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(71) Applicant
Mitsubishi Jukogyo Kabushiki Kaisha (Japan),
5—1 Marunouchi 2-chome, Chiyoda-ku, Tokyo, Japan
(72) Inventors
Shozo Kaneko,
Akira Hashimoto,
Tokushi Maruta,
Misao Yamamura,
Kenichi Hisamatsu
(74) Agent and/or Address for Service
Marks & Clerk,
57—60 Lincoln's Inn Fields, London WC2A 3LS

(54) Fuel-reforming apparatus

(57) Fuel-reforming apparatus includes a number of catalyst-filled tubes (4) adapted to be heated up to an elevated temperature by heating from the outside so as to reform fuel to gas containing hydrogen as a main component, the fuel passing through each of the catalyzer-filled tubes (4) which tubes are arranged in a fluidized bed (24). A plurality of pipe burners (5) may be disposed above the bottom floor of the fluidized layer (24). Each of the catalyst filled tubes (4) is preferably designed in the form of a double wall tube (Fig. 13(a)). The fluidized bed (24) is preferably pressurized and drives a gas turbine; combustion gases from the bed may be used to pre-heat combustion air in a heat-exchanger (19).

FIG.2

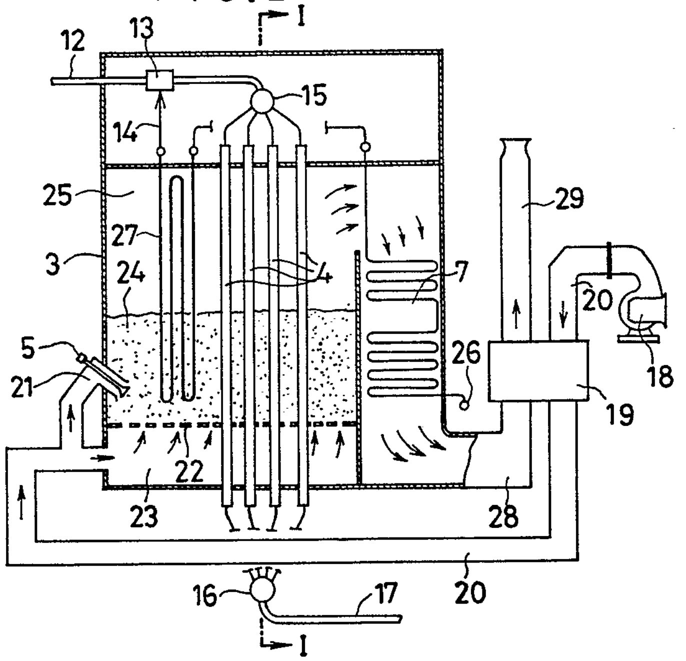

FIG.13(a)

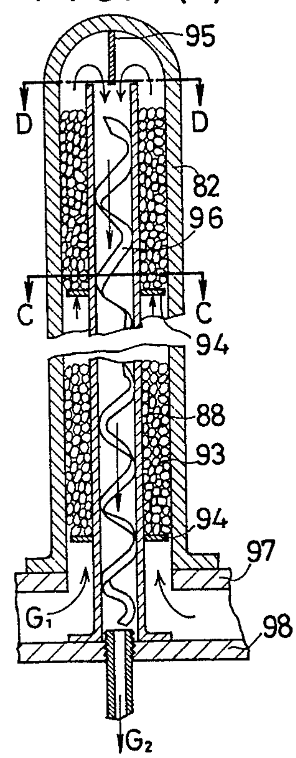

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FIG.1

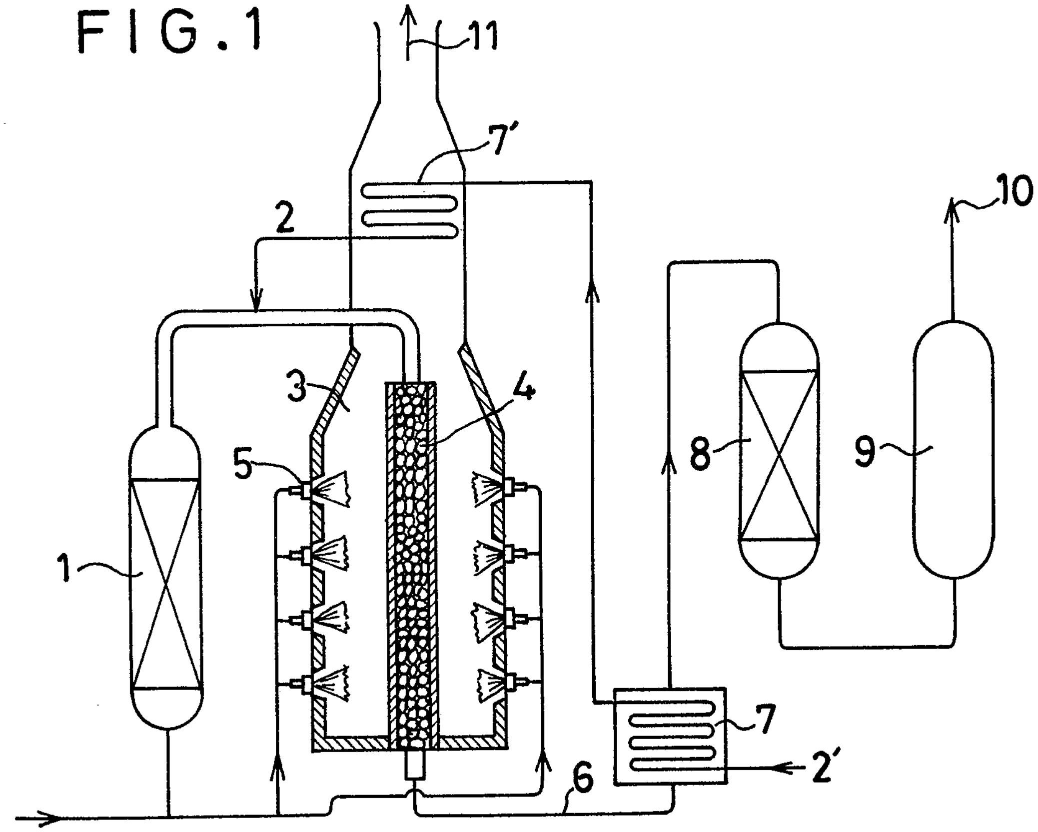
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FIG.2

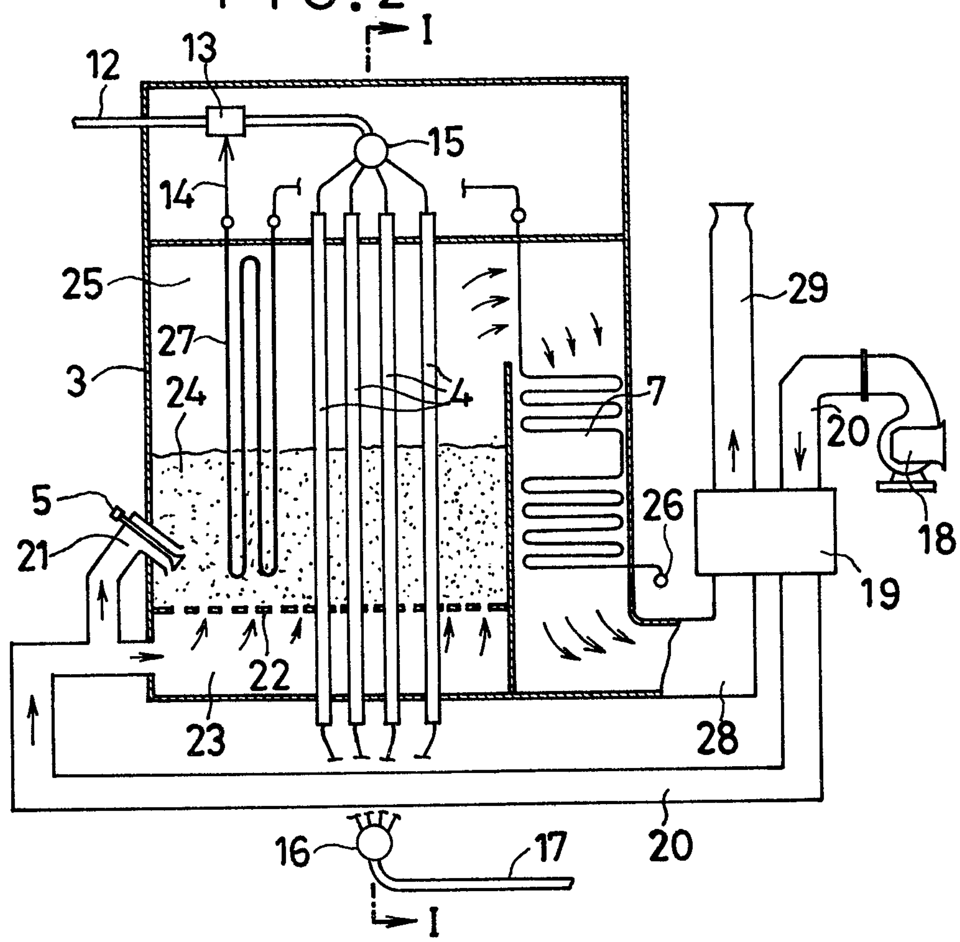
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FIG.3

