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

(11) **EP 4 163 352 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
12.04.2023 Bulletin 2023/15

(21) Application number: **21818532.0**

(22) Date of filing: **31.05.2021**

(51) International Patent Classification (IPC):
C10J 3/00 *(2006.01)* ***C10J 3/20*** *(2006.01)*

(86) International application number:
PCT/RU2021/000230

(87) International publication number:
WO 2021/246904 (09.12.2021 Gazette 2021/49)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **05.06.2020 RU 2020118732**

(71) Applicant: **Feshchenko, Yurij Vladimirovich**
g. Tomsk, p. Aprel, 634045 (RU)

(72) Inventor: **Feshchenko, Yurij Vladimirovich**
g. Tomsk, p. Aprel, 634045 (RU)

(74) Representative: **Jeck, Jonathan**
JECK, FLECK & Partner mbB
Klingengasse 2
P.O.Box 14 69
71665 Vaihingen/Enz (DE)

(54) METHOD FOR GASIFICATION OF CARBONACEOUS FEEDSTOCK AND DEVICE FOR IMPLEMENTING SAME

(57) The method and gas producer for gasification of carbonaceous feedstock materials relates to the field of gasification of carbonaceous feedstock and can be used in the chemical, petrochemical, coke-gas and energy and other related industries, mainly for processing carbonaceous feedstock to produce energy and process gases, synthesis gas production by partial oxidation of a flow containing carbon.

In the method of gasification of carbonaceous feedstock including partial oxidation of carbonaceous feedstock in the oxidation chamber in a mixture of oxygen-containing gas and water vapour, in contrast to the current method, partial oxidation is carried out in a partial oxidation channel which is mounted coaxially in the vertical oxidation chamber, and water vapour supply for partial oxidation of carbonaceous feedstock is carried out at the input and output of the vertical oxidation channel of the combustion chamber.

The gas producer contains a housing, a burner device, a vertical oxidation chamber, manifolds for supplying carbonaceous feedstock, water vapour and oxygen-containing gas, a pipe for discharging gasification products, a slag removal chamber. The difference is that a partial oxidation channel is additionally installed in it, which is coaxially mounted in a vertical oxidation chamber and attached to the upper inner part of the housing, into which a burner device is installed.

The proposed method and device make it possible to obtain elevated hydrogen concentration in technical gases which will allow disposing of heavy oil residues at oil refineries with greater efficiency, accompanied by the production of high-quality motor fuels. What is more, the proposed device can become the main device for chemical processing of coal in the coal-chemical industry. Such a device is equally important for processing coal by hydrogenation, and for obtaining synthesis gas from coal.

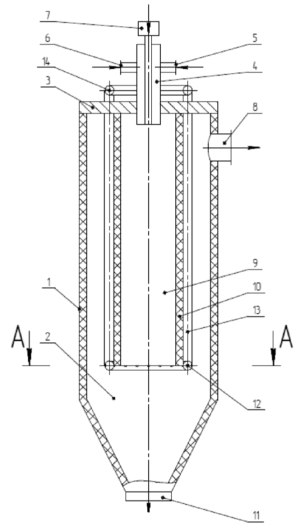

Fig. 1

EP 4 163 352 A1

Description

[0001] The given invention relates to chemical, petrochemical, coke-gas, energy and other related industries, and can be used primarily for processing carbonaceous feedstock to produce energy and process gases, particularly for gasification of carbonaceous feedstock, synthesis gas production by means of partial oxidation of a flow containing carbon.

[0002] Methods of producing synthesis gas by partial oxidation are well known in the technologies currently used. Usually a flow containing carbon (hydrocarbon) such as coal, brown coal, peat, wood, coke, soot or other types of gaseous, liquid or solid fuels, or mixtures thereof, is partially burned in a gasification reactor, i.e. partially oxidized using an oxygen-containing gas, such as pure oxygen or air, optionally enriched with oxygen, etc., thus obtaining a product stream containing, among other things, synthesis gas (i.e. CO and H2) and CO2.

[0003] Coal gasification technologies are mainly divided into three types: gas producers with a fixed-bed, such as gas producers manufactured by Lurgi AG (Germany, Frankfurt am Main) [1, pp.161-167], fluidized or fluidized bed gas producers implemented using the U-GAS, Winkler technologies (USA, Institute of Gas Technology, Chicago) [1, pp. 167-173], and parallel flow gas producers, according to the Shell process (jointly Shell and Uhde companies, Buggenum installation, Netherlands) [1, pp.189-191] and Texaco (USA, Texaco GP, Cool Water and Polk installations) [1, pp.176-180].

[0004] Fixed-bed gas producers have drawbacks due to the low throughput capacity of a single device and the need for expensive synthesis gas and water treatment systems. They also have problems with operational safety.

[0005] Fluidized bed gas producers have low efficiency due to low carbon conversion, difficulties with unloading dry bottom ash and high-volatile ash.

[0006] These disadvantages are dealt with when using the gasification process in a parallel flow. Partial oxidation of almost all types of carbonaceous feedstock accompanied by extraction of technical gases with specified properties can be carried out in gasification devices in a parallel flow. In addition, such gas producers are small in size, and can provide high efficiency in terms of the gasified feedstock.

[0007] The disadvantages of gasification process in a parallel flow include the following:

1. Gasification of any types of solid and liquid fuels in the parallel flow can be effectively carried out only when they are finely dispersed, usually with a particle size of less than 75 microns. At the same time, large fractions of feedstock particles can significantly reduce efficiency of the process and quality of the produced gases.
2. In order to obtain technical gases with the highest possible hydrogen yield (water gas, synthesis gas and their mixtures) during gasification of solid and liquid fuels, it is necessary to use water vapour or oxygen vapour mixture for oxidation of feedstock, which creates difficulties for ignition of the mixture while maintaining the required optimal temperature of the process between 900-1100° C [2, p. 26-27, p.31].

[0008] There is another type of a gas producer operating according to the Koppers-Totzek method [1, pp.174-176]. This method involves utilization of atmospheric pressure. According to the Koppers-Totzek technology specially prepared crushed and dried fuel enters the fuel storage bin, from where it is fed by dosing screws into mixing nozzles and then into an ellipsoid reaction chamber which hosts from two to four burner mixing nozzles located opposite each other. In the burner nozzles the pulverized fuel is mixed with oxygen and water vapour in such a way that water vapour creates a steam jacket on the outside of the carbon dioxide torch, thereby protecting the refractory lining of the reaction chamber from slagging, erosion and exposure to high temperatures inside the torch. Combustion temperature inside the torch is 1500-1700° C and its level is maintained depending on the melting temperature of the ash. The ash in liquid form is removed from the bottom of the reaction chamber into a special device where it is cooled and granulated. The disadvantages of the given gasifier include:

1. Increased oxygen consumption compared to the other types of oxygen-vapour gas producers;
2. Small hydrogen yield due to high temperatures;
3. Decreased safety due to the fact that even minor deviations from the nominal mode can lead to formation of an explosive concentration of gaseous products inside the reaction chamber.
4. Strict requirements for structural materials used in construction of the gas producer due to high process temperatures.

