

CLEAN FUELS

for a sustainable energy economy

BIO-OIL PRODUCTION FROM BIOMASS the pyrolysis process

Colophon

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CONTENTS

1	PRINCIPLES OF PYROLYSIS TECHNOLOGY	3
2	STATE-OF-THE-ART	5
3	USE OF BIO-OIL	6
4	PLANT FLOW SHEET	7

1 PRINCIPLES OF PYROLYSIS TECHNOLOGY

Thermal liquefaction (pyrolysis) of organic matter is a long existing technology. Since the 1960s the firm Lurgi, e.g., sold a pyrolysis reactor that served to convert various fractions of oil into light liquid forms. This concerns fast pyrolysis (often referred to by the term ‘flash pyrolysis’), which is used to achieve a maximum yield of liquids. The specific adaptation of this technology to biomass feeds, so as to produce “bio-oil”, however, is rather new although the scientific literature dates back to the mid 1980s. Pyrolysis takes place under elevated temperature, and in the absence of air, and is actually a cracking process. Under pyrolysis conditions, the biomass feed material cannot combust, and the long chains of carbon, hydrogen and oxygen compounds break down into smaller molecules, in the form of gases, condensable vapours (tars and oils), and solid charcoal.

Typical products of pyrolysis, and their yields are:

- Bio-oil (maximum 60-70 m% of the dry ash free biomass feed)
- Gas (10-20 m% of the dry ash free biomass feed)
- Coal (10-20 m% of the dry ash free biomass feed).

Depending on the circumstances of the chemical reactions (pressure, temperature and residence time) different product mixes result. A typical example of the product composition of a simple atmospheric pyrolysis reaction is shown in Figure 1.¹

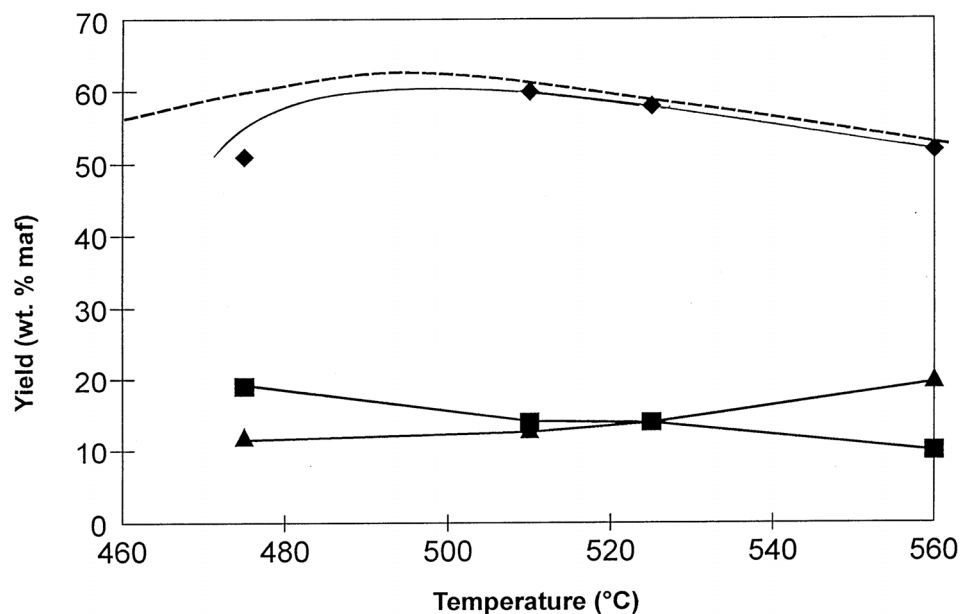


Figure 1, The typical composition of pyrolysis products, depending on process temperature (the example is for a typical type of biomass and process: bagasse from sweet sorghum, processed at atmospheric pressure). Legend: — bio-oil; — coal; • gas; ... bagasse from sugar cane. (Source: Jan Piskorz, et al., Fast pyrolysis of sweet sorghum and sweet sorghum bagasse, *Journal of Analytical and Applied Pyrolysis* 46 (1998) 15-29)

Product quality control is done by means of the indicated process parameters of pressure, temperature and residence time. This project employs atmospheric pressure and is able to manage product quality to the required fuel standards.

