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A PYROLYSIS PILOT UNIT INTEGRATED TO A CIRCULATING FLUIDIZED BED BOILER - EXPERIENCES FROM A PILOT PROJECT

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ABSTRACT

A novel integrated pyrolysis pilot plant has been built in Tampere, Finland by Metso, in co-operation with UPM, Fortum and VTT. A 7 tons of bio-oil per day (2 MW_{fuel} input) fast pyrolysis unit has been integrated with Metso's 4 MW_{th} CFB pilot boiler. Test runs of bio-oil production have been carried out during 2009-2010. More than 80 tons of bio-oil has been produced and utilization tests have been started in district heating burner applications.

INTRODUCTION

Bio-oils from plant residues are an alternative to fossil fuels. The industrial feedstocks forest residues, forest industry residues, and some agricultural residues such as straw can be used. It has been estimated that these residues offer a considerable, potential source for conversion. The use of bio-oil (bio crude, fast pyrolysis oil, flash pyrolysis oil, pyrolysis liquid) as a fuel oil in industrial kilns, boilers, diesel engines, and gas turbines has been tested. Further use in the production of chemicals and feedstock for synthesis gas production (and the further production of transportation fuels and C1-chemicals) is also being developed. Bio-oil has also been upgraded on a small scale, to transportation fuel fractions. However, at the moment bio-oil is only used commercially in the food flavoring industry (1).

Once produced, bio-oils can be shipped, stored and utilized much like conventional liquid fuels, if their specific fuel properties are taken into account. As experienced in test use over the years, bio-oil qualities have varied considerably. However, once larger scale observations are available, the specific properties of bio-oils will be better understood and proper utilization procedures developed.

Introducing a new fuel, for example bio-oil, into the markets, will not be easy. Bio-oil is different to conventional liquid fuels and many challenges remain. In view of such difficulties, a stepwise market introduction is proposed: bio-oil would first replace fuel oil in boilers, where its properties would not prove prohibitive. An example of such a chain has been presented earlier (2). Once the entire chain from biomass to fast pyrolysis plants to heat utilization has been proven, other applications may be demonstrated.

There is general awareness of the current competition for good quality biomasses for use as fuel. Biomass is especially popular in power production, with market incentives in place in many EU countries to produce green electricity. Power plants will remain large users of wood fuels, since, for example, modern fluidized-bed boilers can use several types of biomass. To compete on the markets, bio-oil

production must provide a higher payoff for the investor than the current alternatives.
The bio-oil production potential of the European pulp and paper industry has been analyzed by Sipilä et al (3). Their findings show that the European pulp and paper industry alone has the potential to build up to 50 pyrolyzers integrated with fluidized-bed boilers. In the short-term, the bio-oil market lies in fuel oil and natural gas replacement in lime kilns and boilers. The challenge is to develop and demonstrate a technical and economic concept for these applications.

Metso, UPM, and Fortum have agreed on a joint venture forming part of a more extensive development program focusing on the development of pyrolysis technology and its introduction on the market. This joint venture, which targets the promotion and advancement of research on an integrated bio-oil concept, involves expertise in the implementation of this concept across the entire value and production chain. Metso is in charge of delivering the related technology. UPM, a raw material supplier, plant operator and user of the final product, and Fortum, plant operator and user of the final product, complete the value chain. VTT (Technical Research Centre of Finland) is a research partner in the work.

INTEGRATED PYROLYSIS PILOT

Metso has built the world's first integrated pyrolysis pilot plant in Finland in co-operation with UPM, and VTT. A 7 tons of bio-oil per day (2 MW_{fuel}) fast pyrolysis unit has been integrated with Metso's 4 MW_{th} circulating fluidized bed pilot boiler, located at Metso's R&D Center in Tampere. This project is also partly funded by TEKES, the Finnish Funding Agency for Technology and Innovation. The joint venture was begun in 2007 (Fortum joined in August 2009), the pilot plant was finalized in early 2009, and hot commissioning took place during the spring and summer of 2009.

The hot sand of a fluidized bed boiler offers a considerable opportunity to integrate the pyrolysis and combustion processes. A fluidized bed boiler acts as a heat source for pyrolysis, in addition to which it can easily combust the coke and uncondensed gases produced during the pyrolysis process, into electricity and heat. In this way, high efficiency can be achieved also for pyrolyzed fuel. In addition, when integrated with a fluidized bed boiler, pyrolysis represents a cost efficient way of producing bio-oil, which can be used to replace fossil oils. Considerable savings can be achieved in operating costs and the price of the investment in both new boiler projects and retrofit solutions. Industrial, fluidized bed boilers are very large in size, totaling several hundreds of megawatts at their largest, for which reason even large pyrolyzers can be integrated. The operation of the entire integrated plant can be optimized through efficient and intelligent automation. It may be possible to produce electricity, heat and bio-oil at the same boiler plant in the future.

