SGAB-RP-034

EMPYRO: IMPLEMENTATION OF A COMMERCIAL SCALE FAST PYROLYSIS PLANT IN THE NETHERLANDS

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ABSTRACT: Empyro has been established with the aim to demonstrate the fast pyrolysis technology of BTG Bioliquids on a commercially relevant scale of 25 MW_{th}. Preparations already started in 2009, but the actual construction of the pyrolysis oil production plant just began early 2014. Regarding plant capacity, 5 t/hr of clean wood will be converted into about 3.2 t/hr of pyrolysis oil. Excess heat generated from the combustion of the by-products (gas and char) is used for the generation of steam. Subsequently, this steam is used to provide the heat for the biomass dryer, and to run a steam turbine for generating electricity. Finally, any excess steam is sold to AkzoNobel. Commissioning of the plant started early 2015, and first batches of oil have been produced. Gradually, the production capacity will be increased to its maximum of over 20 million liters of pyrolysis oil annually. A guaranteed long-term off-take of the pyrolysis oil is of utmost importance. Agreement has been reached with FrieslandCampina on a 12-year delivery contract for the majority of the oil (>75%). They will utilize pyrolysis oil to substitute natural gas and generate 40 t/h of 20 bar(g) process steam for use in the milk powder production. The new boiler has been installed on their site, and commissioning will take place in Q2/Q3-2015. The pyrolysis oil will replace 12 million cubic meters of natural gas, the equivalent annual consumption of 8,000 Dutch households, which saves up to 20,000 tons of CO_2 emissions per year.
Keywords: Fast Pyrolysis, demonstration, combustion, biomass

1 INTRODUCTION

Fast pyrolysis is a process in which organic materials are rapidly heated to 450 - 600 °C in absence of air. Under these conditions, organic vapours, permanent gases and charcoal are produced. The vapours are then condensed quickly to pyrolysis oil. Typically, 50-75 wt.% of the feedstock can be converted into fast pyrolysis bio-oil (FPBO). Pyrolysis enables the transformation of difficult-to-handle biomass of different nature into a clean and uniform liquid. Pyrolysis oil can be used for the production of sustainable energy and chemicals. Its energy density is four to five times higher than that of the original solid material, which offers important logistic advantages. Depending on the specific technology, the other products (charcoal and gases) are used within the process, generating the heat for the system, while the remainder can be converted to electricity, heat or steam. The pyrolysis system classifies itself as a cogeneration unit, and depending on the use and objectives in many cases as a poly-generation unit.

FPBO is presently entering the energy market to replace fossil fuel oils and natural gas. In Europe, the first commercial size pyrolysis plants are under commissioning, viz. in Joensuu (Finland) by Fortum/Valmet, and in Hengelo (Netherlands) by BTG-BTL/Empyro. The principal differencebetween these demonstration production plants is the reactor type employed: the Fortum unit is using a fluidized bed reactor, whereas the Empyro plant is based on mechanical mixing. Combined FPBO production capacity exceeds 60 million litres annually, and the FPBO will be replacing fuels in stationary applications (boilers and furnaces). In this paper the Empyro project will be further discussed.

2 FAST PYROLYSIS PROCESS

BTG-BTL's patented fast pyrolysis technology includes fast heating of biomass followed by rapid condensation of the vapors produced. BTG -one of the pioneers in pyrolysis- started their fast pyrolysis developments in the nineties with a new reactor concept in which no inert gases were required while enabling rapid mixing of biomass and hot bed material. This concept was the result of research done at the University of Twente where rapid mixing was achieved by mechanical mixing inside a rotating cone reactor. Over the years, BTG further improved and optimized the concept. The resulting unique BTG design is characterized by an intense mixing without the need of an inert carrier gas. This results in a remarkably small reactor, reduced system complexity and minimum downstream equipment size. In 2007 BTG Bioliquids BV (BTG-BTL) was established to further commercialize the technology and related IPR was transferred from BTG to BTG Bioliquids. At that time also the development of the Empyro project was initiated.

In BTG-BTL's process biomass particles at room temperature and hot sand particles are intensively mixed in the reactor resulting in rapid heating and a quick release of organic vapors. The produced vapors pass through several cyclones before entering the condenser, in which the vapours are quenched by re-circulated oil. The pyrolysis reactor is integrated in a circulating sand system composed of a riser, a fluidized bed char combustor, the pyrolysis reactor, and a down-comer. In this concept, char is burned with air to provide the heat required for the pyrolysis process. Oil is the main product; non-condensable pyrolysis gases are combusted and can be used e.g. to generate additional steam. Excess heat can be used for drying the feedstock.

