(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 November 2017 (30.11.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/204703 A1

(51) International Patent Classification:
C10B 53/02 (2006.01) *C10B 1/04* (2006.01)
C10B 21/18 (2006.01) *C10B 51/00* (2006.01)

(21) International Application Number:
PCT/SE2016/050479

(22) International Filing Date:
24 May 2016 (24.05.2016)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant: **ENVIGAS AB** [SE/SE]; Björnholmsvägen 20, 931 91 Skellefteå (SE).

(72) Inventor: **JOHANSSON, Harry**; Norra Yttervik 155, 931 91 Skellefteå (SE).

(74) Agent: **ZACCO SWEDEN AB**; P.O. Box 5581, Valhallavägen 117N, 114 85 Stockholm (SE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

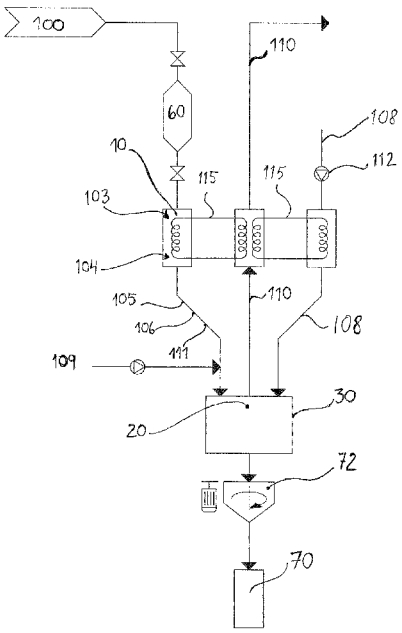
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report (Art. 21(3))*

(54) Title: PROCESS AND REACTOR FOR PRODUCING BIOCHAR FROM RENEWABLE MATERIAL

Fig. 1



(57) Abstract: The present invention relates to a process for producing biochar from biomass material in a reactor comprising the following steps: -supplying biomass material (100) into a material chamber (10) of the reactor; - drying the biomass material (100) by evaporating moisture from the biomass material (100); -pyrolysing the biomass material (100) to obtain biochar (105) and pyrolysis gas (106); -supplying gasification air (108) and pyrolysis gas (106) to a reaction chamber (30) in the reactor; -combustion of gasification air (108) and pyrolysis gas (106) in the reaction chamber (30); -removing exhaust gas (110) from the reaction chamber (30); -heating the biomass material (100) by indirect heat from the exhaust gas (110). The present invention relates also relates to a reactor for producing biochar from biomass material (100).

WO 2017/204703 A1

Process and reactor for producing biochar from renewable material

The present invention relates to a process for producing biochar according to the preamble of claim 1.The present invention also relates to a reactor for producing biochar from renewable material according to the preamble of claim 14.

Extensive use of coal and other fossil fuels globally largely contributes to the greenhouse gas emissions. It is recognized that it is possible to reduce such gas emission from the exisiting coal power plants by replacing larger or smaller shares of fossil coal fuel with charcoal from renewable sources without major reconstructions of existing process or infrastructure. Also the steel industry may replace fossil carbon fuels with renewable charcoal and thereby reduce emissions of carbon dioxide and other greenhouse gases. Thus there is a large demand for renewable charcoal produced at low cost in a process demonstrating high efficiency and having good environmental performance. However, during production of charcoal from renewable sources a large amount of exhaust gas such as carbon monoxide and non-combusted hydrocarbons are generated. If the temperature is unfavourable also tar and particles are formed which disturbs the process. Solid charcoal may be obtained as product of pyrolysis of biomass carried out at temperature above 300 °C. Pyrolysis of biomass is a thermal decomposition occurring in the absence of oxygene. Biomass may be pyrolised in a solid fuel gasification reactor. There are three different kinds of prior art solid fuel gasification reactors, counter current gasification reactor, co current gasification reactors and cross current gasfication reactor, with reference to flow direction of fuel and gasification air. Typically solid fuel gasification reactors have a low gasification temperature which results in high heat content in the gas in combination with high tar content. Since there is a large demand for charcoal from renewable resources it is desirable to eliminate or circumevent one or more of the above-identified disadvantages.

An object of the present invention is to provide a process for producing charcoal from renewable resources which operates with a high gasification temperature, and results in exhaust gas with a low tar content. Another object of the present invention is to provide a energy efficient continuous slow pyrolysis process for producing charcoal from renewable resources.

These objects are realised with a process for producing biochar comprising the following steps:

-supplying biomass material into a material chamber of a reactor

- drying the biomass material by evaporating moisture from the biomass material

-pyrolysing the biomass material to obtain biochar and pyrolysis gas

-supplying gasification air and pyrolysis gas to a reaction chamber in the reactor

-combustion of gasification air and pyrolysis gas in the reaction chamber

-removing exhaust gas from the reaction chamber

-heating the biomass material by indirect heat from the exhaust gas.

Advantageous embodiments are described in the dependent claims and the following description.

In particular the invention provides a simple process for producing charcoal from feedstock such as wood waste. The inventive process can use wet raw material without pre-drying, this is also beneficial for the resulting exhaust gas which has a high heat value and very low tar contents. The process for producing charcoal according to the invention is further advantageous in that the obtained charcoal product has a very good quality.

The process according to the invention is suitable for producing renewable charcoal from several types of feedstock of renewable material such as biofuels, biomass, plant material, wood, wood waste, wood chips and forest residues such as bark.

Another advantage is that the feedstock is fed by gravitation through the reactor, thus no further means are necessary for conveying the feedstoch through the reactor. This also permits that the size of particles of the feedstock can be widely varied.

Apart from the advantageous production of charcoal, the inventive process provides high gasification temperatures and low outlet temperature of the exhaust gas.The generated exhaust gas may be used for heat production and to operate gas engines for production of electricity. Furthermore the electrical power consumption for running the inventive process is low.

Another advantage is that the coal conversion may be optimized when steam generated in the drying and pyrolyzing phase penetrate the hot charcoal bed. Furthermore, the process provides that the gasification air in the reaction zone reaches temperatures above 1000 °C and generate a reaction zone with temperatures above 1200 °C. This is advantageous in that the exhaust gas has a low tar content. Moreover, the process provides that output temperatures of the exhaust may be less than 600 °C, this is a result of the efficient indirect heat transfer of sensible heat from the exhaust gas to the biomass material, the product gas and the preheating of gasification air.

A further aspect of the invention relates to a reactor suitable for producing charcoal from renewable resources which acheives the corresponding advantages as the process according to the invention. Further advantageous features of the invention are defined in the dependent claims.

