

## **Wellman Process Engineering Ltd. 6 t/d fluid bed fast pyrolysis process: 1998-2002**

In 1998, I was asked by Wellman Process Engineering Ltd. [WPEL] to join them as a process engineer in support of an EU funded project, Contract JOR3-CT97-0197 "Development Of Advanced Fast Pyrolysis Processes For Power And Heat", in partnership with BTG, the Netherlands, KARA, the Netherlands, Aston University, UK, Ormrod Diesels, UK and IWC, Germany.

The overall objective for Wellman Process Engineering Ltd. was to design and build a fluidised bed fast pyrolysis plant to produce pyrolysis liquids for engine testing. My role was the design of the fluidised beds, mass and energy balances and subsequent build and commissioning. The plant was designed as shown in the flowsheet and description at the end, with an annular char combustor around the central fluid bed pyrolysis reactor. This arrangement was to use the byproduct char and cleaned syngas after liquids recovery to heat the process, given the excess of energy in the char and non-condensable gas. The project within WPEL was led by Mr. Richard McLellan. During my time at WPEL, I also worked on projects relating to their 2.5 MWe updraft gasification technology and carrying out mass and energy balances for the process, coupled with power generation in IC engines. There were also other minor projects relating to liquids collection and producer gas for a glass foundry.

Outside of my part-time job at WPEL, I was working on downdraft gasification for Shawton Engineering, which then formed a specific subsidiary company, Biomass Engineering Ltd., to focus solely on downdraft gasification. Publications relating to this work are given at the end. There were also other activities within C.A.R.E. Ltd.

I was also working part-time at Aston University on various projects, multiple papers listed at the end relating to a wide range of subject areas.

### **Pyrolysis Plant**

The plant was also one of the first to obtain Integrated Pollution and Control [IPC] authorisation in October 2000. The plant has been built to various British standards for mechanical, civil and electrical design.

The full civil, mechanical, instrument engineering and process design of the system was completed, and the system constructed and installed at the Wellman site in Oldbury, England. There were five main unit operations, which are all skid-mounted:

- Biomass feeding and handling
- Fast pyrolysis and char recovery
- Liquids recovery
- Gas recycling and processing
- Liquids storage

The system included wood feeding through to product storage, with recycling of the pyrolysis gases to act as a fluidising medium in the pyrolysis reactor and provide process heat. The system was also highly automated and fully instrumented for the determination of mass and energy balances.

The process was granted IPC authorisation in November 2000 - the first plant in the UK to gain authorisation for liquids production, which was a major achievement given the severe lack of operational pyrolysis plants in the UK at that time.

Initial hot commissioning of the char combustor was started in November 2000, but stopped in January 2001 when the IPC authorisation expired and was superseded by Integrated Pollution Prevention and Control [IPPC], which came into force in August 2000.

Cost of the new permit under IPPC was expected to be £50,000, but came a range of additional requirements on stack monitoring for dusts and contaminants, which WPEL did not have the budget for: an estimated additional cost of over £200,000. So, some hot commissioning of the unit was carried out, but the method being employed was very slow (described at the end) and consequently the plant was shut down in early 2003 when WPEL decided that they could not fund the IPPC permit requirements and modifications were needed to the heating of the annular char combustor.

### **Estimated Liquids Costs**

As part of the overall project, an estimation of the production costs of the liquids varied from €15.2/GJ at 250 kg/h to €5.1/GJ at 10 t/h.

### **Conclusion**

WPEL were taken over by another company and the owner promised to invest into the technology, but this did not happen and so the plant was mothballed in 2003.