[0009] There is also the Destec method of coal gasification to enlarge the feedstock types by switching from natural gas to coal, which was originally developed by Dow Chemical [1, pp.180-183]. A two-stage in-line gas producer with liquid slag removal was developed for coal gasification. Fuel is fed to the reactor in the form of a coal-water suspension (coal / water = 60 / 40%) under high pressure generated by the pump. High-purity oxygen (95%) produced by a special installation is used as a gasifying agent. The gas producer operates at a pressure of 2.75 MPa and temperature of 1371°C. However, process temperature depends on the type of utilized fuel and in case of presence of a more refractory ash, process temperature increases due to liquid slag removal. The coal-water suspension is fed into the lower part of the gas producer simultaneously mixing with oxygen. Partial oxidation of coal occurs, thus providing endothermic reactions in thermal energy gasification zone. The slag formed at the first stage is removed into a water bath and then used in construction. The crude producer gas enters the upper lined part of the reactor, where a coal-water suspension is additionally added. In this part, the reaction of fresh fuel with the producer gas obtained at the first stage of the process takes place. At the second stage, the combustion temperature of the producer gas increases, and the ongoing endothermic reactions contribute to its cooling to a temperature of about 1038°C.

[0010] The disadvantages of this gas producer include:

1. Technological problems stemming from utilization of coal-water suspension;
2. Small hydrogen yield due to high temperatures and high pressures;
3. Large yield of carbon dioxide CO_2 compared to other direct-flow gasifiers (i.e. it yields less caloric gas than its analogues);
4. Strict requirements for structural materials used in construction of the gas producer stemming from high process temperatures.
5. Utilization of highly purified oxygen as a gasifying agent.

[0011] The "PRENFLO" (PRessurized Entrained-FLOw) process with vapour production (PSG) by Thyssenkrupp AG [1, pp.183-186] is used under increased pressure with any type of solid fuel (coal, petroleum coke, biomass). The process is based on the Koppers-Totzek technology. The prepared fuel is gasified at a pressure of about 4 MPa in the gas producer.

[0012] The gasification temperature is higher than the melting point of the ash (1400-1600° C) which allows for liquid slag removal. The advantage of this process is the dry supply of fuel which is the feedstock of gasification. Finely dispersed coal (80% of volume smaller than 0.1 mm) is fed together with oxygen and vapour through four burners installed in the same horizontal plane at the bottom of the gas producer. The disadvantages of this gas producer include:

1. Small hydrogen yield due to high temperatures and pressure (in the chemical industry, it is used only when elevated hydrogen concentration in the process gas is not required);
2. High temperature and pressure cause strict requirements for the materials used in the construction of the gas producer and significant financial costs for its production.

[0013] There is also a carbon-containing feedstock gasifier (RU No. 2237079, IPC C10J3/20, issued in 27.09.2004) which is another type of carbonaceous feedstock gas producer and can be used in chemical, petrochemical, coke-gas, energy and other related industries for processing carbonaceous feedstock to produce energy and process gases. The gasifier contains a vertical gasification chamber, a burner with nozzles for supplying carbonaceous feedstock and oxygen-containing gas, a manifold for supplying water vapour, nozzles for supplying pulverized carbonaceous feedstock, a pipe for removing gasification products (in the lower part of the gasification chamber), a slag removal chamber. It is also equipped with a special unit consisting of a burner placed in the center of the block above the gasification chamber, and injectors located around the burner on the periphery of the block above the gasification chamber to create a steam curtain to protect the coating of gasification chamber from overheating. The gasification chamber is a cylindrical pipe ending with a conical slag removal chamber while the gasification chamber is conditionally divided into oxidizing and reduction parts. The process in the oxidation zone is carried out at a temperature of 1500-3000°C, and in the reduction zone by vapour supply, the temperature drops to 1000-1600°C.

[0014] The disadvantages of this gas producer include:

1. Small hydrogen yield due to high temperatures;
2. Reduced thermal efficiency of the device when using a gasifier as a source of thermal energy, since the presence of free hydrogen and a large amount of carbon monoxide indicate incomplete combustion.
3. Placement of the gas outlet pipe in the lower part of the gasification chamber leads to the insertion of significant amounts of slag and ash into the flues gas ducts and gas distribution system, which can lead to a short life span of the gasifier.

[0015] There is also a gasification method performed by the PRENFLO PDQ gas producer by Thyssenkrupp AG [1, pp.186-189] which is considered to be the closest analogue of its predecessor PRENFLO PSG functioning according to the Koppers-Totzek process. In this gas producer, fine coal dust is gasified in a mixture of oxygen and water vapour in a vertical oxidation chamber at a temperature of 1400-1600°C. Oxidation of coal actually occurs under adiabatic conditions, as the oxidation chamber is made in a form of a channel mounted coaxially to the outer wall of the gas producer separated from the outer wall by an annular space washed by coal oxidation products, which maintains the temperature in the oxidation chamber close to 1400-1600°C. The supply of coal dust and a mixture of oxygen and water vapour is carried out through 4 horizontal burners in the upper part of the oxidation chamber. The oxidation chamber merges into rapid water cooling chamber into which water is injected through vants located along the ring in the cooling chamber, cooling the oxidation products to a temperature of 200 - 250°C.

[0016] The closest to the proposed device is the gas producer [1, pp.186-189] employing the specified method-prototype containing a manifold for feeding water vapour and oxygen to the burners, a manifold for feeding a gas-coal mixture to the burners, an oxidation chamber that passes into a rapid water cooling chamber which is a cylindrical pipe coaxially arranged inside the gas producer housing ending with a conical slag removal chamber. There is an annular gap between the slag removal chamber and the central pipe of the rapid cooling chamber through which the raw oxidation generator gas and water vapour exit the cooling chamber then rise along the inter-wall gap between the cooling chamber pipe and the gas producer housing and exit the gas producer into the pipe for removal of gasification products for further processing.

[0017] A sharp change in the movement of the gas flow in the rapid cooling chamber, leading to the fact that the movement of gases downwards after the passage of the slit gap between the pipe of the cooling chamber and the slag removal chamber changes into an upward movement, allows separating a significant amount of slag and ash with their insertion into the conical slag removal chamber. The slag removal chamber is connected to the slag removal system.

[0018] Slag from the gasifier can be used as a building material.

[0019] The disadvantages of this gas producer include:

1. Small hydrogen yield due to high temperatures and pressure (in the chemical industry these gas producers are used only when elevated hydrogen concentration in the process gas is not required). Total hydrogen is not more than 22-32% (as for all direct-flow gas producers based on Koppers-Totzek technology (Shell-Koppers process)), whereas for Lurgi layered gas producers the hydrogen concentration in dry gas is 36-40%, for Winkler fluidized bed gas producers [1, pp.169-170] the hydrogen concentration lies within 35-45% [4, p.30].
2. High temperature and pressure cause strict requirements for the materials used in the construction of the gas producer and significant financial costs for its production.
3. Increased specific oxygen consumption per 1 ton of gasified coal for all direct-flow gas producers based on Koppers-Totzek technology is 540-650 m^3, whereas for Lurgi layer gas producers it is 220-300 m^3, and for Winkler fluidized bed gas generators it is 350 m^3 [4, pp. 30-33].
4. To ensure stable ignition and maintain stable combustion of the mixture, in addition to increased oxygen consumption, a horizontal arrangement of burners is used in the oxidation chamber, which does not allow reducing the process temperature to temperatures of 900-1100^{0}C (optimal synthesis gas production temperatures), because at such temperatures (900-1100°C) the ash of the majority of coal types is in the solid phase, which means that it can accumulate on the walls of the combustion chamber which leads to its slagging and further failure of the gas producer.
5. Too rapid cooling of gases to a temperature of 200-250°C does not allow obtaining additional hydrogen by the reaction:

$$CO + H2O = CO2 + H2 + 10300 \text{ kcal.}, \qquad (1)$$

as even at a temperature of 800°C, the degree of decomposition of water vapour decreases by an order of magnitude compared to 1000°C, and for the same residence and contact time in 1 sec, the degree of conversion of water vapour at 800°C will be only 0.5% of the conversion at 1000°C [2, p.29]. This means that at lower temperatures there will be no reaction at all, which is confirmed by an increase in the equilibrium constant of this reaction (1) at 500°C by 100 times compared to 1000° C [3, p. 102].