In this specification the product obtained by the herein described process is referred to as renewable charcoal, charcoal from renewable material or biochar, these terms are considered alike and are used interchangeably throughout the specification. Furthermore the terms feedstock, raw material, injection material or input material are considered alike and are used interchangeably throughout the specification.

The expression "sensible heat" means the heat transferred to a thermodynamic system which results in a temperature change in the system. Sensible heat only increases the thermic energy in a system.

The invention will now be described in more detail with reference to an exemplifying embodiment thereof and also with reference to the accompanying figures in which

Fig. 1 illustrates a flow chart for the process according to the invention

Fig. 2 schematically illustrates a sectional view of an embodiment of a reactor for producing renewable charcoal from renewable resources according to the invention.

Fig. 3 schematically illustrates the reaction zone of the reactor in Fig.2 in operation.

Fig. 1 schematically illustrates a flow scheme for the process for producing biochar from renewable material in a reactor according to the present invention wherein biomass material 100 is supplied to a biomass material storage container 60. The biomass material is further conveyed to a material chamber 10 wherein the biomass material is dried by evaporating moisture in a drying phase 103 by indirect heat 115 transferred from exhaust gas 110. In the material chamber the biomass material 100 is further pyrolysed in a pyrolysis phase 104 by transferring indirect heat 115 from exhaust gas 110 to obtain biochar 105 and pyrolysis gas 106. The heated pyrolysis gas 106, approx. 700 °C, biochar 105 and steam 111 are supplied to a reaction chamber 30 which holds a reaction zone 20. The heated pyrolysis gas 106 and gasification air 108 are mixed the reaction zone 20. The gasification air 108 is preheated to approx. 900 °C by indirect heat 115 transferred from exhaust gas 110 prior to entering the reaction zone.

Furthermore ambient air 109 is fed into the reaction zone 20 together with the pyrolysis gas, to improve the quality of the obtained biochar.

In the reaction zone 20, pyrolysis gas 106 and gasification air 108 are mixed and combusted and the obtained exhaust gas 110 is removed from the reaction zone 20 and sensible heat in the exhaust gas is indirectly transferred to the biomass material and the gasification air, such that that the exhaust gas of approx. 600 °C leaves the reaction chamber 30, and finally the biochar 105 and ash is removed from the reaction chamber 30.

Biochar is removed from the reaction chamber 30 by a outlet feeder 72 which feeds the biochar to a charcoal output container 70.

The process for producing biochar from biomass material in the reactor according to the invention includes the following reactions: Vapor is released and heated steam is formed in th drying phase. In the pyrolysis phase dry biomass is pyrolised to obtain char coal and pyrolysis gas. The pyrolysis gas contains mainly volatile hydrocarbons. In the reaction zone, preheated gasification air is introduced into the reaction zone and fuel and pyrolysis gas are combusted, resulting in high temperature exhaust gas which is used for indirect heating of the biomass material in the drying and pyrolysis phase. A part of the charcoal is combusted.

When the gas, steam and pyrolised gas, penetrate the hot bed of char coal the steam will react with the carbon. The reaction will generate hydrogen via the water gas shift reaction.

$CO_g + H2O_g \leftrightarrow CO2_g + H_2$ (Reaction 1)

However this reaction occurs high up in the reactor.

The following reactions also play a substantial role in the later, warmer parts of the reactor

$C_s + H_2O \rightarrow H_{2g} + CO_g$ Δ131 Kj/mol (Reaction 2)

This reaction occurs when the excess steam passes the hot charcoal in the lower parts of the reactor and increases the amount of carbon that leaves the reactor as gas. However the reaction is endotherm and cools the hot charcoal bed. To secure reaction temperature some minor amount of air might have to be introduced in the char coal bed.

In the warmest part of the reactor a Boudouard reaction plays a role and affects the relative content of carbon monoxide and carbon dioxide.

$C_s + CO_{2g} \leftrightarrow 2\ CO_g$ (Reaction 3)

At temperatures above 700 °C the formation of carbon monoxide becomes favorable over carbon dioxide which makes the pyrolysis gas react with the hot charcoal bed to produce a more carbon monoxide rich gas. The raw pyrolysis gas is likely low on carbon dioxide so it is unlikely that this happens to any major extent.

Both reaction (1) and (3) are reversible and are influenced by temperature, residence time and partial pressure of carbon dioxide and steam. Depending on the conditions in the reactor, these reactions will influence the gas composition and the charcoal production.

One reason for the low amount of carbon dioxide early in the drying phase is due to the reactor initially being filled with a large amount of wet woodchips with a charcoal bed at the bottom. As the reactor heats up, the humidity will evaporate before the pyrolysis process can begin which produce large amounts of steam and relatively small amounts of pyrolysis gas.

This steam reacts with the hot charcoal bed in reaction (2) and forms water gas (mostly carbon monoxide and hydrogen). Some carbon dioxide and water is produced as more air is introduced into the gas stream in the cracking zone.

As more of the biomass material is dried and the temperature rises, the pyrolysis gas, becomes more dominant which reacts via reaction (1) in the pyrolysis process to produce more carbon dioxide and hydrogen higher up in the reactor. As the amount of product gas increases, the amount of ethylene and acetylene also increases as they form only during pyrolysis and not from water gas.

The energy content of the gas is quite low as an energy content of 4-6 MJ/Nm3 is to be expected when gasifying biomass with air or air/steam. This is due to the high moisture content of the fuel as it favors hydrogen over carbon monoxide in the syngas which has lower energy content.

Fig.2 schematically illustrates a reactor 1 according to the invention. For purpose av illustration no biomass material or charcoal bed is shown in this figure. The reactor according to the invention may be describes as a solid fuel gasification reactor and operates as two step indirect regenerative heat exchanger provided with a first step wherein biomass material is indirectly pyrolysed without added oxidants to obtain renewable charcoal and a second step wherein preheated gasification air is used for gasifying some of the biochar from the first step and also cleaning the exhaust gas from soot and tar, whereby very hot exhaust gas is produced that is used to indirectly preheat the gasification air and pyrolyse the biomass material in the first step. This allows the hot exhaust gas to drive both the pyrolysis process and the preheating of the gasification air. In particular, the process may be defined as a continuous slow pyrolysis process wherein the sensible heat in the exhaust gas from the reaction is indirectly transferred to the biomass material to achieve drying and pyrolysis of the material to obtain renewable charcoal in an highly energy efficient reactor.