The process is illustrated in Figure 1. Hot solids from the pilot boiler are led into an entrained flow reactor, in which solids (sand and char) are separated from the gas stream and returned to the boiler circulation loop. The formed pyrolysis gases are condensed in a 2-stage scrubber and condenser system. The remaining non-condensable gases are recycled to the reactor as fluidization medium, while surplus

NCG's are led to the boiler through a lance. Product oil from the condensing stage is led to an intermediate storage tank.

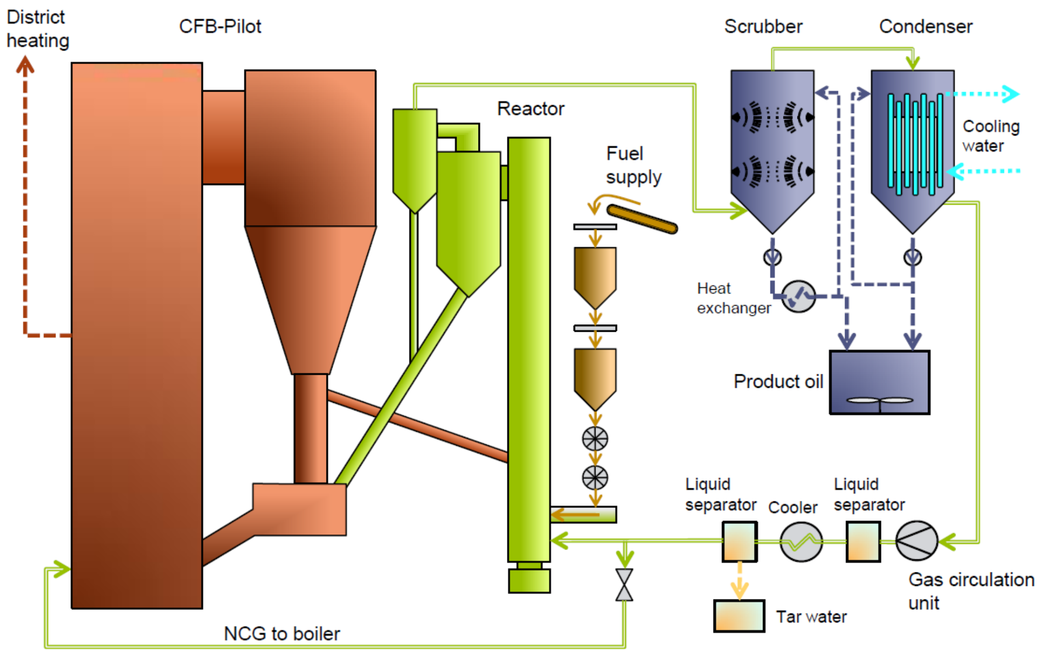

Figure 1. Pyrolysis pilot unit flowsheet

First results from bio-oil production have been encouraging. During the first season of test runs, more than 80 tons of bio-oil has been produced. The integrated concept has been verified as a reliable and flexible technology for the production of bio-oil. Compared to stand-alone pyrolysis unit with a non-optimal small boiler for combustion of pyrolysis by-products (char and pyrolysis gases), the integrated concept is easy and smooth to operate. For pyrolysis having a steady and smooth flow of input energy (i.e. boiler sand) to pyrolysis is a considerable advantage from the operator point of view.

The integration of pyrolysis and combustion processes has been successful. Pyrolysis process can be started, operated and shut down without compromising boiler process. The controllability of the integrated concept has also been good. One of the critical features of pyrolysis is the ability to maintain constant reactor temperature during operation. An example of the controllability of the integrated concept is shown in Figure 2. Since pyrolysis reactor is integrated directly to the boiler, there is an interest to find out how potential boiler temperature variations effect pyrolysis temperature. Boiler temperature disturbances are seen in Figure 2. It may be seen that pyrolysis temperature control handles rapid changes of boiler sand temperature smoothly.