[0020] The main objective of the invention is to create an effective method of gasification in a parallel flow of carbonaceous feedstock such as coal, brown coal, peat, wood, coke, soot or other types of gaseous, liquid or solid fuels, or mixtures thereof by partial oxidation of carbonaceous feedstock in a mixture of oxygen-containing gas and water vapour and a device for its implementation in order to obtain the maximum possible hydrogen yield during gasification of carbonaceous feedstock.

[0021] The technical result of the claimed invention is the production of producer gas with increased hydrogen concentration. What is more, the ignition stability is achieved and the necessary partial oxidation temperature is maintained.

[0022] The proposed technical result is achieved due to the fact that in the known method of gasification of carbonaceous feedstock, including partial oxidation of carbonaceous feedstock in an oxidation chamber in a mixture of oxygen-containing gas and water vapour, partial oxidation is carried out in a partial oxidation channel coaxially mounted in the oxidation chamber, and the supply of water vapour for partial oxidation of carbonaceous feedstock is carried out at the input and output of the partial oxidation channel of the combustion chamber.

[0023] It is most efficient to carry out partial oxidation in the flow of a mixture of oxygen and water vapour in the partial oxidation channel of the oxidation chamber at a temperature of 900-1100^{0}C which is provided by changing the volume of vapour at the input to the partial oxidation channel.

[0024] It is advisable to maintain a temperature within 800-1000^{0}C at the output of the partial oxidation channel of the oxidation chamber, which is provided by changing the volume of vapour at the output of the partial oxidation channel.

[0025] It is advisable to ignite the mixture of carbonaceous feedstock and the vapour-oxygen mixture and maintain their stable combustion by feeding the combustion products to the input of the partial oxidation channel from the burner device installed along the axis of the partial oxidation channel.

[0026] It is preferable to choose longer residence time of combustion products in the oxidation channel than the combustion time of the biggest particle of feedstock.

[0027] The size dimensions of the partial oxidation channel are optimally chosen based on the ratio:

$$L \geq (4*G*T_b)/(\pi*\rho(t_o)*D^2),$$

where

L - the length of partial oxidation channel;
D - the diameter of the partial oxidation channel;
G - the mass entry of oxidation products into the partial oxidation channel;
T_b - the combustion temperature of the biggest particle of carbonaceous feedstock;
t_o - the calculated temperature of oxidation products in the partial oxidation channel;
$\rho(t_o)$ - the calculated density of oxidation products in the partial oxidation channel.

[0028] Solid fuels in the form of coal, brown coal, peat, wood, coke, soot, or gaseous and liquid fuels, or mixtures thereof can be used as carbonaceous feedstock.

[0029] The technical result is also achieved by the fact that the well-known gas producer for gasification of carbonaceous feedstock, containing a housing, a burner device, a vertical oxidation chamber, manifolds for supply of carbonaceous feedstock, water vapour and oxygen-containing gas, a pipe for discharging gasification products, a slag removal chamber, additionally contains a partial oxidation channel which is coaxially mounted in a vertical oxidation chamber and attached to the upper inner part of the housing in which the burner device is installed.

[0030] For the best result the upper part of the housing is made in the form of a removable lid in which a burner device is installed.

[0031] The pipe for discharging gasification products can be installed in the side of the gas producer housing, closer to the upper part of the gas producer.

[0032] It is optimal to make gas producer for gasification of carbonaceous feedstock containing upper and lower vapour manifolds made in the form of hollow rings connected by downpipes, the axes of which are parallel to the axis of the outer housing, while the upper collector is mounted on the outside of the gas producer lid, the downpipes are placed on the outside of the partial oxidation channel, and the lower vapour manifold is located at the output of the oxidation channel and is equipped with vents for vapour to exit into the flow of partial oxidation products.

[0033] It is optimal to perform the burner device in the form of a diffusion burner equipped with annular channels located coaxially around the diffusion burner and made with the possibility of supplying oxygen-containing gas, carbonaceous feedstock and water vapour to the annular channels.

[0034] It is reasonable to make the inner walls of the oxidation chamber in the form of a coil the upper output of which is connected to the upper vapour manifold through the hot vapour distribution unit, and the lower output is connected to an external water vapour producer.

[0035] The inner walls of the oxidation chamber can be made in the form of coaxially arranged toroid-shaped containers that provide the possibility of supplying water vapour from below the oxidation chamber to the gas producer lid.

[0036] The partial oxidation channel can be made with external thermal insulation.

[0037] The proposed method of gasification of carbonaceous feedstock such as coal, brown coal, peat, wood, coke, soot or other types of gaseous, liquid or solid hydrocarbon fuels, or mixtures thereof as well as the device for its implementation are unknown from the prior art, therefore the proposed solutions satisfy the condition of patentability of the invention referred to as 'the novelty'.

[0038] Analysis of the state of the art for compliance of the proposed solutions with the patentability condition of the invention referred to as 'the inventive level' showed the following.

[0039] In the proposed method of gasification of carbonaceous feedstock such as coal, brown coal, peat, wood, coke, soot or other types of gaseous, liquid or solid fuels, or mixtures thereof by partial oxidation in a mixture of oxygen-containing gas and water vapour in order to maximize the production of hydrogen, in contrast to the traditional devices, the oxidation process is divided into 2 stages: first, partial oxidation is carried out under adiabatic conditions in a thermally insulated oxidation channel at optimal temperatures of 900-1100^{0}C in a flow of oxygen and water vapour mixture, and then the resulting gases are further oxidized at the output of the partial oxidation channel only by water vapour with the temperature in this zone being maintained within the optimal temperature range of 800-1000°C. In the proposed device for implementing the proposed oxidation method, in contrast to analogues, all processes are carried out under conditions that exclude a sharp increase in pressure in the reaction zones. In addition, the proposed method allows for stable ignition and combustion in the resulting two-phase flow both on the surface of the particle and in the gas phase, due to the stable supply of additional thermal energy from combustion products coming from the built-in burner device in which liquid or gaseous fuel is burned. The combustion products from the burner device enter the partial oxidation channel along the axis of the channel mixing with carbonaceous feedstock and a vapour oxygen mixture.

