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— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

WO 2017/122005 A1

(54) **Title**: SYSTEM AND APPARATUS FOR RECOVERING ENERGY FROM WASTE, METHOD FOR PRODUCING A CLEAN FEEDSTOCK AND SOLID FEEDSTOCK

(57) **Abstract**: A system comprising a pyrolysis means and oxidising means for recovering energy from waste is provided. The pyrolysis means may be heated by heat from the oxidising means. A method for producing a clean feedstock for recovering energy comprising the steps of: receiving waste material; separating the material into combustible and non-combustible material and/or into clean and non-clean waste material; blending the waste material with a binding agent or filler; and compressing the material into a puck or pellet, or other solid fuel. The application further describes a solid feedstock for use in energy recovery via pyrolysis, the feedstock having a minimum calorific value of between 15 and 24 MJ/kg and a moisture content of between 4 and 8%, the feedstock being in the form of a pellet or puck.

SYSTEM AND APPARATUS FOR RECOVERING ENERGY FROM WASTE, METHOD FOR PRODUCING A CLEAN FEEDSTOCK AND SOLID FEEDSTOCK

Field of the Invention

The invention relates to apparatus, systems and processes for recovering energy from waste materials, primarily using pyrolysis (advanced thermal treatment).

Background to the Invention

There have been many early attempts to develop, build and operate large-scale waste to electrical energy systems with pyrolysis as the main process step rather than gasification or biomass systems. However, such systems have, so far, not met the expectations of the parties. There is a desire for non-combustion of sustainable non-fossil fuel plants in the UK and worldwide. In particular, there is a desire for small local systems using the local waste to generate heat or electrical energy. The power grid is set up to take power into the system due to the recent success of wind power and solar cells. This is being managed and will facilitate communities being provided with electricity generated locally. It would be advantageous for this to be achieved using locally produced waste. This would be particularly desirable for islands or remote locations, allowing those communities to generate their energy, waste heat, and if required desalinated water for drinking.

The inventors have developed a system for recovering energy from waste, using pyrolysis. The energy can be provided in electrical form or combustible fluids such as organic materials, coal, gas or oils. Although renewable organics are preferential in certain countries; fossil fuels can also be utilised or a mixture of both.

Summary of the Invention

The invention provides a system for the recovery of energy from waste. The invention further comprises a method for recovering energy from waste. It also provides a feedstock for use in that method and a method for producing the feedstock.

A detailed description of the invention follows, by way of example, only. It refers to the figures in which:

Figure 1 shows a pyrolyser that may be used in the invention, comprising an oxidiser.

Figure 2 shows a multi tube pyrolyser that may be used in the invention.

Figure 3 shows a flow diagram including the various aspects of the system of the invention.

Detailed description of the Invention

The invention provides a method for recovering energy from waste material, the method comprising:

providing a first, typically clean, feedstock; and

pyrolysing the feedstock to produce pyrolysis gas and char.

The heat generated can be used to create steam and hence power via turbine and generators. The combustible gas produced which may be used in a gas engine or turbine to generate power.

The invention further provides an apparatus or system for carrying out the method. It comprises at least one pyrolyser. Typically, the apparatus or system comprises a pyrolysis means and an oxidation or combustion means. The pyrolysis means generally comprises at least one pyrolyser. The combustion or oxidising means generally also comprises at least one pyrolyser, but that pyrolyser is provided with an oxidiser.

Pyrolysis, as known in the art, is the thermochemical decomposition of organic material in the absence of oxygen. It results in the production of char and pyrolysis gas. In the method of the invention, pyrolysis is carried out on a clean feedstock, typically that is a feedstock that is substantially free of fossil fuel, for example it comprises less than 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.1% fossil fuel. It may also be substantially free of bio-waste, for example it comprises less than 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.1% bio-waste. Typically, the feedstock is prepared to meet the requirements of government or other funding initiatives that provide a revenue for the use of clean waste to energy systems (such as carbon credits or the ROC system in the UK).