### **Lessons learnt**

- The change in regulation was a major project drawback and led to the end of the project, despite representations made to the Environment Minister, Micheal Meacher. There was no lee way for a biomass plant.
- The bed heating design, although it worked very slowly, did not function as intended and the LPG pre-heating should have been an external combustor using the combusted gases to fluidise both reactor for more rapid heat-up. This would have worked much better.
- The technology was correct, the conditions for it were not – regulation was very strict, and every project should consider all potential impacts from local and national regulations well in advance and draft an application. Discuss the draft first with authorities off the record, get feedback and amend as required.
- The overall plant emissions for an entire year in terms of dust, SOX, NOx and CO would have been less than a diesel-powered taxi. No pragmatism in the Environment Agency to see this, so WPEL paid the price.
- I personally gained considerable experience in the design and build and initial hot commissioning of my first large pyrolysis plant for liquids, but it's been the only one never to make liquids.

## WPEL Process Description

### Start-up and operation

The plant is started up in two stages; operation of the char combustion system followed by operation of the pyrolysis system.

The char combustor R03, which consists of a sand bed, is preheated using LPG [Liquefied Petroleum Gas] burners until the temperature is such that char combustion can be supported. Char is then fed and the sand bed fluidised with air. Once the external sand bed has reached an adequate temperature for char combustion to occur self-sufficiently [ $\sim 400^{\circ}\text{C}$ ], the LPG burners are turned off.

The second stage involves heating the inner sand bed to a sufficiently high temperature for pyrolysis to occur. Nitrogen gas is purged through the wood hopper into the pyrolysis system and circulated such that the inner sand bed is gently fluidised. The downstream liquid collection systems that include the quench system and the electrostatic precipitators are started up and once they are ready to receive pyrolysis products, wood is fed into the inner reactor R01.

### Normal operation - Biomass Feeding

Prepared biomass, typically wood, is transported from ground level to the wood hopper [V01]. The wood is conveyed to the hopper by means of a vacuum system whereby the wood is sucked up to the hopper. An air fan pulls the air through the top of the wood hopper, which acts as a cyclone and wood drops out into the hopper. Residual wood dust is trapped in filters fitted to the top of the hopper. The carrier air then passes through a drum filter before being discharged into atmosphere via the exhaust fan F03.

To prevent the escape of gas from the process, wood is fed via a lock hopper system. The wood in the hopper moves downwards to the base and is assisted by a nitrogen sweep system on the interior surface of the hopper. Periodically, the hopper when filled with wood is purged with nitrogen after sealing. The wood is then discharged into the smaller feed hopper [V02], which is then sealed. The wood is then fed initially through a metering screw [C02], followed by a high-speed screw [C03] to convey the biomass rapidly into the reactor [R01].

### Pyrolysis

The pyrolysis reactor is a cylindrical vessel, heated externally by burning the by-product char in a fluidised bed of sand [R03]. Some heat is also supplied to the pyrolysis reactor by the fluidising gas. When the wood enters the reactor, it is rapidly heated between  $450$  to  $550^{\circ}\text{C}$  to give three products, a solid char residue, organic vapours and water and non-condensable gases. The wood thermally degrades into a solid char, organic vapours, water and non-condensable gases [CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub> and some higher hydrocarbons].

## Product Separation and Recovery

The pyrolysis products are removed from the reactor in the gaseous products and enter two cyclones in series [S01 and S02], designed to remove over 99 wt% of the product char from the gases. The char drops from the base of each cyclone into a steel receiver [V04 and V05], where it is allowed to cool. Each container, when full, is isolated with a slide valve before being disconnected and removed. The by-product char is manually transferred periodically to the char hopper [V03] from where it is fed to the char combustor and burned to provide the heat for the process. The original plan was for a screw [C06] to do this, but this was shelved at this time.

The remaining gases, aerosols and organic vapours are piped into the quench vessel [S03]. The products are contacted with cooled recycled pyrolysis liquids, causing the products to coalesce, condense and collect. The recycled liquids remove the sensible and latent heat from the products. The remaining ~1 wt% char still left in the gas will end up in the product liquid. The pyrolysis liquid is collected in the quench system sump and some is pumped to storage and the remainder is pumped through a water cooled plate heat exchanger [HE02] and then back into the quench vessel. The non-condensable gases and aerosols are piped to the electrostatic precipitators [S04 and S11]. The electrostatic precipitator generates a high voltage electric field where the aerosols become rapidly charged and migrate towards the anode where they lose their charge and form a free flowing liquid. The liquids drain off the electrode and collect in the bottom of the electrostatic precipitators. A small diaphragm pump [P03] periodically drains the electrostatic precipitators back into the quench vessel.