[0040] At the same time, the ignition stability and maintenance of the required temperature in the oxidation channel is supported by the supply of thermal energy from the burner device built in the upper part of the gas producer housing when burning any fuel regardless of the type of carbonaceous feedstock entering the gas producer for oxidation, for example, with the help of air oxygen, unlike the prototype and other traditional methods in which stabilization is maintained by means of high oxygen consumption for burning part of the oxidized carbonaceous feedstock with obtaining high temperatures of 1400-1600°C and a pressure of 27-40 atm in them, and as a result, with a small hydrogen yield. Conducting the process under optimal conditions and temperatures for gasification allows, in contrast to the prototype where the burners are mounted across the vertical axis of the gas producer, which leads to high temperatures when combustion product flows collide, using inexpensive materials with significantly lower material consumption and heat resistance in the design of the gas producer. Consequently, the proposed group of inventions satisfies the condition referred to as "the inventive level".

[0041] The proposed method and device for gasification of carbonaceous feedstock are illustrated by drawings, where

Fig. 1 presents the overall scheme of the gas producer for gasification of carbonaceous feedstock;
Fig. 2 depicts the section scheme of the gas producer;
Fig. 3 presents the scheme of the burner device of the gas producer;
Fig. 4 presents the schematic diagram of the gas producer with a coil for heating vapour and cooling the housing wall;
Fig. 5 presents the schematic diagram of the gas producer with a set of toroid-shaped containers for heating vapour and cooling the wall of the gas producer.

[0042] The proposed gas producer for gasification of carbonaceous feedstock contains a housing 1, an oxidation chamber 2, a housing lid 3 (Fig. 1), a burner device 4 (fig. 4) with a diffusion burner 7, oxygen supply pipes 5 and a mixture of water vapour and carbonaceous feedstock 6, a pipe 8 for discharging generator gases, a partial oxidation channel 9 with thermal insulation 10, with a vapour supply manifold 12 into the space at the output of the oxidation channel 9, as well as downpipes 13, (fig. 2) supplying vapour from the upper vapour manifold 14 to the vapour supply manifold 12. A slag removal chamber 11 is installed in the lower part of the housing.

[0043] Fig. 2 presents the A-A section (Fig. 1) of the gas producer, which shows a variant of arrangement of the vapour supply vants 15 in the vapour supply manifold 12. Fig. 3 shows a diagram of the burner device 4 with a built-in diffusion burner 7 with an air supply channel 16, with a fuel supply channel 17 (for example, fuel oil or gas fuel), with ignition electrodes 18, a mixing diffuser 19, with an oxygen supply channel 20 and a vapour supply channel 21. Fig. 4 shows a diagram of the gas producer according to Fig. 1, supplemented by a coil 22 for heating vapour and cooling the thermal insulation of the wall of the gas producer housing 1, a vapour input pipe 23 into the coil 22, a vapour distribution unit 24 into the vapour mixing unit with carbonaceous feedstock 25 and into the manifold 14, a coal supply pipe 26 into the mixing unit 25. Fig. 5 shows a diagram of the gas producer according to Fig. 1, supplemented by toroid-shape tanks 27 for heating vapour and cooling the thermal insulation of the wall of the gas producer housing 1, a vapour input pipe 23 into the coil 22, a vapour distribution unit 24 into the vapour mixing unit with carbonaceous feedstock 25 and into the manifold 14, a coal supply pipe 26, U-tubes 28 connecting toroid-shaped containers 27 among themselves.

[0044] The proposed method and gas producer work as follows.

[0045] Wet vapour enters the coil 22 through the nozzle 23 (Fig. 4) where it is heated by the outgoing producer gases through the pipe 8 discharging producer gases. Through the coil 22, vapour enters the vapour distribution node 24, where it is divided into 2 flows. Part of the vapour enters the mixing unit 25, where the vapour picks up fine carbonaceous feedstock for example, coal dust coming through the nozzle 26, and the resulting coal-vapour mixture enters through the nozzle 6 (an ejection device or a sluice (not shown in the drawing)) into the burner device. The burner device is a combined burner 4 (Fig.3) in the center of which there is a diffusion burner 7 for burning liquid or gaseous fuel in the air. The combustion products of the diffusion burner with a temperature of 1500-2000°C create the centre of the gas stream whirled by the mixing diffuser 19 of the burner 7 mixing the oxygen flows entering through the nozzle 5 into the channel 20 and the vapour-coal mixture entering through the nozzle 6 into the channel 21.

[0046] In order to obtain the maximum possible amount of hydrogen during gasification of hydrocarbon particles in a parallel flow it is essential to solve several complex tasks, production of producer gas by an endothermic chemical reaction in particular

$$C + H_2O = CO + H_2 - 31700 \text{ kcal} \qquad (2)$$

with a significant loss of thermal energy simultaneously with burning up part of carbonaceous particles in oxygen (in the total flow of vapour and oxygen-containing gas) and maintaining the process temperature in the range of 900-1100^{0}C.

[0047] In order to obtain the required result it is necessary to perform the process at low pressure (for instance, the pressure close to the atmospheric one), then, according to the Le Chatelier principle, the process according to (2) will be shifted to the right. The principle of Le Chatelier establishes that in case of an outside impact on a system in a state of equilibrium by means of a change in one of the factors determining the equilibrium, the direction of the process which weakens such impact in the system increases. Since the reaction (2) produces 2 moles of gas (CO and H_2 instead of one mole of H_2O) with an increase in pressure as a result of an increase in the volume of gases, then by decreasing the pressure in the reactor, it is possible to force the system to return to equilibrium, accelerating the reaction (2) with production of CO and H_2 gases. Conversely, when the pressure in the reactor increases the pressure in the system decreases due to slowing down reaction (2). Technically, this means that it is necessary to prevent an increase in pressure during oxidation process, i.e. it is necessary to prevent an increase in gas dynamic resistances to the movement of the gas flow. Consequently, the design of the channels through which the oxidation products move should not have sharp constrictions and the combustion of carbonaceous particles should preferably be carried out during movement in the flow and not in a closed chamber.

[0048] To maintain the necessary temperature, it is rational to burn a part of carbon in oxygen according to the reaction

$$C + O_2 = CO_2 + 94300 \text{ kcal} \qquad (3)$$

which happens almost instantly at 1000°C, but when the temperature decreases its speed decreases too [1, p.24]. However, to maintain the reaction (2) a significant amount of water vapour is used and it takes away thermal power and the heat input from the reaction (3) occurs gradually while the particles burn up. Therefore, it is rational to divide the water vapour into 2 parts where the first part of the vapour enters through the burner device, and the second part used for partial oxidation of feedstock enters the flow of partial oxidation products at the output of the oxidation channel after burning up of carbonaceous feedstock into the space between the vertical wall of the gas producer housing and the wall of the oxidation channel. In addition, the division of water vapour supply makes it possible to conduct a controlled reaction at the output of the oxidation channel

$$CO + H_2O = CO_2 + H_2 + 10300 \text{ kcal} \qquad \text{according to formula (1)}$$

with an increase in hydrogen in producer gas. As the reaction (1) is exothermic, the temperature increase will lead to the shift of equilibrium to the left (i.e. towards the feedstock) according to the Le Chatelier principle. However, for this reaction the limit is the temperature of 1000°C (it is proved by the equilibrium constant dynamics [3, p.102] and experimental data [2, p.30]). It means that the supply of water vapour at the output of the oxidation channel will allow the reaction (1) to develop and reduce the gases temperature to 700-800°C preventing it from rising above 900-1000°C. Therefore, it is optimal to maintain the temperature at the output of the oxidation channel in the range of 800-1000^{0}C.