The pyrolysers used in the invention maybe any appropriate pyrolysers. Suitable pyrolysers are described in PCT/GB2015/051939 or EP1465965 at least. The pyrolysers may be single tube or multi tube.

The method may also comprise the steps of providing a second feedstock, typically comprising waste that is not classified as clean. It may further comprise the step of oxidising the second feedstock, optionally following pyrolysis. When the method comprises this step, the heat generated by the oxidising of the second feedstock may be used for the pyrolysis of the clean waste. Accordingly, the method may include the step of using the heat generated by oxidising of second feedstock to pyrolyse the clean waste.

To allow oxidising of non-clean waste, the system or apparatus comprising a combustion or oxidation means, typically at least one of the pyrolysers provided with an oxidiser. Accordingly, the system generally comprises at least two pyrolysers, one of which is provided with an oxidiser. The system may comprise a plurality of pyrolysers, some with oxidisers, some without. For example, the system may comprise at least one, two, three, four, five, six or more pyrolysers without oxidisers. The system may also comprise at least one, two, three or more pyrolysers with oxidisers. In one embodiment, the system comprises six pyrolysers without oxidisers and three pyrolysers with oxidisers. Typically the pyrolysers without oxidisers are multi tube pyrolysers. The system may allow the oxidisers to be switched on or off, allowing all the pyrolysers to run without oxidation, if needed.

The method may also comprise the step of removing the char. The char may be removed using any appropriate means, including, for example, a cyclonic separator. Char and/or ash from the separator may then be removed and collected centrally. The method may also comprise the step of ensuring that the char/ash is inert and, if not, treating it such that it is inert. The system may also comprise at least one, optionally more than one, means for recovering any recoverable product from the char. For example, the product may be recovered by dissolving the char in an acid bath and then boiling off the acid. Alternatively, the char may be used to manufacture products such as building block, paving stones or aggregate as opposed to being sent to land fill sites.

The method may also comprise the step of conditioning the pyrolysis gas. The pyrolysis gas may be delivered to a gas treatment system. The gas treatment system may, for example, combine or reform the gas using typically a steam gas catalytic gas reformer. It may then refrigerate and/or compress the gas. This creates a dense, high calorific value gas or liquid. Undesirable acid components may be removed from the gas using, for example, the solution described in EP1951410. Accordingly, the system may comprise a gas treatment system. It may further comprise a refrigeration system. It may also comprise a compressor. Some or all of the gas may be stored. Stored gas may be used to start the system, if required. Alternatively, to avoid storing excess combustible gas, it may be oxidised in order to generate further steam and heat.

The gas may be used to fuel one or more gas engines. The gas engines may be used to power one or more generators to generate electrical energy. Appropriate gas engines are well known in the art. Accordingly, the method may also include the step of combusting the gas in a gas engine to power a generator to produce electricity. The system of the invention may include one or more gas engines. The gas engine may be connected to the output of the pyrolyser following gas conditioning, or conditioner, by an appropriate conduit. Any waste heat from the system can report to waste heat recovery boilers or heat exchangers and feed a process to generate waste oil capable of driving liquid or dual fuel engine to again drive a generator to produce electrical power.

Alternatively, or additionally, the gas may report to a steam boiler to reduce its temperature. The gas may also be used in an industrial gas turbine or a Rankine cycle.

Where the gas is combusted in an engine, an exhaust will be produced. The exhaust may be delivered to one or more heat exchangers. Heat from the oxidising of the non-clean feedstock may also be delivered to the heat exchangers. Any appropriate heat exchanger may be used, such as a steam recovery boiler. The heat or steam produced may then be used in other steps of the method or parts of the system. For example, it may be used to dry the feedstock before pyrolysis or oxidising or for steam reforming of the gas over a catalytic bed. It may also be used to drive a steam engine, such as an Organic Rankine Cycle engine e.g. Heliex Power and/or the heat engine supplied by Viking. Such engines may be used to generate electrical power. Alternatively, the engines may be used to drive compressors useful for reducing the volume of the pyrolysis vapours.