The inventive reactor 1 for producing biochar from biomass material comprises a reactor vessel 5 which defines a biomass flow path extending from an inlet 7 to the reactor vessel 5 through to an outlet 71 from the reactor vessel, in which thermal decomposition of the biomass material progresses as the biomass material passes through the reactor vessel thereby obtaining renewable charcoal 105 and exhaust gas 110. The sensible heat in the exhaust gas indirectly dries and pyrolysis the incoming biomass feedstock in the absence of oxygen to renewable charcoal or biochar. Heat 115 from the heated exhaust gas is also indirectly transferred to the gasification air supplied to the reactor. This results in that the exhaust gas leaves the reactor at a reduced temperature which is advantageous.

The reactor vessel 5 comprises a material chamber 10, a reaction chamber 30, a gasification air conduit 40 and an exhaust gas channel 50 . The reactor vessel 5 is also provided with a biomass storage container 60 and a renewable charcoal output container 70.

The reactor vessel 5 comprises an longitudinally extended hollow enclosure arranged preferably in a vertical direction or near vertical direction. The reactor vessel and in particular the reactor chamber may be constructed of very heat resistant material such as Crom-Alloys , AlO3 and/or different ceramics for high temperatures and reducing conditions.

The reactor vessel has an upper part which houses the material chamber 10 and a lower part which houses the reaction chamber 30. The rector vessel is configured as cone shape cylinder stacked onto a cylindrical reaction chamber.

The reactor vessel and the material chamber is provided with an upper end 5.1 which is closed and provided with a biomass material inlet 7 to supply biomass material from a biomass storage container 60 connected to the reactor vessel.

The biomass storage container 60 is provided with closing devices 61,62 arranged above and below the biomass storage container 60 to avoid that steam 111 or pyrolysis gas 106 moves upwards in the material chamber and into and through the container 60. The upper end 5.1 of the reactor vessel is further provided with a passage 8 for the exhaust gas channel 50.

The upper part of the reactor vessel, the material chamber 10, is provided with an outer mantle 11. The outer mantle 11 illustrated in Fig. 2 is provided with a cross section with an area which increases in the downwards direction, such that the outer mantle 11 of the reactor vessel has a conical form. Preferably, the outer mantle 11 is configured with an essentially circular cross section, however, it is also possible to have an oval or or square shaped cross section.

The lower part of the reactor vessel houses the reaction chamber 30 which holds the reaction zone 20 and the charcoal bed 25 when the slow pyrolysis process of biomass material is in operation in the reactor vessel. In the lower end 5.2 of the reactor vessel, a biochar output container 70 is arranged below the reaction chamber 30. The reaction chamber is made of high quality construction grade steel and insulated inside with high temperature ceramic insulation.

The reactor vessel 5 further comprises an exhaust gas channel 50 and a gasification air conduit 40 arranged inside the material chamber 10 of the reactor vessel. In the embodiment of the reactor vessel shown in Fig. 2, the gasification air conduit 40 is arranged along a longitudinal centre line (marked out above the reactor vessel in Fig. 2) of the reactor vessel 5, and the gasification air conduit 40 is arranged inside the exhaust gas channel 50 such that the exhaust gas channel 50 and the outer mantle 11 of the reactor vessel are concentrically arranged around the gasification air conduit 40.

It should be noted that other configurations of exhaust gas channel 50 and gasification air conduit 40 arranged inside a material chamber 10 of a reactor vessel are also possible. Depending on the size of the reactor, the reactor vessel and material chamber may comprise several exhaust gas channels and gasification conduits. The dimensions and quantity of the material chambers, exhaust gas channel and gasification air conduit are designed based on case specific parameters.

The exhaust gas channel 50 is configured inside the material chamber 10 and is longitudinally extended between an channel outlet 50.1 arranged in the upper end 5.1 of the reactor vessel 5 and an channel inlet 50.4 arranged in the reaction chamber 30, such that, in operation of the reactor the exhaust gas is conveyed vertically upwards from the reaction zone.

The exhaust gas channel 50 has a channel wall, herein also called first heat transfer surface 54, which is made of a material suitable for efficient heat transfer. The whole channel wall, from the channel inlet 50.4 to the channel outlet 50.1 , operates as a heat transfer surface. The temperature of the surface varies along the length of the channel wall throughout the process.

The exhaust gas channel 50 has a main section 50.2 arranged in the material chamber. The main section 50.2 is preferable cylindrical and has a cross section which is essentially the same along the whole length of the material chamber. However, the cross section area of the main section 50.2 is substantially smaller than the cross section area of the outer mantle 11 of reactor vessel 5 as illustrated in Fig. 2. The dimension of cross section of the exhaust gas channel 50 must be however adapted such that sufficient gas flow can pass through the channel with a suitable flow rate.

Fig. 3 shows that the exhaust gas channel 50 is enlarged in the lower end and is provided with a conical section 50.3 and an channel inlet 50.4 having a rim 50.5. The conical section 50.3 has an increasing

cross section area in the downward direction towards the channel inlet 50.4. The channel inlet 50.4 may be provided with a cylindrical section 50.6 as shown in Fig. 3.

The reaction chamber 30 is further provided with distribution means 55 configured as a disc which is arranged below a gasification air outlet 41 and essentially aligned with the rim 50.5 of the channel inlet 50.4. The distribution means 55 has a cross section area which is smaller than the cross section area of the channel inlet 50.4 such that a gap 55.1 is formed between the distribution means 55 and the rim 50.5. The pyrolysis gas and steam entrained in the biochar and coming from the material chamber passes the gap 55. 1 to enter the reaction zone 20.

The conical section 50.3 and the channel inlet 50.4 forms a space wherein the reaction zone takes place when the reactor is in operation. The reaction zone 20 is further limited by the distribution means 55 which avoids that gasification air is directed on to the charcoal bed. Instead the gasification air is directed towards the heated pyrolysis gas.

The enlarged lower end of the exhaust gas channel is advantageous in that large volume of high temperature exhaust gas 110 can be removed from the reactor bed 25 but still keep a low exhaust gas flow rate in the region such that turbulence in the reaction zone 20 can be avoided. Turbulence may create an undesirable drag of particles with the exhaust gas flow 110 which should be avoided. It is therefore necessary to avoid high flow rates and turbulence in the reaction zone and the exhaust gas channel. The layout of the reaction chamber 30, the lower end of the exhaust gas channel 50, the gasification air conduit 40 and the distribution means 55 are therefore particularly configured to achieve a slow, low turbulent, gas movement in the reaction chamber 30 and the reaction zone 20. Another advantage is that low flow rates improves heat transfer from the exhaust gas 110 to the biomass material 100.

