Title: MOBILE SYSTEM FOR DRYING AND PYROLYSIS OF LIGNOCELLULOSIC MATERIALS BY INTERRUPTED COMBUSTION

Abstract: This invention describes a process for the drying and pyrolysis of a wide choice of hgnocellulosic materials using a device which is sufficiently compact, lightweight and robust to allow transport and operation while in motion. The process involves a pre-heated continuous feed of lignocellulosic materials and time/temperature-controlled pyrolysis by interrupted combustion within a wholly or largely self-fuelled pyrolysis vessel which is suitable for mounting on a self-propelled vehicle or on a trailer and from which char, pyrolysis oil and pyrolysis gas can be recovered.
MOBILE SYSTEM FOR DRYING AND PYROLYSIS
OF LIGNOCELLULOSIC MATERIALS
BY INTERRUPTED COMBUSTION

The present invention relates generally to the drying and pyrolysis of a wide choice of lignocellulosic materials within a device which is sufficiently compact, lightweight and robust to allow its transport on a self-propelled vehicle or on a trailer and to allow its operation when in motion as well as when stationary.

There is a long history to the art of pyrolysis of lignocellulosic materials of diverse type, but industrial application has been hindered by the fact that most pyrolysis devices are large and constructed at a fixed location or small and of quite limited output. Many existing pyrolysis processes also operate only by batch processing, rather than by continuous feed.

The aim of the current invention is to provide the combination of mobility, continuous throughput and rapid pyrolysis. Such attributes open the way to economical, on-site, on-demand servicing of industries such as agriculture, forestry and general greenwaste.

The accompanying drawings (Figures 1 to 4) illustrate a preferred drying and pyrolysis unit that may be utilised in the present invention.

The first stage of the process is to provide a continuous feed of suitably cut, granulated or chipped lignocellulosic materials sourced, for example, from crop waste, plantation prunings or green waste. The feed mechanism can be configured to provide an initial drying stage, using hot exhaust gas from the pyrolysis unit.

The pyrolysis unit is a vertical metal cylinder fitted with multiple fixed or removable decks, variously slotted, perforated and/or screened, and with a rotating central shaft which carries arms from which hang rakes of varied type.

The chamber above the top deck (designated as Deck 1 in Figure 1) is intended to be primarily a drying chamber, but if relatively dry lignocellulosic feed material is introduced then there may also be some charring occurring within this chamber. One or more chambers formed by decks below the top deck (such as that designated as Deck 2 in Figure 1) continue the drying process, but with increasing amounts of charring. The penultimate chamber (designated as Deck 3 in Figure 1) is intended to complete the charring process and the bottom chamber (designated as Deck 4 in Figure 1) serves as a final collection chamber for char prior to its discharge from the pyrolysis vessel.

The floor of the bottom deck is typically neither slotted nor perforated because it acts as a collection surface for char which is raked for discharge typically through a lateral port (Figure 4). An upper deck or a set of multiple, similar-
purpose decks has a floor characterised by concentric slots (Figure 1) which are used in conjunction with suitable rake tines to harvest and remove promptly to a lower level any adequately charred and consequently brittle lignocellulosic material. These upper decks also have a bulk transfer opening (Figure 1) which is designed to permit bulky, uncharred or incompletely charred lignocellulosic material to drop to a lower deck level after at least one complete revolution of the rakes. The deck floor immediately above the bottom deck (Figure 3) may be slotted or perforated, but has no bulk transfer hole because this deck serves as the final charring chamber, from which feed material can transfer only after final charring has rendered it sufficiently brittle to be broken by the rakes and harvested by dropping through the deck slots or perforations. The continuous harvesting downwards of brittle, charred material into a chamber essentially devoid of oxygen is the process which serves to interrupt the combustion of the lignocellulosic feed material, thereby preventing its continued combustion to an ash product.

