**Pyrolysis Activities [2006-2010]**

My third article last week focused on biomass gasification and the development of a 250 kWe downdraft gasifier to a commercial product, with grid export of the electricity produced. As I mentioned in that article, I was working on multiple projects concurrently and over the next 4 years, concluded some and started work on others:

- Life Cycle Assessment of slow pyrolysis for power production at 4-8 MWe.
- Technical advice, arranging financial support and assistance on several gasification projects [500-2000kWe].
- Chemical engineering and process design assistance for a 4 t/h conventional pyrolysis kiln, tar cracker, scrubber and selection of gas engines.
- Provision of flowsheets for a 2 t/h fast pyrolysis plant utilising feedstocks in India.
- Commissioning and assistance in operation of a 250 kg/h slow pyrolysis plant for char products and power generation in Australia. Assessment of process performance and scale-up to 4 t/h of dry feed material.
- Course presentations on biomass combustion, air quality standards, biomass gasification and pyrolysis at the Centre for Alternative Technology, Wales for Alternative Technology MSc in Renewables in the Built Environment Course [since 2008].
- Design of gas cleaning unit operations for biomass gasification combined heat and power projects to 9 MWe.
- Cost benefit analysis of the use of encroachment bush in thermal conversion systems in Namibia – evaluation of options for heat, power and products [https://www.careltd-thermal.com/projectprofile04.pdf].
- Feedstock evaluation for large scale gasification and high temperature pyrolysis [analysis, characterisation, testing, mass and energy balances].
- Large scale biochar production for soil applications.
- Independent assessor to the UK Technology Programme [Low Carbon Energy Technologies].
- Gasification technology assessment for large scale power applications.
- Design, construction and operation of a 300 kg/h fluid bed biomass fast pyrolysis plant for power production in the UK.

Due to the ever increasing workload, I had to take on staff to help. Mr. Mark Coulson started in 2005 and then Drs. Elma Gyftopolou and Katie Chong in late 2008 and 2009 respectively. Dr. Antzela Fivga also worked for a time with me later around 2014.

The increasing workload saw me taking on projects as far away at Australia and from 2005-2006, I spent 4 months at BEST Energies in Australia working on their 6 t/d augur pyrolysis process with gas cleanup with syngas use in a Mirrlees Blackstone converted diesel engine and with char activation.

In 2005, biochar was still not mainstream and Dr. Stephen Joseph was using the name, “agrichar” for the product and had ongoing growth trials with green waste chars and later chicken litter chars. The time in Australia gave me a great insight to an integrated plant, and I was assisting with kiln design and gas cleaning. This was very useful practical experience and was a great interaction with the BEST Energies staff: Dr. Stephen Joseph, Peter Klatt, Adriana Downie, Robert Downie, David Klatt, Jason Smith, Brett Rittenhouse and many others who helped and assisted with the equipment. There were several rigs on site referred to as, "Daisy, " El Toro" and "C4H4", so these were the names we used.

Daisy ~ 10kg batch dry biomass

One in Australia, one in the USA

El Toro ~ 40kg/hr dry biomass

Designed and Built in Australia – Shipped to USA
Operated from Dec 2005- July 2006

C4H4 ~ 300kg/hour continuous biomass (dry basis)

Engine and generator running on Syngas

Time spent there was always productive and many discussions on many aspects of pyrolysis and a great opportunity to be at the start of the modern era for biochar. There was a conference next year in Terrigal, which then formed the basis for IBI.

In 2007, I was a contractor to the Namibian Agronomic Board on assessing the options for the conversion of encroachment bush to charcoal, pyrolysis liquids, power and also gasification to power. This was in collaboration with local participants and was a very interesting project, as no one was considering charcoal produced from simple batch kilns as a soil amendment. A short summary is referenced above, but there is a full report [2009] which I can issue upon request.

Report reference: Honsbein, D., Peacocke, C., and Joubert, D. 2009.Incentive scheme for invader bush management– A cost benefit analysis. Windhoek, Namibia: Namibian Agronomic Board. Windhoek, Namibia.

**Recovery and conversion of sapropel from the bottom of the Black Sea [2008-2010]**

In 2008-2009, I worked on a project to assess the feasibility of using sapropel – a 10,000 year old high ash, saline, organic layer at the bottom of the Black Sea as an energy carrier by pumping it to the surface [ from 1200-2000m depth], centrifuge the sapropel onboard, drying it onboard the ship using a 100 $MW_{th}$ gas fired boiler and then transporting the dried sapropel to shore. The material would then be transported to a coal fired power station to be burnt as a, "green fuel". Upon analysis of this material, given below, it was clear to me that this would never be an energy vector for power generation in Romania. The dry HHV was well below the typical threshold of 8 MJ/kg as shown in Table 1 below. It also turned out that the sapropel composition varied significantly with depth through the variable thickness layer on the bottom of the Black Sea.

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**Table 1. Marine sediment sample analysis – before pyrolysis**

| Sample code | C | H | N | O [3] | S | Cl | Ash [4] | HHV [MJ/kg] |
|---|---|---|---|---|---|---|---|---|
| S1 | 18.57 | 2.17 | 1.08 | 16.24 [3] | 2.55 | 4.70 | 54.71 | 7.0 [1] |
| S3 | 11.35 | 1.24 | 0.69 | 13.10 [3] | 1.57 | 3.27 | 68.78 | 4.0 [2] |
| Sapropel 1 | 17.22 | 2.67 | 0.95 | 1.88 [6] | 2.34 | 4.7 | 70.25 | 8.1 [5] |

Notes:
1 MJ/kg calculated average from 5 standard formulas [range 6.4-7.6 MJ/kg]
2 MJ/kg calculated average from 5 standard formulas [range 3.3-4.6 MJ/kg]
3 by direct analysis
4 inorganic matter and other unidentified elements
5 MJ/kg calculated average from 6 standard formulas [range 6.1-9.4 MJ/kg]
6 by difference [probably erroneous value]

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The plan was to build 5x €500m dredgers to recover this material. I was extremely concerned that basic "due diligence" did not appear to have been done, however there were also plans to extract an additional layer of material – coccolith- to be recovered, dried and used in industrial gas cleaning as it was basically $CaCO_3$. A coccolith is a microscopic, mineralized plate of calcium carbonate $CaCO_3$ secreted by unicellular marine phytoplankton called coccolithophores. I was also not convinced that this was a good idea either.

