(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 284 245 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
16.02.2011 Bulletin 2011/07

(51) Int Cl.:
C10J 3/50 *(2006.01)*

(21) Application number: **10183554.4**

(22) Date of filing: **09.12.1998**

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI NL PT SE
Designated Extension States:
LT LV RO

(30) Priority: **09.12.1997 DK 142397**

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
98958839.7 / 1 021 499

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(54) Fluid bed reactor with particle separator and reaction chamber

(57) Gasification of solid carbonaceous material is performed in a circulating fluidised bed (CFB) gasifier which comprise a CFB reaction chamber (1), a particle separator (2) for separation of char-containing particles from the outlet gas (32) of the CFB reaction chamber, and a particle recirculation duct (5) for recirculation of the separated particles to the CFB-reaction chamber. The particle recirculation duct (5) comprises a char reaction chamber (3) for gasification of char contained in the recirculating particles. The function of the CFB gasifier may be controlled in different ways. Compared to the use of more traditional CFB gasifiers in which the char must be converted in the CFB reaction chamber, e.g. a cheaper and more compact construction, increased efficiency and increased fuel flexibility are achieved. The gasification process is well suited also for biofuels and waste products that have a high content of alkaline and chlorine.

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The invention relates to a method and an apparatus for gasification of solid carbonaceous material in a circulating fluidised bed (CFB) gasifier, which comprise a CFB reaction chamber, a particle separator for separation of particles containing char from the exit gas of the CFB reaction chamber and a particle re-circulation duct for re-circulation of the separated particles to the CFB reaction chamber. The re-circulation duct comprises a char reaction chamber for gasification of char contained in the separated particles.

[0002] In the most simple and most widespread types of CFB gasifiers, the char oxidation happens primarily in the CFB reaction chamber. The re-circulation duct may comprise a particle accumulation for the purpose of preventing that a large amount of gas flows from the CFB reaction chamber to the particle separator via the re-circulation duct, and/or for the purpose of controlling the rate of particle re-circulation. Such constructions are often designated as "non mechanical particle locks" and in English literature one distinguishes between subtypes that are typically designated: seal pots, J-vaives, and L-valves. In all of the mentioned versions, the function is based on the addition of a gas for mobilising, i.e. ejecting and/or fluidisation of particles in the particle valve. However, it is typical for such solutions that the added gas flow is small compared to the gas flow that is further added to the CFB reaction chamber. Furthermore, it is common practice to choose a gas with a low oxygen content as mobilising gas because the use of a oxygen containing gas such as atmospheric air may course damages on construction materials and particle sintering due to more or less locally increased temperatures.

[0003] Especially for the above-mentioned simple versions of CFB gasifiers, it is necessary to choose a temperature in the CFB reaction chamber that is sufficient to make the char react willingly with the gasification agent. Even for reactive fuels such as biomass, this often means that the possibilities for achieving a high char conversion are limited by the tendency for problematic agglomeration and/or deposition of ash and bed material, when the temperature is increased.

[0004] CFB gasifiers wherein re-circulation of particles takes place via a char combustion chamber are also known. This way, an elective conversion of the char and a more energy containing gas from the CFB reaction chamber can be achieved. Hence, the heating of the re-circulating particles means that the addition of oxidising agent to the CFB reaction chamber can be reduced. However, some major disadvantages are that the choice of combustion conditions leads to a need for a large square section in the char reaction chamber and that a considerable part of the fuel energy is converted to thermal energy in a considerable stream of hot flue gasses from the char combustion chamber.

[0005] It is also known to configure the CFB reaction chamber in such a way that a slowly and consequently high dense fluidised layer is formed in the bottom of the CFB reaction chamber to which char is re-circulated. The construction is more simple than the solution with two separate reaction chambers and also in this way it can be achieved that the oxidising agent is primarily used for oxidising char particles located in the slowly and densely fluidised layer. However, the possibilities for optimising the process conditions independently of each others in the CFB reaction chamber and the heavily fluidised layer are decreased, and moreover, the possibilities of retaining small particles will be limited by the elutriation of small char particles from the densely fluidised layer.

[0006] The invention provides a method for gasification of solid carbonaceous material in a circulating fluidised bed (CFB) gasifier, which method comprises addition of the carbonaceous material to a CFB reaction chamber in the gasifier, addition of oxygen-containing gasification agent to the gasifier, rejection of particle loaded product gas from the reaction chamber, separation of particles from the product gas and re-circulation of separated particles to the reaction chamber, and the method of the invention is characterised by converting char contained in the re-circulating particles to a combustible gas by adding a considerable part, preferably the main part and even better at least 75 % of the amount of oxygen added to the CFB gasifier in the form a oxygen-containing gasification agent to a char reaction chamber which exist in the re-circulation path for the separated particles.

[0007] In an improved version of the invention, the above mentioned definition of the distribution of added oxygen, not only consider the mass of free molecular oxygen but also oxygen bound in water vapour, carbon dioxide and other oxidising components that may be added to the CFB gasifier However, also in this case the possible addition of oxygen bound in components such as SiO_2 and Al_2O_3. which in the sense of gasification are not acting as oxidising, are disregarded as also oxygen chemically bound in the fuel.

[0008] The invention provides improved possibilities for converting solid carbonaceous fuel to a combustible gas. Compared to simple CFB gasifiers without a separate char reaction chamber, it is not least advantageous that a low temperature can be maintained in the CFB reaction chamber meaning that:

- the risk of operating disturbances due to deposition, sintering and agglomeration of ash and other particulate material in the CFB reaction chamber and down stream process path are decreased,
- the CFB reaction chamber and components in the down stream process path are made cheaper. This is as a consequence of highly reduced volume flow of gas, cheaper ceramic liner and reduced building height,
- the need for system-complicating, loss-providing, corrosional, ash depositional and in other ways problematic cooling of the product gas may be minimised and potentially completely avoided,

- the liberation of alkaline and chlorine to gas phase are limited and the following rebinding in solid phase is increased. This means that the content of these components in the product gas simply can be minimised by separation of particles from the product gas,
- the retention of chlorine and alkaline can be further improved by adding materials containing calcium,
- shorter start-up and closing-down time can be achieved due to the lower operating temperature as well as the possibility of choosing a thinner wall construction.

[0009] The above mentioned advantages will be pronounced if the outlet temperature of the CFB reactor is decreased to the range 500-700°C and especially for very volatile fuels such as biomass and household waste preferably to 500-600 °C.

