. It is seen that IRR is especially sensitive to product sales price. IRR is also quite sensitive to organic yield and to a lesser extent to plant investment cost.

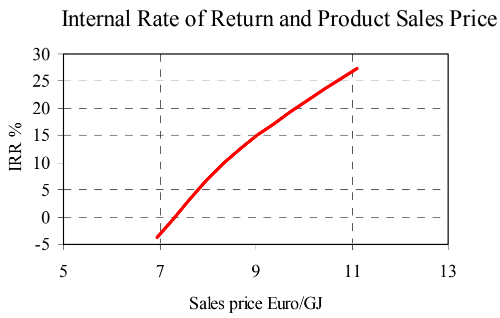

Figure 6. Internal rate of return

4 SUMMARY

Total of about 40 tonnes of pyrolysis oil has been produced at a pilot facility for combustion tests and other uses. Most of the oil was combusted in a district heat boiler. Additionally combustion tests in a medium scale boiler were carried out too. Emissions from combustion were very low, practically as low as with mineral oils. However, handling of pyrolysis oil is relatively expensive due to a low pH, and other fuel characteristics should be improved too. Two techniques are studied: preparation of emulsions from fuel oils and PO, and hot vapor filtration. Both of the new technologies are currently at laboratory or process development unit-scale. There are two means of introducing PO to renewable fuel markets: either improve PO fuel quality in such a manner that it can replace light fuel oil, or reduce PO costs so that PO will be able to compete with heavy fuel oil.

Project www-pages are available at http://www.combio-project.com/.

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