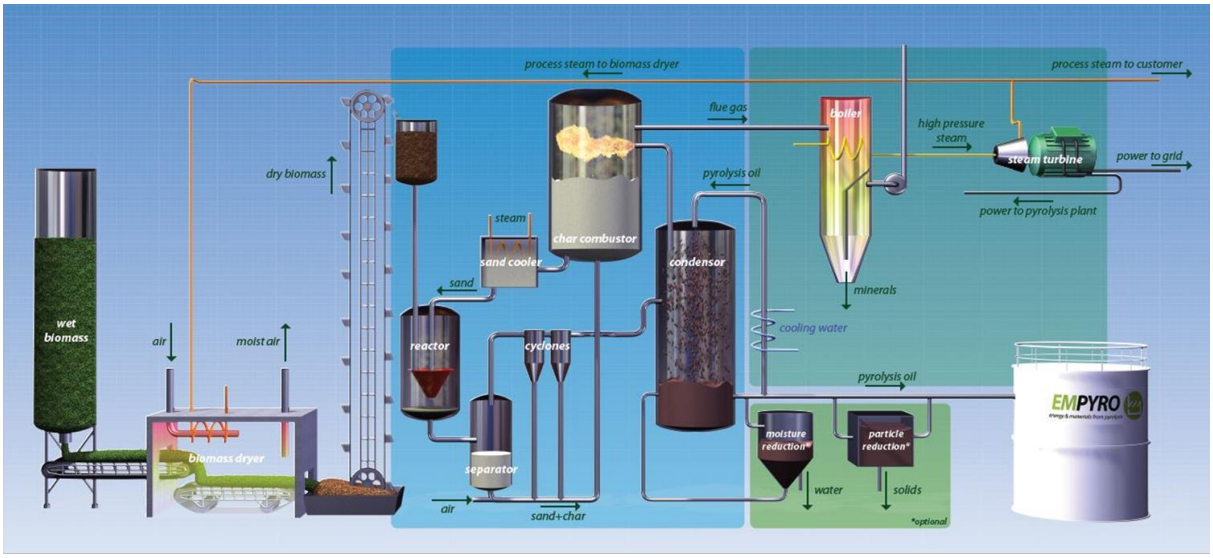

Figure 1: Simplified process flow scheme of the Empyro plant

3 EMPYRO PROJECT

Empyro is the acronym of the European project as well as the name of the company implementing the process in the Netherlands. In this section the different aspects of the realization of the project are further described.

3.1 Project objectives

The main objective of Empyro is to build and operate a 25 MW_{th} polygeneration pyrolysis plant for the production of electricity, process steam and fuel oil from woody biomass. The process steam and electricity is used locally, whereas the pyrolysis will be transported to an external customer replacing natural gas. The plant will be used by BTG Bioliquids as a reference plant to demonstrate the suitability of their pyrolysis technology as well as the application of the pyrolysis liquid on a commercial feasible scale.

The plant will provide detailed information on e.g. the pyrolysis oil production, plant availability and maintenance, the exact manpower requirements & skills, accurate capital costs, technical specifications and long-term performance. Furthermore, it will provide warranty conditions for the process outcomes, viz. operability, possible variations in steam, electricity and pyrolysis oil, its quality, the price and consistency.

3.2 Process flow diagram

A simplified process scheme of the Empyro plant is depicted in Fig. 1. Woody biomass is stored in two vessels of 200 m^3 each. From the storage vessel the biomass is fed to a dryer to achieve a moisture content of around 5 wt%, and subsequently introduced in the pyrolysis reactor at a rate of up to 5 ton/hr. In the reactor the biomass is mixed with hot sand, and pyrolysis reactions will take place. The vapor is led to a spray condenser collecting the main liquid product. In the design a pyrolysis oil yield of 65 wt% is assumed. Sand and char are sent to a fluidized bed combustor where all char is combusted to reheat sand. Char is therefore not a separate product. In the freeboard of the combustor the permanent gases from the oil condenser are added and combusted. Excess heat is is used to generate steam in the heat recovery boiler. Minerals are removed from the bottom of this unit. A steam turbine is included in the plant to generate electricity. Optionally, pyrolysis oil can be filtrated and/or partly dewatered if needed for the application of the liquid. At site a maximum of 250 m^3 can be stored.

3.3 Biomass feedstock

The Empyro plant is designed for feeding woody biomass. In the first years of operation clean woody crumbles and fines –a byproduct from pellet handling and storage in the Netherlands- will be utilized. This feedstock hardly needs any further pre-treatment. The particle size is already suitable for feeding the pyrolysis process, whereas the moisture content is just above an acceptable level of 10 - 12 wt%. A relative small dryer has been installed by Amandus Kahl to dry the feedstock to a moisture content of 5 wt%.