Low or high grade heat may also be used to drive other systems requiring heat energy if economically viable. An example of this may be to use the heat to drive a system for converting food waste into usable fuel. Food waste, such as potato peelings, may be digested using a crude ethanol system. The waste may be brewed into waste vegetable beer and distilled in a tower to make 70% or above ethanol. The process may be driven by heat generated by the system of the invention. The resultant ethanol may be added to liquid fuels used in or produced by the method of the invention, to increase their energy potential. Dehydrated food waste from process may then be included in the second feedstock. Food waste can also be added into low calorific value refuse derived (RDF) waste material to increase the calorific value.

Alternatively, or in addition, the exhaust may be delivered to one or more Corona plasma plugs in order to dissociate the exhaust gases into solids and OH. The resulting OH may be injected into the gas engine, in effect increasing the calorific value of the engine feedstock. This method uses disassociation of SOx & NOx but has the ability to also disassociate CO2.

The used exhaust may then be delivered to an abatement system for the extraction of any acid components and the removal of any solid waste. In particular, undesirable particulates, NOx, SOx may be removed prior to delivery to a stack. This can also be carried out using the solution described in EP1951410. A Continuous Emissions Monitoring System may be provided in the stack to ensure that the final exhaust meets environmental requirements.

Also provided is a method for producing a clean feedstock suitable for use in the system of the invention. It is advantageous to produce such a feedstock, so that the quantum and quality of the gas produced in the pyrolysers can be controlled. In particular, the feedstock typically has a minimum calorific value of between 15 and 24mJ/kg. The feedstock typically has a moisture content between 4 - 8%. Generally, the feedstock may be in the form of a pellet, puck or continuous log that expands when it enters the pyrolyser. Such pellets and pucks are well known in the art.

The method of producing the feedstock may comprise the step of receiving waste material, typically at a weighbridge. The material may be sampled, to ascertain its makeup. It may then be separated into combustible and non-combustible material and into clean and non-clean waste material. The separation step may comprise removal of inert waste, such as sand or glass, removal of ferrous material using a magnetic conveyor and removal of plastics and other light non-desirable components using an eddy conveyor. The material sampling may utilise a fanning laser with a vibrometer and the use of seismic measurements which produce a detailed 3D density map based on the sounds go around or through the material with a database recognising the velocity changes of the sound signal used to identify materials such as plastic building waste etc.

Once separated, the material may be shredded, and then dried. The material may be dried using heat from the energy recovery method.

The material may then be blended with a binding agent or filler, such as woodchip or sawdust. A heat carrying high density material, such as sand, glass beads or metal may be included with the material. That high density material may be removed following pyrolysis recycled back into the feed, as described in WO2009/138757-A2 (Aston University, UK). The material may then be compressed by pressing through a die.

The waste materials included in the feedstock have different melting and vapour temperatures. By setting the temperature in the pyrolysers appropriately, it is possible to control the output of the pyrolysers. For example, setting the correct temperature can allow coal to be partially pyrolysed, to produce ash or char containing pyrites. The pyrites may be removed from the ash or char and recyclyed. The partially pyrolysed coal and ash may then be used to produce coke for use as a smokeless household fuel or for use in a solid fuel boiler

Figures 1 and 2 below show pyrolysis units for use in the invention. Figure 2 shows a modular pyrolysis multi tube unit for use in pyrolysis of the clean feedstock. As an example, such a unit can treat 10,000 tonnes per annum of treated RDF to produce the pyrolysis gas. Figure 1 shows a multiple tube pyrolyser with a single oxidiser. It can be used for combustion of non-clean feedstock, in order to generate the heat required to feed the pyrolysis units in figure 2 i.e. provide a parasitic heat load. Typically, the unit in figure 2 will require 30% of the heat produced to pyrolyse the feedstock. In an embodiment comprising six pyrolysing units and three combustion units, only two of the combustion units should be needed to run the pyrolysers. The remaining combustion unit may be on standby, or used to generate heat for use in other parts of the system.