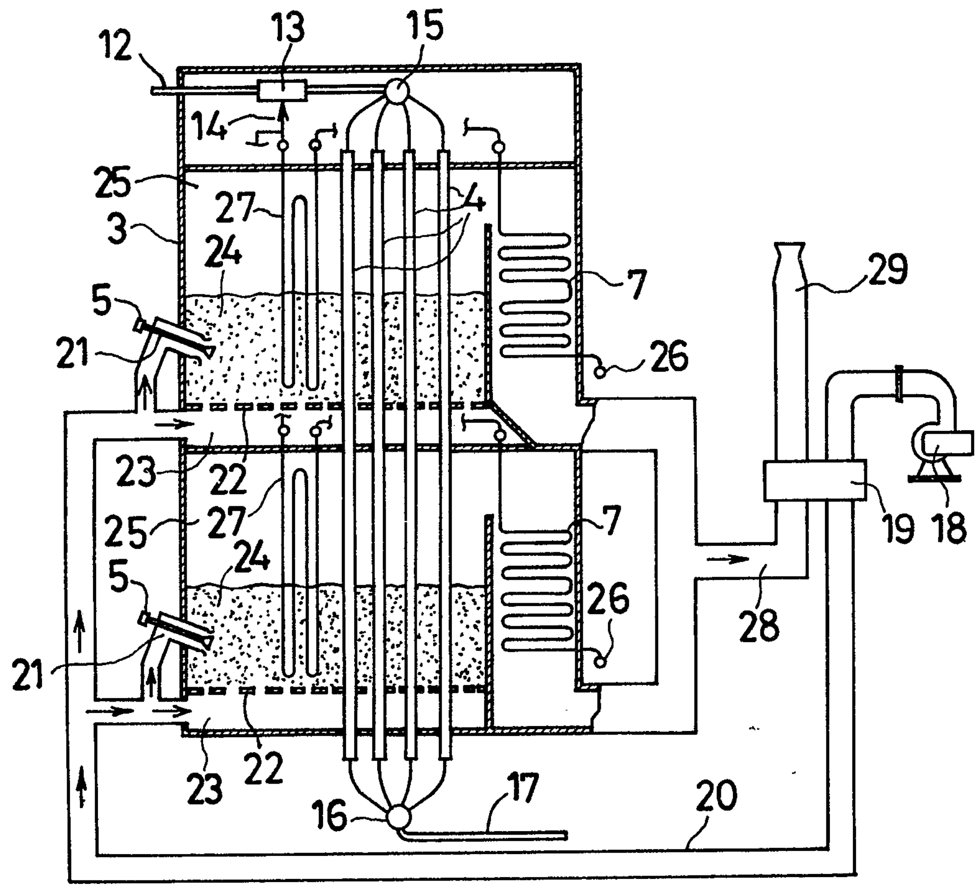
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FIG.4

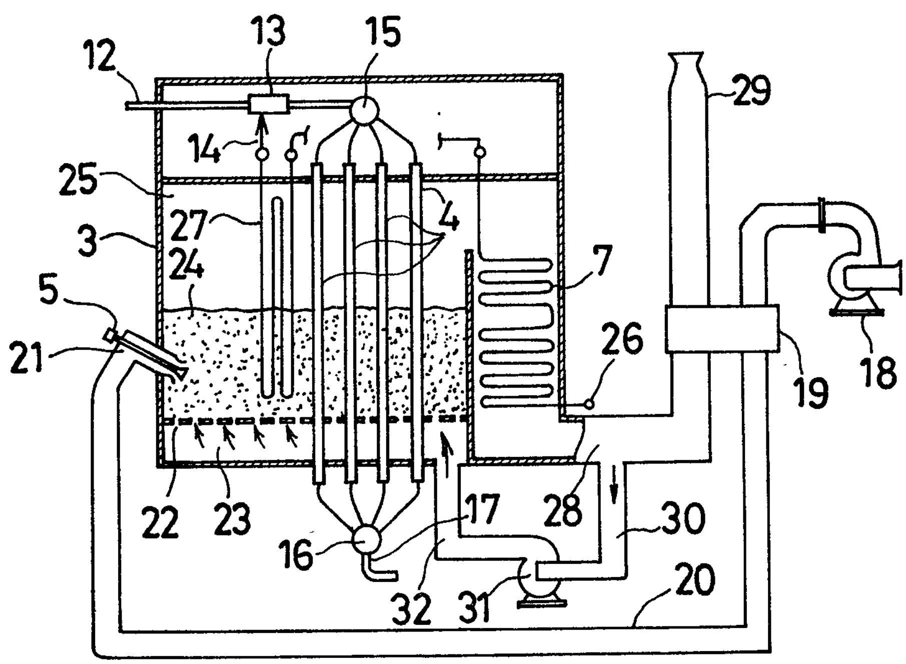
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FIG.5(a)

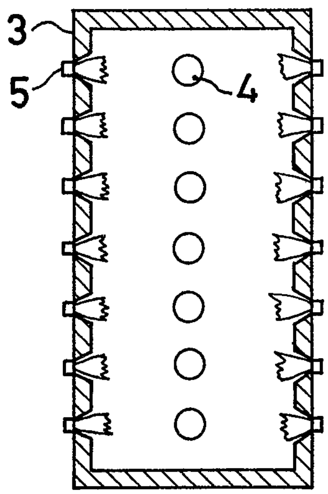

FIG.6

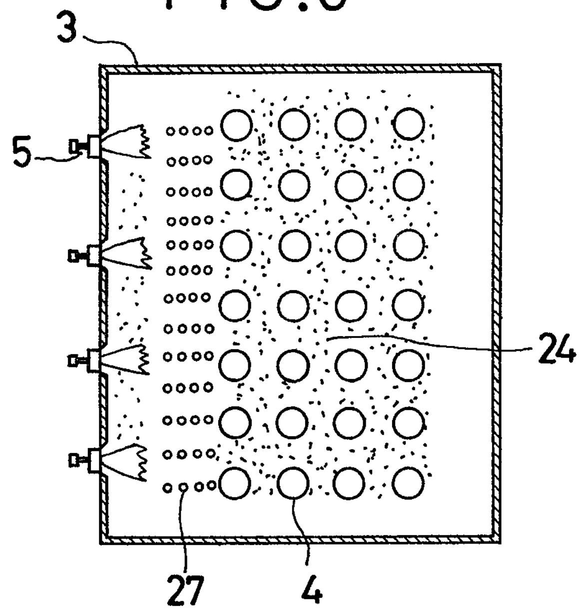

FIG.5(b)