[0010] Compared to the use of known CFB gasifiers with separate char reaction chambers, the method of the invention is very advantageous because:

- the CFB reaction chamber as well as the char reaction chamber contributes to the production of combustible gas,
- the need for square section in the char reaction chamber and ducts/components rejecting product gas from the char reaction chamber is limited by the limited addition of oxygen-containing gasification agent,
- the need for cooling and/or water vapour addition are also limited by the limited addition of oxygen-containing gasification agent.

[0011] The primary function of the CFB reaction chamber is to secure an effective pyrolyse-wise (by pyrolysis a thermal decomposition only due to heating is to be understood, i.e. excluding decomposition due to oxidation) conversion of the fuel, which typically can be achieved at a considerably lower temperature than necessary for effectively oxidising the char particles in a low oxygen atmosphere. Especially in fluidised bed reactors, wherein the fuel achieves an effective thermal contact with hot particles, especially volatile fuels such as biomass and household waste achieve a high pyrolyse-wise conversion to gas.

[0012] Instead of trying to convert the resulting char residue in the CFB reaction chamber, the char is transported to the top of the CFB reaction chamber together with the further content of particular material of the product gas. The limited extend of char oxidation in the CFB reaction chamber is lowering the tendency for the creation of a large amount of fine char and ash particles in the CFB reaction chamber, which improves the possibilities for effectively separating char and ash particles by the aid of the following particle separator.

[0013] From this separator the major part of the separated particles and preferably at least 90 % thereof is transferred to the char reaction chamber, wherein the char is converted by adding a proper oxygen containing gasification agent such as atmospheric air, pure oxygen, water vapour or mixtures thereof

[0014] In order to achieve the simplest possible construction, it is preferred that the mentioned conversion of the char is mainly performed in a single reaction chamber but naturally the char conversion could be distributed on several more or less physically separated reaction chambers,

[0015] The need for adding oxygen to the char reaction chamber will depend on the amount of char produced in the CFB reaction chamber which amount depends on the fuel as well as the more specifically chosen reaction conditions in the CFB reaction chamber, including particularly the temperature, mixing conditions and the size of the fuel particles. An effective gasification of the char added to the char reaction chamber as well as a proper release of thermal energy may however be anticipated by adding free molecular oxygen to an amount which is below 0.8 and preferably below 0.6 times the amount which would be necessary for a stoichiometric combustion of the char. Considerably lower consumption and higher heating value can be pursued by optimising the process conditions for achieving high concentrations of oxygen-lean or oxygen free components such as CH_4 and higher hydrocarbons in the outlet gas This e.g. by supporting the naturally performing catalytic phenomena and/or by adding catalytically active material. Compared to converting the char by combustion using a surplus of oxygen, the invention allows a reduction of the square section of the char reaction chamber and that the char reaction chamber contributes to the production of combustible gas.

[0016] The conversion of the fuel by pyrolysis in the CFB reaction chamber do not need the addition of oxygen, which means that especially highly volatile fuels such as many types of biomass can be gasified effectively in the gasification process by adding less than 0.4 and preferably less than 0.3 kg of free molecular oxygen per kg of dry fuel. The CFB reaction chamber as well as the char reaction chamber may additionally be fed with further gas such as water vapour, re-circulated product gas and flue gas. A major purpose may be to keep up proper temperatures and fluid dynamic conditions in the respective reaction chambers during varying choice of fuel and load,

[0017] The char oxidation in the char reaction chamber will result in that the particles re-circulating in the CFB gasifier achieve a temperature increase in the char reaction chamber and due to that, the thermal energy necessary for sustaining the mainly endothermal pyrolysis processes in the CFB reaction chamber can fully or partly be added by the addition of the circulating particles.

[0018] The method according to the invention may of course comprise further characteristics such as:

- the process may be fed with others than the mentioned particular materials for the purpose of stabilising the particle size distribution and/or absorption of various components such as components containing sulphur- and alkaline,

- one or several particle streams may be drained from the process, e.g. for the purpose of changing the particle size distribution and/or the chemical composition of the particular material and/or to avoid accumulation in the system and/or for the purpose of utilising the drained materials in other relations,
- drained particles may fully or partly be returned to the gasification process after a proper processing such as size classification, crushing, agglomeration as well as any other mechanical, thermal and chemical treatment,
- larger or smaller parts of the main components and connection ducts of the process including e.g. the char reaction chamber may be composed of cooled or uncooled components,
- the described process may be used at pressures being considerably higher as well as considerably lower than atmospheric pressure,
- the char bed may be utilised as a "loop seal", which e.g. is achieved by letting the particle inlet duct from the re-circulating particle separator exhaust at a level below the bed surface in the char reaction chamber,
- one CFB reaction chamber may be equipped with two or more particle re-eirculation ducts,
- one particle re-circulation ducts may serve several CFB reaction chambers,
- particle separators as well as other components of the process may be integrated in the CFB reaction chamber construction and/or in each other.

[0019] In addition, several other characteristics may, dependent on the application, give considerable further advantages.

[0020] In order to ascertain an effective pyrolysis, it is appropriate that the fuel addition to the CFB reaction chamber happens in a way that gives an intensive contact between the fuel and the particles in the CFB reaction chamber, i.e. it is appropriate that the feeding happens to a turbulent area that has a high particle concentration. Such conditions are most easily established near the bottom of the CFB reaction chamber. However, the desired effective contact may also be achieved by adding the fuel to a process stream which brings the fuel into the CFB reaction chamber and preferably to the bottom of the CFB reaction chamber.

[0021] For the method according to the invention, it is considered an advantage to keep the exit temperature of the CFB reaction chamber below 700 °C and preferably below 600 °C. In addition to the earlier mentioned advantages from low temperatures, this also limit the tendency for produced gaseous components to react further while producing solid carbon including soot. The temperature measured in the lower part of the CFB reaction chamber will preferably be limited accordingly.

[0022] The above mentioned low temperatures also enhance the possibilities for binding chlorine contained in e.g. straw, household waste and certain types of plastic into e.g. materials containing calcium such as limestone added to the process. In such cases, it is an advantage that the transport of particles to the upper part of the CFB reaction chamber secures an effective contact between e.g. added calcium containing particles and chlorine containing gasses When firing fuels and waste products containing chlorine, a further important characteristic may be the addition of calcium containing materials to the gasification process such as to the CFB reaction chamber. The particle separation in order to re-circulate particles via the char reaction chamber may be performed using any type of particle separator, such as.