To me, this seemed to be a very energy intensive way to recover a material with 80-98wt% water in it to be burnt in a power station. I assessed the energy requirements and the client noted that it did not appear favourable, and they requested some fast pyrolysis work to be done. CARE Ltd. contracted with Aston University to pyrolyse samples of sapropel to assess the possibilities for pyrolyzing the material into a char, liquids and/or syngas. In summary, the yields are shown in Figure 1 overleaf. The recovered char was typically 7wt% C and over 77wt% ash.

I presented an overall mass and energy balance that showed that recovery of the sapropel, centrifugation, drying on board, transport to shore, further transport to a power station did not make energetic or economic sense. The perceived value of the coccolith would not offset the sapropel extraction costs either and eventually the client realised that it was never going to be feasible and the project was brought to a close.

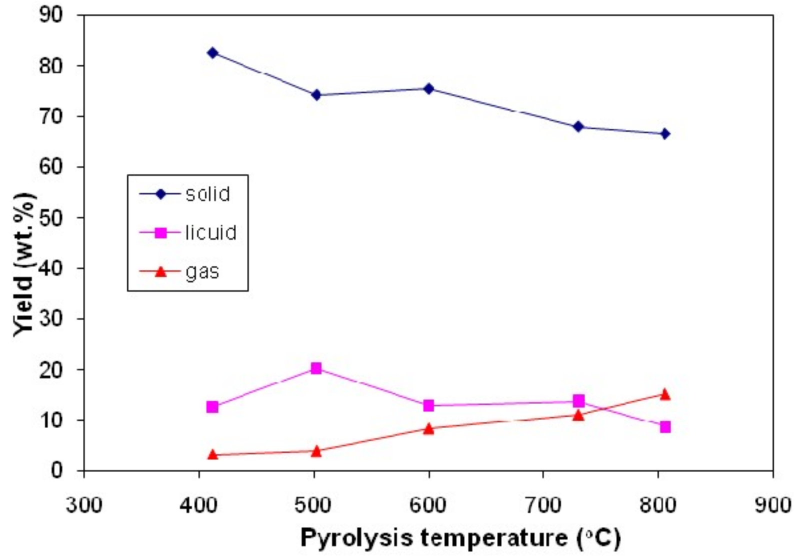


**Figure 1. Pyrolysis yields from the fast pyrolysis of dried sapropel in a fluid bed reactor**

Modelling of gasification of the dried sapropel was also not advantageous and that it would need to be co-gasified with wood just to offset the ash content of the sapropel. Modelling of gasification of the sapropel with increasing $O_2$ enrichment did not improve things to a commercial basis for its use in gasification as shown in Table 2 below.

**Table 2. Gasification of dry sapropel – gas HHV v's $O_2$ concentration in the gasifying agent. Comparison with wood [15wt% water content, wet basis]**

| Vol% $O_2$/ Vol% $N_2$ | Dry producer Gas heating value [$MJ/_n m^3$] | Gasification efficiency [%] |
|---|---|---|
| 20/80 | 0.2 | 27 |
| 40/60 | 0.8 | 49 |
| 60/40 | 1.3 | 52 |
| 80/20 | 1.9 | 53 |
| 100/0 | 2.5 | 54 |

It turned out that there had been prior efforts to sample this material at depth, but purely for understanding of the layers of material deposited in the Black Sea at different times and locations – all highly variable as would be expected.

To date, this has been my biggest "avoided cost" of €2.5B for the 5 dredgers, which were to be built.

**Lessons learnt**

- Time spent working on thermal conversion systems, at different scales and feedstocks is always invaluable and take the opportunity when it arises to work on plants of all sizes, throughputs and feedstocks – in a safe manner.
- I typically ask some basic questions when asked to look at any project. Has anyone else tried it before? Did the process succeed technically? If so, how they currently make money? If they aren't making money, then unless you can demonstrate a clear path to a lower cost process with acceptable profits – don't do it.
- Lots of things are technically feasible, it does not mean that they are commercially marketable or make money. Assess the overall techno-economics and for biochar applications, the LCA.
- Sometimes the bigger win is NOT proceeding. This is where a good feasibility study, overall process modelling [mass and energy balances, PFDs, energy integration, emissions compliance] and the right due diligence can avoid costly mistakes.
- Recruit skilled staff who can land on the ground running and deliver immediately.

**Publications 2007-2010**

<u>Non-refereed or partially reviewed</u>


- D. Chiaramonti, A. Oasmaa, Y. Solantausta and C. Peacocke, "The use of biomass derived fast pyrolysis liquids in power generation: engines and turbines", Power Engineer. Vol. 11 (2007) No: 5, p. 3 – 25.


<u>Commercial Reports</u>


- Honsbein, D., Peacocke, C., and Joubert, D. 2009. "Incentive scheme for invader bush management– A cost benefit analysis". Windhoek, Namibia: Namibian Agronomic Board. Windhoek, Namibia.