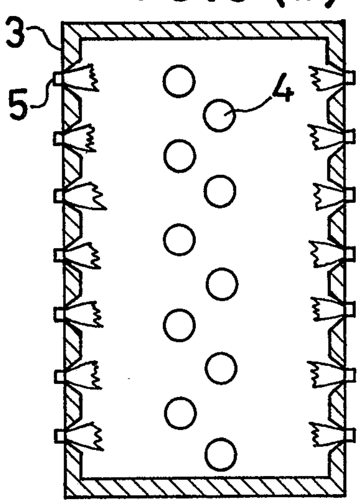

FIG.7

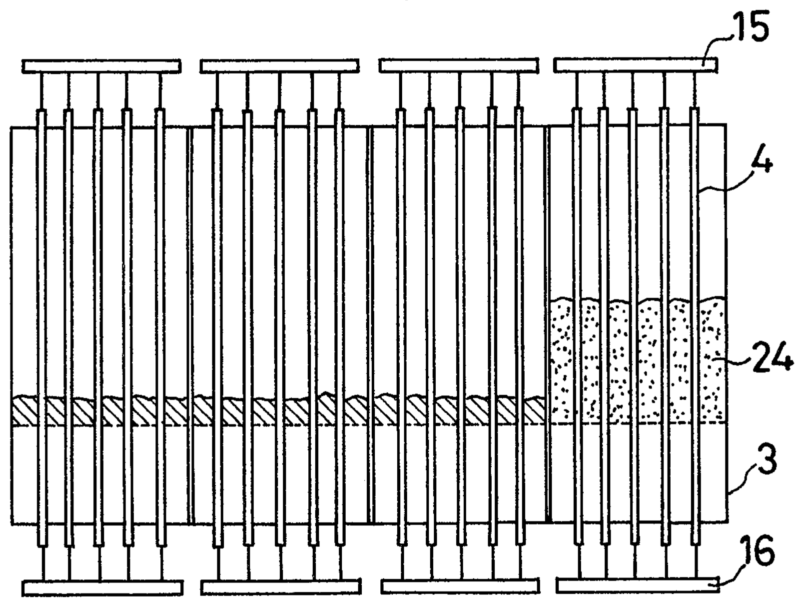

FIG.8

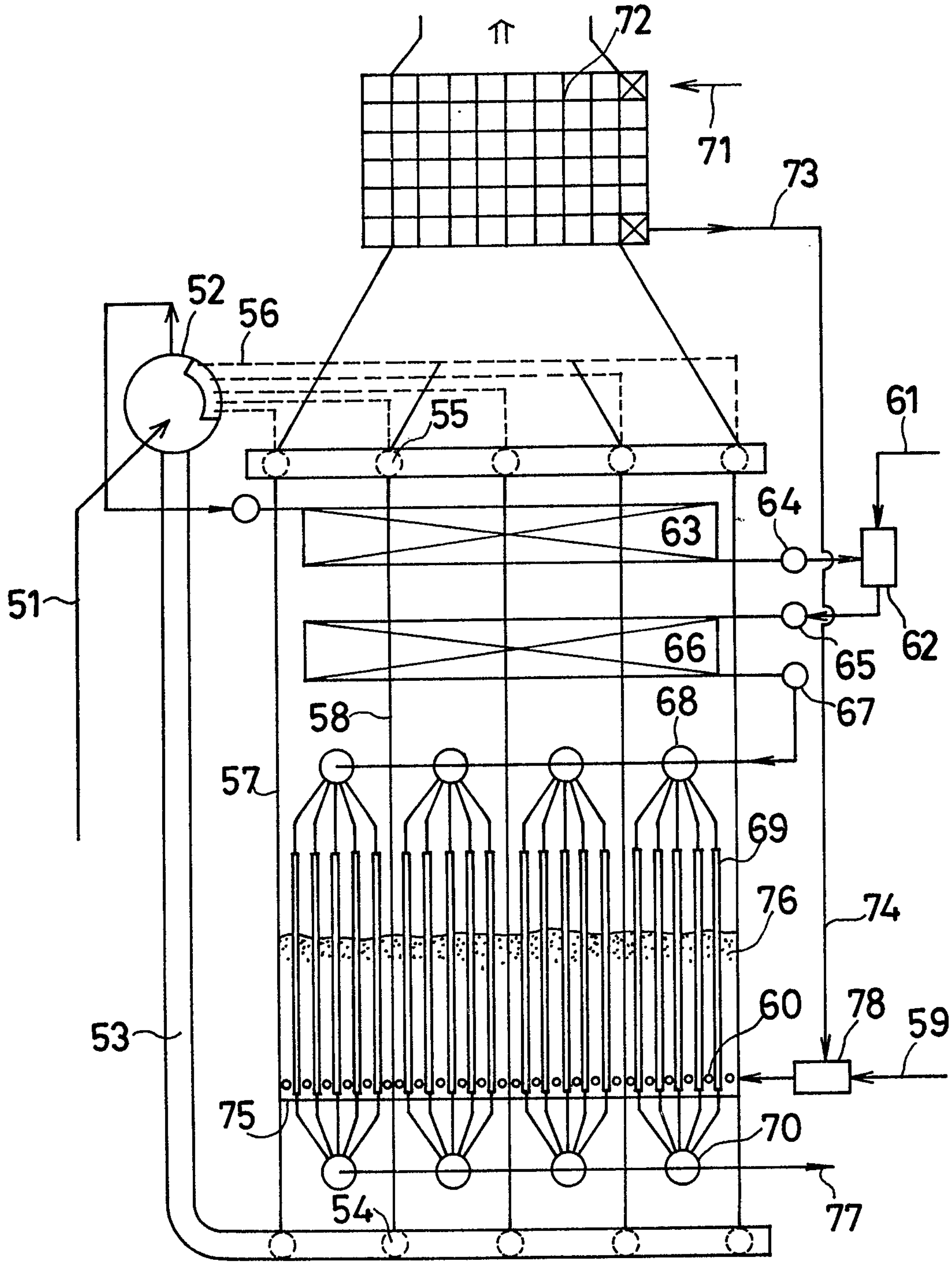
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FIG.9

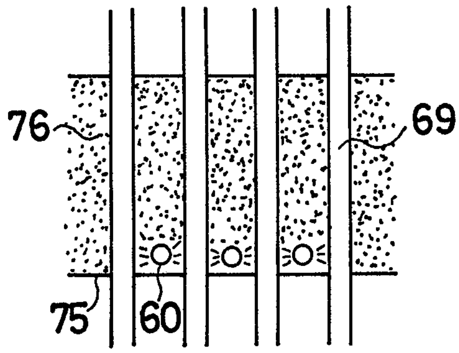


FIG.10

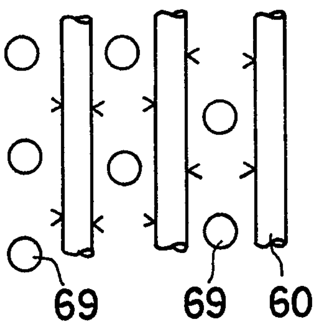


FIG.11(a)

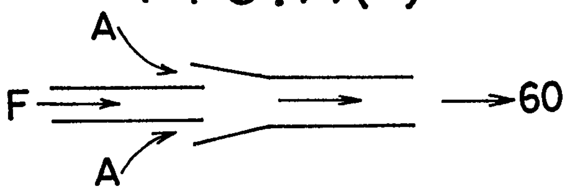


FIG.11(b)