As shown in the process diagram in figure 3, in section 1, waste material is processed into pellets. The material is received, inspected, separated, and dried if necessary. It may be combined with filler or binding agent and/or with heat storing material. It is then pelleted or otherwise compressed, into individual or continuous feedstock pucks.

As shown in figure 3, the waste(s) are transferred to the various pyrolysers as required. The material is pyrolysed and the pyrolysis gas reports to the char removal cyclone/gasifier, depending upon its confirmation. Char and any other solids are removed within the cyclone. Any gas produced is then transferred to a pyrolysis product treatment unit which may contain gas and oil treatment systems. Any gas from the gas conditioning unit may be cooled and compressed, as shown in the gas treatment section of figure 3, and stored as desirable fuel to drive internal combustion engines, or turbines, in order to produced rotational energy as the case may be: for example, electricity generation for power export, displacement of fluids for stored energy systems.

Exhaust from the engines, or turbines, may be passed to one or more systems which incorporate plasma corona plugs, to generate OH following the disassociation of acid components. The exhaust may also be delivered to a heat exchanger, the resulting steam may be used to run one or more turbines. The exhaust may be treated, for example with MonoChem® solution, to remove acidic components and delivered to the discharge stack, or, if the calorific value proves to be beneficial to the pyrolysis process this can then be re-incorporated to the feed process, to use the heat energy available.

Claims

1. A method for recovering energy from waste material, the method comprising the steps of:

providing a first feedstock; and

pyrolysing the feedstock in a pyrolyser to produce pyrolysis gas and char.

2. A method according to claim 1, further comprising the steps of:

providing a second feedstock; and

oxidising the second feedstock, wherein the heat generated by the oxidising of the second feedstock is used for the pyrolysis of the first feedstock.

3. A method according to claim 1 or claim 2, wherein the first feedstock comprises or consists of clean waste.
4. A method according to any preceding claim, wherein the second feedstock comprises or consists of waste that is not classified as clean.
5. A method according to any preceding claim, further comprising the step of removing the char from the pyrolyser.
6. A method according to claim 5, wherein the char is separated, optionally using a cyclonic separator.
7. A method according to any preceding claim, further comprising the step of conditioning the pyrolysis gas.
8. A method according to any preceding claim, further comprising the step of refrigerating or compressing the gas.
9. A method according to any preceding claim, further comprising the step of starting the pyrolysers used in the method with gas previously produced by the method.
10. A method according to any preceding claim, further comprising the step of using the gas to fuel one or more gas engines, particularly to generate electricity.
11. A method according to claim 10, comprising delivering an exhaust produced by the gas engine to a heat exchanger.
12. A method according to claim 10, further comprising the step of delivering the to one or more Corona plasma plugs.
13. A method according to any preceding claim, further comprising the step of delivering the used exhaust to an abatement system for the extraction of any acid components and the removal of any solid waste.
14. A method according to any preceding claim, further comprising the step of delivering heat from the oxidation of the second feedstock to a heat exchanger.