The exhaust gas 110 formed in the reaction zone 20 reaches a temperature of at least 1100 °C. The exhaust gas is conveyed through the exhaust gas channel 50 between the inside of the exhaust gas channel wall, the first heat transfer surface 54, and the gasification air conduit wall herein also referred to as second heat transfer surface 44 whereby heat 115 is indirectly transferred from the exhaust gas 110 and supplied to the biomass material bed 15 in material chamber 10 and to the gasification air 108 inside the gasification air conduit 40. The exhaust gas 110 is thereby cooled and leaves the exhaust gas outlet 50.1 with a temperature of approx. 350-400 °C.

In one embodiment the reactor vessel 5 is provided with a ventilator (not shown in the figures) arranged in the gasification air conduit 40 to ensure under-pressure in the reactor.

In the embodiment of the reactor vessel shown in Fig. 2, the gasification air conduit 40 is configured as a pipe and arranged inside the exhaust gas channel 50. The gasification air conduit 40 is preferably made of a material suitable for efficient heat transfer. The gasification air conduit 40 is longitudinally extended between a gasification air conduit inlet 42 arranged in a passage 4 in the upper end 50.1 of the exhaust gas conduit 50 and a gasification air outlet 41 arranged in the reaction zone 20. In operation, gasification air 108 is conveyed through the gasification air conduit 40 vertically downwards directly into the reaction zone 20.

The gasification air outlet 41 is located in the reaction zone 20 a short distance above the distribution means 55. This is advantageous in that the reaction and the temperature increase does not take place inside the charcoal bed 25 or directly in connection to the charcoal bed. An increase in the gas volume in direct connection with the charcoal bed gives rise to turbulence which may carry particles or non-combusted coal particles with the exhaust gas, which is undesirable.

The gasification air conduit 40 is configured with a cross section area substantially smaller than the cross section area of the exhaust gas channel 50.

The gasification air conduit functions as second heat transfer surface 44 for transferring heat 115 from exhaust gas 110 moving upwards on the outside of the gasificiation air conduit 40 to preheat gasification air 108 conveyed downwards to the reaction zone 20.

The gasification air 108 may be supplied by an fan 112 (as indicated in Fig. 1). The gasification air flow rate determines the exhaust gas flow rate. The gasification air flow rate also determines the heat power output.

The reactor vessel 5 comprises a material chamber 10 is arranged around the exhaust gas channel 50. The material chamber is limited by an inner circumference formed by the exhaust gas channel wall 51, and an outer circumference formed by the outer mantle 11 of the reactor vessel, such that the material chamber 10 is provided with an annular cross section.

AS shown in Fig. 2 the outer mantle wall 11 is conically formed in the longitudinal direction and the exhaust gas channel 50 has a cross section which is the same along the whole length of the channel. Therefore, the distance between the gas channel wall 51 and the outer mantle 11, herein also defined as the width of the material chamber 10, increases in the downwards direction. This is advantagoues in that the biomass material 100 gradually flows downwards through the material chamber 10 by gravity from a material inlet 7 in an upper end 5.1 of the reactor vessel to a biochar output 71 in a lower end 5.2 of the reactor vessel. This is advantageous in that the material is moved down with no additional mechanical means.

The material chamber 10 is arranged to receive biomass material from a biomass supply container 60 connected to the upper end of the reactor vessel. In operation, the process according to the invention is suitable to utilise biomass material having a moisture content of more than 20 % and preferably less than 50%.

The biomass material 100 forms a biomass material bed 15 inside the material chamber 10. The material bed 15 bears against the outer mantle wall 11 and the outside of the exhaust gas channel wall 51. The exhaust gas channel wall functions as a first heat transfer surface 54.

The layout of the reactor vessel creates benficial flow directions of the biomass material 100, the exhaust gas 110 and the gasification air 108 which is efficiently utilised for heat exchange purposes.

In operation of the reactor the biomass material 100 and the gasification air 108 are conveyed downwards in the same direction. Furthermore, the biomass material 100 and exhaust gas 110 are moved, conveyed, in opposite directions relative to each other. As a consequence also the gasification air 108 and exhaust gas 110 are conveyed in opposite direction. This is advantageous in that the outgoing exhaust gas is counter current heat exchanged against both the gasification air and the biomass material.

The process according to the invention is operated as a continuous process. The process for producing the renewable charcoal 105 according to the invention is initited by firing of fuel in the charcoal outlet 71 below the reaction chamber. Furthermore, in operation, in a steady state condition, the process is self-sustaining, thus only a minor part of the supplied biomass material is combusted and generate the necessary heat for sustaining the process.

In one embodiment of the process the reactor vessel 5 is pressurized above atmospheric pressure, which improves the charcoal production.

By pressurizing the reactor vessel the dimensions of the reactor vessel may be reduced. Furthermore the energy content in the exhaust gas increases. In one example the energy content at atmospheric pressure is 4 MJ/Nm3, and if the pressure is increased to 2 Bar, the energy content in the exhaust gas is 8 MJ/Nm3.

Another advantage is that the dew point temperature and exergy value rises for the remaining steam which has the benefit that the steam can be used as heating medium in a district heating system. Another advantage is that the energy content in the exhaust gas increases with decreasing steam content.

In a continuous process the biomass moves down through the material chamber 10 and through the process phases taking place in different process zones.

In a continuous process the upper part 10.1 of the material chamber 10 may be referred to as a drying zone. In operation heat 115 is indirectly transferred from heated exhaust gas 110 to wet feedstock 100 located in the upper part 10.1 of the material chamber 10 such that the feedstock dries and moisture evaporates. The evaporated moisture forms steam 111 which is moved downwards through a pyrolysis zone and pyrolysis phase of the material 105 and the charcoal bed 25. The temperature variation in the material chamber 10 determines the location of the different process zones.

The reaction chamber 30 receives the pyrolised material from the material chamber 10 and a charcoal bed 25 is formed around the periphery of the reaction chamber 30 and below the exhaust gas channel inlet 50.4 and a reaction zone 20 is formed above the bed of hot charcoal 25.

In the reaction zone, several reactions play a role. Heated pyrolysis gas is mixed with the preheated gasification air resulting in oxidation and combustion which generates heat.

The pyrolysis gas 106 is indirectly heated by the exhaust gas 110 in the pyrolysis process to approximately 700 °C prior to supplying the pyrolysis gas to the reaction zone 20 and the gasification air 108 is indirectly preheated by the exhaust gas to approximately 900 °C, prior to entering the reaction zone. The gasification/carburation temperature is in the range of 1000°C – 1300 °C, preferably the reaction zone reaches a temperature of at least 1100 °C.