## Gas Use

The cleaned gas from the electrostatic precipitators enters the gas buffer tank [T07] on discharge from the recycle gas fan [F02]. Some water vapour condenses and is drained periodically from the gas buffer tank and is added to the pyrolysis liquids. An inclusive demister pad removes any residual aerosols. The gas is then piped through a preheater [HE03] which raises its temperature prior to oxidation with air in the catalytic combustor [R02]. The temperature of the gas rises due to oxidation and is used to fluidise sand bed in the pyrolysis reactor [R01]. Excess recycle gas is oxidised in a separate catalytic combustor [R04] with excess air and the resultant gases vented to atmosphere. The gases are inerted during their passage over the catalyst and no thermal NO<sub>x</sub> is generated.

## Other

The combustion gases from the char combustor are cooled with a water spray to reduce the temperature to ~ 600°C. The cooled gases pass through two cyclones in series [V06 and V07] to remove entrained char fines and ash. The char and ash drop into receivers [T06 and T09 respectively]. The remaining gases are then passed through two exchangers in series, the recycle gas preheater [HE03] and the air preheater [HE01]. The gases are then vented to atmosphere.

## Shutdown

The wood supply and char supplies are stopped and the reactor then completes the pyrolysis of residual wood in the system. The gas is recycled around the system for several minutes to ensure that there are no remaining vapours in the system and to oxidise any remaining flammable gases using the catalytic combustor. The now inerted gas is then slowly vented from the system via the excess gas catalytic combustor.

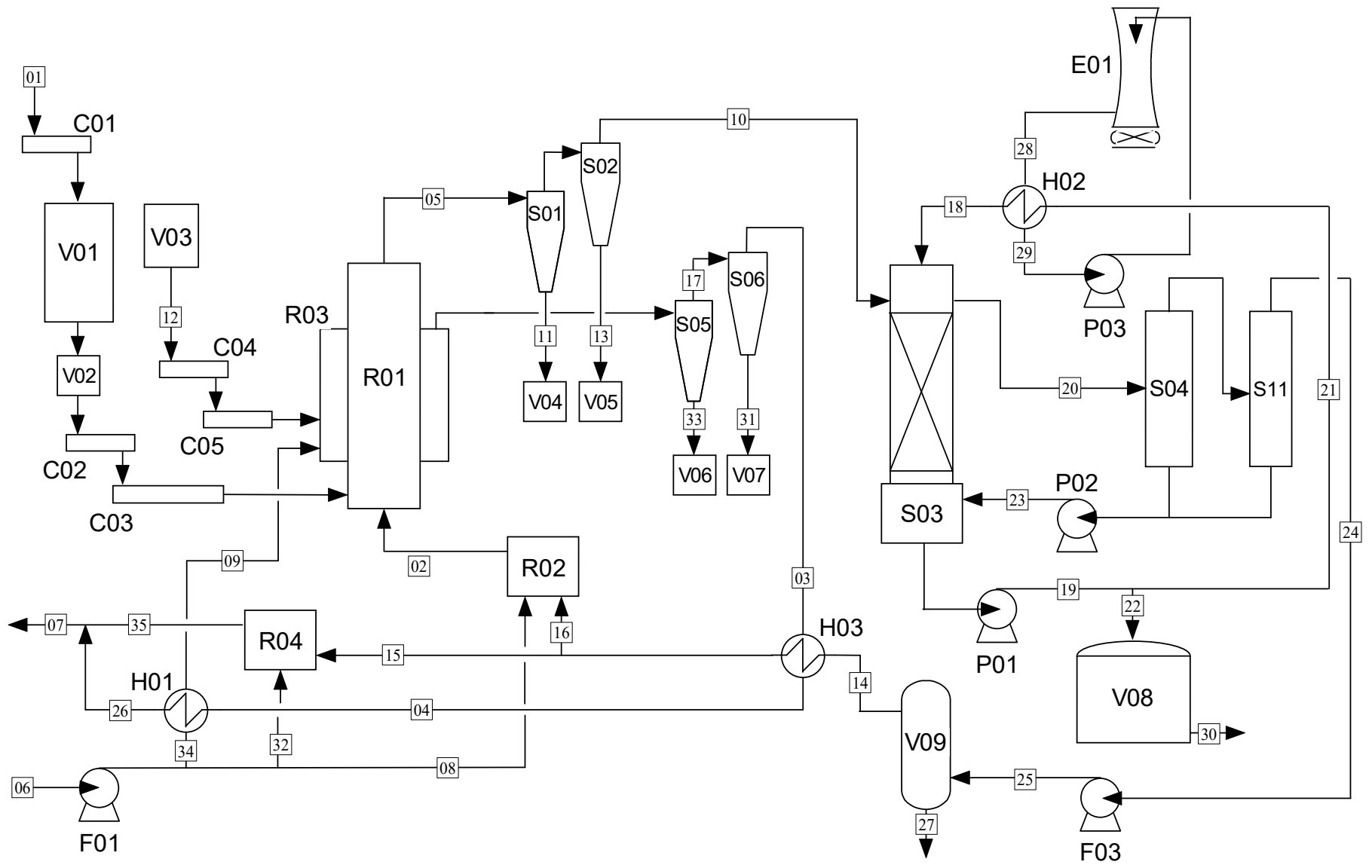
A full Hazard and Operability study was carried out after the determination of the detailed flowsheet and this has been taken into account in the writing of the operational manual, upon which the summary of the plant operation has been based.

