DEVELOPMENT OF A LOW EMISSION BIOFUEL CHAIN FOR HEAT BOILERS

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ABSTRACT: A biofuel chain for the production of heat has been assessed. It has been shown that high quality liquid biofuel can be produced from industrial wood fuel qualities. Emissions when firing this liquid biofuel in a 0.5 MW boiler are comparable to those of mineral oils. Performance data for several critical process steps have been provided. Development work aiming at improving fuel quality has been carried out. Basic biofuel combustion data has been generated. Integrated pyrolysis is assumed in feasibility assessments. Alternatives for improving the economics are discussed.
Keywords: Biofuel, bio-oil, pyrolysis oil, district heating, heat generation, feasibility

1 OBJECTIVES

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

- Improving **economic competitiveness** of the bioenergy chain being developed through
- Generation of process **performance data** of pilot-scale pyrolysis oil (PO) production,
- 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 vapour filtration, and
- Defining three classes of preliminary PO **fuel specifications**.

During the course of the project, two of the industrial partners (Neste and Vapo) decided to stop the development work on the concept. The principal reasons were:

- Increase of the feedstock (wood) price in the Finnish market,
- Cost of transportation of PO was estimated to be higher than initially assessed,
- Standard fuel pumps employed in small boilers did not endure in the required service.

It thus became necessary:

- To identify alternative feedstock for the proposed concept, and
- To identify alternative pumps for the required medium- and small-scale boiler service and test them.

2 INTRODUCTION

The pyrolysis process is able to produce high yields of liquid products, which can be utilised with less emission than solid fuels even in urban areas in the small to medium size class. However, there had been no long-term experiences with pyrolysis liquid use in these size classes before this project.

To confirm the concepts proposed and to satisfy future market requirements, the project has generated data and know-how on selected technical and economic aspects related to the whole utilisation chain (Fig. 1).

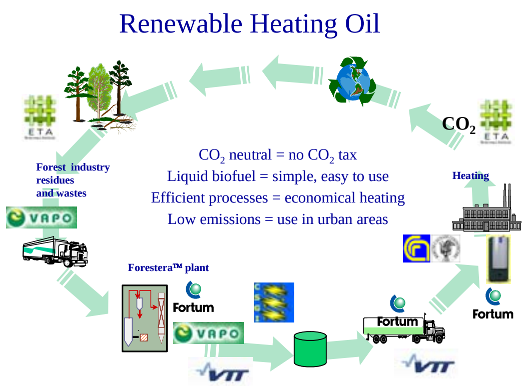

Figure 1: Project structure and the biomass utilisation chain studied

Large quantities of PO have been produced, and long-term utilisation tests have been carried out to provide performance data for future assessments.

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 fulfil specifications required by users.

Usage 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 (LFO) is replaced. In small scale it is assumed that no modifications for the existing equipment are needed when using emulsions of PO and LFO.

3 RESULTS

3.1 Feedstock

Initially, logging residues were selected as the raw material in Finland for the pyrolysis pilot plant. The residues consist of the tops and branches of the spruce dominated loggings. Market price for these residues was increased recently from about 8 to above 12 e/MWh (Fig. 2). Occasionally, up to 20 €/MWh has been paid of wood fuels in spot markets this year in Finland – largely due to the CO_2-emission trading.

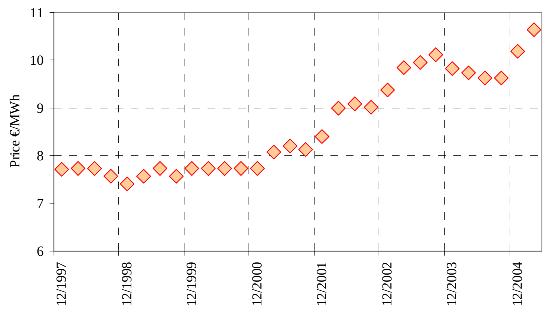

Figure 2: Consumer price of wood fuel in Finland for heat production 1998-2005 (VAT not included).