Since the exhaust gas 110 provides indirect heat 115 for drying and pyrolysis of the biomass material and preheats the gasificiation air, the exhaust gas 110 is cooled dowm during the upwards movement in the exhaust gas channel, and at the exhaust gas outlet, the exhaust gas temperature is approximately 350- 400 °C.

As a result of the high gasification temperature, benifical thermal cracking of the gaseous biomass tars can take place in the reaction zone 20 resulting in very low amount of tar in the exhaust gas 110, and a high heat value may be acheived. This is advantageous in that less fuel energy from the coal conversion process is used in the gasification process. The heated steam from the drying phase enhances the tar cracking process.

In the charcoal bed 25 below the reaction zone and in the periphery of the reaction chamber 30, coal conversion by reduction takes place. In operation, vapor evaporated from biomass material from the drying phase is brought through the hot charcoal bed during coal conversion, which may reduce the charcoal production.

The reaction chamber 30 is further provided with an air intake 35 arranged in the side walls of the reaction chamber and next to the charcoal bed 25, to supply ambient air 109 to the charcoal bed. This ensures the quality of the renewable charcoal obtained in the process.

The reactor vessel further comprises a material output, a renewable charcoal outlet 71, provided in the lower part of the reactor vessel to remove the renewable charcoal. A biochar output container 70 is connected to the charcoal outlet 71. The charcoal outlet 71 is provided with a rotating outlet feeder 72, configured as an inclined rotating disc which rotates by means of a motor 73. The residence time for supplied biomass material in the reactor depends on the outlet feeding rate. The outlet feeding rate determines the mass flow rate of the material movement by gravity through the material chamber which allows for a continuous operation and which also makes it possible to use the exhaust gas in a combustion motor to produce electricity. The outlet feeding rate is stepless regulated, which results in that different biochar product qualities can obtained, torrified as well as charred biochar.

The quality of the biochar obtainable by the method according to the invention depends on the type of feedstock material and the outlet feeding rate. However, the biochar produced by the inventive process has proven to have high specific surface, high micro-porosity and large absorption capacity. Typically, the process yields approximately 30% biochar in relation to biomass material supplied to the reactor. The production of biochar and biocoal can also be increased by the use of additional substrates.

The reactor further includes means for controlling and regulating the process. These means includes temperature sensors, thermocouples, differential pressure transmitters and thermal mass flow controllers arranged in several different disctinct positions on the outside of the exhaust gas channel wall, the first heat transfer surface 54, the outer mantle 11, the reaction zone 20, the exhaust gas channel 50 and the biochar outlet 71.

In operation, the temperature of the first heat transfer surface 54 is carefully controlled in the drying phase and the pyrolysing phase respectively. The temperature varies along the length of the first heat transfer surface 54 throughout the process, which influences the production process. The reactor has very few movable parts except for the outlet feeder. This is advantageous in that less maintenance is necessary.

It will be understood that structural modifications are possible within the concept of invention. It should be understood that the different embodiments are freely combinable with each other.

The invention is therefore not restricted to the illustrated and described embodiment thereof, since changes and modifications are possible within the scope of the accompanying claims.

CLAIMS

1. Process for producing biochar from biomass material in a reactor comprising the following steps:
-supplying biomass material (100) into a material chamber (10) of the reactor
- drying the biomass material (100) by evaporating moisture from the biomass material (100)
-pyrolysing the biomass material (100) to obtain biochar (105) and pyrolysis gas (106)
-supplying gasification air (108) and pyrolysis gas (106) to a reaction chamber (30) in the reactor
-combustion of gasification air (108) and pyrolysis gas (106) in the reaction chamber (30)
-removing exhaust gas (110) from the reaction chamber (30)
-heating the biomass material (100) by indirect heat from the exhaust gas (110).

2. Process according to claim 1 comprising conveying the biomass material (100) through the material chamber (10) by gravitation.

3. Process according to claim 1 or 2 comprising drying the biomass material (100) by supplying indirect heat (115) from the exhaust gas (110).

4. Process according to any of previous claims comprising pyrolysing of the biomass material (100) by supplying indirect heat (115) from the exhaust gas (110).

5. Process according to claim 1 comprising transferring heat (115) from the exhaust gas (110) to the biomass material (100) via a first heat transfer surface (54).

6. Process according to claim 1 comprising transferring heat (115) from the exhaust gas (110) to the gasification air (108) via a second heat transfer surface (44).

7. Process according to any of previous claims comprising conveying the exhaust gas (115) between the first heat transfer surface (54) and the second heat transfer surfaces (44).

8. Process according to any of previous claims comprising supplying gasification air (108) directly via a gasification air conduit (40) to the reaction zone (20).

9. Process according to any of previous claims comprising mixing pyrolysis gas (106) with gasification air (108) in the reaction zone (20).

10. Process according to any of previous claims comprising conveying exhaust gas (110) upwards from the reaction zone (20).

11. Process according to any of previous claims wherein the reaction zone (20) reaches a temperature of at least 1100 °C, preferably above 1200 °C.

12. Process according to any of previous claims wherein the pyrolysis gas (106) is indirectly heated in the pyrolysis process to approximately 700 °C prior to supplying the pyrolysis gas (106) to the reaction zone (20) and wherein the gasification air (108) is indirectly heated to approximately 900 °C, prior to entering the reaction zone (20).

13. Process according to any of previous claims wherein the reactor vessel (5) is pressurized above atmospheric pressure.

14. Process according to any of previous claims wherein gas flow in the reaction zone is a low turbulent gas flow.

15. Reactor for producing biochar from biomass material (100) comprising a reactor vessel (5) having a material chamber (10) and a reaction chamber (30)
characterized in that the material chamber (10) is provided with a biomass material inlet (7) arranged to supply biomass material (100) in an upper end (5.1) of the material chamber,
that the reaction chamber (30) is connected to the lower end of the material chamber (10),
that the reactor vessel (5) is provided with a biochar outlet (71) in the lower end of the reactor vessel (5), that the reaction chamber is provided with a reaction zone (20),
that the reactor vessel () is provided with a gasification air conduit (40) configured to supply gasification air (108) to the reaction zone (20),
that the reactor vessel is provided with an exhaust gas channel (50) configured to remove exhaust gas (110) from the reaction chamber (30),
that the exhaust gas channel (50) is configured for transferring heat to the biomass material (100) from the exhaust gas (110).

16. Reactor according to claim 15 comprising that the material chamber (10) is configured such that the biomass material (100) is conveyed from the upper end (5.1) of the material chamber (10) to the biochar outlet (71) in the lower end by gravitation.