- dynamic separators such as turn chamber-, labyrinth-, and cyclone separators,
- barrier filters such as high temperature bag filters, porous ceramic filters and granular bed filters,

including using various combinations of e.g. the mentioned separators.

[0023] In a preferred version of the invention, the product gas from the CFB reaction chamber is at first cleaned in a primary dynamic type of particle separator and thereafter in a secondary separator of more effective type. The re-circulation of particles through the char reaction chamber is in this case primarily performed from the first mentioned primary dynamic separator. The secondary separator may e.g. be a highly efficient barrier filter, but also a cyclone separator being more efficient than the primary separator including a multi cyclone separator. Further particle separation/gas cleaning may also in this version take place prior to the primary separator (using a pre-separator) as as after the secondary separator.

[0024] Hence, sufficient retention of char in the process will in most cases be achievable by the aid of a proper dynamic type primary separator, where as a barrier filter is better suited for fulfilling potential severe demands about low content of particles and other problematic components in the product gas. Hence, improved possibilities for binding problematic components such as chlorine, sulphur and alkalines in the filter cake as well as possibilities for oxidation of fine char particles are achieved by using a barrier filter. Improved char oxidation can be achieved by adding a proper oxidation agent such as atmospheric air, oxygen, or water vapour in the gas path prior to the filter

[0025] Especially barrier type filters of the type moving granular bed seems advantageous because:

- the product gas achieves a more effective contact with particular components contained in the product gas,
- effective retention/conversion of problematic components in the product gas can be achieved by adding chemically active particles such as limestone

and/or catalytically active particles to the filter, which may be done by adding such particles to the product gas prior to the filter and/or in form of the particular filter media which is currently added to the granular bed filter and preferably in counter current to the product gas.

- non-reversible blocking may be counteracted during operation by a more or less continuous replacement/processing of the filter media,
- excessive temperatures in the filter due to exothermal processes such as char oxidation can be counteracted by currently adding filter particles with a lower temperature than the temperature that would otherwise appear at the point of the addition,
- the filter may be used as an alternative to more traditional gas coolers, i.e. considerable cooling of the product gas may be achieved by cooling a particle circuit comprising the granular bed filter,
- the cooling of the product gas may this way be achieved without heat absorption surfaces being in direct contact with corrosive components in the product gas, and this way cooling medias cooling the particle circuit may be heated to high temperatures such as above 500°C, which allows a more efficient utilisation of the subtracted heat,
- the heat obtained by cooling the particle circuit may e.g. be returned to the gasification process by fully or partly using the heat for e.g. preheating the gasification agent or fuel drying and/or the heat can be used for heating a working media in an electricity producing process such as by superheating water vapour or heating a gas stream which is afterwards expanded in a gas turbine.

[0026] Hence, in a preferred version of the invention, the product gas from the CFB reaction chamber is passing a filter of the type moving granular bed. Also in this case, additional gas cleaning can be achieved by the aid of separators/filters located prior to as well as after the moving granular bed filter, and particles may be re-circulated and/or drained from all of the included filters.

[0027] It is also a possibility to use a barrier filter such as a granular bed filter as a re-circulating and possibly the only separator. In such cases it will be particularly relevant to remove ash and other potential residue products from the stream of separated particles instead of from a succeeding secondary filter and it would be relevant to construct the drains from the CFB process such as to selectively drain the reaction products which are aimed to be removed from the process For example, the particles separated from the barrier filter may be partitioned in two or several size classes and afterwards the smallest particles may be extracted from the gasifier. The later mentioned controlled agglomeration of ash particles is a further example of how such selective draining can be established.

[0028] In order to avoid an excessive pressure loss and that the product gas to a large extent carry small particles through the filter, the granular bed filter typically has to be dimensioned for low gas velocities such as below 3 m/s and preferably below 1.5 m/s which corresponds to a large flow square section compared to e.g. the flow square section of the CFB reaction chamber. In order to also achieve a compact plant, it is therefore an interesting possibility to integrate the granular bed filter in the top of the CFB reaction chamber, i.e. in a way that makes the granular bed filter more or less surround the top and while the product gas is added to the granular bed filter more or less directly from the top of the CFB reaction chamber and preferably in a rotational symmetric way. In those cases where it is a wish to reduce the particle content of the process gas before it passes the granular bed filter, a pre-separation of particles may be performed by initially passing the product gas from the top of the CFB reaction chamber through a pre-separator such as a turn chamber separator, which may also be fully or partly integrated in the CFB reaction chamber and surrounding it in a more or less rotational symmetric way.

[0029] It is clear that the above described methods and corresponding apparatus for cleaning and possibly also cooling of gasses using a granular bed filter can also be used in connection with any other methods and apparatus than those described here.

[0030] Adding the oxidation agent mainly to the particle re-circulation path including the char reaction chamber gives good opportunities for effectively converting the char In a preferred version of the invention, this advantage is enhanced by the mean temperature of the char reaction chamber being higher than the mean temperature of the CFB reaction chamber and preferably at least 50 °C higher. Regardless the potential choice of controlling the process on the basis of temperatures measured in other levels, mean temperatures here are to be understood as the temperatures existing in approximately half the height of the respective reaction chambers.

[0031] In a preferred version of the invention, the addition of the thermal energy needed for the predominantly endothermal pyrolysis processes is fully or partly obtained by adding particles from the char reaction chamber to the CFB reaction chamber, which particles have a higher and preferably at least a 25 °C higher temperature than the temperature of the product gas leaving the CFB reaction chamber.

[0032] Further preferred characteristics of the invention may contribute to forms of the char reaction chamber aiming a further optimised char conversion. This is by e.g.

- arranging the char reaction chamber as a slowly fluidised bubbling bed of particles, wherein the main part of the gas added to the char reaction chamber is added as fluidising gas,
- keeping the superficial velocity in the char reaction chamber below 1 m/s and preferably below 0.5 m/s. This minimises the tendency for mechanical wear on the char particles and also for their premature departure from the char reaction chamber along with

the product gas,

- the horizontal square section of the char reaction chamber being larger than the square section of the CFB reaction chamber and preferably at least twice as large. This is in order to allow a sufficient supply of gasification agent at a low superficial gas velocity,
- extracting particles intended for re-circulation to the CFB reaction chamber from the bottom of the char reaction chamber, where the char concentration can be expected to be considerably lower than in the top.

