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Fast pyrolysis of lignocellulosics in a twin screw mixer reactor

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ABSTRACT

A process development unit (PDU) with 10 kg/h biomass capacity was designed, built and operated for fast pyrolysis of biomass. A twin-screw type reactor, in earlier applications used for treatment of coal, oil shale, oil sand and oil refinery residues, was used. Test campaigns with a variety of biomass types were performed. The results with hard-wood, softwood, wheat straw and wheat bran are reported and discussed in this paper, verifying the suitability of the twin screw reactor along with a new product recovery procedure. Liquid pyrolysis condensate, termed bio-oil, is the main product of FP and the yields are about 65 ± 10 wt.% for wood but only about 50 ± 10 wt.% for cereal straw, which is a typical result for all fast growing types of biomass with higher ash content. These product yields and properties are similar to those found for other FP reactor types and recovery procedures.

1. Introduction

The development of fast pyrolysis (FP) of biomass was initiated more than 30 years ago in the wake of the oil price crisis in 1973 and 1980. The charming idea was the conversion of abundant woody biomass in a cheap, single and simple conversion step by FP at 500 °C into a liquid condensate termed bio-oil, with the aim to substitute a substantial part of crude oil based fuel oils and motor fuels. The work was pioneered by Scott and co-workers at the University of Waterloo in Canada [1–4], a country exhibiting large forest biomass resources. In the EU extensive research, development and demonstration work was supported by the European Commission and co-ordinated by Bridgwater since 1995 [5–7]. The actual technology status of FP is reviewed by Bridgewater in [8] and the actual state-of-the-art in active countries is reported by Meier [9]. Although some pilot plants in the MW-range exist and first commercial plants are erected, no general breakthrough of this technology can be observed. Crude bio-oil is a mix of several hundred constituents and has a poor quality regarding the direct use as a motor fuel. It is unstable and not miscible with diesel or gasoline. Quality improvements by upgrading procedures or other bio-oil applications are reviewed by Czernik and Bridgwater [10] and Xiu [11]. A multistage hydrogenation process to upgrade bio-oil to a refinery feed is reported by Venderbosch [12].

Therefore, the aim of the FP process development work at KIT is not bio-oil production for direct use as a fuel oil, but serves as a first step for a pressurized entrained flow (PEF) gasifier in a BTL (biomass to liquids) process for synthetic bio-fuel production by preparing a densified and unified liquid feed from various types of biomass [13,14,15]. A large PEF gasifier for syngas generation [16,17] is the central step of a thermo-chemical biorefinery and is followed by syngas cleaning and the catalysed production of organic platform chemicals or liquid transportation fuels, according to the concept of the bioliq process currently under development at KIT [18].

A mixture of solid biochar particles suspended in liquid bio-oil is termed bio-slurry or biosyncrude and produced by FP as an intermediate fuel with high energy density allowing for a more convenient handling, storage, and transportation compared to the original biomass. Simultaneously, a slurry is a suitable gasifier feed which can easily be pumped and atomized into a pressurized entrained flow gasification reactor [13,19]. Bio-oil contains ca. 60 ± 10% of the initial biomass energy, but combined with the pyrolysis char, the energy content in a bio-slurry can be raised to almost 90%.

Compared to the application of bio-oil in internal combustion engines, a much lower quality is sufficient for gasification. Contamination with solids and especially ash containing char particles is a main obstacle for more challenging applications. In a slagging entrained flow gasifier [25] ash is even needed to generate a molten slag layer at the inner gasifier wall to protect it from corrosion and erosion. The lower quality requirements for the gasifier feed also allow some simplifications of the FP process itself: No perfect separation of char from the condensate is needed. In this paper even a simultaneous recovery of pyrolysis char together with the pyrolysis condensate has been investigated, and the results are reported.

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Another characteristic of the FP process at KIT is the use of a special pyrolysis reactor type. The so called twin screw mixer reactor has originally been developed in Germany by Lurgi half a century ago for the FP of materials like coal, oil shale or vacuum residues of an oil refinery [20,21,22,23] and was already applied commercially. Twin screw mixer reactors operated at 600 °C with up to 1.1 m outer screw diameter and 600 m^3/h circulating heat carrier were already built [25]. The essential design characteristic is the circulation of a hot grainy heat carrier in a closed loop via the twin screw mixer reactor and a heat exchanger. The heat exchanger and the reactor are the source and the sink of heat in the closed loop. Heat carrier circulation is maintained either by a pneumatic or a mechanical heat carrier lift followed by gravity flow.

This paper describes design and operation of a FP process development unit (PDU) with a twin screw mixer reactor with 10 kg/h biomass capacity. Product yields and compositions of pyrolysis char, condensate, and gas from hardwood and softwood as well as from wheat straw and wheat bran pyrolysis are reported and discussed. Conclusions are drawn in view of a reasonable further development direction for biomass FP, as it will be conducted utilizing the 2 MW_{th} FP pilot plant also available at KIT.

2. Description of the FP process development unit

Fig. 1 shows a flow scheme of the PDU designed for 10 kg/h biomass feed capacity. The facility consists of a feeding section, a heat carrier loop for FP operated at 500 °C, a cooling section for product recovery and a final section for production and handling of bio-slurry products. These sections are described in the following in more detail.