17. Reactor according to claim 15 or 16 comprising that the exhaust gas channel (50) is longitudinally extended between an exhaust gas outlet (50.1) arranged in the upper end of the reactor vessel (5) and an exhaust gas channel inlet (50.4) in the lower end of the vessel.

18. Reactor according to any of claims 15-17 comprising that the gasification air conduit (40) is longitudinally extended between an gasification air conduit inlet (42) arranged in the upper end of the reactor vessel (5) and an gasification air conduit outlet (41) in the lower end of the vessel.

19. Reactor according to any of claims 15-18 comprising that the exhaust gas channel (50) and the a gasification air conduit (40) are arranged inside the material chamber (10).

20. Reactor according to any of claims 15-19 comprising that the gasification air conduit (40) is arranged inside the exhaust gas channel (50).

21. Reactor according to any of claims 15-20 comprising that the lower end of the exhaust gas channel (50) is enlarged and holds the reaction zone (20).

22. Reactor according to any of claims 15-21 comprising that the lower end of the gasification air conduit outlet (41) is located a short distance above the lower end of the exhaust gas channel inlet (50.4).

23. Reactor according to any of claims 15-22 comprising the exhaust gas channel inlet (50.4) is provided with distribution means (55) for distributing the gasification air (108) in the reaction zone.

24. Reactor according to any of claims 15-23 comprising that the exhaust gas channel (50) is configured as a first heat transfer surface (54).

25. Reactor according to any of claims 15-24 comprising that the gasification air conduit (40) is configured as second heat transfer surface (44).

26. Reactor according to any of claims 15-25 comprising that the material chamber has an annular cross section and is arranged around the exhaust gas channel (50).

27. Reactor according to any of claims 15-26 comprising that the reactor vessel (5) is provided with an outer mantle (11) which has an increasing cross section area in direction towards the reaction chamber (30).

28. Reactor according to any of claims 15-27 comprising that the material chamber (10) is configured in between the reactor vessel outer mantle (11) and the exhaust gas channel wall (51), and that the width of the material chamber (10) increases in the direction towards the reaction chamber(30).