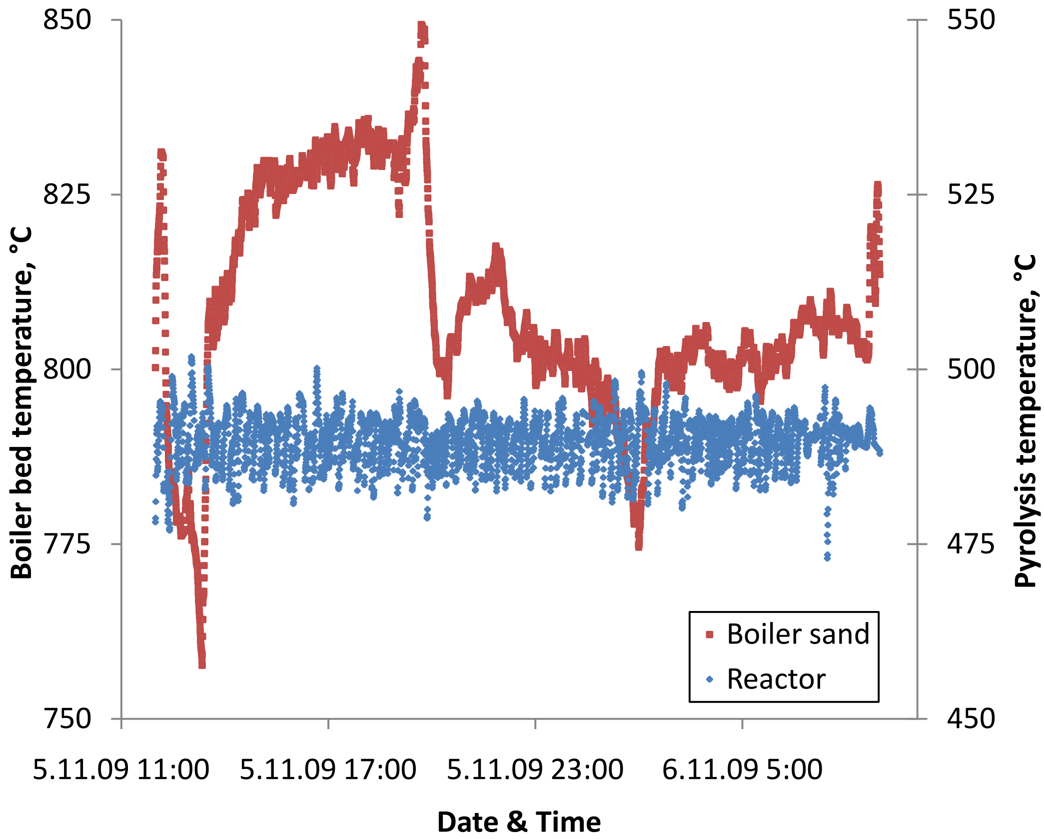

Figure 2. An example of pyrolysis reactor temperature control

Solids contents in bio-oil have been below 0.2 wt-% using pine as feedstock without any additional solids removal stage. Removal of solids from extractive-rich (forest residues) bio-oils is challenging and needs further development. A continuous centrifuge has been used successfully (Figure 3), other methods will also be developed.

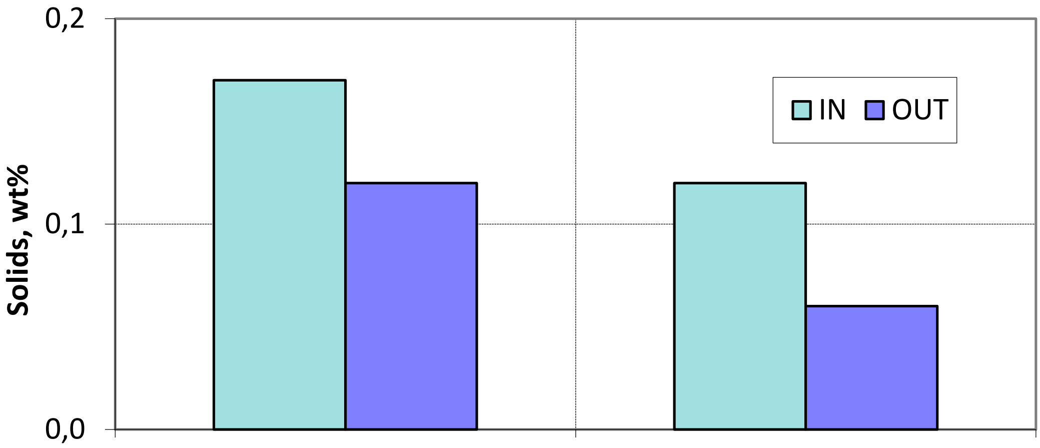

Figure 3. Solids removal by on-line centrifuge, average solids reduction 40 wt% from two measurements

QUALITY CONTROL

A quality control chain will be developed for the whole chain from biomass selection to oil use. Feedstock drying down to 8 – 10 wt-% moisture content is monitored with on-line moisture analyzer. The ground and dried feedstock is then analyzed for fuel oil properties. The amounts of volatiles and/or ash give indication on pyrolysis organic yields (Figure 4).