15. A method according to any preceding claim, further comprising the step of delivering waste heat from any step of the method to a heat exchanger.
16. A method according to any preceding claim, comprising the step of using the heat or steam output of the heat exchanger to dry or condition the feedstock before pyrolysis or oxidation.
17. A method according to any preceding claim, comprising the step of using the heat or steam output of the heat exchanger for steam reforming of the pyrolysis gas over a catalytic bed.
18. A method according to any preceding claim, comprising the step of using the heat or steam output of the heat exchanger to drive a steam engine.
19. A system for recovering energy from waste material, the system comprising a pyrolysing means and an oxidising means, wherein the pyrolysing means comprises at least one pyrolyser without an oxidiser and an oxidising means comprises at least one pyrolyser provided with an oxidiser.
20. A system according to claim 19, wherein the pyrolysing means is arranged to be driven at least partially by heat generated by the oxidising means.
21. A system according to either of claims 19 or 20, further comprising a separator for separating char and ash produced in the pyrolysing means.
22. A system according to any of claims 19 to 21, further comprising a char treatment means, for recovering material from the char.
23. A system according to any of claims 19 to 22, further comprising a gas treatment system or gas conditioner, typically connected to the output of the pyrolysing means.
24. A system according to any of claims 19 to 23, further comprising a gas refrigeration system.
25. A system according to any of claims 19 to 24, further comprising a compressor.
26. A system according to any of claims 19 to 25, further comprising one or more gas engines, typically connected to the output of the pyrolysing means, or to the gas conditioner.
27. A system according to any of claims 19 to 26, further comprising one or more steam boilers, heated at least partially by output from the pyrolysing means.
28. A system according to any of claims 19 to 27, further comprising a heat exchanger, arranged to receive waste heat from the oxidising means and/or from the exhaust from the gas engines and/or from any other part of the system.
29. A system according to any of claims 19 to 28, further comprising at least one Corona plasma plug and a means for delivering an exhaust from the one or more gas engines.

30. A system according to any of claims 19 to 29, further comprising at an abatement system for the extraction of any acid components and the removal of any solid waste, the abatement system being arranged to receive the exhaust from the one or more gas engines, or from any other part of the system.
31. A method for producing a clean feedstock for use in the method of any of claims 1 to 18, comprising the steps of:

receiving waste material;

separating the material into combustible and non-combustible material and/or into clean and non-clean waste material;

blending the waste material with a binding agent or filler; and

compressing the material into a puck or pellet, or other solid fuel.

32. A method according to claim 31, further comprising the step of drying the waste material, typically using heat from the method of any of claims 1 to 15.
33. A method according to claim 31 or 32, further comprising the step of shredding the waste material.
34. A solid feedstock for use in the method of claims 1 to 18, the feedstock having a minimum calorific value of between 15 and 24mJ/kg and a moisture content of between 4 and 8%, the feedstock being in the form of a pellet or puck.