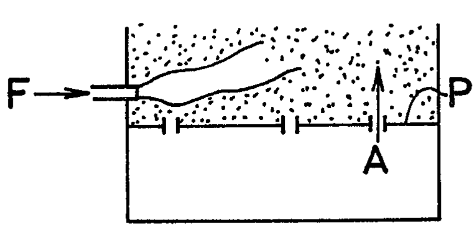
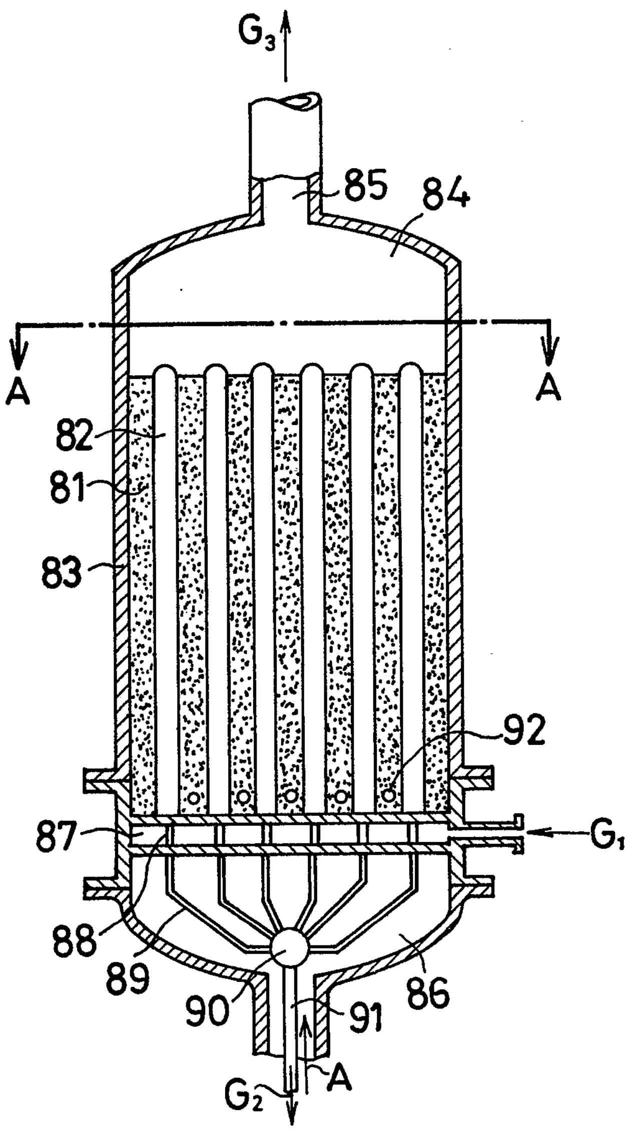


FIG.12(a)



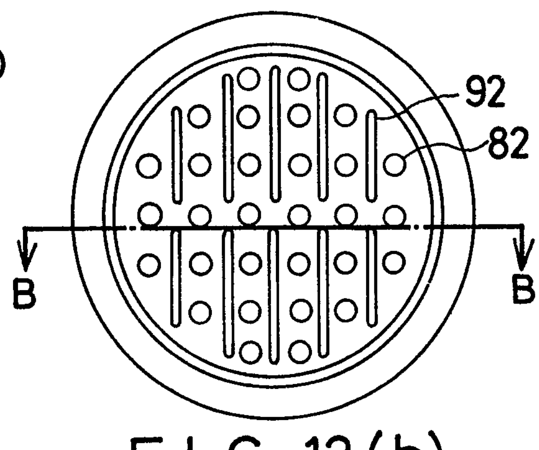


FIG.12(b)

FIG.13(c)

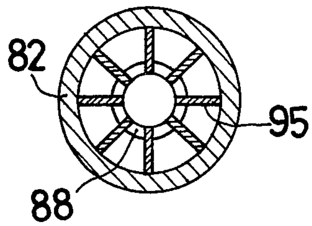


FIG.13(a)

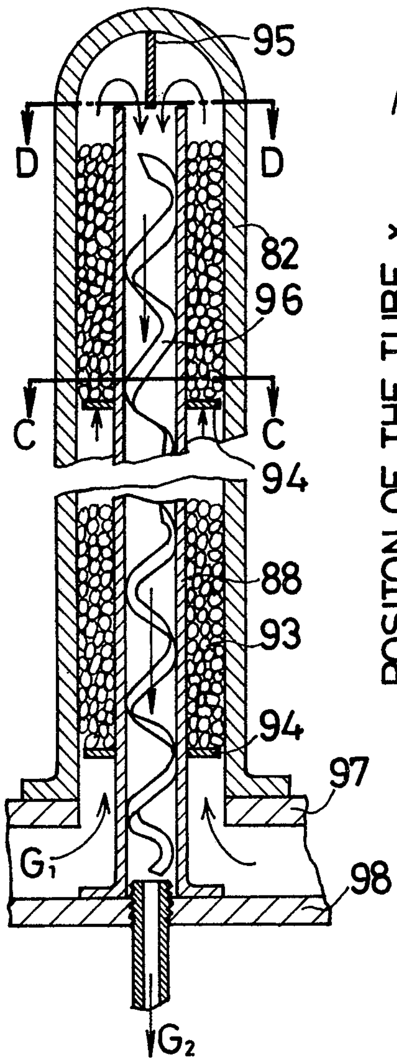


FIG.13(b)