2.1. Feeding section

A batch of up to 100 kg crushed, dry lignocellulosic biomass is kept in a closed feed storage vessel. A small characteristic biomass particle length L of less than 0.5 mm and a water and ash content both below ca.10 wt.% are desirable feed properties. Wood was fed as sawdust, whereas chopped straw was further grained in a hammer or knife mill, especially to smash the thick ca. 5 wt.% stem nodes, which present a bottleneck to rapid heating-up as required for FP. Drying is achieved by passing a stream of warm air through the well mixed feed bag prior to operation

An expensive feed flow control system with a continuous balance turned out to be rather sensitive to minor process disturbances and caused frequent process disruptions. It was finally abandoned and replaced by a calibrated simple and robust screw feeder with volumetric flow control, which supplies the FP reactor with a sufficiently constant volume flow of feed material in a range of 6–16 kg/h.

2.2. Heat carrier loop

The purpose of the heat carrier is to supply the heat for pyrolysis by quickly mixing a cold or preheated feed with a surplus of hot carrier material of ca. 550 °C. The hot heat carrier loop consisting of the FP reactor, a bucket elevator and an electric heater constitutes the technically most complex and expensive section of the facility. Other design options e.g. a pneumatic lift of 1 mm quartz or SiC sand with the hot flue gas of pyrolysis gas combustion are discussed elsewhere [24,25,26].

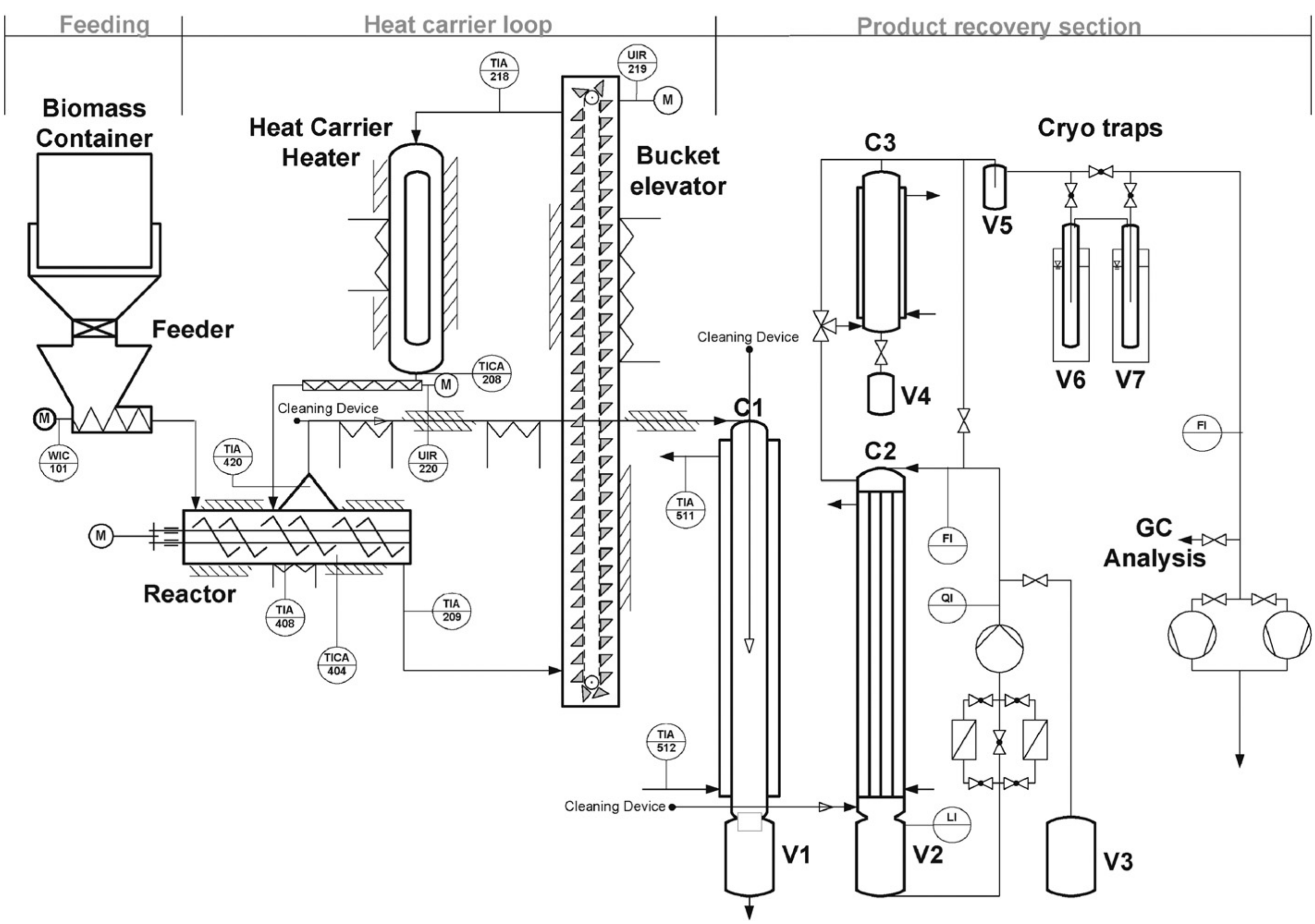

Fig. 1. Simplified flowsheet of the fast pyrolysis process development unit (PDU).