## Commissioning and Operation

Hot commissioning was performed from November until January 2001, totalling 200 hours. The first stage of hot commissioning involves heating the char combustor. The concept is to heat the sand bed using two LPG burners located in the top section of the reactor and periodically agitating the sand bed to absorb the heat. Once the bed temperature exceeds the auto-ignition temperature of propane (450°C) four LPG gas nozzles located in the sand bed enable the introduction of propane within the bed for direct combustion and sand heating.

Theoretically, the propane should initially combust above the bed and as the bed temperature rises, the flame should propagate into the bed and bring the sand temperature up to its operating temperature of 800-1,000°C. However, difficulties have been experienced in getting the sand bed to pick heat from the upper burners and so heating of the combustor is impracticably slow. When lower gas nozzles are turned on combustion appears to occur in the freeboard and the majority of the heat is lost in the flue gases. There are two likely reasons for this behaviour.

Firstly, the upper burners are located too high in the char combustor and we now believe that ideally the flame from the upper burners should contact the sand directly. Combustion of propane in the bed is possibly being hindered by inadequate air/gas mixing within the sand bed. Temperatures of 480°C were achieved in the char combustor, with wood being fed to the unit. However, due to the restrictions of the IPC licence, hot commissioning had to stop in late January 2001.





**WPEL Fast Pyrolysis Plant: 6 t/d [1998-2002]**

## **Publications 1998-2002**

### Fully refereed-journal

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### Non-refereed or partially reviewed

- N.M. Robinson, G.V.C. Peacocke and A.V. Bridgwater, "Improved Ablative Pyrolysis System", in *Biomass for Energy and Industry - Proc. of the 10th European Conference and*

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- G.V.C. Peacocke, N.M. Robinson, E.H. Salter, H. Sheena, and A.V. Bridgwater, "Design Aspects of Fast Pyrolysis Reaction Systems for liquids from biomass", I.Chem.E. Research Event, 1998, Newcastle, April 1998, available on CD-ROM, Institute of Chemical Engineers, Rugby, UK
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