3.4 Permits

A number of permits are needed to allow the construction and operation of the plant in the Netherlands like a building permit, environmental permit, and water permit. Additionally, one should also take care of specific issues related to Nature2000 law. Although a large number of (supporting) documents are required, the overall permitting process went on quite smoothly. Early 2012 all permits were in place. The permitting process has not negatively influenced the overall implementation time.

3.5 Implementation

The design of the plant has been a joint effort of project partners BTG Bioliquids (pyrolysis section), HoSt (steam & turbine section) and Stork Thermeq (heat recovery boiler). Zeton has been contracted to build the plant in modules in their workshop in Enschede and do the initial functional testing. This work started in January 2014, and in October 2014 the modules were transported to site. Although the distance between Zeton's workshop and the site is only 5 km, transport was partly done by ship. Re-assembly was completed in Q4 of 2014. Early 2015 the functional testing of the plant started. Process commissioning started by the end of the 1st quarter, and the first tons of oil were produced.

3.6 Products

The Empyro plant can be considered as a polygeneration unit as it will produce three different products simultaneously. Besides the main product FPBO also process steam and electricity will be generated. The latter two products will be partly used internally to run the process. Excess process steam is delivered to the nearby site of AkzoNobel, whereas the electricity is delivered to the grid. An overall energy efficiency of 85% is achieved in this way.

Figure 2: The Empyro demonstration plant

4 PYROLYSIS OIL APPLICATION

It is of upmost importance to have a proper and long-term off-take agreement for the FPBO, and Empyro was able to conclude such contract with FrieslandCampina, a large dairy company in the Netherlands. Their site is just 30 km from the Empyro site.

4.1 Pyrolysis oil combustion

Due to the unusual properties of pyrolysis oils the application in boilers needs careful consideration. Stork Thermeq extensively tested different grades of fast pyrolysis oil in their test boiler (9 MW_{th}) in Hengelo [1]. It was demonstrated that cofiring with natural gas leads to stable combustion and low emissions.

4.2 Steam boiler

A new natural gas fired boiler was designed by Stork and constructed for FrieslandCampina suitable to co-fire pyrolysis oil. In the boiler, process steam will be produced (40 t/hr at 20 bar) for the milk powder process. The boiler can accept up to 70 wt% of pyrolysis oil (which is equal to the full capacity of Empyro), but 100% back-up of natural gas is always available guaranteeing continuous steam supply to the core processes of FrieslandCampina. Meanwhile, the boiler has been installed on-site and will be commissioned in Q2/Q3 – 2015.

4.3 Pyrolysis oil transport

The pyrolysis oil will be transported from Empyro (Hengelo) to FrieslandCampina (Borculo) by tank truck. The distance is only 30 km. An on-site small storage facility of about 100 m^3 is available.

5 FINANCING AND ECONOMICS

The total investment in the Empyro project is around 19 M€. This figure includes site preparation, engineering, permitting, equipment plant construction, steam connection (pipe bridge). The financing is based on a combination of grants, loans and equity.

For the Empyro case the oil production costs are around 300 €/ton based on a biomass feedstock price of 80 €/dry ton. On energy basis, it corresponds with a price of 18-19 €/GJ. In the Netherlands a financial support scheme (SDE^+) is effective to promote renewable heat. It covers the difference between renewable heat and the fossil alternative. In Fig. 3 an indicative cost breakdown of the oil price is given. It is clearly observed that main contributors are the biomass feedstock costs and financing costs.

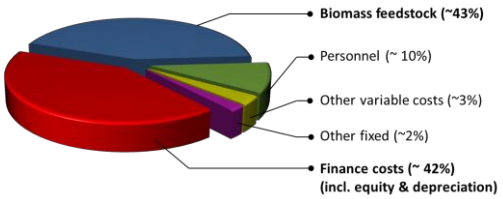

Figure 3: Indicative cost breakdown of pyrolysis oil production (Empyro case)

A reduction in oil production costs will be achieved after having installed several plants (learning curve, multiple units, reduced labour costs, etc) as well as by using cheaper biomass feedstock. The reduction in production price of the pyrolysis oil will not be related linearly with biomass feedstock price as cheaper feedstock leads typically to lower oil yields. An indication of the pyrolysis oil production cost range is shown in Fig. 4. Exact prices will depend on the actual case and specific local circumstances like e.g. possible nearby off-take of process steam.