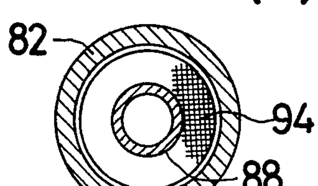


FIG.14

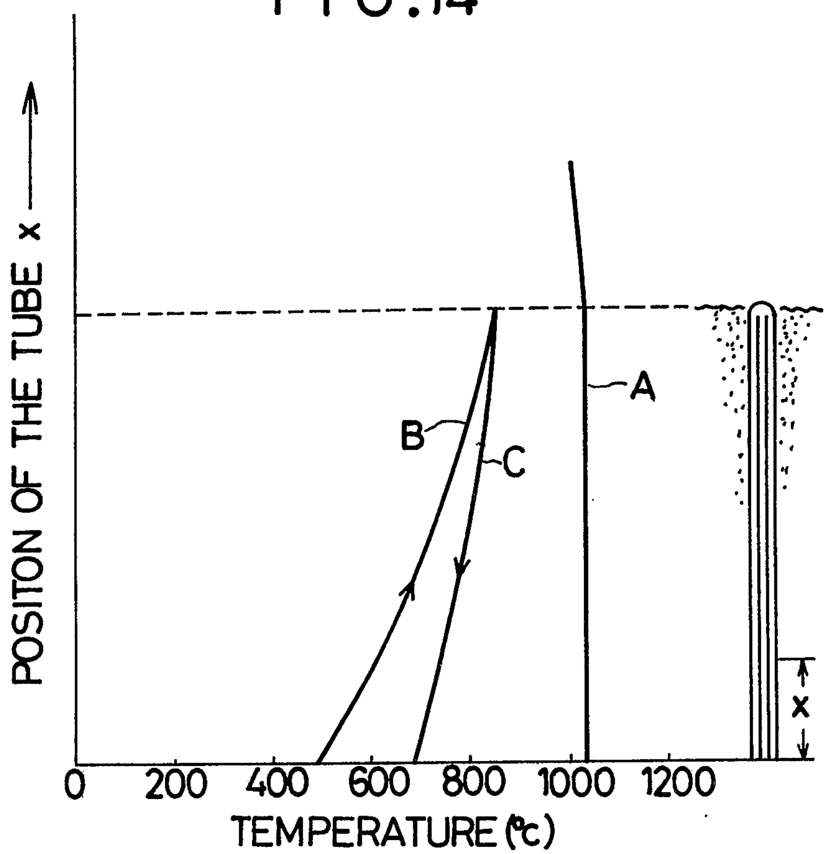
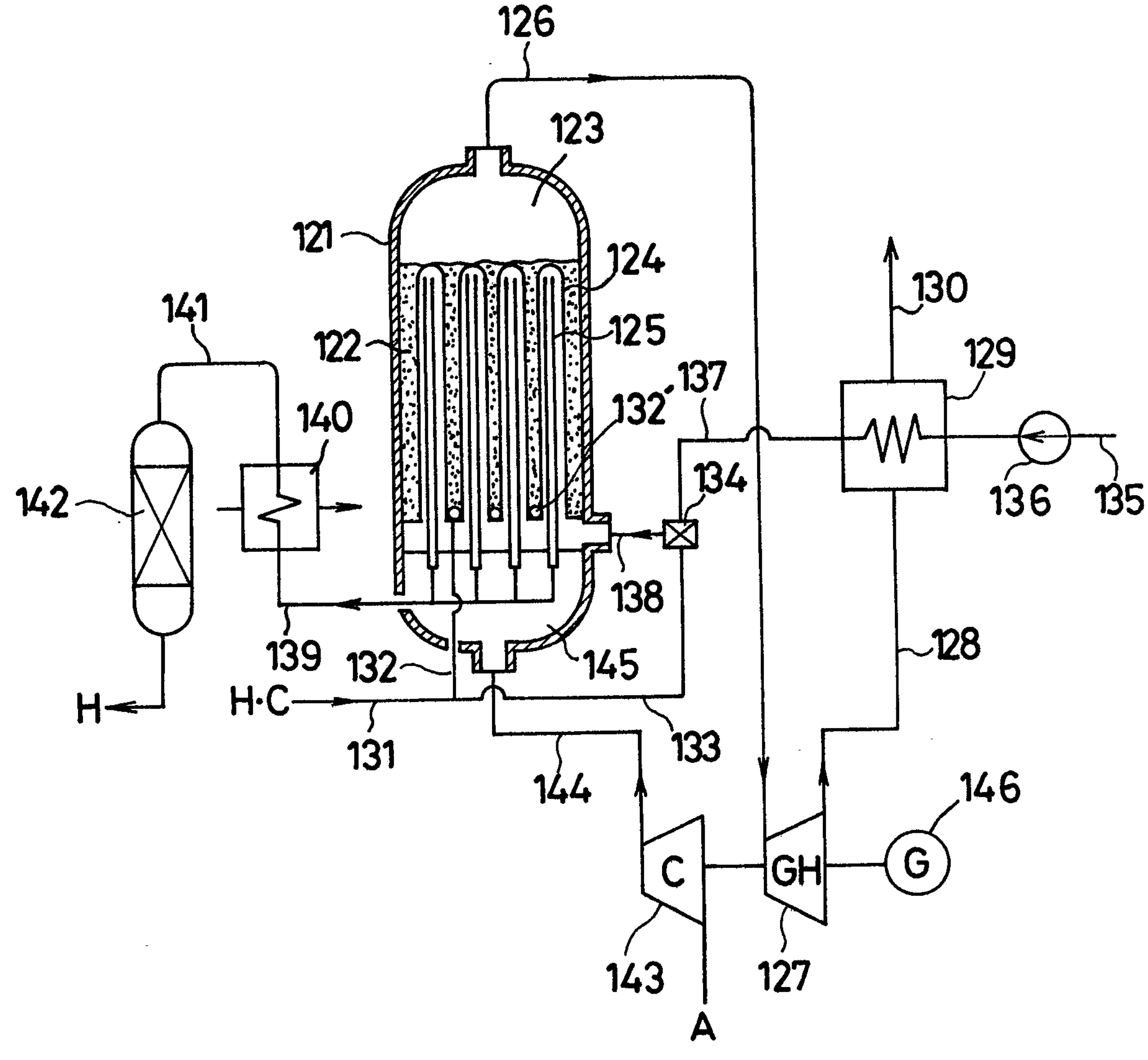


FIG.15



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SPECIFICATION

Fuel-reforming apparatus

The present invention relates to an improved fuel reforming apparatus.

Fuel reforming apparatus refers to an apparatus for converting hydrocarbon based fuel to gas containing hydrogen as a main component and many fuel reforming apparatuses of the above-mentioned type have been hitherto installed in chemical plants.

To facilitate understanding of the present invention it will be helpful that a hitherto known fuel reforming apparatus is described briefly.

Fig. 1 schematically illustrates a conventional fuel reforming apparatus. The most popular fuel reforming apparatus is referred to as steam reformer in which fuel reforming is carried out by way of the steps of adding steam to fuel such as CH_4 or the like, causing the mixture of fuel and steam to pass through a layer of catalyzer at an elevated temperature, for instance, in the range of 750 to 900°C to reform it to gas containing hydrogen as a main component, converting the residual carbon monoxide to CO_2 with the aid of a CO converter and removing CO_2 to obtain a high purity of gas containing hydrogen.

Specifically, fuel such as CH_4 or the like delivered from a supply source located outside the fuel reforming system as illustrated in Fig. 1 is first desulfurized in a desulfurizer 1 and it is then added with steam 2 so that the mixture of fuel and steam is supplied into a plurality of catalyzer filled tubes 4 arranged in the steam reformer furnace 3. The catalyzer filled tubes 4 are heated up to an elevated temperature in the range of 750 to 900°C by radiant heat emitted from wall surfaces of the steam reformer furnace 3, said wall surfaces being heated by operating a number of burners 5. While the mixture of fuel and steam passes through a layer of catalyzer in each of the catalyzer filled tubes 4, it is caused to reform to gas containing hydrogen. Thus reformed gas 6 containing hydrogen as a main component is subjected to heat exchanging in a heating tube 7 in which heat exchanging is effected between reformed gas 6 and water 2′ which is delivered to the heating tube 7 from a supply source located outside the fuel reforming system and thereafter it is introduced into a CO converter 8 in which residual carbon monoxide is converted to CO_2. After leaving the CO converter 8 the reformed gas enters a CO_2 absorbing tower 9 in which residual carbon dioxide is removed therefrom. A high purity of hydrogen 10 thus obtained is taken out of the fuel reforming system. On the other hand, combustion gas 11 coming up from the steam reformer furnace 3 is subjected to heat exchanging in the heat exchanging portion 7′ in which heat exchanging is effected between combustion gas 11 and steam 2 generated in the heating tube 7 and thereafter it is discharged into the outside atmosphere.

However, it has been found that the conventional fuel reforming apparatus as constructed in the above-described manner has the following drawbacks.

(1) The catalyzer filled tubes 4 in the steam reformer furnace are exposed to a very high temperature and therefore heat resistant metallic material constituting them is forced to operate under the ciritical condition. For the reason they tend to rupture when they have any locally increased thermal load or unbalanced temperature distribution, resulting in an occurrence of leakage of gas therefrom. This causes the steam reformer furnace to be designed with substantially reduced thermal load and to assure that thermal load is uniformly distributed across the furnace the latter is constructed in larger dimensions with a large number of burners mounted on the wall surfaces. Accordingly, the conventional steam reformer furnace is manufactured at an expensive cost with wide space required for installation.

(2) After leaving the catalyzer filled tubes 4 combustion gas is usually subjected to heat exchanging in a heat exchanger in which heat exchanging is effected between combustion gas and water (steam) but not heat recovery is practiced at the lower temperature area in the flue. Accordingly, the conventional steam reformer furnace is operated at a lower thermal efficiency.

(3) To assure that the furnace is operated with thermal load being reduced and uniformly distributed thereacross the catalyzer filled tubes are usually heated indirectly by heating furnace walls lined with refractory material, said furnace walls being heated by means of a number of burners. In view of protection of refractory material there is necessity for reducing a rate of temperature change when the furnace starts or stops its operation. This means that it takes long time to cause the furnace to start or stop its operation.

(4) The minimum load is usually determined 50% or more or less and therefore the furnace is operated with highly reduced load only with much difficulties.

(5) Since the conventional steam reformer furnace is designed under the operating condition of normal pressure, it is constructed in larger dimensions. Moreover, since it has negative pressure, there is necessity for mounting an induction type blower.

Hence, the present invention has been made with the foregoing drawbacks of the conventional fuel reforming apparatus in mind and its object resides in providing an improved fuel reforming apparatus which has excellently high operational characteristics and can be manufactured at an inexpensive cost. Now, the characterizing features of the fuel reforming apparatus of the invention will be noted below.

