LIQUEFACTION OF BIOMASS AND ORGANIC WASTE BY INTERMITTENT FLUID BED PYROLYSIS (IFB PYROLYSIS)

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ABSTRACT

From economic and technical perspectives it is briefly reviewed how pyrolytic liquefaction is a technology for turning wastes into valuable products. Clean Fuels developed the Intermittent Fluid Bed (IFB) technology by means of which pyrolytic liquefaction becomes efficient and cost-effective. A worldwide patent application has been filed. IFB technology is characterised by a phased reactor operation: a productive phase during which the bed's heat buffering capacity is used, followed by a phase of temperature restoration. The R&D carried out into IFB pyrolysis is described, involving reactor issues such as phase duration, bed solids circulation, manners of reactor temperature restoration, and solid residues removal (charcoal, ash). A complete liquefaction plant for biomass, involving the IFB pyrolysis technology, has been designed. The plant design is compared with designs that employ alternative reactor concepts.

INTRODUCTION

What is pyrolytic liquefaction?

Pyrolytic liquefaction is a chemical conversion of the total organic matter offered to a process. It is not a physical process such as extraction, which gives fatty acids that are contained in seeds. Pyrolytic liquefaction can be applied to virtually all types of biomass including organic wastes and plastics. Very high heating rates at the reaction interface are needed,in the absence of oxygen

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(it is heating, rather than combustion). For biomass typically temperatures of 450-550 ^{o}C. Residence time of the resulting vapours inside a pyrolysis reactor is very short, in the order of 1-10 s. The time of solids conversion is usually longer, up to 30 s. Finally, the pyrolysis vapours are rapidly cooled to quench any further chemical conversion. When pyrolysing biomass, the products are liquid organic condensates (‘bio oil', bio crude', ‘pyrolysis oil'), consisting of compounds of fragmented cellulose, lignin, etc., as well as water, charcoal and combustible gases.

Good reasons for pyrolytic liquefaction

Liquefaction is done for two major reasons:
- Tradability (volume reduction, storability, pumpability, transportability) (see Table 1).
- Use efficiency (storability, pumpability, compact conversion equipment, high-pressure conversion equipment).

The economic prospects of the technology are systematically analysed by Siemons [1] in comparison with alternatives.

TABLE 1 - TRADING PROPERTIES OF BIO-FUELS AND MINERAL COAL

Fuel type	Density (kg/m^3)	Energy density (MJ/m^3)
Straw	130	1890
Wood pellets	650	11400
Charcoal (lump)	200	5800
Pyrolysis oil	1300	22400
Coal	1000	25000

REACTOR PRINCIPLES OF PYROLYTIC LIQUEFACTION

Existing reactor concepts

The specific constraints regarding heating rate of reactants, and vapour residence time are determinative for the design of suitable reactor concepts. A major principle of heat transfer to the reactant is the mixing of the reactant with heated sand. Mixing principles used are: bubbling fluid bed (BFB), circulating fluid bed (CFB), and mechanically mixing (cone, twin screw). The vapour residence time can be minimized by using a small reactor volume and/or by diluting the vapour with an inert gas. Heating of the reactor bed is done in different manners. In the case of BFB, this is usually done by means of fire tubes, or by means of heated inert gas, or by means of partial combustion in a specific zone of the BFB, or by removing cooled sand from the reactor and replacing it by externally reheated sand (see Figure 1). The latter option is also used in the case of CFB, and of the mechanically mixed reactor beds. A review of these and other principles and of those who apply them is given by Bridgewater [2], and Henrich [3]. In so far as we are aware only the alternatives of fire tubes (A in Figure 1) and of the externally heated sand loop (D in Figure 1) have been employed commercially. Specific challenges for concept A are in the heat transfer to the BFB at large scale (Czernik [5]), and, for concept D in creating the external loop of hot sand at quite elevated temperatures (400-900 ^{o}C).

