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Estimation of the production cost of fast pyrolysis bio-oil

J.G. Rogers*, J.G. Brammer

Bioenergy Research Group, Chemical Engineering and Applied Chemistry, Aston University, Aston Triangle, Birmingham B4 7ET, UK

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ABSTRACT

A number of papers and reports covering the techno-economic analysis of bio-oil production has been published. These have had different scopes, use different feedstocks and reflected national cost structures. This paper reviews and compares their cost estimates and the experimental results that underpin them. A comprehensive cost and performance model was produced based on consensus data from the previous studies or stated scenarios where data is not available that reflected UK costs. The model takes account sales of bio-char that is a co-product of pyrolysis and the electricity consumption of the pyrolysis plant and biomass pre-processing plants. It was concluded that it should be able to produce bio-oil in the UK from energy crops for a similar cost as distillate fuel oil. It was also found that there was little difference in the processing cost for woodchips and baled miscanthus.

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1. Introduction

The need to reduce our consumption of fossil fuel for both environmental and resource scarcity reasons has led to interest in the use of bio-oil produced by fast pyrolysis of biomass for electricity generation, heating and chemical production. Pyrolysis is the process of thermal degradation in the absence of oxygen. If biomass undergoes rapid pyrolysis it produces a mixed liquid product (bio-oil), non-condensable gasses and a high carbon char. This process has been studied for around 20 years and a few commercial plants have been constructed. There are a number of different basic designs of pyrolysis reactors and these have been reviewed elsewhere [1,2]. It was decided to concentrate on bubbling fluidised bed reactors in this paper as they are realisable at a commercial scale and have been widely studied.

A number of techno-economic studies of bio-oil production and use has been published [3–7]. They use different methodologies, plant sizes, extents of supply and feedstocks. This

paper collates data from these to develop a consensus techno-economic model of a pyrolysis plants. This is a comprehensive model which takes into account the value of the surplus char by-product, the electrical consumption of the process and the thermal requirement of the plant. The model also covers the biomass handling and pre-processing plants. A later paper will cover the use of bio-oil for electricity generation.

Although the processes considered are generic the costs relate to a UK application. All costs in this study have been converted to Pound Sterling at the exchange rates at the base date of the publication they were taken from, and inflated to 2009 values using the Chemical Engineering Plant Cost Index or other appropriate indices. The exchange rates in 2009 were £1 = \$1.567 = €1.123.

The UK does not have large areas of forest; consequently this study has concentrated on the use of energy crops. Short rotation coppiced willow and miscanthus are both grown on a limited commercial scale in England, and both are considered here.

* Corresponding author. Tel.: +44 (0)1225383057.

E-mail address: J.G.Rogers@bath.ac.uk (J.G. Rogers).

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2. Background to fast pyrolysis bio-oil

This paper is only concerned with bio-oil produced by fast pyrolysis of biomass. This process is optimised to produce the maximum liquid yield. This is an emerging technology and a range of different plant configurations has been tried at laboratory and prototype scales [1,2]. Pyrolysis plants can be split into 3 generic types: fluidised beds, mechanically mixed, and ablative. The majority of operating experience with commercial scale pre-production plants is with fluidised bed reactors; consequently this paper will concentrate on these. A basic flow diagram of such a plant is shown in Fig. 1. The heart of the system is a bubbling fluidised bed which is indirectly heated to 500 °C by exhaust gases from a combustor that burns pyrolysis gas and some of the by-product char. Milli-metre sized particles of dry biomass are fed into the fluidised bed and rapidly break down into the pyrolysis products. The pyrolysis products (fine particles of solid char, vapours, aerosols, and gasses) leave the reactor with the circulating gas. The char is removed by one or more cyclone separators. The remaining pyrolysis products are then quenched with cool bio-oil which coalesces the aerosol droplets and condenses the vapours to form bio-oil. The non-condensable gases are then blown back into the reactor as fluidising gases for the fluidised bed. The gases leave the quench at around 50 °C. It is advisable to reheat them to near the bed temperature before they enter the pyrolysis reactor to avoid local cooling of the reactor and bed. This is done in the gas reheater, a non contact heat exchanger which heat up the circulating pyrolysis gases

while cooling the exhaust gases from the pyrolysis reactor's heating jacket. The pyrolysis gases add to the mass of the circulating gas and the surplus gas is bled off to be burnt in the combustor. A biomass dryer is used to dry the biomass to an acceptable level for pyrolysis (less than 10% moisture measured on a wet basis); this is heated by the exhaust gas from the gas reheater. The dryer also has a separate char combustor for use if the biomass moisture level is above the designed value.