[0049] To complete the oxidation-reduction reactions (2) in the partial oxidation channel, its size dimensions (diameter and length) must ensure that the burning particle stays in the channel at least for as long as its burnup time (significantly increasing thermal efficiency of the process) which critically depends on the size of the burned particle. For example, an anthracite particle with a diameter of 100 microns burns up in oxygen for 7.1 seconds, but a particle with a diameter of 50 microns burns up for 0.413 seconds [3, p.210]. Knowing the particle size of the gasified feedstock and its hourly consumption, it is easy to calculate the size dimensions of the oxidation channel.

[0050] The most important condition for the stable operation of a gas producer with particle in flow gasification is stable ignition and combustion in the resulting two-phase flow, where combustion occurs both on the surface of the particle and in the gas phase. For the stability of the process it is important for the flame propagation velocity to be higher than the two-phase flow velocity, otherwise the flame will fail and the oxidation process will stop. In well-known gas producers of flow-line gasification including the closest analogue of the "PRENFLO" PDQ this problem is solved in the following way. They increase the combustion rate of coal particles increasing the pressure and temperature of the process by means of increasing the oxygen supply and burning more coal according to reaction (3). In addition, they increase the residence time of particles in the reactor by arranging the burners perpendicular to the flow. What is essential in the design of the prototype is that the increase in pressure in the oxidation chamber is achieved by narrowing at the output of the oxidation chamber in the form of a rocket nozzle which innately requires liquid slag removal and high temperatures because otherwise the narrowing channel will be quickly slagged.

[0051] In the proposed device, this problem is solved differently. In order to obtain a permanent ignition source and stabilize the partial oxidation process the burner device, preferably embedded in the lid of the gas producer, is a combined diffusion burner in the center of which along the axis the actual diffusion burner for burning gaseous or liquid fuel is embedded. It is equipped with annular channels arranged coaxially around the built-in diffusion burner designed with the possibility of supplying oxygen-containing gas, carbonaceous feedstock and water vapour to these annular channels. It means the source of additional heat for igniting the mixture and maintaining a stable oxidation process in the proposed method is the heat of the combustion products of liquid or gaseous fuel fed along the flow of the reacting oxygen vapour mixture and carbonaceous feedstock. Such a scheme of combustion process allows obtaining a stable ignition of the two-phase flow and maintaining its combustion until there is stable heat generation according to reaction (3) and compensating for heat losses in the reaction of carbon and carbon monoxide with water vapour. Thermodynamic calculations of variants of such process show that the power of such a built-in burner comprises 10-25% of the power of the carbon burned by the reaction (3) and it is sufficient for organizing a stable process with an inflow temperature not exceeding 1100^0C.

[0052] Thus, the proposed method allows for stable ignition and combustion in the resulting two-phase flow both on the surface of the particle and in the gas phase due to the stable supply of additional thermal energy from combustion products coming from an integrated burner device in which liquid or gaseous fuel is burned. The combustion products from the burner device enter the partial oxidation channel along the axis of the channel, mixing with carbonaceous feedstock and oxygen vapour mixture.

[0053] Adjustment of flow rates of vapour, coal and oxygen in the oxidation channel 9 (Fig. 4) helps to set the temperature of 900-1100° C monitored by thermal sensors (not shown in the drawings). The second part of the vapour from the distribution unit 25 through the pipes 13 enters the vapour supply manifold 12 and through the vents 15 is fed into the space at the output of the oxidation channel 9, where carbon monoxide is oxidized to carbon dioxide to produce hydrogen. The calculated amount of vapour should in total provide cooling to a temperature not higher than 900-1000°C to prevent reverse reactions according to formula (1). The resulting producer gases are fed through the producer gas output pipe 8 for cooling and purification and further processing (for example, for organic synthesis or to a membrane separator with further supply of the resulting hydrogen for coal hydrogenation). The bulk of the slag and ash formed as a result of coal combustion enters the slag removal chamber 11. They are disposed of by the system afterwards.

Description of a real case

[0054]

1. To produce hydrogen for the coal hydrogenation plant, a prototype gas producer was built according to the scheme of Fig. 5 for partial oxidation of coal. The characteristics of raw coal type were determined: average ash content - 12%; moister content - 8%; carbon content in the organic matter of coal (COM) - 77%; hydrogen content in COM - 5%. The raw coal was crushed, dried in a drum dryer and finely ground on a crusher with a particle size of less than 100 microns (80% of particles with a size of less than 50 microns). The consumption of dry coal was 1 ton per hour.

2. An oxygen extraction unit with a capacity of 300 m^3 per hour or 390 kg per hour was chosen as an oxygen source.

3. The volume of the amount of water for the oxidation of coal and the proportions of the distribution of vapour volumes through the burner and manifold at the output of the oxidation channel were selected from thermodynamic calculations of thermal balances of chemical oxidation and reduction reactions. As a diffusion burner built into the burner device a fuel oil burner with a thermal capacity of 200 kW was used. The burner can burn 20 kg of fuel oil in 20x10.8 = 216 m^3/hour of air or 276.5 kg/hour of air during a 60-minute period.

4. Up to 150 kg of vapour per hour were supplied to the input of the partial oxidation channel through the burner device. The calculated temperature of the combustion products at the output of the partial oxidation channel was 952°C which fits into the optimal temperature limit of 900-1100°C.

5. Vapour supply from the manifold (pos.12, Fig.5) was carried out through 3 rows of vents with a spray angle between the rows of vents equal to 120°. The volume of vapour coming through the manifold (pos.12 Fig.5) was 250-300 kg per hour.

[0055] The regulation of vapour volumes entering through the burner device and through the manifold was carried out according to the data of the three temperature sensors built in at the output of the oxidation channel and data from temperature sensors built into the annular gap between the oxidation channel and the gas producer housing 20 cm above the output of the oxidation channel (3 pcs).

[0056] The selection of size dimensions of the partial oxidation channel (pos.9, Fig.6) was determined by the residence time of combustion products in the oxidation channel. This value should preferably be longer than the combustion time of the biggest particle of the feedstock. Coal dust with particle size of up to 50 microns (80%) and up to 80-90 microns (20%) was fed to the gas producer. The combustion time of a particle with the size of 50 microns was 0.41 seconds, and with the size of 100 microns - 7 seconds. Under the condition of the complete reaction of coal in the oxygen vapour flow about 826 liters of gases were obtained at a temperature of 1000^0C per second. When selecting the diameter for the partial oxidation channel of 0.85 meters and the length of the oxidation chamber of 6 meters, the residence time of the particles in the oxidation chamber was 7.9 seconds, which exceeded the theoretical combustion time of a coal particle of the biggest size.

[0057] The composition of gases (dry) under the mode with maximum hydrogen yield averaged in volume %:

H2 - 52.3%,
N2 - 10.0%,
CO - 12.4%,
CO2 - 25.3%.

[0058] Oxygen consumption per 1 ton of dry coal was 300 m^3 per hour, vapour consumption per 1 ton of dry coal was 370 - 430 kg.