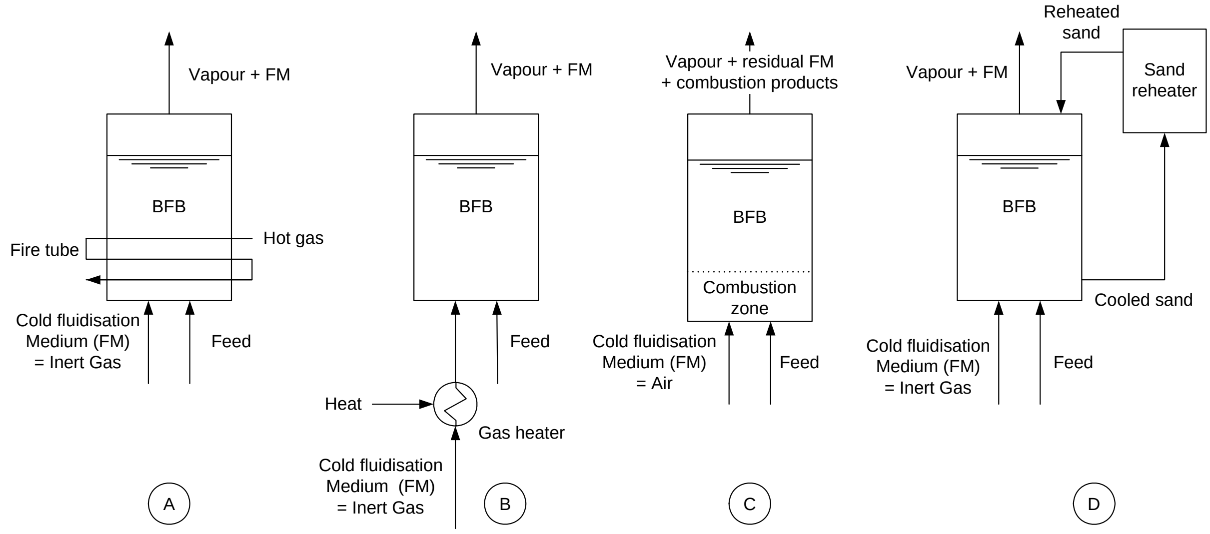

Figure 1, Reactor heating principles. The rightmost concept D of an external sand loop is also used for CFB and mechanically mixed reactors.

From our experience we confirm the view expressed by Bridgwater [4], that although the reactor is at the heart of a pyrolytic liquefaction process, it probably represents at most only about 10-15% of the total capital cost of an integrated system. Nevertheless, the selection of the reactor concept has a very large influence on the required system periphery, including the system control mechanism, its costs, and vulnerabilities. Therefore, systematic reactor engineering may result in substantially reduced costs of the overall processing plant.

An Intermittent Fluid Bed

A prevailing basic assumption in the design of the reactor concepts discussed above, is the view that the flow of reactants and products should be kept relatively constant, and that stationary conditions should be created inside the reactor. **We dropped this starting-point.** Rather, we observed that a fluidised sand bed is not only a good mixer with excellent heat transfer properties, but that **a fluidised sand bed is also a heat buffer**. And we wondered whether we could make use of this property to substantially simplify the overall system. The idea was to design a phased reactor operation, constituted by a production phase during which stored heat would be released to the reactants and the bed temperature would reduce, followed by a heating phase during which the bed temperature would be restored and energy would be accumulated. Past research of fast pyrolysis showed that the process is effective over a substantial temperature window of at least 50-80 ^{o}C. See, e.g., the research published by Piskorz [6] (Figure 3). This demonstrated that phased reactor operation should possible in principle. A schedule is presented in Figure 2. Phase switching is achieved by setting the on/off valves situated in the various material flows.

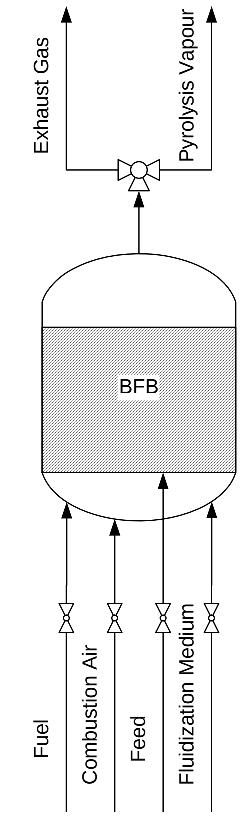

Figure 2, An IFB pyrolyser.

First estimates of dimensions and operating intervals were not very convincing of the practicality of this idea, though. For a realistic reactor size (height = 2 m, diameter = 0.7 m, ΔT = 40 °C, feed rate = 500 kg/h), we found a production interval of only 240 s. This was solved by drastically increasing the involved quantity of sand inside the BFB. A draft tube was incorporated so that the vapour residence time was limited to only 2 s (Figure 4). This gave a production interval lasting over 1800 s. For the temperature restoration phase, a fuel is combusted inside the BFB. The direct heat transfer to the bed material is very efficient, and in this manner the bed temperature can be restored during an interval of approximately 900 s. To this end many fuel types can be used. Residual charcoal of the pyrolysis process, if it is not very valuable, is a preferred fuel since it is already available from a preceding production phase, ready for use inside the reactor. However, the charcoal can be blown out of the bed, using inert gas, and another fuel for restoring the bed temperature can be used instead.

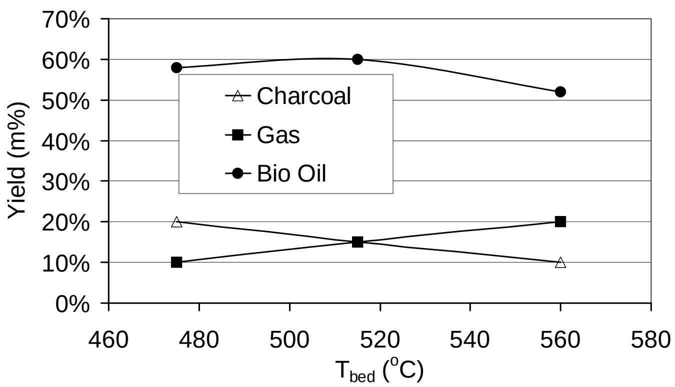

Figure 3, Yield of fast pyrolysis products (cited from Piskorz [6])

R&D carried out during 2008-2009

The research regarding the IFB pyrolysis concept carried out in 2008-2009 was focussed on the following issues.

- Phase duration (solution: draft tube, dating back to 1976)
- Temperature restoration. This involved selection of suitable fuels (charcoal, gas, biomass, other), and specifically the behaviour of charcoal as a restoration fuel (applicable air factor, ignition conditions, quantity needed).
- Bed solids flow control. This concerned pressure distribution for an internally circulating FB, and gas distributor design for modular operation. There is only few literature about this issue (LaNauze [7]).
- Separation and collection of charcoal / ash from the sand bed.

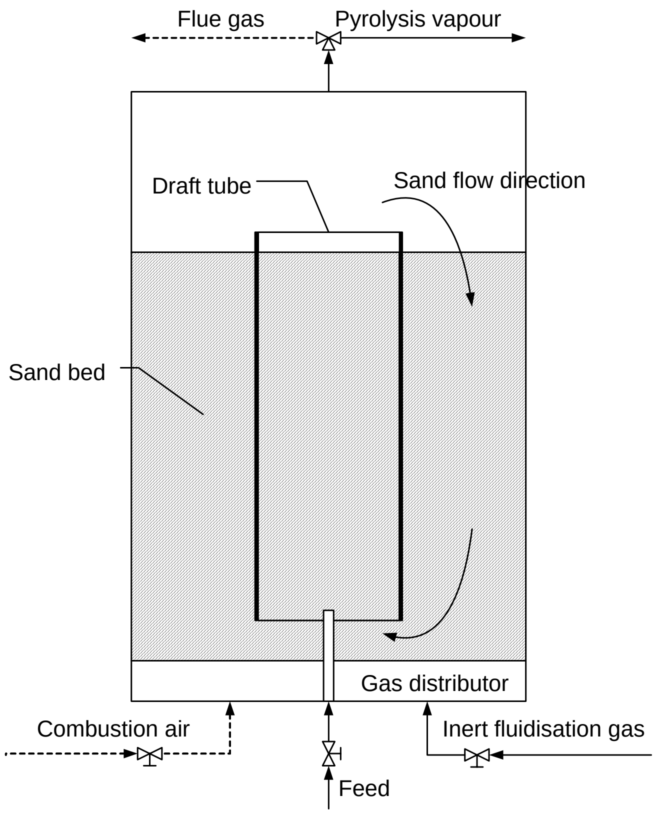

Figure 4, IFB pyrolyser with draft tube.

PLANT DESIGN AND COMPARISON WITH OTHER CONCEPTS

Taking an IFB pyrolysis reactor as the core, a complete plant for the pyrolysis of biomass was designed to the level of a detailed design. This includes P&IDs, a designbook specifying equipment dimensions, and a computer simulation model yielding mass balances, elemental balances, and energy balances for the various process components. The simulation model enables the theoretical research into the pyrolysis behaviour of a variety of biomass feed types.

In a comparison Figure 5 shows the complexities of a plant with an external sand loop and a plant employing the IFB concept. Two reactors are used in either case. For the IFB case, two reactors are operated in counter-phase, so that prior and posterior operations (feed preparation and vapour condensation) can be executed in a continuous manner. The simplifications achieved as a result of the IFB concept are evident: Complex equipment is made redundant, and the plant can be constructed on a single floor. Additional to reduced capex, there are also operational advantages: vulnerability to equipment failure and wear have been minimized, and the piping system following the reactor exit has become self-cleaning since hot oxygen containing gas is washed through during every production cycle.

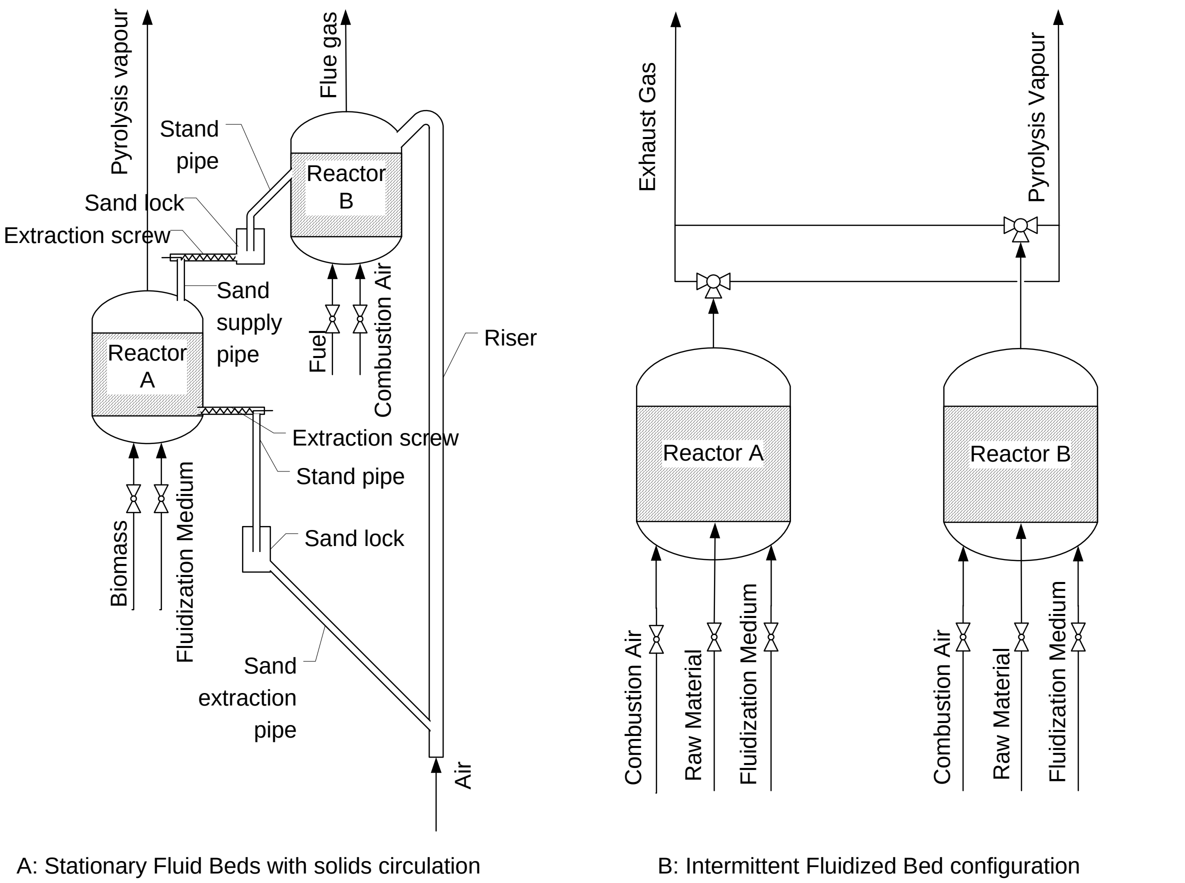

Figure 5, Comparison of two reactor concepts including auxiliary equipment.

Computer simulation confirmed by laboratory tests showed that the concept is suitable for biomass with ash contents that vary up to 45%. This may occur with manure based biomass feeds, such as chicken litter and digester residues. For higher ash contents, support fuels in addition to charcoal would be required. In case of lower ash contents, there is a surplus of charcoal, for removal from the reactor. However, charcoal is not the only suitable fuel for the IFB pyrolysis process. In some cases the charcoal would be a valuable biochar growing substrate. In that case it can be easily segregated out off the reactor. Pyrolysis process gas would be a suitable substitute fuel for the charcoal that is removed. When charcoal is the fuel of choice, note that the ash still contains most of the minerals that are valuable to a fertiliser manufacturer. As combustion conditions are mild, the ash usually does not agglomerate leaving the minerals accessible.

A review of plant characteristics is as follows:
Economy:

- Flexibility for sustaining fuels
- No liquid waste
- High plant availability: robust, self-cleaning piping system
- Low maintenance costs
- Reduced investment costs

Products:

- Controlled moisture content in bio-oil (by strip gas)
- Flexibility for input materials (low- and high-ash)
- Excess heat (feed stock drying, process heat)
- Excess gas for electricity generation
- Excess charcoal (depending on ash contents)
- High-quality ash (not agglomerated)

For IFB processes and systems, including but not limited to pyrolysis, a world-wide patent has been applied. It has been published in fall 2009.

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