(1) It is constructed in smaller dimensions with the minimized space required for installation and it is operated at an inexpensive cost.

(2) Heat recovery from exhaust gas is effectively carried out and therefore it is operated at a high thermal efficiency.

(3) It starts or stops its operation for a very

short period of time.

(4) It can be operated with substantially reduced thermal load.

To accomplish the above object a variety of research and development works have been heretofore conducted. As a result of these research and development works it has been found that it can be accomplished satisfactorily by employing a fluidized layer system for the fuel reforming apparatus in which a number of catalyzer filled tubes are arranged in the fluidized layer so as to allow them to be heated from the latter and moreover mounting an air preheater at the low temperature area in the flue through which exhaust gas coming from the steam reformer furnace flows, said air preheater serving as a heat exchanger in which heat exchanging is effected between combustion gas and combustion air to carry out heat recovery from the former effectively.

Specifically, there is proposed according to one aspect of the invention an improved fuel reforming apparatus of the type including a plurality of catalyzer filled tubes adapted to be heated up to an elevated temperature by heating from the outside so as to reform fuel to gas containing hydrogen as a main component, said fuel passing through each of the catalyzer filled tubes, wherein the improvement consists in that the catalyzer filled tibes are arranged in a fluidized layer.

Further, there is proposed according to other aspect of the invention an improved fuel reforming apparatus of the above-mentioned type, wherein the improvement consists in that the catalyzer filled tubes are arranged in a fluidized layer and a heat exchanger is mounted in a predetermined position in which heat exchanging is effected between outgoing combustion gas and incoming combustion air.

Further, there is proposed according to another aspect of the invention an improved fuel reforming apparatus of the above-mentioned type, wherein the improvement consists in that the catalyzer filled tubes are arranged in a fluidized layer and a recirculating passage is provided through which a part of combustion gas extracted from a flue is caused to recirculate in the pressurized state.

Further, there is proposed according to further another aspect of the invention an improved fuel reforming apparatus of the above-mentioned type, wherein the improvement consists in that the catalyzer filled tubes are arranged in a fluidized layer constituted by non-combustible fluidizing material and a plurality of pipe burners are disposed above the bottom floor of the fluidized layer.

Further, there is proposed according to still further another aspect of the invention an improved fuel reforming apparatus of the above-mentioned type, wherein the improvement consists in that the catalyzer filled tubes are designed in the form of a double wall tube respectively.

Furthermore, there is proposed according to yet further another aspect of the invention of the above-mentioned type, wherein the improvement consists in that the fluidized layer is constructed in the form of a fluidized layer operating in the pressurized state and a gas turbine is installed in a predetermined position which is driven by combustion gas.

Other objects, features and advantages of the invention will be readily apparent from reading of the following description which has been prepared hereinafter in conjunction with the accompanying drawings.

The accompanying drawings will be briefly described below.

Fig. 1 schematically illustrates a conventional fuel reforming apparatus.

Fig. 2 schematically illustrates a fuel reforming apparatus in accordance with the first embodiment of the invention.

Fig. 3 schematically illustrates a fuel reforming apparatus in accordance with the second embodiment of the invention.

Fig. 4 schematically illustrates a fuel reforming apparatus in accordance with the third embodiment of the invention.

Fig. 5 is a cross-sectional plan view of a steam reformer furnace in the conventional fuel reforming apparatus.

Fig. 6 is a cross-sectional plan view of a steam reformer furnace in the fuel reforming apparatus of the invention.

Fig. 7 is a vertical sectional side view of the fuel reforming apparatus taken in line I—I in Fig. 2.

Fig. 8 schematically illustrates a fuel reforming apparatus in accordance with the fourth embodiment of the invention.

Fig. 9 is a fragmental vertical sectional view schematically illustrating how a plurality of pipe burners are arranged in the fluidized layer of the fuel reforming apparatus of the invention.

Fig. 10 is a fragmental plan view schematically illustrating how the pipe burners are arranged relative to a plurality of catalyzer filled tubes in the fluidized layer.

Fig. 11(a) schematically illustrates how fuel and combustion air are preliminarily mixed with one another prior to entering a pipe burner.

Fig. 11(b) schematically illustrates that there is necessity for providing a perforated distributing plate for the conventional fluidized layer.

Fig. 12(a) is a vertical sectional view of a fuel reforming apparatus in accordance with the fifth embodiment of the invention taken in line B—B in Fig. 12(b).

Fig. 12(b) is a cross sectional view of the fuel reforming apparatus taken in line A—A in Fig. 12(a).

Fig. 13(a) is a vertical sectional view of a double wall catalyzer filled tube employed for the fuel reforming apparatus of the invention.

Fig. 13(b) is a cross-sectional view of the double wall catalyzer filled tube taken in line C—C in Fig. 13(a).

Fig. 13(c) is a cross-sectional view of the double wall catalyzer filled tube taken in line D—D in Fig. 13(a).

Fig. 14 is a diagram schematically illustrating how temperature is distributed across the double wall catalyzer filled tube for the fuel reforming apparatus as illustrated in Figs. 13(a) to (c), and

Fig. 15 schematically illustrates a fuel reforming apparatus in accordance with the sixth embodiment of the invention.

Now, the present invention will be described in a greater detail hereunder with reference to the accompanying drawings which illustrate preferred embodiments of the invention.

First, description will be made as to the first embodiment of the invention with reference to Fig. 2. In the drawing reference numeral 3 designates a steam reformer furnace, reference numeral 12 does a fuel tube horizontally extending above said steam reformer furnace 3 to feed fuel into a plurality of catalyzer filled tubes 4 therethrough, reference numeral 13 does a mixer disposed at the position located midway of said fuel tube 13 so as to mix fuel with steam therein and reference numeral 14 does a steam communication tube extending between the mixer 13 and the steam heater 27 to connect the former to the latter so that steam is fed into a flow of fuel therethrough.

Further, reference numeral 15 designates an inlet tube collector disposed before the catalyzer filled tubes 4 so as to connect the fuel tube 12 to the catalyzer filled tubes 4 to distribute the mixture of fuel and steam into each of the catalyzer filled tubes 4, said inlet tube collector 15 being located above the steam reformer furnace 3, reference numeral 4 does a plurality of catalyzer filled tubes each of which stands upright within a fluidized bed 24 in the steam reformer furnace 3, reference numeral 16 does an outlet tube collector disposed behind the catalyzer filled tubes 4 to collect therein reformed gas containing hydrogen as a main component which comes from the catalyzer filled tubes 4 after completion of reforming reaction, said outlet tube collector 16 being located below the steam reformer furnace 3, and reference numeral 17 does a reformed gas tube extending from the outlet tube collector 16 to deliver reformed gas out of the reforming system therethrough.

Reference numeral 18 designates a forcible blower disposed outside the steam reformer furnace 3 to forcibly feed pressurized combustion air to a burner 5, reference numeral 19 does an air preheater mounted at the position located downstream of the forcible blower 18 and midway of the air duct 20 to preheat combustion air therein by heat exchanging effected between combustion air and hot waste gas, reference numeral 20 does an air duct by way of which the forcible blower 18 is connected to the preheater 19 and the latter is in turn connected to the burner air chamber 21 so as to feed combustion air to the burner air chamber 21 disposed outside the steam reformer furnace 3 therethrough, reference numeral 5 does a burner mounted on the side wall of the steam reformer furnace 3 and reference 21 does a burner air chamber into which combustion air is collected and stored prior to entering the burner 5.

Reference numeral 22 designates an air distributer arranged at the lower part of the steam reformer furnace 3 so that air flows upward through a number of holes on said air distributer 22 and it is then uniformly distributed to build a fluidized layer 24, reference numeral 23 does an air chamber disposed below the air distributer 22 in the steam reformer furnace 3, reference numeral 24 does a fluidized layer for heating a plurality of catalyzer filled tubes 4 and a steam heater 27 in the steam reformer furnace 3 and reference numeral 25 does a free board section in the steam reformer furnace 3.