[0059] From the information source [4, p.31] describing the prototype installation according to the Shell-Coppers technology, the following average indicators are revealed:

H2 - 25.6%
CO - 65.6%
CO2 - 0.8%
CH4 - 8.0%

[0060] The oxygen consumption was 644 m^3 per ton of dry coal, and the vapour consumption was only about 100 kg per ton of dry coal. It is obvious that the hydrogen yield according to the proposed method and device is 2 times higher than that of the prototype, oxygen consumption is 2 times lower. The process temperature is lower (1100° C) too, compared to the prototype in which the process takes place at a temperature of 1400-1600°C. In the proposed device the water vapour consumption is almost 4 times higher, but the elevated hydrogen yield is precisely determined by decomposition of water.

[0061] The given example of a specific implementation of the claimed method and device for its implementation shows that in the installation of the proposed gas producer, the results obtained on the hydrogen yield significantly exceed the hydrogen yield indicators compared to the prototype. At the same time, the total consumption of water vapour for partial oxidation of coal was 370-430 kg per 1 ton of coal. Oxygen consumption was 300 m^3 per ton of coal. The total yield of hydrogen was about 65 kg per hour, while in the prototype it is about 32 kg per hour.

[0062] The proposed invention can find wide application in gasification of carbonaceous feedstock, due to ensuring efficient gasification in a parallel flow of carbonaceous feedstock, such as coal, brown coal, peat, wood, coke, soot or other types of gaseous, liquid or solid fuels, or mixtures thereof in order to obtain producer gas with the highest possible hydrogen concentration. At the same time, the required parameters of the produced gas are easily regulated by changing the flow rates of oxygen, vapour, gasified feedstock and the power of the built-in burner.

[0063] The gas producer can be used in the chemical, carbon and petrochemical industries (ammonia, methanol, synthetic fuels, etc.), coke and gas, energy and other related industries for processing carbonaceous feedstock to produce energy and gases. Elevated concentration of hydrogen in the technical gases produced in the proposed device will allow efficiently disposing of heavy oil residues at oil refineries together with producing high-quality motor fuels. For the coal chemical industry the proposed device can become the main basic device for chemical processing of coal. Such device is equally essential both for processing coal by hydrogenation and for obtaining synthesis gas from coal.

Reference list:

[0064]

1. Alyoshina A. S., Sergeev V. V. Gasification of solid fuel: textbook. St. Petersburg: Publishing House of the Polytechnic University, 2010. - 202 p.
2. Rambush N. E. (translated from English) Gas producers - M.-L.: GONTI, 1939. -413p.
3. Pomerantsev V.V., Arefyev K.V. and others. Fundamentals of the practical theory of combustion: textbook for universities - L.: Energoatomizdat, 1986. - 312p.
4. Schilling G.-D., Bonn B., Kraus U. Coal gasification - Moscow: Nedra, 1986. - 175p.

List of terms

[0065]

1. Housing
2. Oxidation chamber
3. Gas producer lid
4. Burner device
5. Oxygen supply pipe
6. Pipe for supplying a mixture of water vapour and carbonaceous feedstock
7. Built-in diffusion burner
8. Pipe for the discharge of producer gases
9. Partial oxidation channel
10. Thermal insulation of the oxidation channel
11. Slag removal chamber
12. Lower vapour manifold
13. Downpipes
14. Upper vapour manifold
15. Vapour supply vents in the manifold

16 Air supply channel

17. Fuel supply channel
18. Ignition electrodes
19. Mixing diffuser
20. Oxygen supply channel
21. Vapour supply channel
22. Vapour heating coil
23. Vapour input pipe into the coil
24. Vapour supply distribution unit
25. Vapour mixing unit with carbonaceous feedstock
26. Coal supply pipe to the mixing unit
27. Toroid-shaped containers for vapour heating
28. U-tubes for connecting toroid-shaped containers

Claims

1. The method of gasification of carbonaceous feedstock, including partial oxidation of carbonaceous feedstock in an oxidation chamber in a mixture of oxygen-containing gas and water vapour **characterized in that** partial oxidation is carried out in a partial oxidation channel which is mounted coaxially in a vertical oxidation chamber, and water vapour supply for partial oxidation of carbonaceous feedstock is carried out at the input and output of the partial oxidation channel of the oxidation chamber.

2. The method, as claimed in claim 1, **characterized in that** partial oxidation is carried out in the flow of the oxygen-containing gas and water vapour mixture in the partial oxidation channel of the oxidation chamber at a temperature of 900-1100^{0}C which is maintained by changing the volume of vapour at the output of the partial oxidation channel.

3. The method as claimed in claim 1 **characterized in that** at the output of the partial oxidation channel of the oxidation chamber the temperature is maintained within 800-1000°C which is provided by changing the volume of vapour at the output of the partial oxidation channel.

4. The method as claimed in claim 1 **characterized in that** the ignition of the carbonaceous feedstock and vapour-oxygen mixture and maintenance of their stable combustion is carried out by feeding the combustion products to the input of the partial oxidation channel from the burner device mounted coaxially in the partial oxidation channel.

5. The method as claimed in claim 1 **characterized in that** the residence time of combustion products in the oxidation channel is longer than the biggest feedstock particle’s combustion time.

6. The method as claimed in claim 1 **characterized in that** the size dimensions of the partial oxidation channel are

chosen based on the ratio:

$$L \geq (4*G*T_b)/(\pi*\rho(t_0) *D^2),$$

where

L - the length of the partial oxidation channel;
D - the diameter of the partial oxidation channel;
G - the mass arrival of oxidation products into the partial oxidation channel;
T_b - the combustion temperature of the biggest particle of carbonaceous feedstock;
t_0 - the calculated temperature of oxidation products in the partial oxidation channel;
$\rho(t_0)$ - the calculated density of oxidation products in the partial oxidation channel.

7. The method as claimed in claim 1 **characterized in that** solid fuels in the form of coal, brown coal, peat, wood, coke, soot or gaseous and liquid fuels, or mixtures thereof, are used as carbonaceous feedstock.

8. The gas producer comprising a housing, a burner device, a vertical oxidation chamber, manifolds for supplying carbonaceous feedstock, water vapour and oxygen-containing gas, a pipe for discharging gasification products, a slag removal chamber, is peculiar for the fact that the partial oxidation channel is additionally introduced into it. The channel is arranged coaxially in the vertical oxidation chamber and is attached to the upper internal part of the housing in which the burner device is installed.

9. The gas producer as claimed in claim 1 **characterized in that** the upper part of the housing is made in the form of a removable lid, into which the burner device is installed.

10. The gas producer as claimed in claim 1 **characterized in that** the pipe for discharge of gasification products is installed in the side piece of the gas producer housing closer to the upper part of the gas producer.

11. The gas producer as claimed in claim 1 **characterized in that** it contains upper and lower vapour manifolds made in the form of hollow rings connected by downpipes, the axes of which are parallel to the axis of the outer housing, though the upper manifold is installed on the outer part of the gas producer lid, the downpipes are installed on the outer side of the partial oxidation channel, and the lower vapour manifold is located at the output of the oxidation channel and is provided with vents to send vapour into the flow of partial oxidation products.

12. The gas producer as claimed in claim 1 **characterized in that** the burner device is made in the form of a diffusion burner equipped with annular channels arranged coaxially around the diffusion burner and made with the possibility of supplying oxygen-containing gas, carbonaceous feedstock and water vapour to the annular channels.

13. The gas producer as claimed in claim 1 **characterized in that** the inner walls of the oxidation chamber are made in the form of a coil, the upper output of which is connected to the upper vapour manifold through the hot vapour distribution unit, and the lower output is connected to an external water vapour generator.