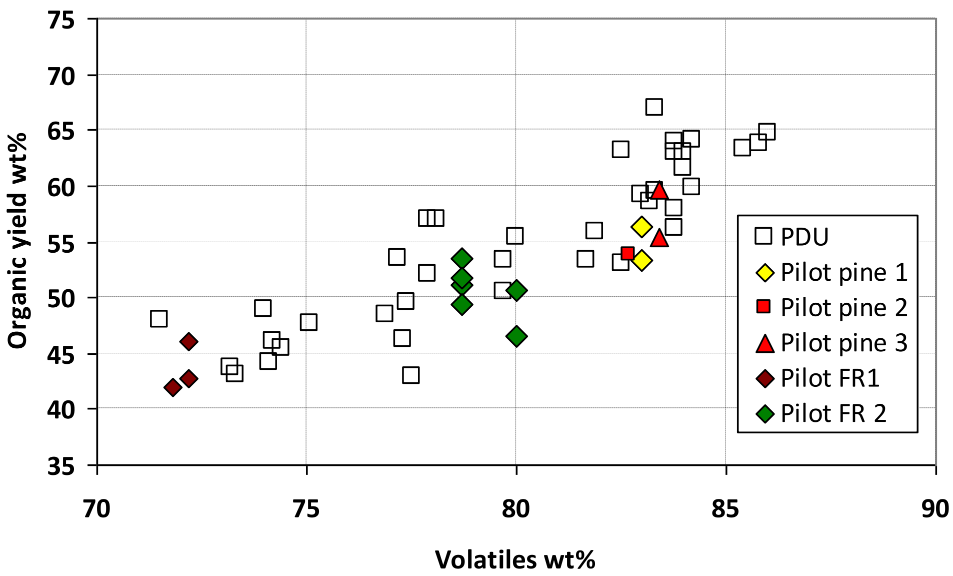

Figure 4. Yield of organic liquids in biomass pyrolysis as a function of feedstock volatile matter, wt % based on dry feed

During pyrolysis, water and solids content in the product liquid will be followed on-line. Due to the novelty of the product medium, pyrolysis oil, analysis was first restricted to laboratory analysis and automatic on-line analyzers, like on-line Karl-Fischer titration. These provide accurate results from samples, but take time and, in the long run, are expensive due to reactant consumption and labor costs. Advances were made in measurement technology for in-line measurement of bio-oil moisture, one of the key properties that are continuously monitored, when Metso's microwave-based analyzers (MCA) were successfully tested. Microwave technology is widely used in e.g. pulp & paper industry for pulp consistency measurements. The in-line analyzer provided a fast response time and consistent results (Figure 5) during the tests and is a good candidate for commercialization. In Figure 5 it can be seen that the MCA (green line) followed quite well the laboratory water content analyses (red □) and KF on-line water analyses (blue ◊). First the seed oil (older oil in condensers) was replaced which can be seen as a decrease in water content. Then the water content balanced to about 26 wt-%. Due to change of feedstock batch into a wetter one, the moisture content started to increase. Around 30 – 35 wt-% water content, inhomogeneous oil is produced and water contents vary until they balance again.