^{1/} Piskorz, Majerski, Radlein *et al.* (1998)

The pyrolysis process costs only few energy - in stationary operation actually only the heat needed for heating-up the biomass feed from ambient temperature to about 500 °C, the energy needed for cooling and condensing the bio-oil vapour, the chimney loss and the convective and radiative heat release of the reactor to the environment. By means of heat integration these losses can be minimised. It is obvious to use part of the by-products (charcoal and gas) to compensate for the unavoidable losses. The surplus can then be used as a fuel, e.g. to produce renewable electricity by means of a gas engine and/or a steam cycle. A pyrolysis unit according to this concept has two major products: bio-oil and renewable electricity. It can be done differently: e.g. by separating out the charcoal surplus and to make a charcoal briquette for the consumer market.

In addition there are emissions to soil and air. To soil, as ash has to be removed. The remaining ash contain all the minerals originally present in the biomass feed. If agri residues are used as a source, the minerals can be returned to the cultivation soil as a fertiliser. This is an ancient and proven practice in sugar and palm oil manufacture. All the emissions to air can comply with applicable environmental law and regulations. The unavoidable emission of CO₂ is renewable since the carbon involved is trapped in the short climate neutral carbon cycle.

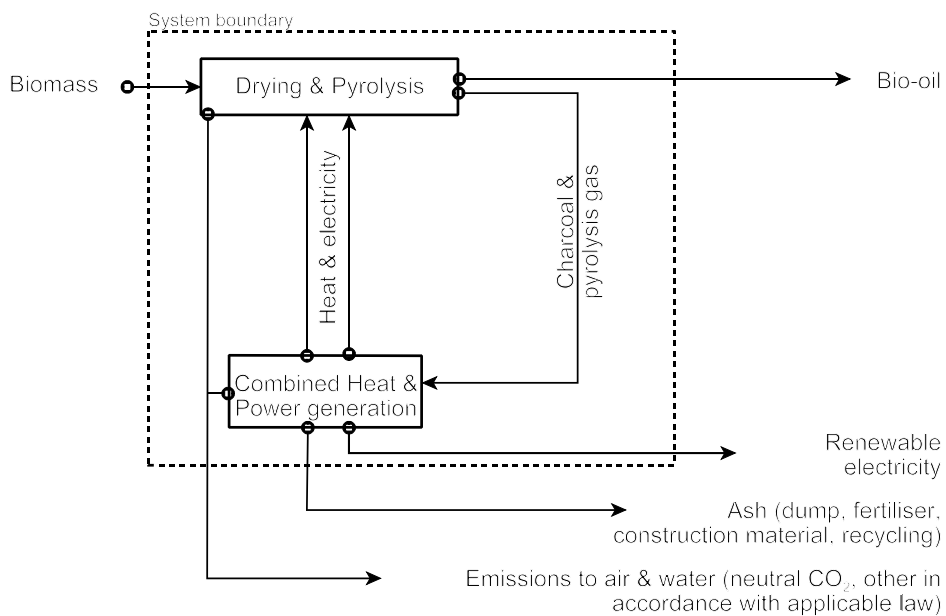


Figure 2, System boundary of the proposed pyrolysis unit.

Bio-oil is suitable as a fuel in industrial furnaces and boilers, including those of power plants. In the case of existing boilers and furnaces only minor adaptations to these units are required.

2 STATE-OF-THE-ART

Table 1 reviews the various technical concepts for biomass pyrolysis that exist today. Four principles can be distinguished. The list of developers is not exhaustive.

Table 1, Pyrolysis processes.

Principle	Reactor type	Developer
Operation with solid heat carrier (e.g. sand, ash):		
Gas fluidised bed	Stationary fluid bed	Dynamotive (CA), Wellmann (UK), Waterloo University (CA), RTI (CA)
	Circulating fluid bed	Ensyn (CA), CRES (EL), VTT (FI)
Mechanically fluidised bed (stirred bed)	Rotating cone	BTG (NL)
	Twin screw	Karlsruhe Research Centre (&Lurgi), Universiteit Twente (NL)
Operation without heat carrier:		
Vacuum pyrolysis	Active cyclone	TNO/Universiteit Twente (NL)
	Flat heating elements	Pyrovac (CA), Uni Laval (CA)
Ablative pyrolysis	Vortex reactor	NREL (USA)
	Rotating hot disk, knives, cylinders	Aston University (UK)

BTG: Biomass Technology Group; CRES: Center for Renewable Energy Sources; NREL: National Renewable Energy Laboratory; RTI: Resource Transform International; TNO: Organisatie voor toegepast natuurwetenschappelijk onderzoek; VTT: Technical Research Centre.

CFUL selected the stirred bed technology as the most promising one in terms of performance, costs and scale-up potential.

Moisture content of biomass feeds: The proper pyrolysis process needs a moisture content below 5-15 % (w). The major reason is cost control. All water that is present in the original biomass ends up in the bio-oil. This is disadvantageous for the distribution costs. The Net Calorific Value of the bio-oil decreases linearly with moisture content (w), and thus the distribution costs increase linearly, in so far as these costs are limited by mass rather than volume. The moisture content of biomass feeds is also relevant for the energy balance of the plant, because equilibrium may be lost if too much heat is required for drying the biomass to the desired level. By mechanical means, that demand a minor quantity of energy, it is possible to control moisture contents at levels that are sufficiently low for a stable plant operation. A thermal dryer, driven by waste heat from the plant, will then be used to further achieve a moisture content of 5-15% (w). The required level of mechanical dewatering is mainly a matter of economic optimisation, and the analysis differs, dependent on the type of biomass involved. In this project the moisture content of the mill-run bagasse (50% w) is acceptable prior to thermal drying to a level of below 10%. Two final observations regarding fuel moisture are: 1) If moisture content of the biomass feed is too high, the bio-oil may separate into two phases. For the application in boilers and furnaces this does not pose a problem. 2) Within wide boundaries, moisture in the bio-oil is not a very important parameter determining combustion performance.

Ash content of biomass feeds: The conversion efficiency of a pyrolysis process is negatively affected by the mineral matter that form the ash during combustion of the

charcoal. The maximum allowable level for stable operation is not known. The Australian firm ESI (Environmental Solutions for the New Millennium) with ash contents of 15% (d).

3 USE OF BIO-OIL

There is vast experience with industrial bio-oil combustion. Recently, a large-scale combustion experiment was carried out in a Dutch 350 MWe, originally gas-fuelled, power plant. Electrabel, the company owning this power plant, was satisfied with the results and signed an MOU for the further usage of bio-oil as a substitute for natural gas. The Dutch boiler manufacturer KARA performed a full-scale demonstration in a boiler of a size (5 MWth) representative to the shell type boilers found in many small industries. Bio-oil is an almost immediate substitute for heavy furnace oil (HFO) and natural gas used in industrial boilers and furnaces. Representative values of its physical and chemical properties are presented in Table 2. Due to large amounts of oxygenated components, biooil has a polar nature and does not mix easily with hydrocarbons. It contains less nitrogen, metals and sulfur than petroleum products. Water is an integral part of the single-phase chemical solution. For wood-derived flash pyrolysis oils, it is reported that phases segregate for moisture contents above about 30%-45% (w).

Table 2, Properties of furnace oil (HFO) and bio-oil (BO).

Fuel	HFO	BO
Fuel composition (wet basis)		
C	82%	47%
H	13%	5%
N	0%	0%
O	0%	29%
S	3%	0%
Mineral matter	0%	0%
Moisture	1%	20%
NCV (kJ/kg)	39600	16200

It is technically feasible to retrofit virtually all types of HFO and natural gas fuelled furnaces and boilers to the use of bio-oil. Although the calorific value of bio-oil is distinctly lower than that of HFO and natural gas, flame temperatures and the velocities and volumes of exhaust gases are close to those associated with these fossil fuels. This is because bio-oil is highly oxygenated and needs considerably less combustion air as a result. Utilisation systems, therefore, do not need adaptations in the heat exchanger and exhaust sections. However, on the burner side, bio-oil is quite different from HFO and gas. This concerns:

- The need of combustion air (smaller amounts are required).
- Bio-oil is acidic (materials of storage tanks, transportation pipes and burners should be selected in view of corrosion resistance).
- Bio-oil is less viscous than HFO (lower atomisation pressures are needed).