14. The gas producer as claimed in claim 1 **characterized in that** the inner walls of the oxidation chamber are made in the form of coaxially arranged toroid-shaped containers made with the possibility of supplying water vapour from below the oxidation chamber to the lid of the gas producer.

15. The gas producer as claimed in claim 1 **characterized in that** the partial oxidation channel is made with external thermal insulation.

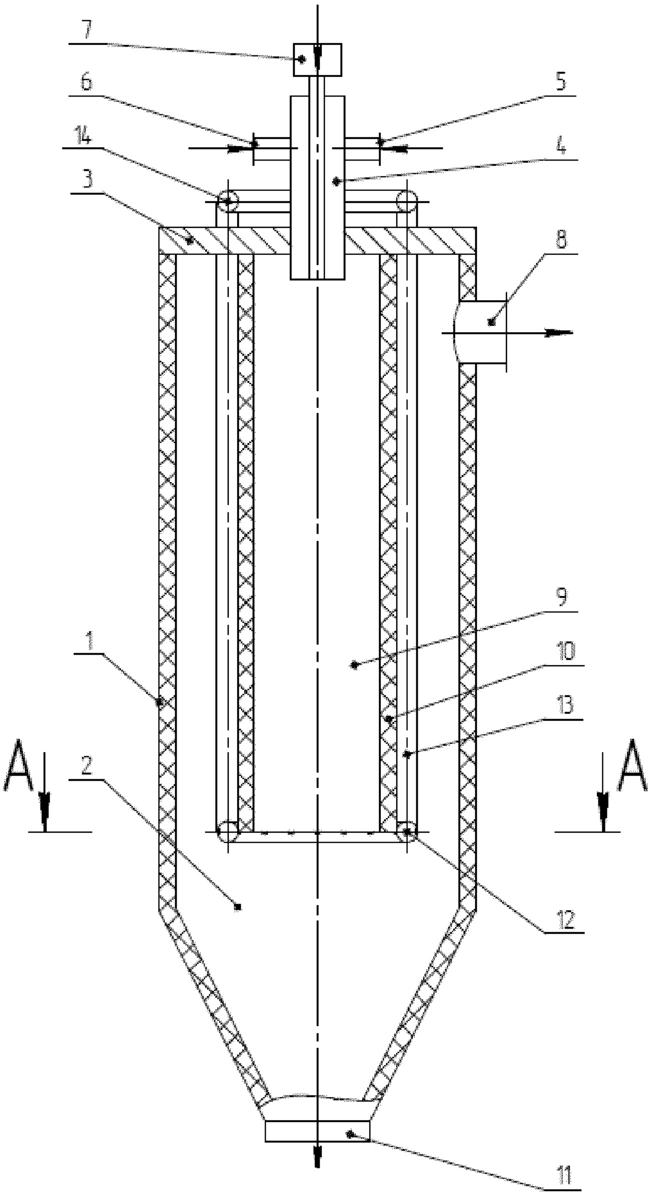

Fig. 1

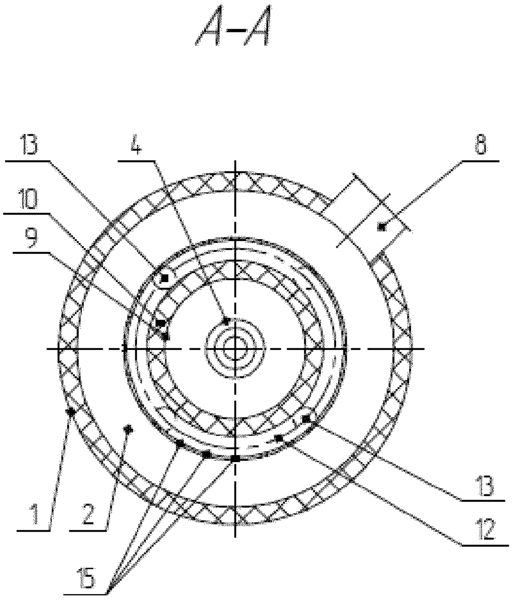

Fig. 2

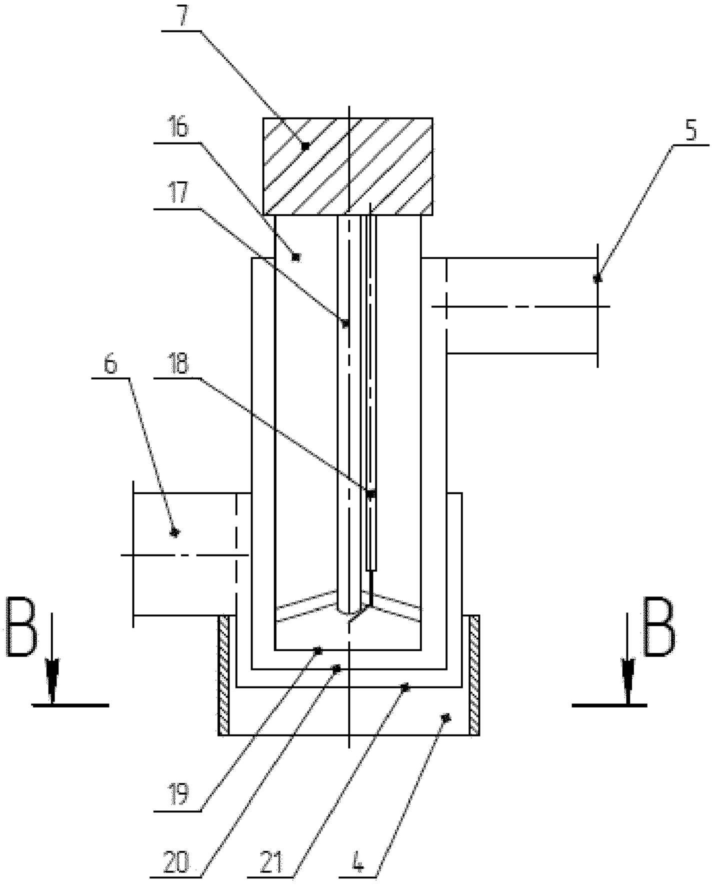

Fig.3

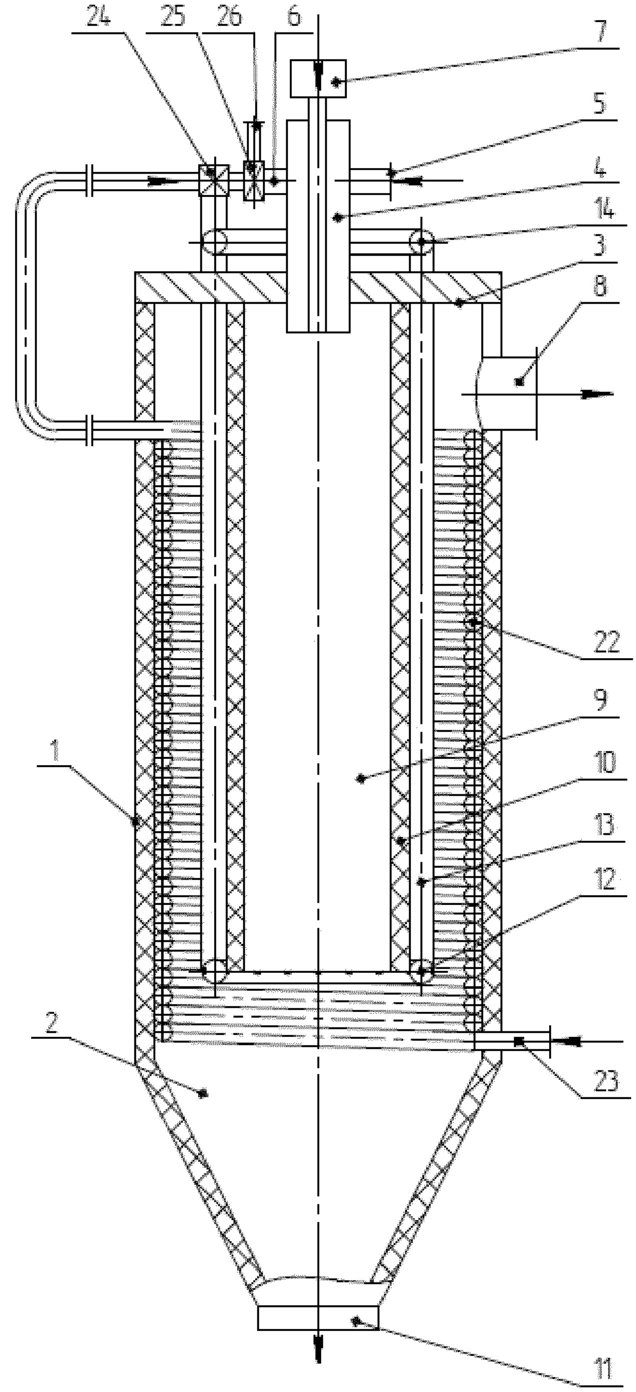

Fig.4

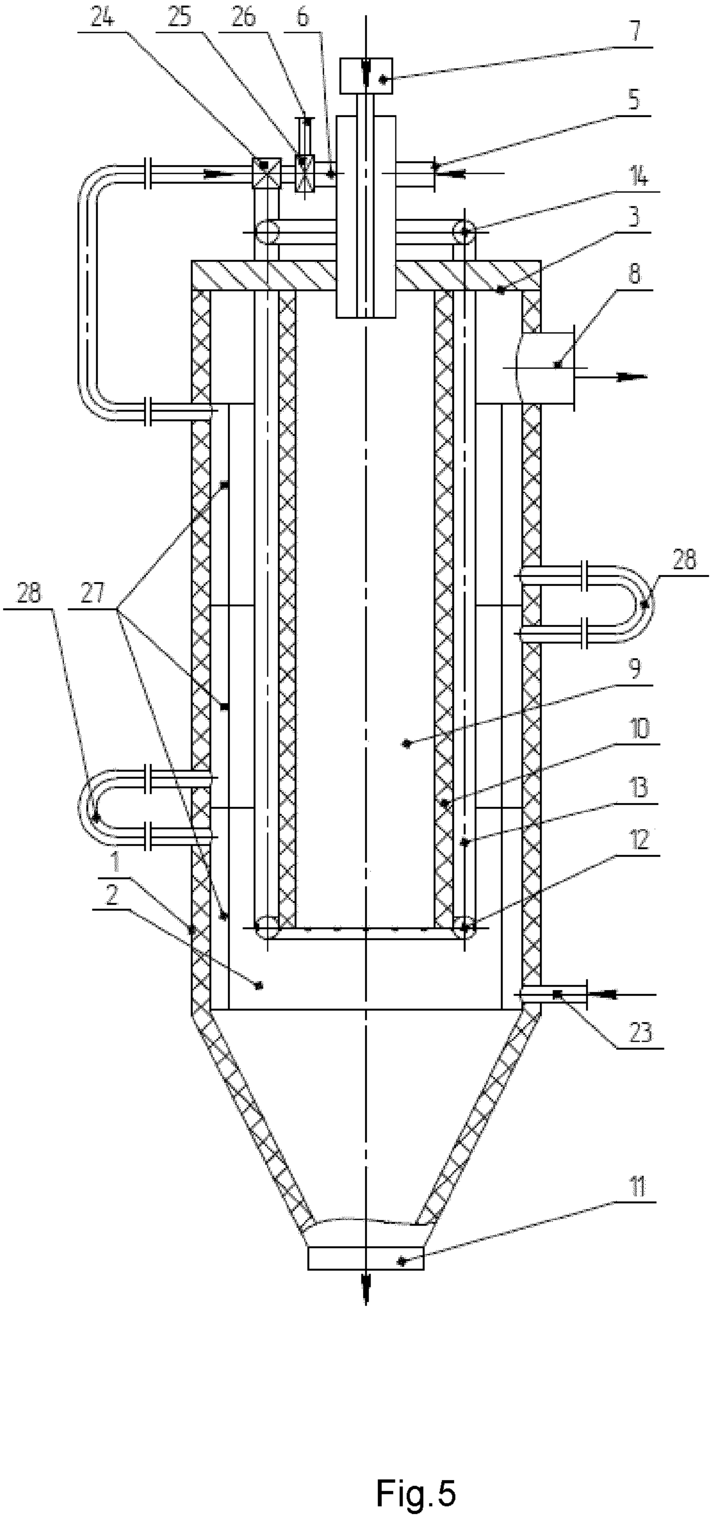

Fig.5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU 2021/000230

A. CLASSIFICATION OF SUBJECT MATTER
C10J 3/00 (2006.01) C10J 3/20 (2006.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C10J 3/00-3/86

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)
Espacenet, PatSearch, PAJ, WIPO, USPTO, RUPTO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
D, A	ALESHINA A.S. et al. Gazifikatsiya tverdogo topliva, Sankt-Peterburg, Izdatelstvo Politekhnicheskogo universiteta, 2010, ISBN 978-5-7422-1597-5, p.186-189, Protsess «PRENFLO» s sistemoy bystrogo okhlazhdeniya goryachego generatornogo gaza (PDQ)	1-15