[0033] Especially in cases where a particularly low gas velocity in the char reaction chamber is preferred, e.g. due to a very weak char and/or the char being very reactive allowing a reduction of the bed height, the innovation may be improved by arranging the char reaction chamber as several mutually super posed char reaction chambers in order to achieve this way a more compact version of the gasification process. In this case, the square section area of the char reaction chamber shall be understood as the sum of the horizontal square section areas of the superposed char reaction chambers.

[0034] The mentioned tendency for char particles to concentrate in the top of the char reaction chamber is partly due to these particles appearing more fluid dynamically light due to a tendency for being less spherical than e.g. particles fluidised in a long time as well as low density/high porosity. Furthermore, some of the char particles will be relatively small. The tendency for lower char density and the formation of small particles is enhanced by the oxidation of the char particles in the char reaction chamber.

[0035] A further possibility for improving the method of the invention is to support the mentioned tendency for segregation in the char reaction chamber. This is by choosing one or several of the following conditions:

- a large bed height, such as more than 1 m and preferably more than 2 m,
- a good distribution of the fluidising gas over the bottom of the char reaction chamber,
- making the surrounding walls of the bed fully or nearly vertical.

[0036] The gasification of many fuels relevant for the method will result in a weak and fine ash. which is difficult to retain using especially dynamic particle separators, and which may give a tendency for fast blocking a barrier filter. Furthermore, it may be a problem to retain especially the smallest char particles in the process in the sufficient time for achieving a satisfying char gasification. It is therefore interesting to pursue a sintering and possibly an agglomeration of the ash- /char particles. E.g. this may be achieved by arranging or controlling the process with the intention of achieving a properly increased temperature in more or less extended fractions of the upper part of the char reaction chamber, where the concentration of fine ash-/char particles will be the highest due to the earlier mentioned segregation. Hence, an important improvement of the invention may be achieved by the addition of (temperature increasing) oxygen and/or (temperature decreasing) water vapour predominantly in respectively the upper and the lower part of the char reaction chamber. Notice, that the earlier mentioned large bed height will also improve the possibilities for creating considerable temperature differences in the char reaction chamber.

[0037] A possible tendency for major temperature differences may of course also be counteracted by the mentioned mechanisms, as also asymmetric addition of a controllable part of the fluidisation gas can moderate the temperature difference due to the increased thermal mixing created this way in the char reaction chamber.

[0038] From what has been mentioned, it is also clear that a more complex solution is to emphasise obtaining the advantages of the mentioned particle segregation as well as the mentioned creation of temperature differences in the char reaction chamber by partitioning the char reaction chamber into several chambers, which e.g. are supplied predominantly char-/ash lean or -rich particles and to which the addition of gasification agent differ concerning amount and composition. A further example on a more complex arrangement of the char reaction chamber is pre-heating the gasification agent in one chamber, and subsequently adding the gasification agent to another chamber.

[0039] In a preferred version of the invention, agglomeration is pursued through the above mentioned methods and to an extent that makes the agglomerated and i.e. enlarged ash particles sink to the bottom of the bed in order to be drained either directly from the bottom or through a compartment to which the particles are added. This method provides the opportunity of selectively and e.g. continuously draining non-combustibe components such as alkalines having a large tendency to form chemical components having low melting points. Some of these components, such as alkali chloride are relatively easy to separate, e.g. by water washing, which gives the opportunity of re-introducing particles refined this way to the process.

[0040] It is clear that the above mentioned methods for agglomerating, draining and possibly refining and re-introducing ash particles are also possible improvements of other methods and apparatuses than the one described here.

[0041] A further possible and considerable improvement of the invention is to cool the particles in the char reaction chamber by a therein located heat absorption surface and preferably a surface in the lower part of the char reaction chamber Hence, a number of advantages may be achieved:

- It becomes possible to limit the process temperature without adding excessive amounts of water vapour, which especially is advantageous in relation to fuels such as coal having a relatively high heating value and a low content of volatile components,

- the mentioned creation of temperature differences in the char reaction chamber may be enhanced by locating the heat absorption surface in the bottom of the char reaction chamber,
- heat can be extracted from the process using a heat transmission media at relatively high temperature. Hence, the corrosive exposure of the heat absorption surface in the lower part of the char reaction chamber is limited due to the corrosive components mainly being released from char particles and therefore it concentrates in the upper part,
- the necessary heat absorption surface area can be limited due to the high heat transmission coefficient that is achievable in especially the, also for earlier mentioned reasons, preferred slowly fluidised bed in the char reaction chamber.

[0042] Due to the volume it occupies, the location of especially a very compact heat absorption surface in the bottom of the char reaction chamber will also act as to limit the need for adding fluidising gas in the bottom of the char reaction chamber. A similar effect of limiting the flow square section area may additionally or alternatively be achieved by locating one or several wall elements reaching up to some level in the char reaction chamber from the bottom of this chamber. Such wall elements may also be applied in order to limit the vertical mixing of the particles.

[0043] Aiming better possibilities of adopting the gasification process for various fuels, yields and applications, the heat absorption via the mentioned heat absorption surface may be made controllable by e.g.

- varying the fluidisation velocity in the part of the bed containing the heat absorption surface
- varying the amount and/or inlet temperature of the cooling media,
- locating the heat absorption surface in a separate fluidised bed, wherein the bed height can be varied for the purpose of exposing a varied fraction of the heat absorption surface,
- varying the temperature in the part of the char reaction chamber wherein the heat absorption surface is located, this e.g. by asymmetric addition of fluidising gas in order to achieve control on the thermal mixing in the bed.

[0044] In order to provide an optimal control on the parameters of the gasification process, re-circulation of particles from the char reaction chamber to the CFB reaction chamber may in a further improved version of the invention be performed via one or several ducts which may contain control means that makes it possible to control the flow of particles, In this version of the invention e.g. improved possibilities: for temperature control may be achieved by bringing the particles into contact with a heat absorption surface in one or severe of the mentioned return ducts. The mentioned possible control means are preferably of a non mechanical type, i.e. the particle flow rate is controlled by adding a gas that mobilise the particles to an extend that depends on the gas addition.