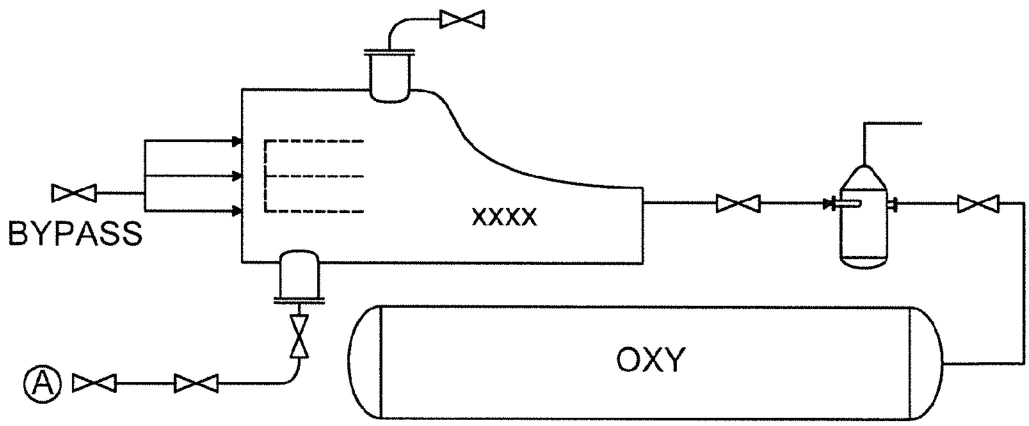

Figure 1

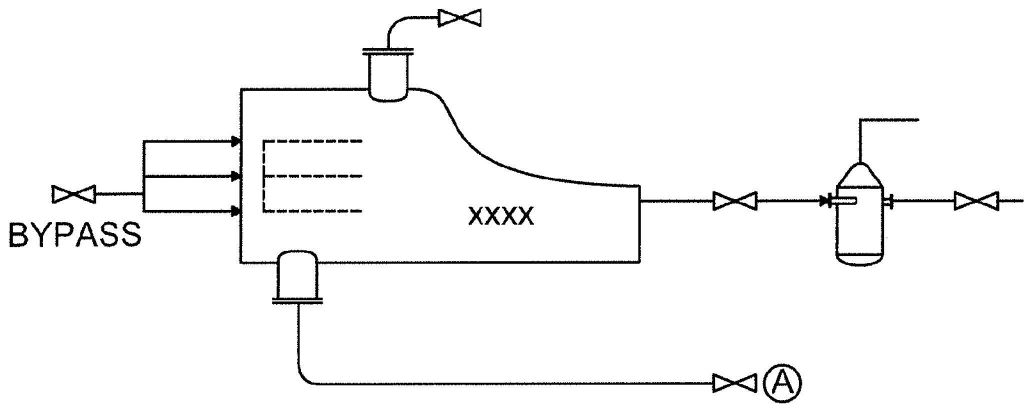

Figure 2

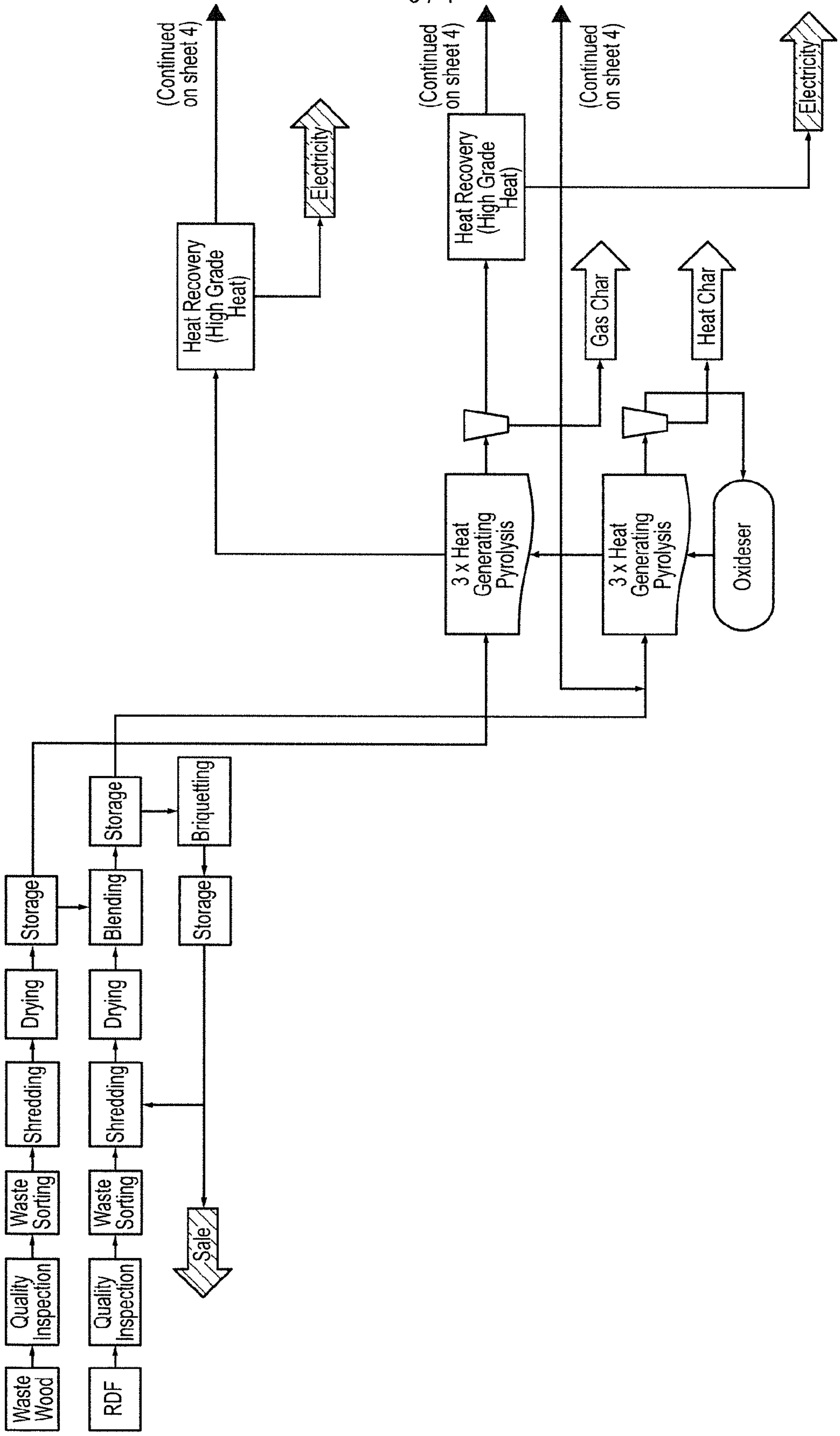
Waste Wood
Quality Inspection
Waste Sorting
Shredding
Drying
Storage
RDF
Quality Inspection
Waste Sorting
Shredding
Drying
Blending
Storage
Briquetting
Storage
Sale
3 x Heat Generating Pyrolysis
3 x Heat Generating Pyrolysis
Oxideser
Gas Char
Heat Char
Heat Recovery (High Grade Heat)
Heat Recovery (High Grade Heat)
Electricity
Electricity
(Continued on sheet 4)
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Figure 3