It has been established [1,2] that the following conditions are required to maximise the yield of good quality bio-oil:

- Rapid heating of the biomass to 500 °C
- Vapour residence times of less than 2 s, with rapid subsequent cooling and condensation
- Feed moisture content of the feed less than 10%
- Particle size of less than 2 mm.

The pyrolysis process is endothermic, with the necessary heat provided by combustion of the non-condensable gases and some of the char. Any char that is surplus can be sold as a high carbon fuel, upgraded to activated carbon for use in waste water or gas purification application, used as a chemical feedstock, or a soil improver and carbon store (bio-char).

Bio-oil is a complex mixture of oxygenated hydrocarbons, some of which are water soluble, and has the following characteristics [8]:

- Immiscible with mineral oils
- Lower heating value 13–18 MJ kg⁻¹

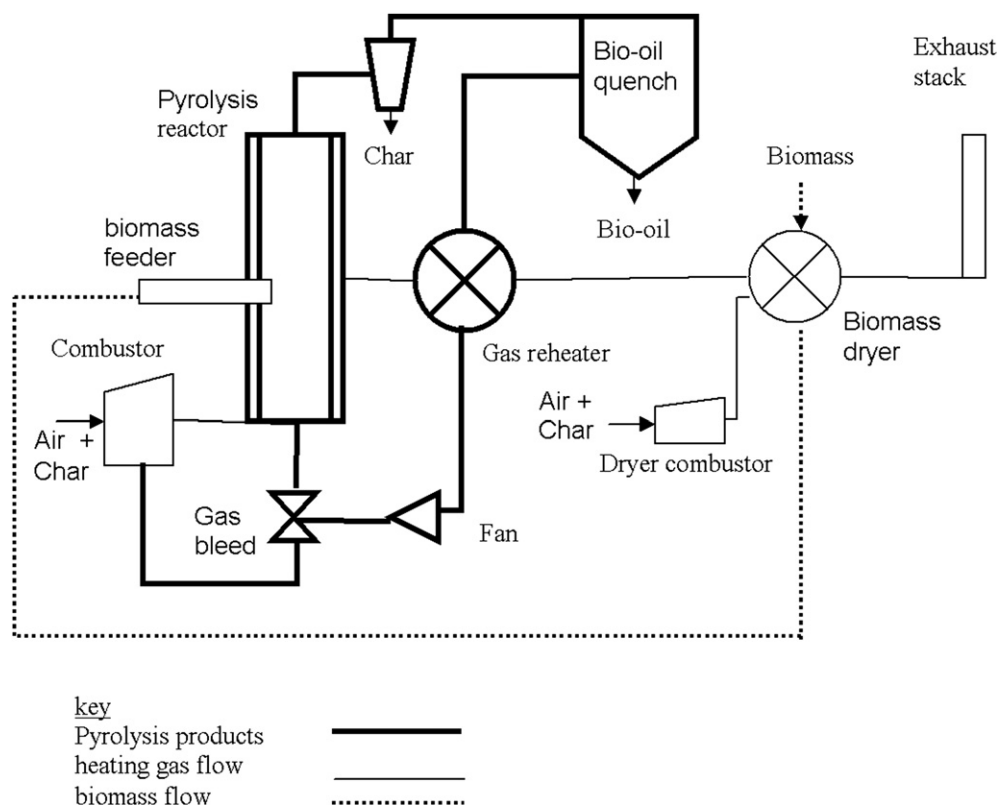


Fig. 1 – Flow model of fast pyrolysis plant.

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