[0045] In a preferred version of the invention, particles are transferred from the char reaction chamber to the CFB reaction chamber via at least one particle re-circulation duct that adds particles into the bottom of the CFB-reaction chamber via a predominantly vertical connection duct. In a corresponding particularly compact construction, the mentioned predominantly vertical connection duct is surrounded by the char reaction chamber and this preferably in a way that the char reaction chamber surround the re-circulation duct as a rotation symmetric ring chamber

[0046] The above mentioned preferred rotation symmetric construction of the char reaction chamber gives also the possibility of performing the earlier mentioned sintering and potentially also agglomeration in a particularly simple and well controlled way. Hence, the addition of gas containing oxygen in order to create a zone with increased temperature in preferably the upper ash and char rich part of the char reaction chamber may be to some few locations and possibly only to a single location in the char reaction chamber. This is by making the particles in the char reaction chamber rotate around the vertical particle re-circulation duct in such a way that especially the small and light particles in the upper part of the ring chamber are passing a zone with increased temperature at a proper time frequency. The mentioned rotation may simply be established by adding one or several process streams such as the gasification agent, the oxidising agent creating increased temperature and re-circulating particles with some momentum in a direction supporting the mentioned rotating movement.

[0047] The above mentioned preferred forms of construction allows the flow of particles through the connection duct to be simply controlled by adding a gas which to an extend depending on the added amount creates a transport of particles upwards into the CFB reaction chamber. In those cases, where it is preferred to minimise the addition of gas to the mentioned predominantly vertical connection duct, the flow square section of the duct can be less than 25 % and preferably less than 10 % of the horizontal square section area of the CFB reaction chamber.

[0048] The vertical part of the connection duct may also be given a considerably larger horizontal square section area and e.g. appear as a downwards extension of the CFB reaction chamber. This way, a larger part of the oxidation agent added to the process may be added to the connection duct, and this way, char oxidation in the connection duct may to a considerable extent supplement the char oxidation in the char reaction chamber. This way it can be counteracted that char particles brought out of the char reaction chamber along with the circulating inert particles leads to losses of unconverted char and also that large char particles accumulates in the bottom of the CFB reaction chamber. The possibility of counteracting the accumulation of large particles is especially an advantage when the expenses for reducing the particle size are to be minimised.

[0049] A further simple possibility is to drain out potential larger non-combustible particles (which e.g. are added to the CFB reaction chamber with the fuel or which are formed as a consequence of agglomeration) from the bottom of the above mentioned predominantly vertical connection duct.

[0050] Depending on the purpose of the CFB gasifier, the product gas from the char reaction chamber may fully or partly be added to e.g. the CFB reaction chamber, the outlet product gas from the CFB reaction chamber or to applications external to the gasification process.

[0051] In a preferred version of the invention, a considerable part and e.g. at least 50 % and preferable at least 75 % of the product gas from the char reaction chamber is transferred to the CFB reaction chamber and preferably to the bottom of the CFB reaction chamber in order to make the gas serve as fluidisation gas,

[0052] However, a particularly simple and therefore attractive possibility is to add essentially all of the product gas from the char reaction chamber to the CFB reaction chamber. The need for a separate system for exhausting and cleaning the product gas from the char reaction chamber may this way be minimised and potentially fully avoided, and moreover, the need for adding further fluidising gas in the CFB reaction chamber can be minimised.

[0053] The latter mentioned is of primary interest in order to minimise the gas streams and the thermal losses in the gasification process and in order to produce a gas with maximum heating value, Hence, in a preferred version of the invention, the product gas added from the char reaction chamber constitutes at least 50 % and preferable at least 80 % of the total stream of gas added to the CFB reaction chamber.

[0054] In a further preferred and particularly simple version, the addition of product gas from the char reaction chamber to the CFB reaction chamber happens in approximately the same vertical level as the surface of the bed in the char reaction chamber. This way the ducting of product gas from the char reaction chamber to the CFB reaction chamber can be short and simple and in the same time there is easy access for achieving a simple and well controlled transfer of particles via a duct connecting the bottom of the char reaction chamber by the bottom of the CFB reaction chamber.

[0055] In further preferred versions of the invention, the product gas from the char reaction chamber is fully or partly passing one or several of the following process steps:

- a particle separator for re-circulation of particles to the char reaction chamber, This is in order to optimise the char conversion and gas production and in order to achieve an increased retention of ash, including the content of mineral components in the char.
- a reaction chamber to which an oxidation agent such as air is also added in order to oxidise fine char particles. This is also for the purpose of increased conversion of char, but the purpose may also be to modify the ash into a more appropriate form, including sintering, agglomerating and/or melting the ash,
- a particle separator and preferably a barrier filter for removing fine ash particles.

[0056] The functions corresponding to several of the above mentioned process steps may of course also be achieved in combination, such as by adding oxidation agent to a particle separator, from which any share of the separated particles is either drained or returned to the char reaction chamber.

[0057] A number of primary process parameters may e.g. be controlled by the aid of a proper combination of the following possibilities:

- Product gas flow by controlling:
  - added amount of fuel
- Temperature in the CFB reaction chamber by controlling:
  - the particle re-circulation rate from the char reaction chamber to the CFB reaction chamber,
  - the temperature of the rc-circulating particles, including by controlling the temperature of the char reaction chamber and/or by controlling the heat absorption via potential heat absorption surfaces, including by controlling the re-circulation through potential cooled particle re-circulation ducts.
- Char conversion in the process by controlling:
  - the temperature in the char reaction chamber,
  - the amount of oxidation agent added to other places, including to the mentioned particle-and gas ducts and up-stream in relation to a potential barrier filter.
- Temperature in the char reaction chamber by controlling:
  - the amount of oxygen-containing gasification agent added to the char reaction chamber,
  - the amount of added water vapour,
  - the extent of cooling
- Particle content and by this the pressure loss in the CFB reaction chamber and/or particularly in the upper part of the CFB reaction chamber by controlling:

  - the size distribution of circulating particles, e.g. by adding/draining preferably large or small particles to/from the particle loop,
  - the amount of fluidisation gas added to the CFB reaction chamber from the char reaction chamber,
  - the amount of additional gas such as re-circuiated flue gas added to the CFB reaction chamber.
  - the rate of particle re-circulation from the char reaction chamber to the CFB reaction chamber.

- particle content and/or bed height in the char reaction chamber by controlling:

  - the amount of oxygen-containing gasification agent added to the char reaction chamber,
  - the flow of water vapour added to the char reaction chamber,
  - addition/draining particles to/from the system, including draining by the aid of a spill-over in the char reaction chambers

[0058] Given a certain amount of fuel, a preferred version of the invention is mainly controlled in the following way:

- desired temperature in the CFB reaction chamber is achieved by controlling the flow of particles from the char reaction chamber to the CFB reaction chamber
- desired temperature in the char reaction chamber is achieved by controlling the amount and/or composition of gasification agent added to the char reaction chamber.

[0059] The desired temperatures in the respective reaction chambers may additionally or alternatively be achieved by the aid of one of the mentioned methods for controllable cooling,

[0060] The method and apparatus according to the invention are, due to the mentioned characteristics, especially advantageous for fuels with one or several of the following, characteristics:

- high content of volatile components, such as above 50 %.
- high content of chlorine, such as above 0.5 %.
- high content of alkaline, such as above 1%.
- low ash softening temperature, such as below 900°C.

[0061] Straw, wood, household waste, plastics containing chlorine, and various types of de-watered sludge are examples on such fuels. However, the possibilities of achieving a high energy efficiency, minimisation of the plant costs and achieving a product gas with a relatively high heating value is also interesting in relation to other solid fuels including coal with one or several of the above characteristics.

[0062] Especially the fraction of product gas produced by pyrolysing the fuel in the CFB reaction chamber, will contain a large fraction of heavy organic components, which, if condensing, may cause problematic depositions and perhaps blockages in ducts and process equipment. The process is therefore of primary interest for system applications wherein the product gas is transferred to its use at a temperature of at least 200 °C and preferably at least 400 °C Such hot and preferably adiabatic transfer of the product gas in the same time minimises the thermodynamic irreversibility and the plant expenses and potential operational problems related to cooling such gasses. However, it is also a possibility that the gas is treated in order to decompose the mentioned heavy organic components.

[0063] The method of the invention is particularly interesting in relation to using the product gas as a fuel in an electricity-producing process, and preferably processes wherein the product gas is used as fuel in a steam boiler, gas turbine, combustion engine, or a fuel cell plant. When the gas is applied in solid fuel fired combustion chambers such as in steam boilers, a particularly interesting option is fully or partly using the product gas as so called "re-burning" gas, i.e. for the purpose of reducing the emission of nitrogen oxides.

[0064] In cases where the particle loop of the gasification process and/or a potential granular bed filter are, as previously described, equipped with one or several heat absorption surfaces, it is a preferred solution that such heat absorption surfaces are cooled by a process stream from the connected gas consuming system, e.g. cooling is by water vapour from a steam circuit or by combustion air for e.g. a boiler, gas turbine or fuel cell. The cooling energy may also be used for drying of potential fuels with high water content and/or for heating any other process stream.

[0065] Due to the content of condensable organic components of high market value, it is also of primary interest to separate such products. This is preferably done by cooling and/or quenching the product gas, and preferably this cooling and/or quenching takes place within a few seconds and preferably within I second after the introduction of the corresponding fuel particles in the reaction chamber.

[0066] Amongst others, it is this way possible to produce liquid fuels including so called bio-oil and chemicals for smoke treatment of food products, In relation to the last mentioned use of the gasification process, it can be advantageous to utilise the good possibilities for controlling and diverging the temperature in the char reaction chamber and the CFB reaction chamber. Hence, it can be appropriate to choose temperatures considerably below 500°C in the CFB reaction chamber,

[0067] By the invention there is also provided an apparatus of the type having a circulating fluidised bed (CFB) gasifier for the gasification of solid carbonaceous material and comprising a CFB reaction chamber, which is connected to a panicle separator, from which particles separated from product gas from the CFB reaction chamber can be returned to the CFB reaction chamber via a particle re-circulation duct, the apparatus also comprising means for adding the carbonaceous material to the CFB reaction chamber and means for adding a gasification agent to the gasifier, and the apparatus according to the invention is characterised by the forming of a char reaction chamber in the re-circulation duct and by that the means for adding the gasification agent are designed for supplying a considerable part and preferably the main part of the amount of oxygen added to the CFB gasifier to the char reaction chamber in form of an oxygen containing gasification agent for converting char, which is contained in the re-circuiating particles, to a combustible gas.

[0068] In the following, the invention will be further explained while referring to the drawing whereon

> figure 1 schematically shows a simple version of the apparatus according to the invention,
>
> figure 2 schematically shows another version of the apparatus according to the invention, and
>
> figure 3 schematically shows a version of the char reaction chamber, which in a simple way makes it possible to perform sintering and/or agglomeration of ash-/charparticles.

[0069] Figure 1 shows schematically an apparatus in the form of a CFB gasifier, that has a CFB reaction space or -chamber I with an outlet 4 for particle loaded gas 32, a cyclone separator 2 for separation of particles from the gas and a char reaction chamber 3, to which the separated particles 33 are added from the separator via a duct 5. Fuel 40 is added to the CFB-reaction chamber at its bottom and in the reaction chamber 1, the fuel is pyrolysing as the consequence of an effective contact to particles 35, which are re-circulated from the char reaction chamber 3.

[0070] The char reaction chamber 3, which is functioning as a gasifier, is primarily a slowly fluidised bubbling bed of the separated particles 33. Oxygen-containing gasification agent such as air and potentially water vapour is added as fluidising gas 36. By the aid of a heat absorption surface 8 located in the bottom of the char reaction chamber 3, a part of the thermal energy from the char gasification is transferred to the cooling media 43.

[0071] Particles 35 are re-circulated from the bottom of the char reaction chamber 1 via a predominantly vertical duct 6, while the rate of re-circulation is controlled by adding a variable gas stream 38 to the vertical duct. A further added gas stream 37 ascertain the mobility of the particles in a short horizontal duct connecting the char reaction chamber 3 to the vertical duct 6

[0072] In order to avoid an accumulation of non-combustible particles and potentially of formed agglomerates, a particle stream 42 may be drained from the lower part of the vertical duct 6.

[0073] Product gas 34 is transferred from the top of the char reaction chamber into the bottom of the CFB reaction chamber 1 via a duct 7, where this gas serves as fluidising gas. Additional fluidising gas 39, such as flue gas from the process using the produced product gas 41, may be added in order to impact the flow condition of gas and particles 31 up through the CFB reaction chamber in a preferred direction.

[0074] Figure 2 shows another version of the apparatus according to the invention, which comprises a number of further possibilities for optimising the gasification process in relation to given fuels and applications.