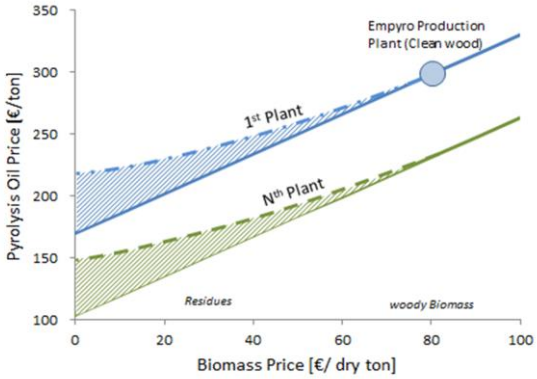

Figure 4: Pyrolysis oil production costs vs biomass feedstock price [BTG data].

6 SUSTAINABILITY & CERTIFICATION

To qualify for the SDE^+ support scheme the sustainability of the chain must proven. The European Renewable Energy Directive (RED, 2009/28/EG) requires a GHG emission reduction of at least 35% increasing to 50% in 2017 and 60% in 2018. Several

Table I: Overview calculation of GHG emission reduction (Empyro case) [2]

Item	Value	Unit
Biomass supply (360 km two-way)	2.2	g CO_2-eq/MJ_{FPBO}
Fast Pyrolysis Process	1.1	g CO_2-eq/MJ_{FPBO}
Total emission Empyro	3.3	g CO_2-eq/MJ_{FPBO}
Allocated to FPBO (energy basis)	70%	
Total emission PO-production	**2.3**	**g CO_2-eq/MJ_{FPBO}**
Transport FPBO to Borculo (60 km two-way)	0.4	g CO_2-eq/MJ_{FPBO}
FPBO combustion	0.5	g CO_2-eq/MJ_{FPBO}
Total FPBO application	**0.9**	**g CO_2-eq/MJ_{FPBO}**
Total emissions PO production & aplication	**3.1**	**g CO_2-eq/MJ_{FPBO}**
Emission per MJ of Heat (95% efficiency)	3.3	g CO_2-eq/MJ_{HEAT}
Fossil reference case	77	g CO_2-eq/MJ_{HEAT}
GHG emission reduction	**96%**	

certification schemes have been evaluated for the production process (Empyro) and the pyrolysis oil application (FrieslandCampina), and the NTA8080 scheme has been adopted for both cases [2]. This scheme requires a GHG emission reduction of at least 70% compared to the fossil reference case.

The evaluation includes the transport of biomass to the Empyro site, processing of the biomass, transport of the pyrolysis liquid to Borculo, and the use in the steam boiler. Calculations have been carried out for the different feedststocks, and the results for the current Empyro case are summarized in Table I.
An overall GHG emission reduction of 96% is achieved, which is well above the required minimum of 70%. Both Empyro and FrieslandCampina received the NTA8080 certificate.

7 REACH REGISTRATION

REACH is short for Registration, Evaluation, Authorization and restriction of Chemicals, and it was introduced in 2007 to combine various European regulations and directives. In 2018 all substances should be REACH registered. In the REACH registration a producer should indicate if a substance is toxic (and to what extent) and how this substance should be handled safely by the user. All substances produced or imported in the European Union in quantities above 1000 kg/y will be obligated for the REACH registration.

In 2013 a FPBO REACH consortium –led by Fortum- was established, with the goal of obtaining REACH registration for FPBO at the ECHA (European Chemicals Agency). FPBO is a so-called UVCB substance (substance of Unknown or Variable composition, Complex reaction products or Biological materials). Late 2013, the consortium submitted a Joint Dossier including a Substance Identity Profile (SIP) [3]. Early 2015, Empyro joint the consortium and its pyrolysis oil has been analysed in detail. All properties were within the limits given in the SIP.

8 SUMMARY

A 25 MW_{th} fast pyrolysis plant has been built in the Netherlands to demonstrate the technology and the application of the oil on a commercially relevant scale. The Empyro plant can be considered as a polygeneration plant as simultaneously oil, process steam and electricity are produced. Plant commissioning is on-going. Excess process steam is delivered to AKZONobel.

A 12-year delivery contract has been concluded with FrieslandCampina for the majority of the oil (>75%). They pyrolysis oil will replace natural gas as a fuel in their newly built steam boiler.

The production of pyrolysis oil by Empyro as well as the use of the oil by FrieslandCampina has been certified according to NTA8080.

9 REFERENCES

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[3]http://pyrowiki.pyroknown.eu/index.php?title=REACH_registration

10 ACKNOWLEDGEMENTS

Financial support from the European Commission (No TREN/FP7EN/239357/"EMPYRO"), the Ministry of Economic Affairs via the Topsector Energie TKI-BBE programme, the province of Overijssel, and the Energy Fund of Overijssel (EFO) is gratefully acknowledged.

11 LOGO SPACE