In Italy, an assessment was carried out by ETA about the potential amount of biomass available in the Tuscany Region for the production of pyrolysis oil. The theoretical potential of biomass residues available for pyrolysis plants was estimated to be around 1.4 million tonnes a year corresponding to about 5 TWh/a.

3.2 Pilot plant operation

Fortum Oil & Gas (now Neste Oil) operated a pilot plant (Figure 3) for the production of PO in 2002–2003 in Porvoo, Finland.

Figure 3: Product storage area of the pilot plant

During this time about 40 tonnes of high quality PO was produced to be used in boilers and other tests within this project. The solids content during production varied from 0.15 to 0.25 weight percent, which was further reduced to below 0.05%. The water content varied from 23 to 25%. The measured PO liquid yield was 65 $\pm$ 2 weight percent liquids. The value somewhat lower than expected is most probably due to the slightly higher feedstock particle size distribution than that in smaller plants, where liquid yields above 70 wt% have been reported for similar feeds.

3.3 Use of PO in boilers

Fortum Oil & Gas developed the combustion equipment outside the EU project together with Oilon Oy of Finland.

Field trials were carried out in a heating oil boiler equipped with a prototype burner at customer's facilities in Saarijärvi, Finland. A total of more than 12 m^3 of PO was combusted and the boiler ran more than 1500 heating cycles. Within the COMBIO project, approximately 4 m^3 was combusted.

The system was totally automated and operated on the basis of a thermostat as is normal for boilers of this type. The start up and shut down was with heating oil.

The emissions from the prototype burner in the boiler were very low, approaching those of a heating oil boiler (Table I). The emissions are generally much lower than when solid wood is used in similar scale.

Results from these tests indicated the need for reduced solids content in the liquid. After liquid solid content was reduced to less than 0.05 weight percent, the nozzles showed no signs of erosion.

Table I: Emissions in medium-size boilers

Boiler size MW	HFO 1 MW	LFO 500 kW	PO 300 kW
Flue gas O2 %	4	4	4
CO (mg/MJ)	15	10	15
NOx (mg/MJ)	100–150	30	30–100[1)]
Tar (mg/MJ)	0	0	~0[2)]
PAH (mg/MJ)	1	0	8[3)]

[1)] NO_X comes from biomass N

[2)] Method used SP-1686. Difference between measured value and background below detection limit.

[3)] Method used SP-1686, Analysis EPA 610

Fortum Värme carried out combustion tests in a 10 MW_{th} boiler at a district heating plant in Stockholm. PO has a low heating value and support fuel was needed. Tall pitch oil or heavy fuel oil are typical support fuels. The boiler is equipped with a rotating cup burner. During the two days, the boiler was operating with PO approximately six hours and the total consumption of PO was about 4 m^3. Emission measurements were carried out, and some results are shown in Table II below. Dust content in flue gas was higher than acceptable. The conclusions from the test were:

- For PO firing to be economic, it must be used without any auxiliary fuel,
- Either the heating value has to be increased, or radiating surface has to be installed in the boiler.

Table II: Emissions in a larger-size boiler

	PO
Flue gas O2 %	4.5
CO (mg/MJ)	10
NOx (mg/MJ)	62
Dust (mg/MJ)	68

Durability of cheap oil pumps was a problem when PO was used. CSGI has recently carried out pump tests, and rotary vane pump appears to have promising features. So far it has been tested continuously 22 days without damage to the pump components.

In addition, spray of emulsions in typical small scale boiler injectors is under investigation. A correlation model has been developed, which will be experimentally validated in a subsequent test campaign. This work is reported separately in this conference [1].

Small-scale boiler tests will be initiated once a reliable pump is established.

3.4 Production of emulsions

After laboratory-scale development, CSGI has designed and built a continuous emulsification unit, which was shipped to VTT to be used in production of PO-LFO emulsion from fresh PO. One run has been carried out so far, where emulsion was produced from forest residue derived PO and LFO.

3.5 Hot vapour filter (HVF)

It has been observed in the medium-scale boiler tests that removing practically all solids from PO is critical for successful operation. One alternative to remove all solids from PO is to use a barrier filter in pyrolysis vapour stream before liquid condensers. HVF operation has been developed in this project.

The first test with a HVF in 2004 was unsuccessful (Fig. 4). During a 5-hour operation, the pressure drop across the filter increased continuously. Back-pulsing of the filter did not yield the desired reduction in pressure drop.

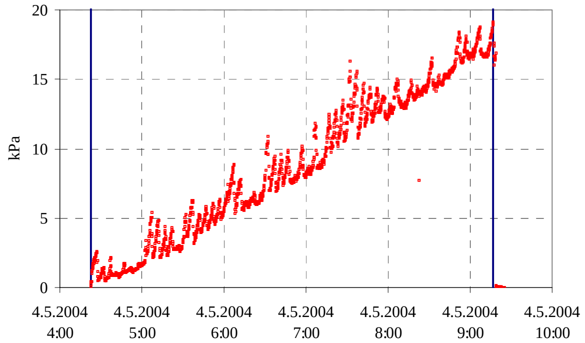

Figure 4: HVF pressure drop in test 19/04

After making modifications to the system, and testing of different operating parameters, a more successful 10 hour test was carried out recently (Fig. 5). Although the pressure drop progress is much more moderate than previously, the base line pressure drop appears still to be increasing.

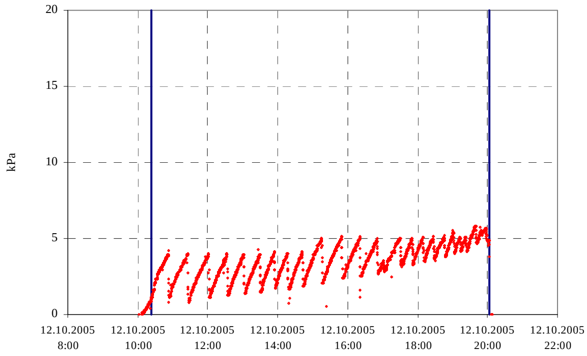

Figure 5: HVF pressure drop in test 41/05

3.6 Pyrolysis cost and performance

Pyrolysis was integrated to a combined heat and power (CHP) plant in an earlier evaluation of the project [2]. The CHP plant has a fluidized-bed boiler, where off-gases and by-product char from pyrolysis is combusted. Hot sand from the boiler is used to supply heat for pyrolysis.

As pointed out above, identification of alternative feedstocks appeared to be necessary for an economic operation in the Finnish situation. Other feedstocks have been identified, one of which is construction wood. The product liquid would be used in industrial ovens, where PO would replace HFO. Price for feed is valued at 1.1 €/GJ.

A new alternative integrated pyrolysis concept was assessed with construction wood. In this concept, PO production is integrated to district heat (DH) production. The scale of operation was reduced from previous 37 to 25 MW_{th} wood feed. The integrated facility produces 13 MWth (corresponding to about 20 000 t/a) of PO and about 6 MW of DH.

The untaxed price for heavy fuel oil has recently increased to around 23 €/GJ in Finland. An internal rate of return (IRR) as a function of product price is presented for the chain in Figure 6. It is seen that even with a low product value (that of HFO) for PO, a reasonable IRR is achieved.

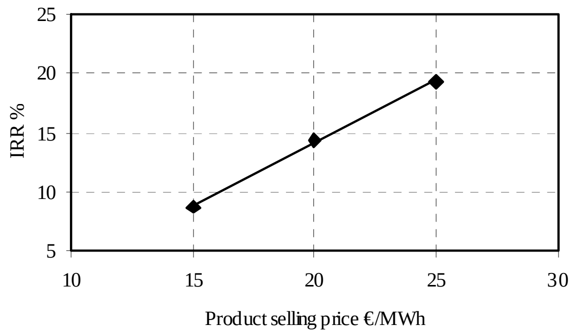

Figure 6: Internal rate of return (before taxes)

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. In addition, combustion tests in a medium-scale boiler were carried out. Emissions from combustion in medium scale were very low, practically as low as with mineral oils. However, fuel characteristics should still be improved. Two techniques are studied: preparation of emulsions from fuel oil and PO, and hot vapour filtration for pyrolysis vapours. Both of the new technologies are currently at laboratory or process development unit-scale.

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

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