[0075] The CFB-gasifier may, besides the already mentioned items, comprise a pre-separator 9 for re-circulating particles directly to the CFB reaction chamber 1, and after the re-circulating separator 2 there may be a secondary separator 10, from which further particles 58 can be re-circulated to the char reaction chamber 3 or be drained at 54. As it is shown, it can also be chosen to drain a partial stream of particles 53 from the primary separator 2, which is particularly relevant, if a highly effective filter is chosen as the primary and potentially the only separator.

[0076] An oxygen-containing gas 44 can, as it is shown, be added in the char reaction chamber for the purpose of creating an increased temperature in locations in the upper part of the fluidised bed. This is primarily done in order to give the ash particles existing in the upper part of the bed a heat treatment, By this method the possibilities for retaining the ash by the following particle separators are improved and/or the ash can be made to agglomerate to an extent that it achieves a sufficient size and mechanical stability to supplement the circulating particular media in the gasifier and/or it may be drained as a relatively coarse particle stream, respectively 50 and 42 through respectively the bottom of the char reaction chamber 3 and the bottom of the CUB reaction chamber 1.

[0077] Alternatively or additionally to heat absorption via the earlier mentioned heat absorption surface 8, heat may be extracted by the aid of a heat transmission media 51, added to a heat absorption surface 11 which i located in e.g. one of two parallel ducts for the re-circuiation of particles to the CFB reaction chamber 1. This way the heat absorption can be effectively controlled using control means 15. These control means are preferably a non-mechanical type and may be combined in a single control mean deciding the share of the re-circulating particle stream that has to pass the heat absorption surface.

[0078] Furthermore, it can be seen that the product gas stream 34 from the char reaction chamber 3 can be treated in:

- a separator 12 which is re-circulating char and ash to the char reaction chamber 3,

- a reaction chamber 13, to which there may be a supply of further char oxidation agent 46 for additional conversion of fine char particles and/or for heat treatment of ash particles,
- a further particle separator 14 for separation of particles 47 from the product gas from the char reaction chamber 3.

[0079] The particle separator 14 may e.g. be a highly effective barrier filter, which cleans the gas in order to fully or partly extract it as a stream 56 in stead of as also shown, adding it to the CFB reaction chamber I or to the exit gas from this chamber.

[0080] It is obvious that the functions corresponding to the process steps 12, 13 and 14 can be combined, e.g. in a single process step, from which particles possibly only partly are re-circulated to the char reaction chamber 3 and to which a an oxidation agent 46 is added.

[0081] Eventually it is shown that additives 52 such as limestone may be added to the CFB reaction chamber. This is in order to enhance the retention of problematical gasses, such as gasses containing chlorine.

[0082] Figure 3 further illustrates the possibility of sintering and possibly agglomerating ash~/ char particles in the char reaction chamber 3. In the case shown, a directional addition of gasification agent 36 as well as the oxygen containing gas 44 to the creation of an overall movement of the particles in the char reaction chamber. This movement makes the ash-/char particles pass a zone having an increased temperature, which appears as a consequence of exothermic reactions between the oxygen-containing gas 44 and combustible components in the char reaction chamber.

[0083] The possibility of giving the ash-/char particles a well defined heat treatment by this simple method is particularly present when the char reaction chamber is constructed rotational symmetric and e.g. as a ring chamber. The horizontal movement of particles indicated in figure 3 corresponds in this case to a rotating movement of particles in the char reaction chamber.

Claims

1. Apparatus for gasification of solid carbonaceous material comprising

- a CFB reaction chamber (1) comprising a fluidized bed provided with means for adding fluidizing gas which CFB reaction chamber (1) has an inlet for carbonaceous material and a top outlet (4) for particle loaded product gas (32),
- a particle separator (2, 10) receiving the particle loaded product gas (32) from the CFB reaction chamber (1) and separating particles from the particle loaded product gas (32), the particle separator (2, 10) comprises an outlet for separated particles (33, 58) connected to a duct,
- a char reaction chamber (3) comprising a fluidized bed and having an inlet for the particles from the particle separator (2, 10),

characterized in that the char reaction chamber (3) comprises means for adding an oxygen-containing gasification agent (36) such as atmospheric air, pure oxygen, water vapor or mixtures thereof and that the apparatus comprises a flow-wise connection (7) conducting product gas (34) from one or several openings in the lower char reaction chamber (3) to one or several openings in the lower part of the CFB reaction chamber (1).

2. Apparatus according to claim 1, wherein one or several of said flow-wise connections comprises means for controlling the flow rate through the flow-wise connection.

3. Apparatus according to claim 2, wherein the control means are of a non-mechanical type i.e. the particle flow rate is controlled by adding a gas that mobilize the particles to an extend depending on the gas addition.

4. Apparatus according to claim 1, 2 or 3, wherein one or several of said flow-wise connections comprise one or several heat absorption surfaces.

5. An apparatus according to any previous claim, wherein the particle separator comprise a primary separator (2) provided with a duct (5) through which separated particles (33) are fed to the char reaction chamber (3).

6. An apparatus according to any previous claim, wherein the CFB reaction chamber (1) comprises an inlet for product gas (34) in approximately the same level as the surface of the bed in the char reaction chamber (3).

7. An apparatus according to any previous claim, wherein the apparatus comprises a separator (12) placed downstream of the char reaction chamber (3) which separator re-circulates char and ash from the product gas (34) to the char reaction chamber (3).

8. An apparatus according to any previous claim, wherein the apparatus comprises a reaction chamber (13) provided with an inlet for char oxidation agent (46) placed downstream of the char reaction chamber (3) in which reaction chamber (13) additional conversion of fine char particles and/or heat treatment of ash particles takes place.