The types of rakes attached to the circulating arms differ from one deck to another, depending on the intended function of the particular deck. In Figure 1 the upper two decks are shown to be equipped with alternating tines of two types. One type consists of short, largely rigid tines which are intended to mix, spread and drag the lignocellulosic material as it dries and begins to pyrolyse from contact with hot combustion gases which have been released from deeper within the pyrolysis unit. The second type of tine is long, springy and designed to scrape along concentric slots within the deck floor. The function of these tines is not only to mix, spread and drag the lignocellulosic material, but also to break up any of the material which has become sufficiently brittle by pyrolysis to be suitable for harvesting by dropping through the slots in the deck floor. Within the penultimate deck (Deck 3 in Figure 1), intended for final charring, the rake tines are fitted with drag chains to encourage maximum breakage of brittle char so that it can be harvested through slots or perforations to the bottom deck (Deck 4 in Figure 1) where cooler temperatures and a scarcity of oxygen interrupt the combustion which would otherwise cause it to proceed to ash. Within the lowest chamber the rake arms are curved scrapers which drag across the bottom deck and sweep the brittle, crushed char towards the outer walls where it can be discharged through a port as the arms circulate.

Exhaust gas is vented via one or more flues, fitted with dampers to control the rate of flow, then a wet scrubber or an afterburner mechanism to control the quality of the emissions and a spark arrestor to control any spark hazard. There is potential to capture and use heat from the exhaust gas and to capture and use incompletely combusted pyrolysis gas.

Control over temperature, oxygen and degree of pyrolysis is achieved by adjusting the rate of input of lignocellulosic feedstock, the number of drying decks, the rate of rotation of the rakes, the rate of forced air injection and the rate of output of flue gas. Typical operating temperatures in the hottest parts of the pyrolysis vessel are 300 to 500 degrees Celsius and typical temperatures in
the bottom char collection deck are less than about 130 degrees Celsius. The residence time of material passing through the pyrolysis unit is adjustable but is generally of the order of seconds to minutes.

The pyrolysis process is initiated by loading lignocellulosic feedstock into the drying and pyrolysis decks, then igniting material in the penultimate deck (Deck 3 in Figure 1). The initial combustion releases enough heat to cause the release of some pyrolysis gas which then acts as fuel to continue the heating, drying and pyrolysis process. To encourage the efficient combustion of the pyrolysis gas some of the unburned gas is recirculated from middle or upper decks in the vessel to the main charring deck by return pipes (Figure 1) which exploit a venturi effect as forced air is injected into the main charring deck. For relatively dry feedstock no supplementary fuel is needed to operate the pyrolysis vessel; for relatively wet or slow pyrolysing feedstock the fuel can be assisted when necessary by one or more gas burners.

The prime intent of the process is to generate useful char, which is suitably cooled and drawn off from the bottom of the pyrolyser unit either for immediate spreading for agricultural purposes or for collection and processing for various uses elsewhere. Pyrolysis oil and surplus pyrolysis gas generated within the unit also can be collected for use.

The pyrolysis unit can be operated in a static location but it is designed to be suitable for mounting on a truck or trailer which is can be registered for road use and which is suitable for use on agricultural land. The initial drying and feeding apparatus may be mounted on the same truck or trailer, or temporarily attached for field use or it may be supported by an accompanying agricultural implement. The char discharge mechanism may also involve the use of an associated spreader implement or a pelletizing/briquetting device and/or an accompanying storage truck, trailer or bin.
What is claimed is:

1. Invention of a drying and vertical pyrolysis unit which is sufficiently compact, lightweight and robust to allow its transport on a vehicle or trailer and its operation while in motion.

2. Invention of a drying and vertical pyrolysis unit which is suitable for continuous feed and transport of a wide variety of lignocellulosic materials

3. Invention of a pyrolysis unit with a controllable temperature profile and a short residence time for feed materials

4. Invention of a pyrolysis unit which not only provides for extraction of solid, liquid and gaseous products of pyrolysis but which uses some of its own lignocellulosic feed and derived pyrolysis gas as a main or sole fuel for continued pyrolysis.
INTERNATIONAL SEARCH REPORT