Reference numeral 26 designates a feed water inlet tube collector into which water to be heated is supplied, said feed water inlet tube collector 26 being connected to a heating tube 7 which extends within the steam reformer furnace 3, reference numeral 7 does a heating tube disposed in the flue section in the steam reformer furnace 3 to generate steam therein and reference numeral 27 does a steam heater extending in the vertical direction in the area located between the side wall of the steam reformer furnace 3 with the burner 5 mounted thereon and the catalyzer filled tubes 4 so as to heat up therein steam which has been generated in the heating tube 7.

Further, reference numeral 28 designates a flue by way of which the flue in the steam reformer furnace 3 is in connection to the air preheater 19 so as to allow combustion gas to be introduced into the latter and reference numeral 29 does a chimney disposed downstream of the air preheater 19 to discharge combustion gas into the air therethrough.

Next, operation of the fuel reforming apparatus constructed in the above-described manner will be described below.

Fuel delivered from a fuel supply source located outside the fuel reforming system flows through the fuel tube 12 and enters the mixer 13 in which it is mixed with steam delivered by way of the steam delivery tube 14. The mixture of fuel and steam is then delivered to the inlet tube collector 15 located above the catalyzer filled tubes 4 so that it is uniformly distributed into the latter. While the mixture flows down through the interior of each of the catalyzer filled tubes 4, it is heated to an elevated temperature by heat transmission from the fluidized layer 24 whereby it is thermally decomposed to generate reformed gas containing hydrogen therein. The thus generated gas including hydrogen as a main component is collected in the outlet tube collector 16 located below the catalyzer filled tubes 4 and it is then transported to the next process via the reformed gas delivery tube 17.

On the other hand, combustion air to be fed to the burner 5 is first compressed by the forcible blower 18 and it is then heated up in the air preheater 19 while heat exchanging is effected between compressed air and combustion gas. The thus preheated air is delivered to the burner air chamber 21 via the air duct 20 to burn fuel fed into the burner 5. A part of compressed air enters the air chamber 23 and then flows upward into the combustion chamber through the distributing plate 22 whereby fluidizing material filled in the combustion chamber is fluidized to build a fluidized layer 24. Combustion gas enters the rear flue via the free board portion located above the fluidized layer 24 to heat water flowing through the heating tube 7 from the feed water inlet tube collector 26 and thereafter it flows into the air preheater 19 via the flue 28. After completion of heat exchanging with combustion air in the air preheater 19 combustion gas is discharged into the air through the chimney 29. Water and/or steam heated in the heating tube 7 flows into the steam heater 27 in which water is fully vaporized and thus generated steam is delivered to the mixer 13.

Next, Fig. 3 schematically illustrates a fuel reforming apparatus in accordance with the second embodiment of the invention. In this embodiment a steam reformer furnace is divided into two fluidized layers 24, that is, upper and lower fluidized layers 24. Owing to the arrangement in that way space required for installing the apparatus can be substantially spared and therefore this embodiment is preferably employable in the case where it should be installed within a strictly limited space.

Next, Fig. 4 schematically illustrates a fuel reforming apparatus in accordance with the third embodiment of the invention. In this embodiment a flue 28 has a recirculating gas inlet duct 30 branching therefrom at the position located upstream of the air preheater 19 and a recirculating gas blower 31 is disposed on the recirculating gas inlet duct 30 so as to compress recirculating gas. Further, a recirculating gas outlet duct 32 is extended between the recirculating gas blower 31 and the air chamber 23 so that combustion gas is recirculated through the fluidized layer via both the recirculating gas inlet and outlet ducts 30 and 32 while it is pressurized by means of the blower 31.

Thus, in the fuel reforming apparatus as constructed in the above-described manner a part of combustion gas is extracted into the recirculating gas inlet duct 30 and it is then introduced into the air chamber via the recirculating gas blower 31 and the recirculating gas outlet duct 32 so that a fluidized layer 24 is built in the same manner as in the foregoing embodiments. The apparatus in accordance with this embodiment has an advantageous feature that conditions for building the fluidized layer 24 can be determined separately from those with respect to combustion air. It should be of course understood that fluidizing can be effected by using the mixture of combustion gas and recirculating gas.

Now, the characterizing features of the fuel reforming apparatus of the invention will be described in more details below.

(1) An essential advantageous feature of the invention consists in that a plurality of catalyzer filled tubes are heated up to an elevated temperature with the aid of a fluidized layer. The most important feature of the fluidized layer is that excellently effective contact is assured among fluidized materials as well as between fluidizing material and fluid (combustion gas) and therefore constant temperature distribution is easily achieved owing to high thermal conduction speed among fluidizing materials as well as between fluidizing material and fluid (combustion gas) irrespective of how high temperature difference exists within the fluidized layer. It results that the catalyzer filled tubes 4 are heated within a constant temperature atmosphere while they are exposed to uniform thermal load, causing a steam reformer furnace to be designed in compact structure. Since the fluidized layer has a thermal conduction coefficient several times as high as that of normal gas flow, it is assured that necessary thermal conducting area can be reduced substantially. Figs. 5(a) and (b) are a cross-sectional plan view of a conventional steam reformer furnace installed in a chemical plant in which fuel is reformed, wherein Fig. 5(a) schematically illustrates that one line of catalyzer filled tubes 4 are arranged in an equally spaced relation and Fig. 5(b) does that two lines of catalyzer filled tubes are arranged in the form of zigzags. Since the catalyzer filled tubes 4 are so designed that they are heated up by thermal energy radiated from the inner side wall of the steam reformer furnace 3 lined with refractory material, it results that the reformer furnace fails to be uniformly loaded with thermal energy with uniform distribution of temperature being achieved across the inner space of the reformer furnace. As will be readily apparent from Fig. 5, a comparatively small number of catalyzer filled tubes can be arranged within the reformer furnace.

On the other hand, Fig. 6 is a cross-sectional plan view of a steam reformer furnace constructed according to the invention. As will be apparent from Fig. 6, the fuel reforming apparatus of the invention is so designed that a plurality of catalyzer filled tubes 4 are heated up by utilizing a fluidized layer with uniform distribution of temperature achieved across the reforming apparatus. As a result a larger number of catalyzer filled tubes 4 than that of the conventional apparatus can be arranged at very close distance kept between the adjacent ones so that the whole apparatus is designed in smaller dimensions with smaller space required for installing it while each of the catalyzer filled tubes 4 has a reduced heat conduction surface owing to the aforesaid high heat conduction coefficient guaranteed.

(2) In case of the conventional fuel reforming apparatus there is necessity for causing the wall surface of the steam reformer surface to function both as a thermal insulating material for inhibiting heat emission toward the outside atmosphere and as a thermal accumulator in which radiated heat is accumulated for heating catalyzer filled tubes. This

leads to increased thickness of refractory material constituting the furnace wall. However, there is fear of causing damage, crack or the like on the layer of refractory material due to thermal stress, provided that the furnace wall has a high rate of temperature change and therefore to assure that refractory material constituting the wall surface is properly protected it is necessary that a rate of temperature change is reduced as far as possible but this causes the fuel reforming apparatus to start and stop its operation only for a long period of time required.

On the other hand, the fuel reforming apparatus of the invention is so constructed that a number of catalyzer filled tubes are heated up by way of heat conduction from the fluidized layer and therefore the wall surface of the reformer furnace is required to function merely as a thermal insulating material for inhibiting heat emission toward the outside atmosphere, resulting in the minimized thickness of wall surface being dimensioned. Thus, refractory material constituting the wall surface is adequately protected from damaging, cracking or the like irrespective of how high a rate of temperature change is determined. This means that a rate of temperature change can be determined high. It should be noted that a rate of temperature change across the furnace wall can be determined extremely high when it is constructed with a number of water tubes contained therein so as to cool it and thereby a time required for starting or stopping operation of the apparatus can be minimized.