****

Fig. 1/3

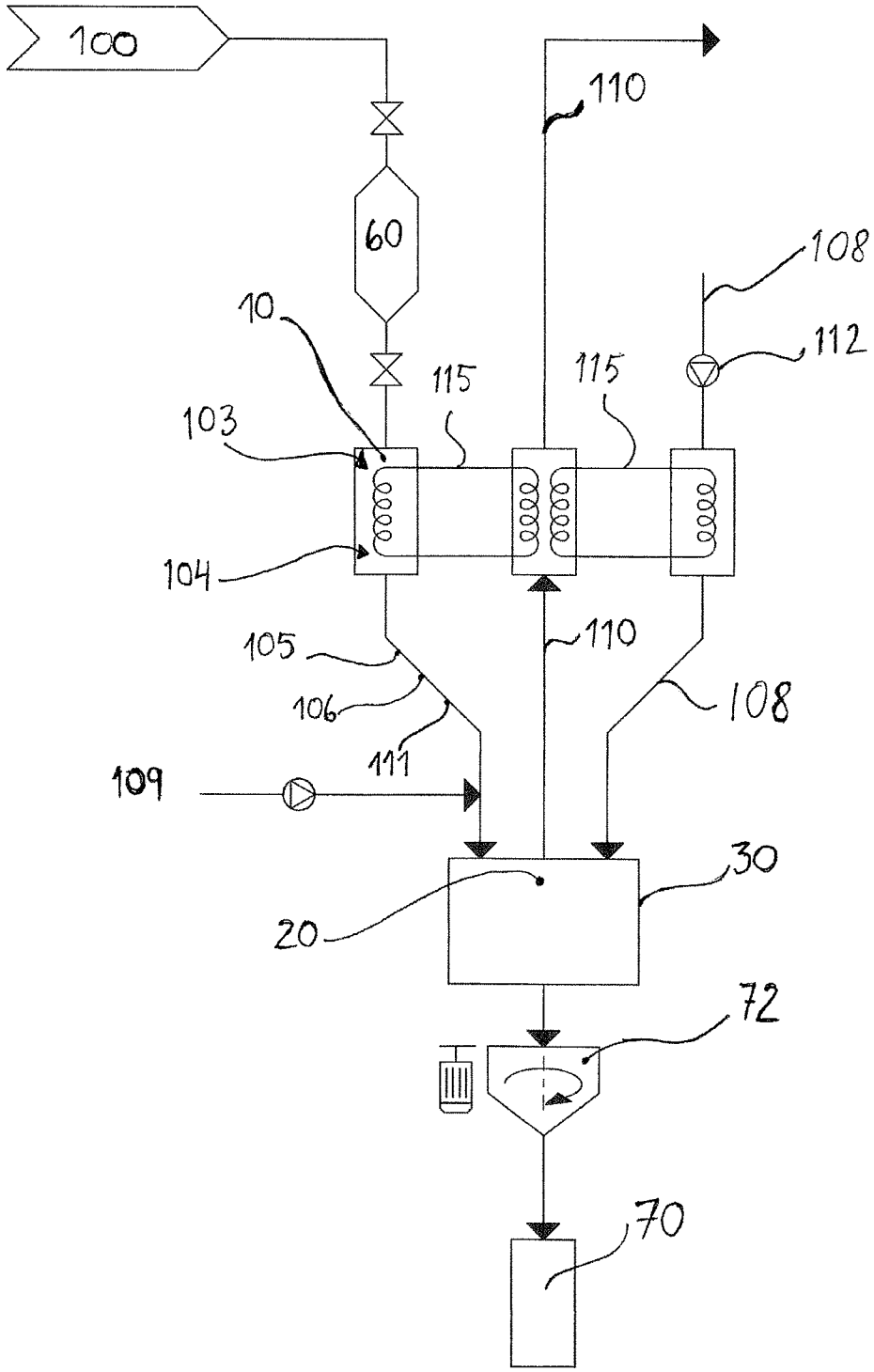

100
110
60
108
10
112
115
115
103
104
110
105
106
108
111
109
30
20
72
70

Fig. 2/3

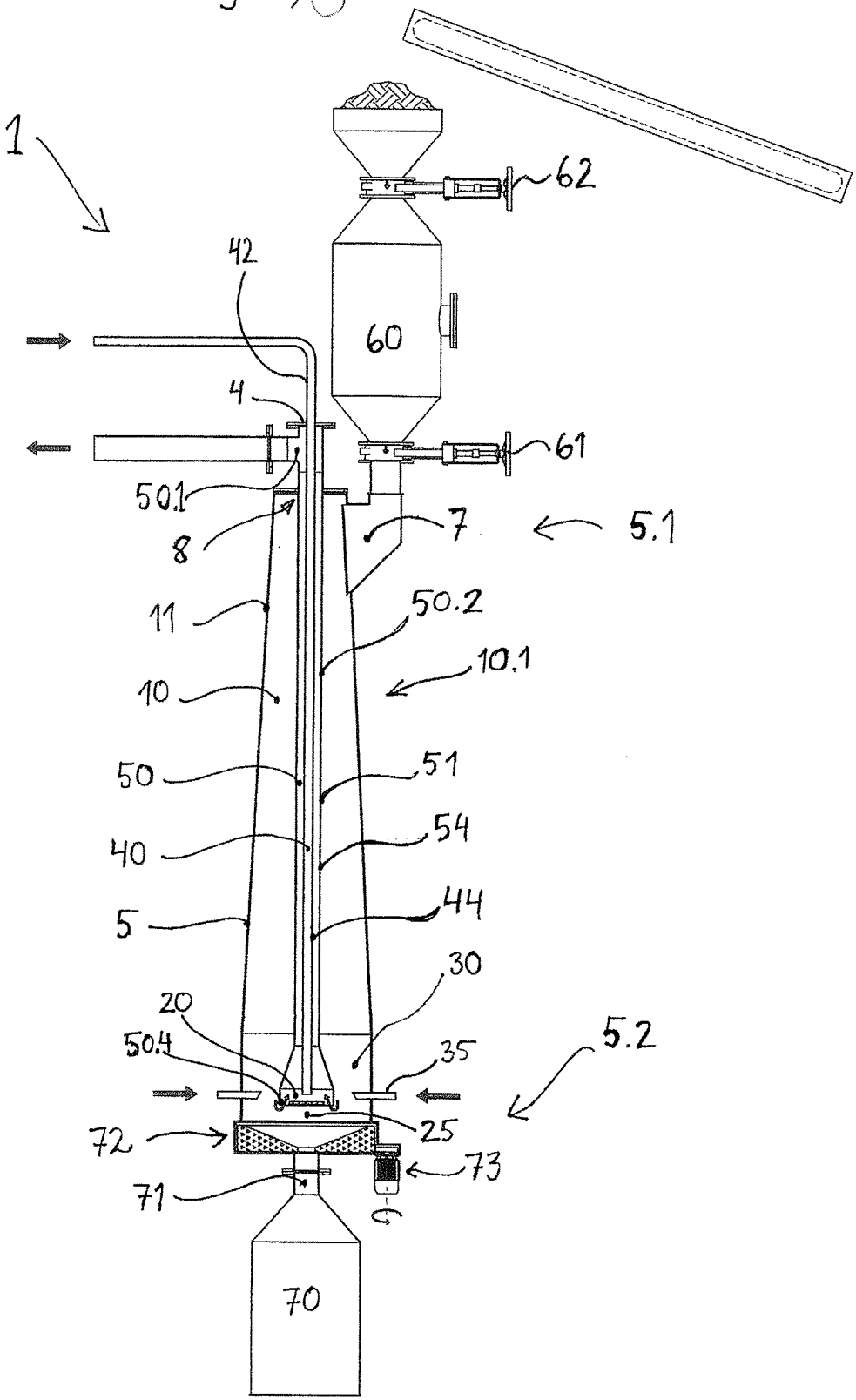
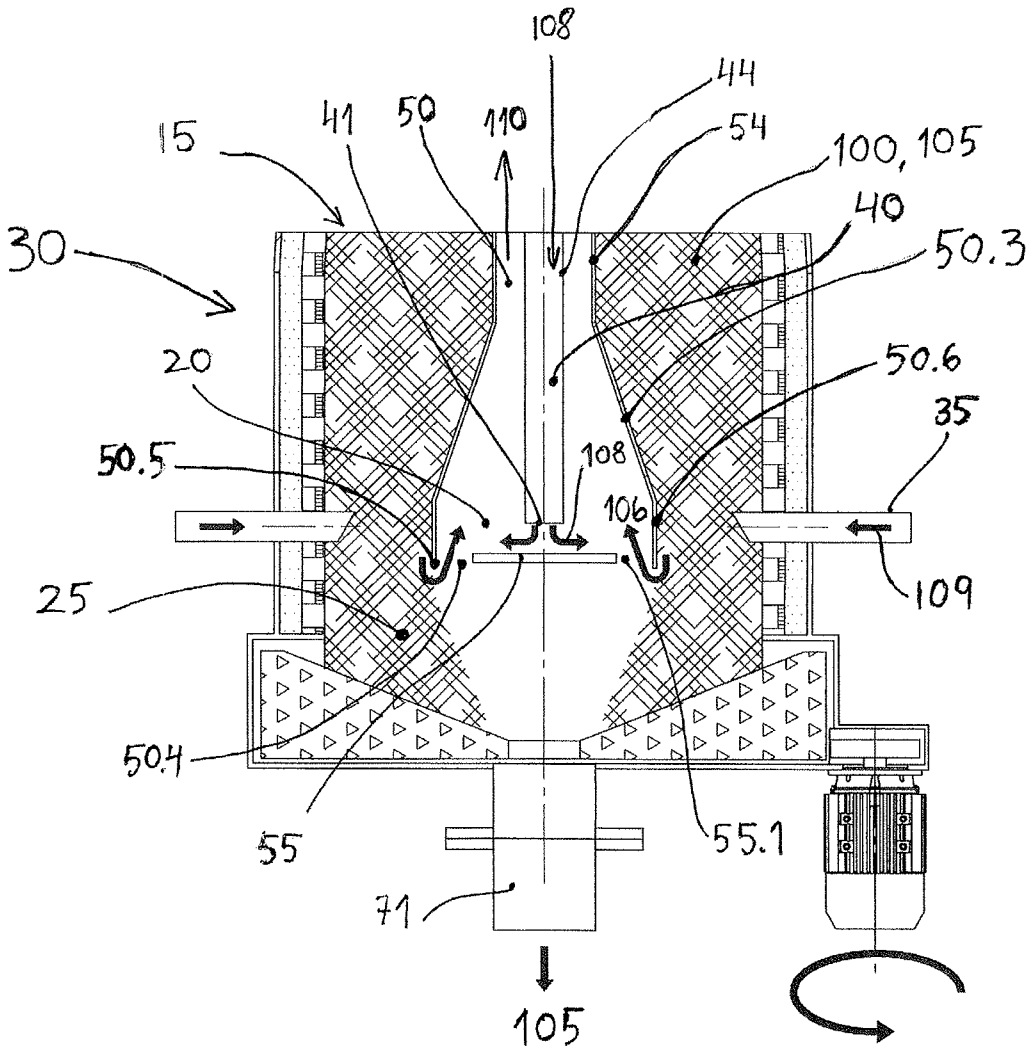