D, A	RU 2237079 C1 (MIKHAILOV VIKTOR VASIL'EVICH et al.) 27.09.2004	1-15
A	RU 67582 U1 (KUZNETSOV ANATOLIY PAVLOVICH et al.) 27.10.2007	1-15
A	WO 1986/000634 A1 (COCKERILL MECHANICAL INDUSTRIES, SOCIETE ANONYME) 30.01.1986	1-15

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

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search 20 August 2021 (20.08.2021)	Date of mailing of the international search report 09 September 2021 (09.09.2021)
Name and mailing address of the ISA/ RU Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 1998)

REFERENCES CITED IN THE DESCRIPTION

Non-patent literature cited in the description

- **ALYOSHINA A. S. ; SERGEEV V. V.** Gasification of solid fuel: textbook. Publishing House of the Polytechnic University, 2010, 202 **[0064]**
- **RAMBUSH N. E.** *Gas producers - M.-L.: GONTI,* 1939, 413 **[0064]**
- **POMERANTSEV V.V. ; AREFYEV K.V.** *Fundamentals of the practical theory of combustion: textbook for universities - L.: Energoatomizdat,* 1986, 312 **[0064]**
- **SCHILLING G.-D. ; BONN B. ; KRAUS U.** *Coal gasification - Moscow: Nedra,* 1986, 175 **[0064]**