Depending on client preferences, dual fuel burners for HFO or gas and bio-oil, or single fuel burners for bio-oil only can be installed. Technical adaptations needed to use bio-oil in stead of HFO and/or natural gas concern:

- Installation of bio-oil storage capacity.
- Installation of pumps and piping.

- Installation of a special bio-oil burner.
- Installation/adaptation of control and safety equipment.

4 PLANT FLOW SHEET

A flowsheet of a 10 MW_{th} pyrolysis plant is presented in Figure 3. Bagasse is dried to a moisture content of 7% (w) with waste heat from the pyrolysis plant. Dried bagasse is fed into the pyrolysis reactor, where it is rapidly mixed with hot sand. Within seconds, the resulting vapours and non-condensable gases are removed from the reactor towards the bio-oil condenser. The heating of the cold bagasse and the evaporation of the available moisture results in a decrease of the sand temperature. By means of an air blown riser, the cooled sand, and the charcoal that results from the pyrolysis reaction, are recycled into a fluidised bed combustor. Here, the charcoal is combusted with additional air. In this way the sand is re-heated. A secondary fuel used in the fluidised bed combustor is the gas consisting of the non-condensable pyrolysis products, taken from the bio-oil condenser. As more energy is contained in the charcoal and pyrolysis gas than necessary to sustain the pyrolysis process, excess energy is removed from the combustor by means of a water evaporator that generates steam for a steam fed turbine placed in a closed condensing cycle. The combustor temperature, and hence the sand temperature, is controlled by the amount of fresh air allowed in the fluidised bed, and the steam flow. The flue gases resulting from the combustion of the charcoal and pyrolysis gas is used to drive the bagasse drier. They leave the plant via a cyclone system to prevent charcoal carry-over into the drier.

In the condenser, the bio-oil is condensed out of the vapours and gases. Condensation is achieved by the re-circulation of part of the bio-oil resulting from the condensation process. The recycled oil is cooled by water in a separate heat exchanger, driven by water cooled by means of a spray pond.

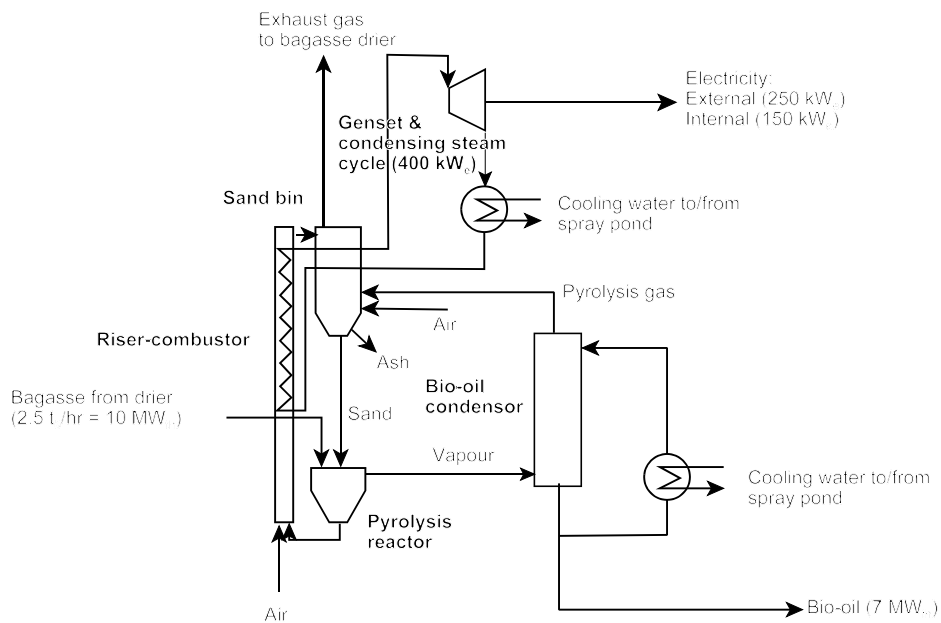


Figure 3, Simplified plant flow sheet.

Designs and cost estimates are available to CFUL for basically 2 plant sizes. One of 4 MW and one of 10 MW (on input NCV). CFUL collaborates with the University of Twente (Group for Thermo-Chemical Conversion of Biomass, Prof. Van Swaaij).

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