1
62
42
60
4
61
50.1
8
7
5.1
11
50.2
10.1
10
50
51
40
54
5
44
30
20
5.2
50.4
35
72
25
73
71
70

Fig. 3/3


108
44
41
50
110
54
15
100, 105
40
30
50.3
20
50.6
35
50.5
108
106
25
109
50.4
55
55.1
71
105

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2016/050479

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: C10B

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, 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	US 20160040070 A1 (MCCHESNEY IAN), 11 February 2016 (2016-02-11); abstract; paragraphs [0001], [0005]-[0020], [0062]-[0067], [0077]-[0081]; figure 1; claims 1-5 --	1-4, 8-10, 14
X	US 20130232863 A1 (STROMBERG BERTIL ET AL), 12 September 2013 (2013-09-12); abstract; paragraphs [0002]-[0004], [0006]-[0008], [0011]-[0017]; figure 1; claims 1,4-6 --	1-4, 8-14
X	US 20080223268 A1 (GEHRING MICHAEL W ET AL), 18 September 2008 (2008-09-18); abstract; paragraphs [0002], [0027]-[0030], [0034]-[0037]; figures 1-3 --	15-17, 23, 27

☒ Further documents are listed in the continuation of Box C. ☒ 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
06-02-2017	06-02-2017
Name and mailing address of the ISA/SE Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Authorized officer Cecilia Nystrand Telephone No. + 46 8 782 28 00

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2016/050479

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 20130185999 A1 (CHEN LI ET AL), 25 July 2013 (2013-07-25); abstract; paragraphs [0001]-[0004], [0063]-[0070], [0081], [0097], [0100]-[0101], [0113]-[0120]; figure 1; claims 1-4,19	15-17, 23, 27
	--	
A	US 20130055633 A1 (CAUSER THOMAS P), 7 March 2013 (2013-03-07); whole document	1-28
	--	
A	WO 2015089556 A1 (RENERGI PTY LTD), 25 June 2015 (2015-06-25); whole document	1-28
	--	
A	US 7077878 B1 (MUEHLEN HEINZ-JUERGEN ET AL), 18 July 2006 (2006-07-18); whole document	1-28
	--	
A	US 20120285814 A1 (DEL MONTE THOMAS R ET AL), 15 November 2012 (2012-11-15); whole document	1-28
	--	
A	US 20110258914 A1 (BANASIAK DENNIS S ET AL), 27 October 2011 (2011-10-27); whole document	1-28
	--	
A	US 5279712 A (CONSTANTINE ANTHONY), 18 January 1994 (1994-01-18); whole document	1-28
	--	

International application No.
PCT/SE2016/050479

Continuation of: second sheet

International Patent Classification (IPC)

C10B 53/02 (2006.01)
C10B 21/18 (2006.01)
C10B 1/04 (2006.01)
C10B 51/00 (2006.01)

US	20160040070	A1	11/02/2016	AU	2014242704	A1	22/10/2015
				CA	2907952	A1	02/10/2014
				EP	2978821	A1	03/02/2016
				GB	2512367	A	01/10/2014
				WO	2014155058	A4	04/12/2014
US	20130232863	A1	12/09/2013	AU	2010203110	B2	31/01/2013
				CA	2710625	A1	19/02/2011
				CN	101993700	A	30/03/2011
				EP	2287278	A2	23/02/2011
				JP	2011042786	A	03/03/2011
				JP	5650948	B2	07/01/2015
				RU	2010134535	A	27/02/2012
				RU	2534085	C2	27/11/2014
				US	20110041392	A1	24/02/2011
				US	8449724	B2	28/05/2013
				UY	32846	A	31/03/2011
US	20080223268	A1	18/09/2008	US	7798077	B2	21/09/2010
				WO	2008115853	A1	25/09/2008
US	20130185999	A1	25/07/2013	CA	2814165	A1	19/04/2012
				CN	103154209	B	24/02/2016
				EP	2627739	A1	21/08/2013
				FR	2965816	B1	25/04/2014
				JP	2013543537	A	05/12/2013
				JP	5913328	B2	27/04/2016
				US	9279089	B2	08/03/2016
				WO	2012049400	A1	19/04/2012
US	20130055633	A1	07/03/2013	US	20120233914	A1	20/09/2012
				US	8276289	B2	02/10/2012
				US	20100242351	A1	30/09/2010
				US	8322056	B2	04/12/2012
WO	2015089556	A1	25/06/2015	AU	2014366887	A1	30/06/2016
				CA	2929977	A1	25/06/2015
				CN	105874038	A	17/08/2016
				EP	3083886	A1	26/10/2016
				US	20160312124	A1	27/10/2016

US	7077878	B1	18/07/2006	AT	295401	T	15/05/2005
				AU	7780200	A	24/04/2001
				BR	0014217	B1	12/07/2011
				CA	2387690	C	14/12/2010
				CN	1376188	A	23/10/2002
				CN	1213129	C	03/08/2005
				CZ	20021021	A3	12/03/2003
				DE	19945771	C1	22/02/2001
				EP	1226222	B1	11/05/2005
				ES	2244476	T3	16/12/2005
				HR	P20020246	A2	30/06/2004
				HU	0202874	A2	28/12/2002
				JP	2003510403	A	18/03/2003
				JP	4264525	B2	20/05/2009
				MX	PA02003116	A	30/09/2002
				PL	194326	B1	31/05/2007
				PL	354103	A1	29/12/2003
				RU	2240341	C2	20/11/2004
				SI	20749	A	30/06/2002
				WO	0121730	A1	29/03/2001
US	20120285814	A1	15/11/2012	AU	2012256032	B2	22/12/2016
				CA	2836126	A1	22/11/2012
				CN	103842101	A	04/06/2014
				EP	2709773	A1	26/03/2014
				US	9005402	B2	14/04/2015
				WO	2012158579	A1	22/11/2012
US	20110258914	A1	27/10/2011	AU	2012256008	A1	19/12/2013
				BR	112013029457	A2	17/01/2017
				CA	2873385	A1	22/11/2012
				EP	2710092	A4	17/12/2014
				US	20120090221	A1	19/04/2012
				US	8425633	B2	23/04/2013
				US	8100990	B2	24/01/2012
				WO	2012158651	A3	21/02/2013
US	5279712	A	18/01/1994	AT	149195	T	15/03/1997
				DE	69217655	D1	03/04/1997
				EP	0584413	A1	02/03/1994