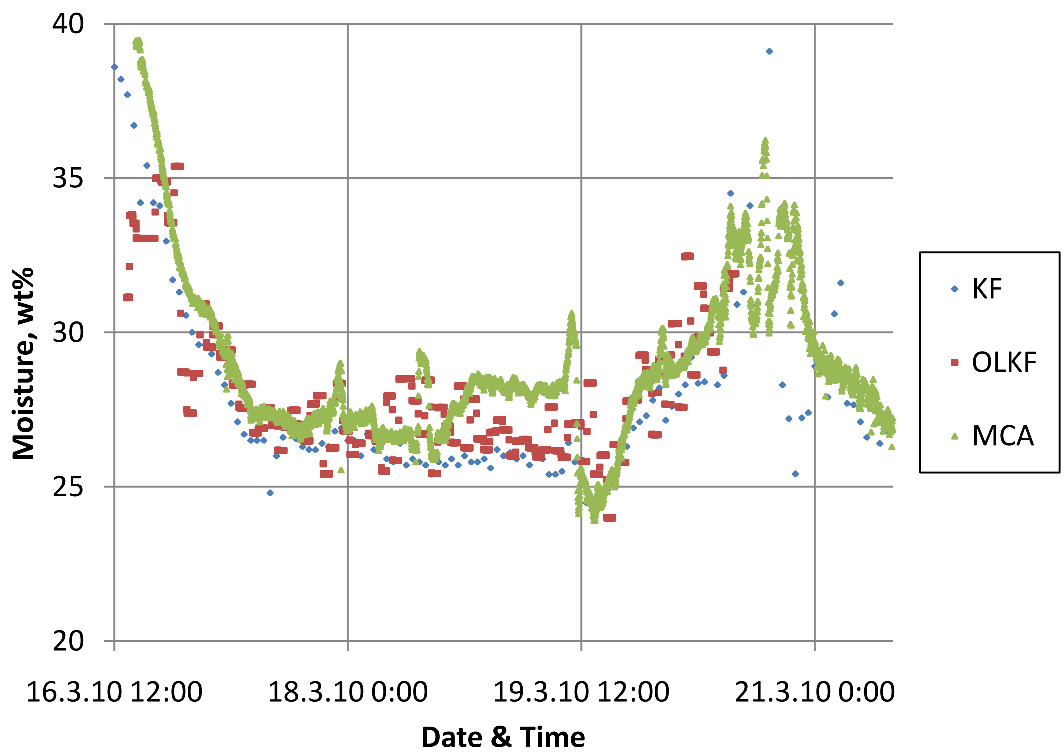

Figure 5. MCA for in-line water content, results from the pilot plant

Particle sizing will be carried out using an on-line particle measurement system developed by Pixact Ltd. Measurement will be based on the high-magnification imaging of particles flowing through the measurement cell and an on-line image analysis procedure. Furthermore, a special algorithm will be used to detect particles in the images. In addition to size measurement, other properties such as shape parameters can also be analyzed. VTT compared the results with a commercial particle counter and a good correlation was obtained. These methods yield reproducible results, but the data is qualitative and intended to register sudden changes in solids concentrations. The results also correlated well with the actual change in solids.

BIO-OIL COMBUSTION

UPM's focus is on using bio-oil as a substitute for both light and heavy fuel oil in heating and combined heat and power plants. Fortum is focusing on replacing heavy fuel oil. Their previous combustion tests in 2002 - 2003 (2) showed promising results in relation to combustion on a small scale (below 1 MW). Oilon has developed two model burners for bio-oils.

Bio-oil was combusted in Fortum's 1,5 MW district heating plant in Masala, Finland. Existing burner was changed to a new bio-oil burner, which is actually a modified heavy fuel oil burner. Total amount of bio-oil combusted in spring 2010 was about 20 tons. One main focus area was overall functionality of bio-oil receiving, storing and pumping system. Receiving system and oil tank were located outside the building. System worked well despite the outside temperature which varied from -20 °C from +10 °C during test period.

Another focus was in burner function. As a result, good reliability and satisfactory turn-down-ratio of 1:3 were gained. Flue gas emissions were close to those of heavy fuel oil - with 4 % O_2 CO emissions ranged from 0 to 10 ppm, and NOx from 300 to 400 ppm. Organic compounds were under 5 mg/m^3n and particulate emission in range of 150 - 200 mg/m^3n.

A new test run in Fortum's district heating plant will be carried out in autumn 2010. After demonstrating the replacement of heavy fuel oil use the focus of UPM will be in light fuel oil replacement.

Based on the experiences, bio-oil is technically suitable for replacing heavy fuel oil in district heating plants. Emissions (CO, NOx, particulate) were close to heavy fuel oil. No significant odors were released in the neighborhood.

SUMMARY

A novel integrated pyrolysis pilot plant has been built to Finland by Metso, in co-operation with UPM, Fortum and VTT. A 2 MW_{fuel} (7 t oil/d) fast pyrolysis unit has been integrated with Metso's 4 MW_{th} circulating fluidized bed boiler, located at Metso's R&D Center in Tampere, Finland.

Test runs of bio-oil production from forest residue chips and sawdust have been carried out during 2009-2010. More than 80 tons of bio-oil has been produced and utilization tests have been started in burner applications.

Quality control methods have been developed and hence water can be followed in-line. On-line solids measurement is under testing.

The integration of the pyrolysis and combustion processes has been successful, and the controllability of the integrated concept has been excellent.

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NOTATION

FR = Forest residue
KF = Karl-Fischer laboratory titration
OLKF = On-line Karl-Fischer analyzer
MCA = Metso in-line analyzer

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