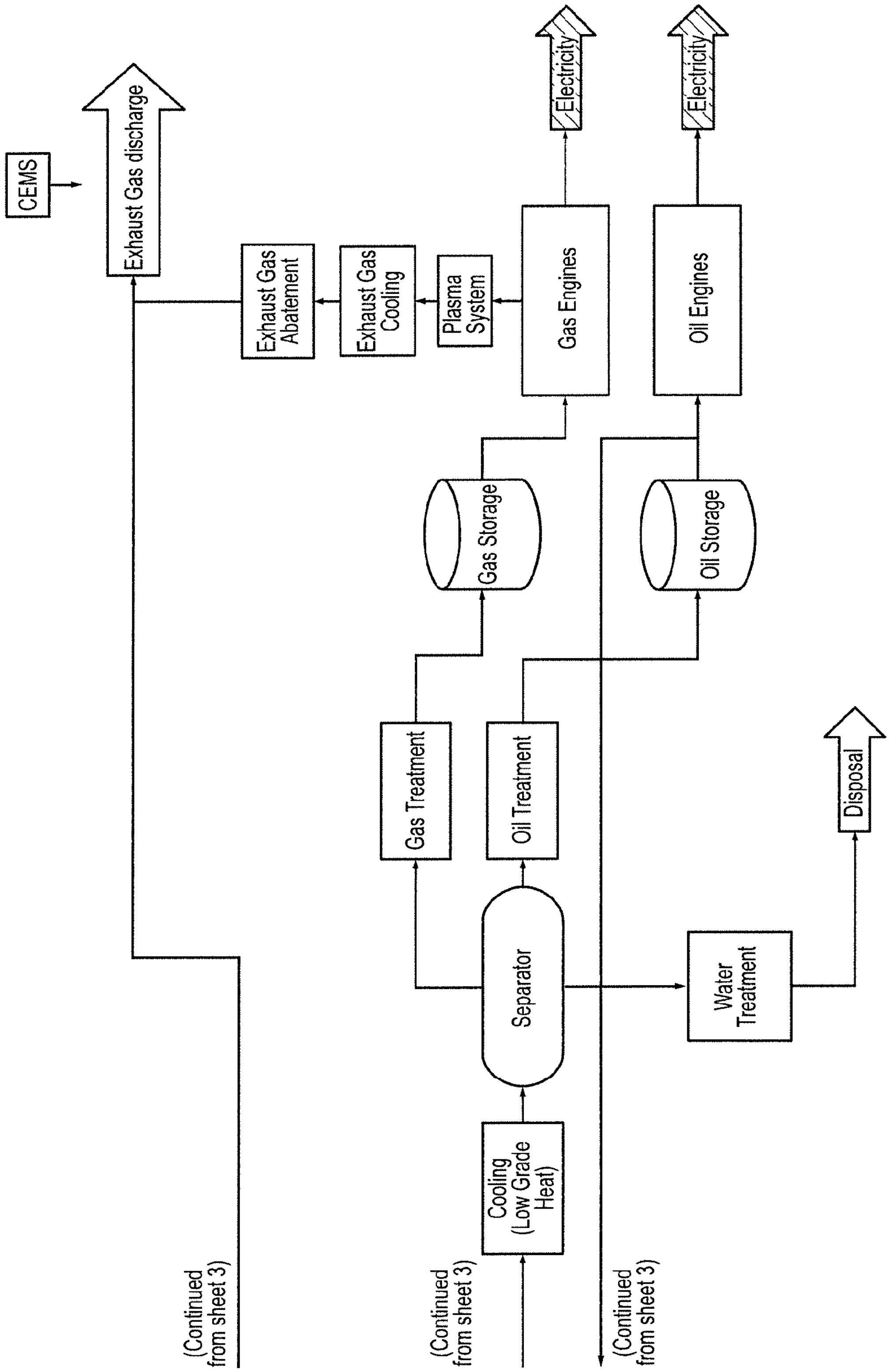

Figure 3 continued

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2017/050059

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10B53/00 C10B53/02 F23G5/027 C10L5/10 C10L5/36
C10L5/46 F02B43/08
ADD.

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)
C10L C10B F02B F23G

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, COMPENDEX, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BAGGIO ET AL: "Energy and environmental analysis of an innovative system based on municipal solid waste (MSW) pyrolysis and combined cycle", APPLIED THERMAL ENGINEERING, PERGAMON, OXFORD, GB, vol. 28, no. 2-3, 18 October 2007 (2007-10-18), pages 136-144, XP022304477, ISSN: 1359-4311, DOI: 10.1016/J.APPLTHERMALENG.2007.03.028 figure 1 2. System description -----	1-18

-/--

[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 doubts 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 taken 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	Date of mailing of the international search report
5 April 2017	12/06/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Zuurdeeg, Boudewijn

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2017/050059

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. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
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:

3. ☐ 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 additional sheet

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

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ 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. ☒ 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.:

1-18

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ 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.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2017/050059

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 100 47 787 A1 (VER ENERGIEWERKE AG [DE]) 28 March 2002 (2002-03-28) figures 1,2 paragraphs [0019] - [0029] claims 1-7 -----	1-18
X	WO 97/44410 A1 (RTI RESOURCE TRANSFORMS INTERN [CA]) 27 November 1997 (1997-11-27) figures 1,2 page 24, 3rd full paragraph -----	1-18
X	US 6 669 822 B1 (FUJIMURA HIROYUKI [JP] ET AL) 30 December 2003 (2003-12-30) figures 1-9 column 4, lines 25-26; claims 1-5 column 7, lines 42-44 column 12, lines 27-31,50-52 claims 1-5 -----	1-18
A	JP S51 114370 A (HITACHI LTD) 8 October 1976 (1976-10-08) claims 1,2 figures 1-6 -----	1-18

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2017/050059

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
DE 10047787	A1	28-03-2002	NONE			
WO 9744410	A1	27-11-1997	AU	725988	B2	26-10-2000
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			CA	2255922	A1	27-11-1997
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FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-18

   Method for recovering energy from waste material

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2. claims: 19-30

   A system for recovering energy from waste

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3. claims: 31-33

   Method for producing clean feedstock

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4. claim: 34

   A solid feedstock