Fig. 1

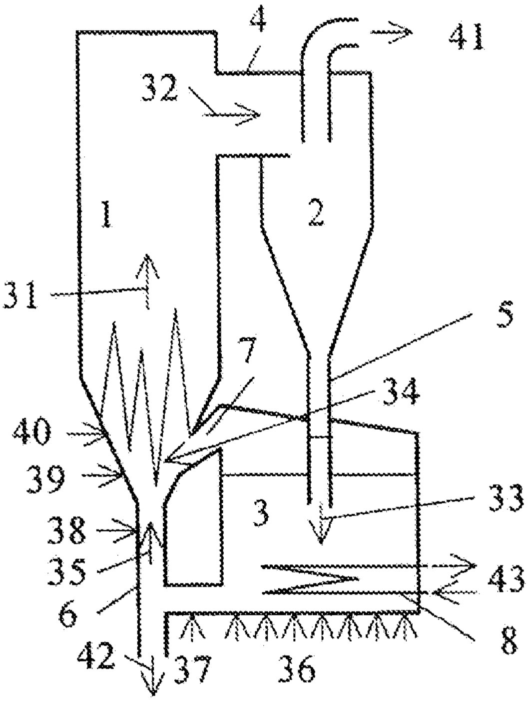
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Fig. 2

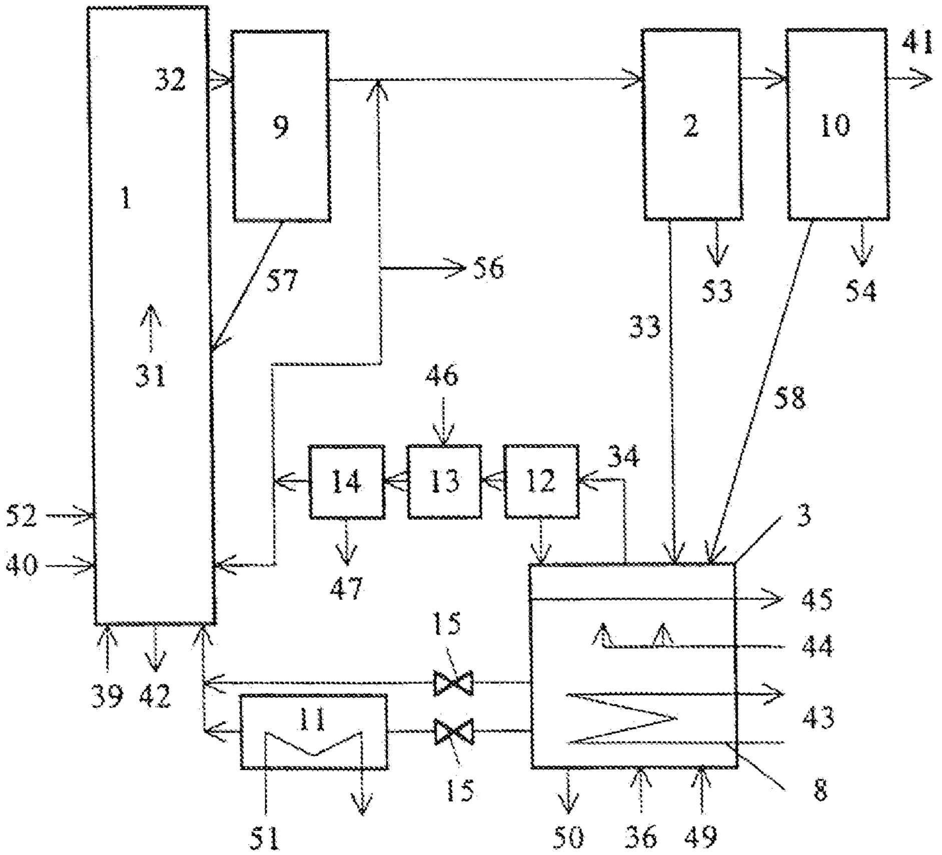
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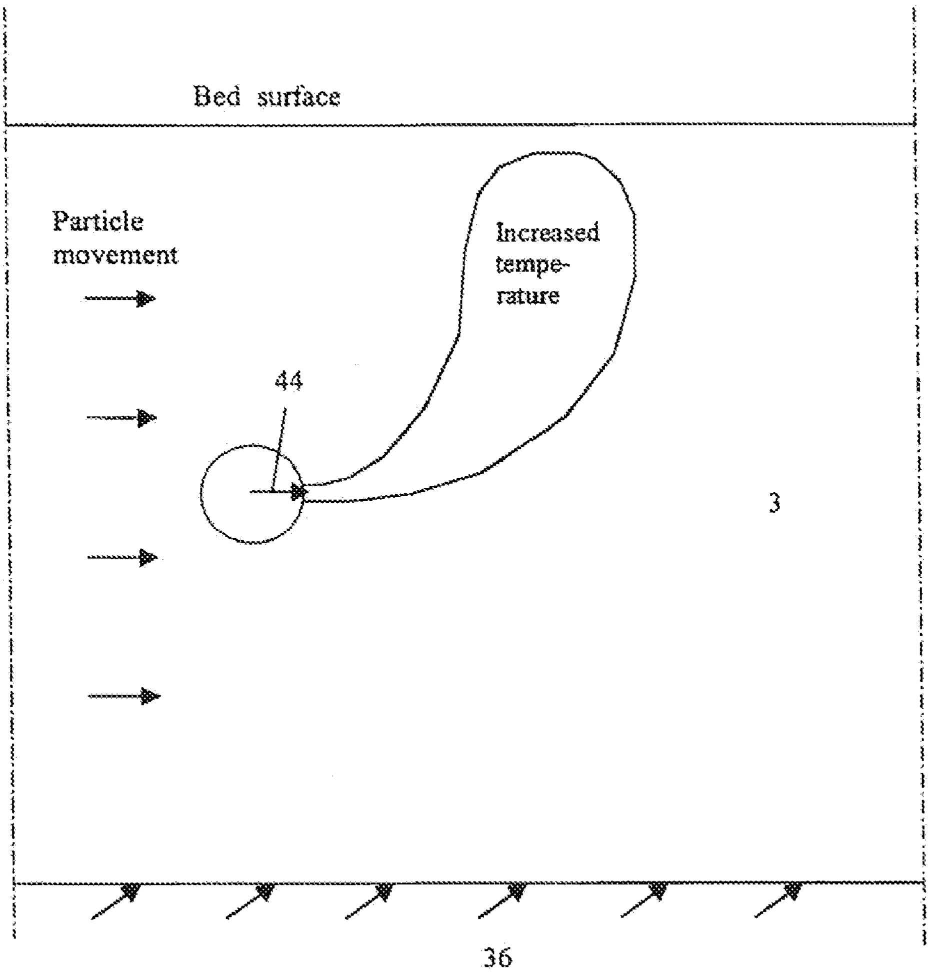
Fig. 3


Bed surface
Particle movement
Increased tempe-rature
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EUROPEAN SEARCH REPORT

Application Number
EP 10 18 3554

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	8 December 2010	Rumbo, Angel

CATEGORY OF CITED DOCUMENTS

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Application Number
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Place of search	Date of completion of the search	Examiner
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