International application No. PCT/AU20 0/000935

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.
C1OB 49/02 (2006.01) C1OB 1/04 (2006.01) C1OB 53/02 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database consulted during the international search (name of database and, where practicable, search terms used)
EPIDOC & WIPO: IPC&EC (C1OB 1/04 or C10B3 or C10B49 or C10B5 1 or C1OB 53/02) & KEYWORDS (lignocellulose, biomass, mobile, control) & like terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Citation of document, with indication, where appropriate, of other relevant passages</th>
<th>Relevant to claim No.</th>
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<td>WO 2006/1 17006 A1 (DANMARKS TEKNISKE UNIVERSITET) 9 November 2006 Abstract; all claims; page 4 lines 13-27; page 8 lines 11-35</td>
<td>Claims 1-4 and Search Statement (see Box II)</td>
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<td>X</td>
<td>GB 2257980 A (DAVID HUTCHINSON YORKSHIRE CHARCOAL COMPANY) 27 January 1993 Page 6 lines 17-30, page 7 lines 8-14, page 9 lines 9-1 0; figure 3; claim 1</td>
<td>Claims 1-4 and Search Statement (see Box II)</td>
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<td>p-X</td>
<td>WO 2009/1 24286 A2 (NORTH CAROLINA STATE UNIVERSITY) 8 October 2009 Abstract; claims 6 &amp; 18, pages 3, 9, 13 and 14</td>
<td>Claims 1-4 and Search Statement (see Box II)</td>
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X Further documents are listed in the continuation of Box C X See patent family annex

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent but published on or after the international filing date
  "L" document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed
  "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
  "X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is considered alone
  "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
  "&" document member of the same patent family

Date of the actual completion of the international search
03 September 2010

Date of mailing of the international search report
- 9 SEP 2010

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Form PCT/ISA/2 10 (second sheet) (July 2009)
**INTERNATIONAL SEARCH REPORT**

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<td>WO 2006/130977 A1 (THE UNIVERSITY OF WESTERN ONTARIO) 14 December 2006 Abstract, figure 5, claim 14</td>
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<td>A</td>
<td>US 5993751 A (MORIARTY et al.) 30 November 1999 Column 2 line 28; column 4 lines 45-48; column 4 line 66-column 5 line 2</td>
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<td>A</td>
<td>US 3983009 A (NEAL et al.) 28 September 1976 Abstract; figures 2 &amp; 3; column 3 lines 40-67, column 5 lines 3-20, 56-61</td>
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</table>
### Box No. II  Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. \[\checkmark\] Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. \[\xmark\] Claims Nos.: 1-4
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
   See supplemental Box

3. \[\square\] Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

### Box No. III  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See supplemental Box

1. \[\square\] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. \[\xmark\] As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. \[\square\] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. \[\square\] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

### Remark on Protest

- \[\checkmark\] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- \[\checkmark\] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- \[\square\] No protest accompanied the payment of additional search fees.
Supplemental Box
(To be used when the space in any of Boxes I to IV is not sufficient)

Continuation of Box No II:

Claims 1-4 have not been searched, as they fail to comply with Article 17(2)(a)(ii) in regards to clarity.

The ISA has established the International Search Report, based on a search which has been limited to the following search statement, as derived from the abstract and description:

A mobile unit and process for pyrolysing lignocellulosic materials, wherein the process comprising the steps of:

- pre-heating or drying continuous feed of lignocellulosic material
- extracting solid, liquid and gaseous products of pyrolysis
- using some of its own lignocellulosic feed and derived pyrolysis gas as a main or sole fuel for continued pyrolysis

wherein time and temperature pyrolysis control is achieved by interrupted combustion within a wholly or largely self-fuelled pyrolysis vessel which is transportable.

Continuation of Box III:

Claims 1 and 2 is directed to a mobile pyrolysis unit which allow its transport on a vehicle or trailer and its operation while in motion. It is considered that the mobile pyrolysis unit comprises a first "special technical feature".

Claim 3 is directed to a pyrolysis unit with a controllable temperature profile and a short residence time for feed materials. It is considered that a pyrolysis unit with a controllable temperature profile and a short residence time for feed materials comprises a second "special technical feature".

Claim 4 are directed to a continuous pyrolysis unit which not only provides for extraction of solid, liquid and gaseous products of pyrolysis but which uses some of its own lignocellulosic feed and derived pyrolysis gas as a main or solve fuel for continued pyrolysis. It is considered that the continuous pyrolysis unit which uses some of its own lignocellulosic feed and derived pyrolysis gas as a main or solve fuel for continued pyrolysis comprises a third "special technical feature".

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

Each of the abovementioned groups of claims has a different distinguishing feature; and they do not share any feature which could satisfy the requirement for being a special technical feature. Because there is no common special technical feature it follows that there is no technical relationship between the identified inventions. Therefore the claims do not satisfy the requirement of unity of invention a priori.

This International Searching Authority did not invite payment of additional fees. This International Search Report has been established based on a search which has been limited to the search statement as in Box II.
This Annex lists the known "A" publication-level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX