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(71) Applicant: **Institut Problem Khimicheskoi Fiziki Rossiiskoi AK**
Moskovskaya obl., 142432 (RU)

(72) Inventors:
- **DOROFEENKO, Sergei Olegovich**
  Moskovskaya obl., 142432 (RU)
- **ZAICHENKO, Andrei Yurievich**
  Moskovskaya obl., 142432 (RU)
- **ZHIRNOV, Alexandr Alexandrovich**
  Moskovskaya obl., 142400 (RU)
- **MANELIS, Georgy Borisovich**
  Moskovskaya obl., 142432 (RU)
- **POLIANCHIK, Evgeny Viktorovich**
  Moskovskaya obl., 142432 (RU)

(74) Representative: **Johnson, Terence Leslie**
Marks & Clerk
90 Long Acre
London
WC2E 9RA (GB)

(54) METHOD FOR PROCESSING CONDENSED FUEL BY GASIFICATION AND A DEVICE FOR CARRYING OUT SAID METHOD

(57) The invention relates to a method for processing condensed fuels, including solid fuel wastes, by pyrolysis and by gasifying the organic constituent thereof. The inventive method can be used for efficiently processing fuels, including fine-dispersed and easily sintering fuels. The inventive method consists in loading a condensed fuel in a reactor to which a gasifying oxygen-containing agent is supplied in a countercurrent manner, in organising a fuel pyrolysis in the reactor and, subsequently, in burning/gasifying pyrolysis carbon residues in the fuel dense layer. The reactor is embodied in the form of a rotary tilting furnace whose tilt angle to the horizon is equal to 22-65° and which is rotatable for stabilising a burning process. Combustible gases produced during pyrolysis and gasification can be used in the form of a fuel.

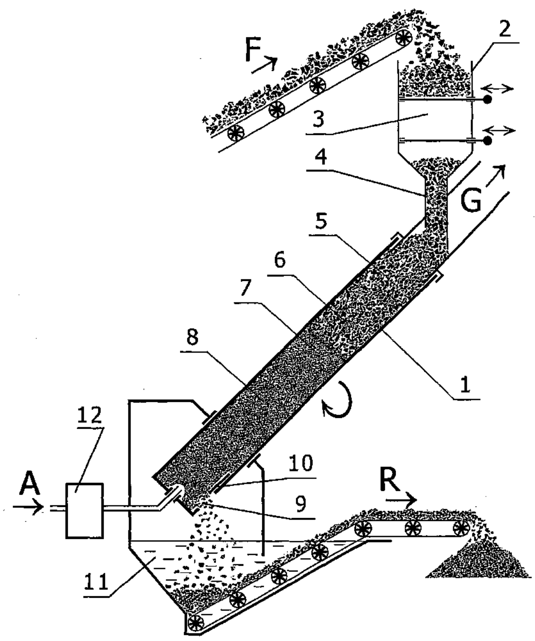

Fig. 1

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Description

FIELD OF THE INVENTION

[0001] The present invention generally relates to methods for processing condensed fuels, including solid fuel wastes, by pyrolysis and by gasifying the organic constituents thereof in a dense layer to produce pyrolysis products and gas fuel used for power generation. The problem of processing low-grade condensed fuels, including solid domestic waste (SDW), coals, oil-slime, biologic mass, is rather urgent because conventional methods of disposal/processing thereof suffer largely from being uneconomical and environment-unfriendly. Considerable advantages are provided by gasifying the condensed fuels which makes it possible to employ advanced power generation techniques with ecologically pure gas emissions.

BACKGROUND OF THE INVENTION

[0002] Various processes have been developed heretobefore for processing condensed fuels in the combustion regime to produce fuel gas, based on successive layerwise gasification of solid organic fuels in countercurrent flow to an oxidizing gas in shaft kilns. A scheme of such type designed for processing pyroshale is described in US-A-2,796,390 (Elliot) and US-A-2,798,032 (Martin et al.).

[0003] A scheme of gasifying solid organic fuels in countercurrent flow to a gasifying agent can be generally described as follows. An oxygen-containing gasifying agent which possibly containing water and/or carbon dioxide are supplied into a combustion zone where oxygen reacts with carbon in a solid fuel in the form of coke or semi-coke at temperatures about 900-1500°C. The gasifying agent is admitted into the reactor in countercurrent flow to the fuel so that at least part of the oxidizing gas is preliminary passed through a layer of hot solid combustion products that are already free from carbon. In this zone the solid combustion products are cooled and the gasifying agent is heated prior to entering the combustion zone. In the combustion zone, free oxygen of the gasifying agent is completely consumed and hot gaseous combustion products including carbon dioxide and steam enter the next solid fuel layer, which is referred to as a reduction zone, where carbon dioxide and steam chemically react with carbon in fuel to produce combustible gases. Heat energy of the gases heated in the combustion zone is partially consumed in the reduction reactions. Gas flow temperature decreases as the gas flows through the solid fuel and gives its heat to the latter. The fuel heated in the absence of oxygen is subjected to pyrolysis. As the result, coke, pyrolysis tars and fuel gases are produced. Gaseous products are passed through a fresh fuel feed to cool the gas and to heat the fuel and reduce its moisture content. And finally, the gaseous product (also referred to as gas product) containing hydrocarbon vapors, steam and pyrolysis tars is withdrawn for subsequent use.

[0004] This scheme has various known applications. RU-2-062284 (Manelis et al.) discloses processing worn automobile tires; RU-2079051 and RU-2152561 (Manelis et al.) disclose processing solid domestic waste, oil-slime and similar oil waste. In the latter case, solid lump inert material is introduced into a reactor along with the processed fuel to provide, in particular, uniform gas permeability of the feed in the reactor. Kiln gas, preferably mixed with air, is used as a gasifying agent, the kiln gas portion in the gasifying agent being increased when the temperature in the combustion zone exceeds 1300°C, and reduced when the temperature in the combustion zone falls below 800°C.

[0005] At the same time, an important problem stays unresolved - the providing of stable combustion behavior when the processed feed material is being gasified. As the processed materials often have nonuniform gas permeability and to form cakes at pyrolysis, the pyrolysis and gasification front may propagate over the reactor section unevenly. "Burnouts" can appear in the processed feed layer, through which mainly gas flow passes, materials fall in cavities formed in combustion, and at the same time substantially gas-impermeable regions can form. As a consequence, temperature distribution in the combustion zone becomes nonuniform and poorly controlled.

[0006] To provide uniform propagation of combustion zones throughout the feed material a method of gasifying wastes is proposed in US 4,732,091 (Gould). The method comprises introducing a solid fuel into an upper section of a shaft kiln. The fuel is caused to move at a controlled rate through a series of chambers horizontally separated by moveable grates, where the fuel is pyrolyzed and burned in countercurrent flow of a vapor/air gasifying agent. The method includes loosening the waste in the course of treatment to provide uniform gas permeability and uniform movement of the processed feed material successively to drying, pyrolysis, gasification and cooling zones. A method is also proposed for controlling the fuel entry into respective zones. However, the prior art method suffers largely from the presence of moveable grates. The moveable grates will be inevitably worn fast in high-temperature zones. Furthermore, particles of dust and tars will deposit on the moveable units of the reactor and disturb its maintenance.

[0007] Rotary kilns are also widely known. They are extensively used for burning cement and combustion of waste. Kiln rotation provides uniform mixing of the material processed. A rotary kiln is known to be used for gasification process, e.g. as taught in US 247,322 issued 30 September, 1881. Application US-2005051066 discloses a method of gasifying a solid fuel in a parallel gas/solid flow using a rotary kiln. US 3,990,865 (Cybriwsky A. & Petersen G.) discloses a gasification process carried out in a slightly tilted rotary kiln having a raw material inlet end arranged higher than the outlet end. Solid carbon-containing material is continuously fed into the rotary kiln. In the kiln, the material which is introduced at a temperature below 600°F (315°C) passes through pre-heating and devolatilizing zones and is gradually heated to 1600°F (871°C); at this temperature the material loses its caking tendency and then enters a gasifying zone, where a vapor-containing oxidizing medium is admitted under the mixed layer, this resulting in formation of combustible gases containing hydrocarbon that are removed from the kiln side where the fuel is fed.

[0008] As the kiln rotates, the processed feed is efficiently mixed by action of gravity, But in the conventional rotary kilns the combustion process occurs mainly above the feed surface. None of the embodiments implemented in such kilns is capable of providing conditions for efficient inter-phase heat exchange typical for a dense porous layer.

[0009] It is the object of the present invention to overcome the deficiencies of the prior art and to enable efficient processing of condensed fuels, including low-calorie fuels, without using additional power sources. The object can be attained in a method for gasifying condensed fuels.

SUMMARY OF THE INVENTION

[0010] The present invention provides a method for processing a condensed organic fuel by gasifying, including: feeding a fuel into a cylindrical reactor; supplying an oxygen-containing gasifying agent into the reactor at the reactor side where the resultant residual solids accumulate; moving the fuel feed along the reactor axis; discharging the resultant residual solids from the reactor; driving-off the products of drying, pyrolysis and combustion as a gas product from the reactor such that gasification is carried out as the fuel successively resides in a heating/drying zone, a pyrolysis zone, a combustion (oxidation) zone and a cooling zone, and the gas flow is filtered through the fuel feed layer while passing successively through the cooling zone, the combustion zone, the pyrolysis zone and the heating/drying zone. The important distinctive feature of the invention is that the combustion process in the dense layer is stabilized by rotating the reactor about an axis tilted relative to the horizon.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

Fig.1 is a general schematic diagram of a device for implementing an embodiment of a method in accordance with the invention.

DESCRIPTION OF THE INVENTION

[0012] A method in accordance with the invention includes the following basic steps that are implemented in respective zones. At a first step, a condensed fuel in solid, liquid of paste state, possibly including solid noncombustible components and moisture (hereinafter referred to as "fuel") is fed into a reactor to successively perform therein drying the fuel and then pyrolysis/gasification of combustible constituents of the fuel. An oxygen-containing oxidizing gas (e.g. air) is supplied into the reactor through the reactor section where the resultant residual solids accumulate, so that to substantially direct the gas flow in countercurrent flow through the dense layer of the fuel feed in the reactor. Fuel passes through a number of zones in the reactor, as described below. First, it passes through a drying zone where the fuel temperature increases to 200°C owing to the heat exchange with the flow of gas product filtering through the fuel; in this zone the fuel is dried, and the gas flow is cooled before driving-off the latter from the reactor. After passing this zone as a gas product, gaseous products of drying, pyrolysis and gasification are removed from the reactor. Then the fuel enters the pyrolysis and coking zone where the temperature increases gradually to 800°C owing to the heat exchange with the gas flow, and combustible constituents of the fuel are pyrolyzed to produce coke. The coked fuel enters then a combustion and gasification zone, where the solid phase has a temperature of 700-1400°C. The coke reacts with the hot oxidizing gas to produce a fuel gas. Residual solids enter a cooling zone where they are cooled by the counter flow of the gasifying agent from the combustion temperature to a discharge temperature. The oxidizing gas counter flow, filtering through the dense layer of residual solids, is in turn heated to a temperature close to the combustion temperature before it enters the combustion zone.

[0013] It should be understood that this classification of zones is somewhat arbitrary. The zones may be defined differently, e.g. based on the gas temperature, content of agents, etc. In particular, in US-A-4,732,091 the same zones are referred to differently. Whatever the classification of zones, the essential feature is that in the countercurrent interpenetrating flows of gas and solid feed material the oxidizing gas (gasifying agent) is preheated on residual solids, and hot gaseous combustion products will further transfer their heat to the raw fuel.

[0014] The invention allows the efficient inter-phase heat exchange that is advantageously provided by the process in the dense layer to be combined with mixing the processed material by action of gravity as the reactor rotates, which is typical to rotary kilns.

[0015] To attain the object of efficient countercurrent gasification in a dense layer and stabilization of the combustion process in a reactor, a condensed fuel is fed into a cylindrical reactor such that to form a dense layer of the fuel feed in the reactor. An oxygen-containing gasifying agent is supplied into the reactor section where the resultant residual solids accumulate, and the fuel is gasified in the reactor by successively passing through the zones of drying, pyrolysis, combustion, gasification and cooling in a gas flow filtering through the dense fuel layer countercurrent to the fuel movement along the reactor axis with a predetermined time of holding in each of the zones. To stabilize the combustion process in the reactor and provide equal time of holding the fuel in the aforementioned zones throughout the dense layer thickness, the cylindrical reactor is mounted with its axis tilted at an angle relative to the horizon and rotated such that the material pours in the direction perpendicular to and along the reactor axis and fills the voids formed when the low-density material bums out. The gasifying agent is supplied at the bottom end of the cylindrical reactor, while the gas product is removed at the opposite end.

[0016] The cylindrical reactor axis is tilted at an angle from 22 to 65 degrees relative to the horizon. With a tilt angle below the lower limit, bulk material will not form a dense layer in the tilted reactor. On the opposite, a layer of solid fuel will be formed with a gas flow above it. The gas flow is not filtered through the fuel, consequently the main advantage of gasification in a dense layer, highly efficient inter-phase heat exchange, will not be realized, as well as uniform process will not be provided over the reactor section. With a tilt angle above the aforementioned range the solid material will not be adequately mixed in case of "burnouts".

[0017] Optimum combination of conditions for the fuel movement along the reactor axis and uniform combustion zone structure will be attained with a tilt angle of the reactor axis relative to the horizon from 40 to 50 degrees.

[0018] Preferably, the reactor rotation period should be sufficiently small to provide mixing of materials in the combustion zone. This will enable the invented process to be implemented in a reactor having a smaller length. To attain efficient rotation effect trough the entire material volume in the combustion zone, provided that the combustion zone dimensions along the reactor axis don't exceed, by an order of magnitude, diameter D (m) of the reactor flow section, a sufficient rotation speed of the reactor must be provided. If the bulk velocity of discharging the residual solids is V,(m^3/h), the average time of holding the residual solids in the combustion zone will be about $\pi D^3/4V$ (hour). Reactor rotation period T should be preferably no more than approximately $D^3/4V$ (hour) to provide no less than triple mixing of the material for the time when it stays in the combustion zone.

[0019] The fuel processed is preferably a solid lump material which is sufficiently permeable to the filtering gas flow. If the fuel is insufficiently permeable, in particular, when fine-dispersed, liquid or paste fuels are processed, a noncombustible solid lump material is fed into the reactor along with the fuel to provide uniform gas permeability of the fuel feed in the reactor and improve conditions of mixing the material in the combustion zone in case of burnouts. When liquid or paste materials are processed, it is not obligatory to preliminary mix them with a solid lump material before feeding into the reactor, because uniform mixing will be provided by the reactor rotation. To provide conditions of mixing the materials in the pyrolysis and combustion zones, the solid inert material added to the feed should preferably have a density different from that of the processed fuel.

[0020] The process is performed in a device for gasifying a condensed solid fuel including a feeder, a cylindrical reactor, a discharge unit, a gasifying agent supply unit, a gas product outlet, a driver for rotating the reactor, seals to provide gas tightness in the reactor rotation, wherein the cylindrical reactor is mounted such that its axis is tilted at a tilt angle from 22 to 65 degrees relative to the horizon; the feeder and the gas product outlet are arranged in the upper section of the reactor, while the discharge unit and the gasifying agent supply unit are arranged in the lower section of the reactor. The tilt angle of the rotary reactor relative to the horizon is preferably from 40 to 50 degrees.

[0021] For providing the fuel move along the axis of the reactor as the latter is rotating, it is necessary to control the discharge of residual solids from the reactor. This is preferably implemented at the expense of natural pouring out of the solid bulk material from holes in the reactor side wall as the reactor rotates. Sizes and number of the holes are chosen to match the solid material portion pouring out per revolution with a desired volume of the material discharge. There should be at least two holes having a linear dimension that doesn't exceed half the reactor internal diameter to provide uniform discharge of the residual solids over the reactor section. Residual solids freely fall out from the reactor to the discharge unit, such as a lock or hydraulic lock, providing removal of the residual solids with preserved gas tightness of the device.

[0022] The holes in the reactor side surface are preferably equipped with free passage control means, such as controlled shutters.

[0023] Alternatively, the reactor can be discharged through a cone having an opening along the reactor axis, the cone secured in the lower section of the reactor, the opening diameter being smaller than half the internal diameter of the reactor.

[0024] To successively hold the fuel in the heating, pyrolysis, combustion and cooling zones, the cylindrical reactor should have a sufficient length. To arrange the respective zones in the reactor, the following relationship between geometrical dimensions of the reactor should be observed:

$$L \cdot \sin\alpha > 3D,$$

where L is the length of the rotary reactor,

α is the tilt angle of the reactor axis relative to the horizon, and

D is the internal diameter of the reactor.

[0025] To maintain the upper feed level in the reactor as the fuel is consumed in pyrolysis, combustion and discharge, the use may made of both measuring the actual level (e.g. by a radiation sensor) and outputting a command to introduce the next portion of the fuel, and a feeder including a vertical cylinder having a smaller diameter than that of the rotary reactor, the lower end of the cylinder extending inside the upper section of the reactor. The feeder maintains a constant level of the fuel feed in the reactor at the expense of pouring the fuel out from a vertical tube as the fuel is consumed in the reactor.

[0026] A better understanding of the invention may be had by reference to the following description of an embodiment schematically shown in Fig.1.

[0027] Condensed fuel F, previously milled, if necessary, and to which a noncombustible solid material is added when needed, is introduced into a reactor 1 through a feeder 2 comprising a feed-lock chamber 3. The fuel enters the reactor through a vertical cylinder 4. The processed fuel level is maintained constant in the reactor owing to pouring the fuel out from the cylinder 4 as the reactor 1 rotates and filling in the material consumed in combustion and removal of ashes.

[0028] In the reactor, the material passes successively through a drying zone 4, a pyrolysis zone 6, a combustion zone 7 and a cooling zone 8. As the reactor rotates, residual solids R pour out through holes 9 equipped with shutters 10, and then they are discharged, continuously or in batches, through a gas-tight discharge unit 11 (a hydraulic lock shown schematically in the drawing). A discharge velocity of the residual solids at which the combustion zone maintains the same position in the reactor, in the middle section of the reactor, is provided by the relationship between free passages of the holes 9, rotation speed of the reactor and consumption of an oxidizer admitted into the reactor.

[0029] Air A, along with steam if required, is supplied by a compressor 12 into the lower section of the reactor. Gas product G is driven-off from the upper section of the reactor and directed to further use which may include purification and combustion in a power equipment. Temperatures in the respective zones are continuously measured, and when the temperatures go beyond the specified optimal ranges the control parameters: rotation speed of the reactor, air intake flow rate, vapor flow rate, are adjusted. A level sensor monitors whether the amount of fuel is sufficient in the feeder, and as the fuel is exhausted fresh portions are fed via the feed-lock chamber 3. To match the discharge velocity of residual solids, free passages of the holes 9 are adjusted: they are increased when the discharge velocity exceeds a desired one, and reduced in the opposite case.

[0030] Owing to the reactor rotation at an angle relative to the horizon, the material is mixed, primarily in the pyrolysis and combustion zones where the volume of fuel significantly decreases and cavities appear. Where the reactor rotates at an angle relative to the horizon, "burnouts" occurring as low-density materials burn out are filled with portions of unburned material falling by action of gravity, this stabilizing the combustion process in the reactor.

[0031] A better understanding of the invention may be had by reference to the following example of practice of the present invention.

EXAMPLE

[0032] A mixture of sawdust with broken firebrick in the 2:1 ratio (by weight) was subjected to gasification in an experimental laboratory reactor made of quartz. A tilt angle of the reactor axis relative to the horizon was varied from 5 to 90 degrees. Direct observation has revealed that with a tilt angle below 22 degrees, no filtering of gas flow through a dense fuel layer takes place because of a cavity formed along the upper generating line of the reactor, through which cavity the gas flow passes over the fuel surface. Where the reactor is in upright position, burnouts form in the fuel layer along the reactor walls within a short operation time, one of the burnouts eventually extending to the feed surface. In this situation the gas product starts burning directly above the feed surface in the reactor. Where the reactor axis deviated from the vertical, burn-out cavities fall down gradually as the reactor rotates. With an axis angle relative to the horizon smaller than 65 degrees, the rise of burnouts to the surface can be completely restrained and the combustion zone can be stabilized in the middle section of the reactor. Within the complete range of angles at which the combustion zone is stabilized, stable flame burning of the gas product is observed, and the residual solids are free from unburned carbon. The combustion front is stabilized best of all when a tilt angle of the axis is from 40 to 50 degrees and the combustion zone dimension along the reactor axis is no more than half the reactor diameter. To provide the stabilized front, the rotation speed should exceed a predetermined value for each tilt angle. It has been estimated that to stabilize the combustion zone the material should be more than once mixed as it passes the distance along the axis of the reactor approximately equal to the diameter of the latter.

[0033] Therefore, the present invention, as compared to the conventional methods, provides an efficient method for gasifying condensed fuels with high yield of gas fuel and high power efficiency.

[0034] Since various modifications of the invention illustrated by the non-limiting example will occur to and can be made readily by those skilled in the art without departing from the invention concept, the invention is not to be taken as limited except by the scope of the appended claims.

Claims

1. A method for processing a condensed organic fuel using gasification, comprising feeding a fuel into a cylindrical reactor, supplying an oxygen-containing gasifying agent into the reactor at the reactor side where resultant residual solids accumulate, moving the fuel feed along the reactor axis, discharging the resultant residual solids from the reactor, driving off the products of drying, pyrolysis and combustion as a gas product from the reactor such that gasification

is carried by successively holding the fuel in a heating/drying zone, a pyrolysis zone, a combustion (oxidation) zone and a cooling zone, and the gas flow is filtered through the fuel feed layer while passing successively through the cooling zone, the combustion zone, the pyrolysis zone and the heating/drying zone, said method **characterized in that** the combustion process in the dense layer is stabilized by rotating the reactor about an axis tilted relative to the horizon.

2. The method according to claim 1, **characterized in that** the rotation speed of the reactor about the axis is selected from the relationship $T<D^3/4V$, where T is the rotation period (hours), D is the reactor flow section (meters), V is the bulk velocity of discharging the residual solids from the reactor, (m^3/hour).

3. The method according to claim 1, **characterized in that** the tilt angle of the reactor relative to the horizon is maintained in the range from 22 to 65 degrees.

4. The method according to claim 3, **characterized in that** the tilt angle of the reactor relative to the horizon is maintained in the range from 40 to 50 degrees.

5. The method according to claim 1, **characterized in that** a noncombustible solid lump material is introduced into the reactor along with the fuel processed.

6. The method according to claim 5, **characterized in that** the noncombustible solid lump material introduced into the reactor has a density different from the density of the fuel processed.

7. A device for processing a condensed fuel comprising a feeder, a cylindrical reactor, a discharge unit, a gasifying agent supply unit, a gas product outlet, a driver for rotating the reactor, seals for providing gas flow tightness of the reactor in rotation, said device **characterized in that** the cylindrical reactor is mounted such that the reactor axis is tilted relative to the horizon at an angle in the range from 22 to 65 degrees, the feeder and the gas product outlet being arranged at the upper section of the reactor, and the discharge unit and the gasifying agent supply unit being arranged at the lower section of the reactor.

8. The device according to claim 7, **characterized in that** the tilt angle of the reactor relative to the horizon is in the range from 40 to 50 degrees.

9. The device according to claim 7, **characterized in that** the lower section of the cylindrical surface of the reactor comprises at least two holes having a linear dimension of no more than half the internal diameter of the reactor.

10. The device according to claim 9, **characterized in that** the holes in the side surface of the reactor comprise means for varying free passages thereof, e.g. controlled shutters.

11. The device according to claim 7, **characterized in that** the lower section of the cylindrical surface of the reactor comprises a cone comprising an opening arranged along the reactor axis and having a diameter smaller than half the internal diameter of the reactor.

12. The device according to claim 7, **characterized in that** the reactor length satisfies the condition: $L \cdot \sin\alpha > 3D$, where L is the length of the reactor, α is the tilt angle of the reactor axis relative to the horizon, and D is the internal diameter of the reactor.

13. The device according to claim 7, **characterized in that** the feeder comprises a vertical cylinder having a diameter smaller than the reactor diameter and arranged with the lower end inside the upper section of the reactor.

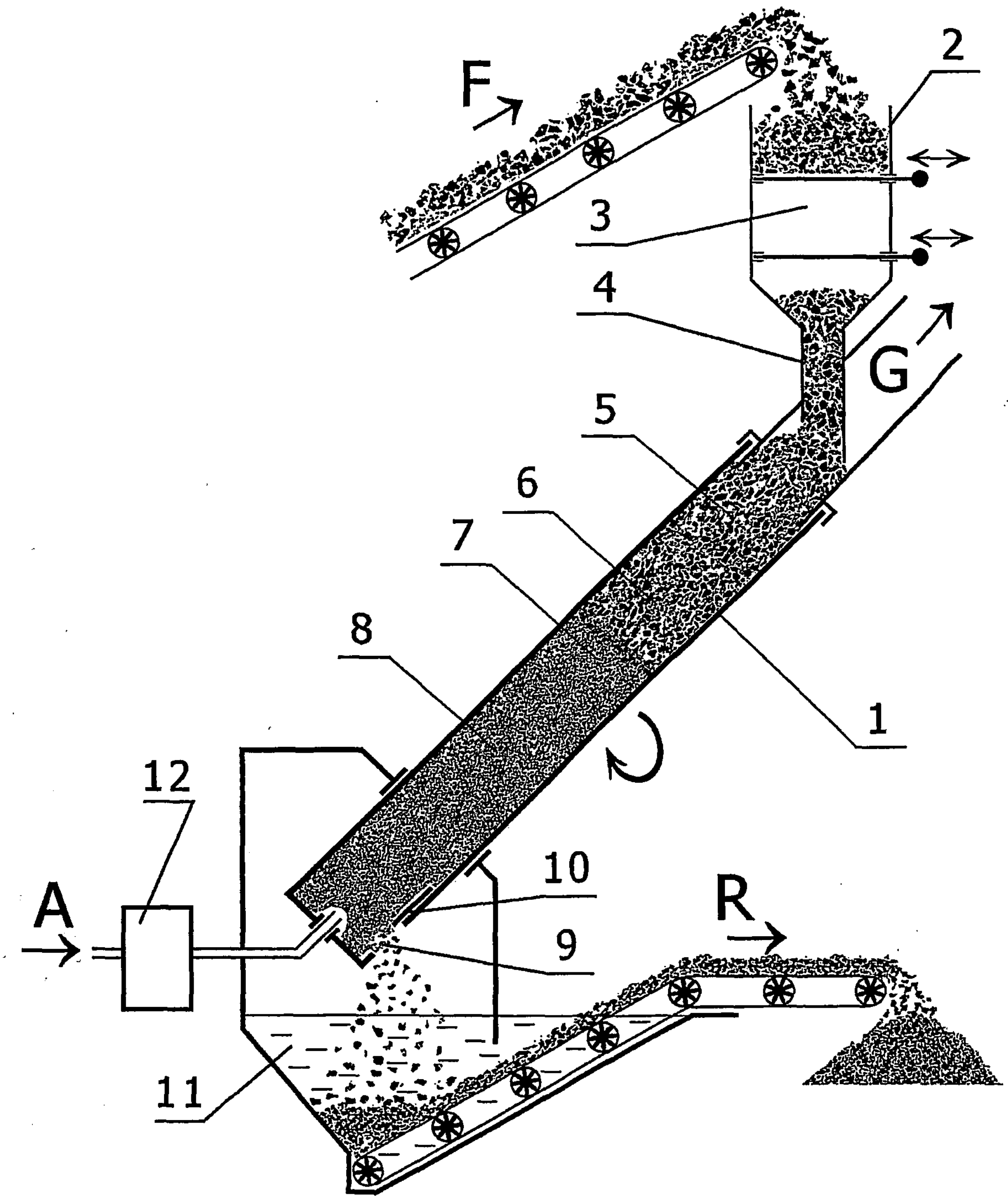

Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU 2007/000200

A. CLASSIFICATION OF SUBJECT MATTER

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)
F23G 5/00 5/027 5/20 5/24 F27B 7/00 7/20 7/32 7/33 C01J 3/00

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

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

RUPAT, RUPAT, OLD, RUPAT NEW, RUABRU, PatFT, PAJ, PCT, Esp@cenet, EAPATIS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	SU 1114342 A (ALLIS-CHALMERS CORPORATION) 15.09.1984, column 1, lines 5-38, column 5, lines 23-41, column 14, lines 32-35, claim 1	1, 5-6 2-4, 7-13
Y A	RU 2152561 C1 (INSTITUT PROBLEM KHIMICHESKOI FIZIKI RAN) 10.07.2000, page 3, left column, lines 26-59, page 4,left column , line 15 - right column, line 36	1, 5-6 2-4, 7-13
A	US 1214164 A (JOHN W. HORNSEY) 30.01.1917	1-13
A	US 6932002 B2 (DAVID F. MAY) 23.08 2005	1-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
30 July 2007 (30.07.2007)	09 August 2007 (09.08.2007)
Name and mailing address of the ISA/ RU Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2005)

REFERENCES CITED IN THE DESCRIPTION

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