(3) To assure that a steam reformer furnace is uniformly loaded with thermal energy the conventional fuel reforming apparatus is required to have a number of burners arranged along the wall surface. On the other hand, in the fuel reforming apparatus of the invention a fluidized layer is employed for heating a plurality of catalyzer filled tubes so that the reformer furnace is uniformly loaded with thermal energy. Owing to the arrangement of the furnace in that way burners are designed in such a manner as to heat fluidizing materials only. Practically, a small number of burners having a high combustion capacity are mounted along the wall surface of the reformer furnace and therefore the number of burners to be mounted can be reduced substantially, compared with the conventional apparatus. Further, owing the arrangement that a group of steam heating tubes are disposed between the burners and the catalyzer filled tubes there is no fear of causing firing flame extending from the burners to directly reach the catalyzer filled tubes, even if the former produce excessively elongated flame because of an occurrence of abnormal firing. Thus, any local overheating does not take place due to the existence of so-called "hot spots".

(4) Since heat recovering is effectively carried out by way of heat exchanging between outgoing combustion gas and incoming combustion air at the combustion gas exhausting section where combustion gas flows at a lower temperature, the apparatus has a high total thermal efficiency.

(5) Fig. 7 is a schematic vertical sectional view of the apparatus taken in line I—I in Fig. 2. As is apparent from the drawing, the steam reformer furnace 3 is divided into four chambers so that operation of the furnace is easily practiced under the partially loaded condition. Specifically, Fig. 7 illustrates that among the four chambers just the right end one is in operation (that is, it is operated in the state of so-called active bed) and the other ones are out of operation (that is, it is in the state of so-called slump bed). This means that the furnace is operated under the working load of 25%. Further, it is also possible to operate it under the working load of 15% or more or less by properly controlling the operating conditions.

(6) Since the fuel reforming apparatus of the invention is so constructed that a part of combustion gas is utilized as a fluidizing gas for the fluidized layer by way of the steps of extracting it from the flue, compressing it with the aid of a blower and causing it to flow through the fluidized layer in the form of recirculation, it is possible to design and operate the apparatus with free factors of which number is more than that of the conventional apparatus.

Next, description will be made as to a fuel reforming apparatus in accordance with the fourth embodiment of the invention with reference to Fig. 8.

In the drawing reference numeral 51 designates a feed water line by way of which feed water is delivered to a steam drum 52. It should be noted that water feeding is carried out in conformance with a volume of steam (H_2O) which is required for fuel reforming. A part of water held in the drum 52 is delivered to lower tube collectors 54 via a downcast tube 53. While water flows upward through a plurality of tubes 57 and 58 from said lower tube collector 54, said tubes 57 and 58 extending along the inner periphral wall of the furnace and the partitions, it becomes a mixture of water and steam with the aid of fluidizing materials 76 serving as a heat conduction medium with which heat generated by pipe burners 60 is transmitted to the tubes 57 and 58. The mixture of water and steam flows back to the steam drum 52 via upper tube collectors 55 and upper tubes 56.

On the other hand, steam coming from the steam drum 52 is superheated in a superheater 63 and the thus superheated steam is then delivered to a fuel-steam mixer 62 via a superheater outlet tube collector 64, said mixer 62 being in connection to a fuel delivery tube 61 by way of which fuel (for instance, CH_4) is delivered thereto.

The mixture of fuel and steam is introduced into a heater 66 via a heater inlet tube collector 65 so that it is heated up to a predetermined temperature in said heater 66. Further, the mixture is introduced into a number of cylindrical catalyzer filled reformers 69 via a heater outlet tube collector 67 and reformer inlet tube collectors 68 so that fuel (CH_4) contained in the mixture is reformed to a required product comprising hydrogen (H_2) and carbon monoxide (CO).

Vanadium-nickel based catalyzer is employed as a typical catalyzer for the apparatus, said catalyzer being typically constructed in the tubular configuration having an inner diameter in the range of 5 to 6 mm, an outer diameter of 16 mm and a height of 19 mm. Reformed gas is extracted out of the apparatus via reformer outlet tube collectors 70 and a product delivery tube 77 so that it is put in use as raw material for fuel cell, power generation or the like purpose.

In the drawing reference numeral 72 designates an air heater disposed at the uppermost end part of the apparatus. Air flows into said air heater 72 via a combustion air delivery duct 71 while it is still at a lower temperature and the thus heated combustion air is then delivered to a preliminary fuel and air mixer 78 via a hot air outlet duct 73 and a hot air inlet duct 74.

On the other hand, waste gas coming from a power plant is adequately mixed with fuel (CH_4) at a predetermined rate of mixing and the mixture of waste gas and fuel is introduced into the mixer 78 via a fuel delivery tube 59 in which it is mixed with combustion air coming from the air heater 72. The mixture of fuel and air is delivered to the burners 60 so as to allow it to be fired therethrough.

Heat generated by combustion of the mixture with the aid of the burners 60 is utilized as a heating medium for heating the reformers 69 in the presence of fluidizing material (sand or the like material) to reform the mixture of fuel and steam to a required product and moreover it is utilized also as a heating medium for generating steam. Since combustion gas is kept still hot usually at a temperature higher than 800°C even after heat is recovered into the reformers 69 in the fluidized layer, it is reused as heat source for heating the heater 66 for the mixture of fuel and steam, the steam superheater 63 and the combustion air heater 72 and it is then discharged out of the reforming system. In the drawing reference numeral 75 designates a floor board on which fluidizing materials are held.

The characterizing features of the fuel reforming apparatus as constructed in the above-described manner will be noted below.

(1) Sand or the like non-combustible material is employed as fluidizing material and therefore more freedom factors are provided for selectively determining the kind of fuel for heating reformers. If fluidizing material is combustible, only a small quantity of fuel can be supplied as auxiliary fuel and the kind of fluidizing material is limited only to solid fuel such as coal or the like. However, in the apparatus of the invention non-combustible fluidizing material is employed and therefore its kind, grain size and others can be selectively determined as required.

(2) As illustrated in Figs. 9 and 10, a plurality of pipe burners 60 are arranged in the fluidized layer including a number of reformers 19 (at the position located in the proximity of the floor board) and owing to the arrangement in that way the following advantageous features are obtainable.

(i) Fluidizing material is uniformly heated.

(ii) A number of burners having a small capacity can be disposed in an equally spaced relation within the fluidized layer with the minimum space required therefor whereby uniform heating is achieved.

(iii) As illustrated in Fig. 11(a), the pipe burner 60 is designed in the form of a previously mixed burner in which the mixture of fuel F and combustion air A prepared in a fuel piping or a mixer is used as material to be burnt therein. By employing a number of pipe burners 60 for the fluidized layer it results that there is no necessity for providing a perforated plate P (usually disposed at the bottom of a fluidized layer) which serves also as a distributing plate, said perforated plate P allowing air A to flow upward into the fluidized bed, as illustrated in Fig. 11(b).

(iv) Since the pipe burners are located above the floor board at the position spaced away from the latter, it is assured that the floor board is protected safely.

The present invention has been described above with respect to a fuel reforming apparatus and it should not be limited only to this but it may be applied to a fluidized layer type heat exchanger or the like device.

Next, the fifth and sixth embodiments of the present invention will be described below.

The fifth embodiment of the invention consists in that a number of catalyzer filled tubes are heated up to an elevated operating temperature within a fluidized layer while the maximum operating temperature of heating source is kept below a predetermined height with uniform temperature distribution achieved across the fluidized layer, said catalyzer filled tubes being constructed in the form of a double wall tube so as to allow heat recovery to be carried out effectively, and that a heat exchanger disposed outside the fuel reforming system can be constructed in the minimized dimensions with a thermal efficiency of the system being improved substantially.

On the other hand, the fifth embodiment of the invention consists in that a number of catalyzer filled tubes are heated up to an elevated temperature within a fluidized layer which is built in the pressurized state, while the maximum operating temperature of heating source is kept below a predetermined height with uniform temperature distribution achieved across the fluidized layer, said catalyzer filled tubes being constructed in the form of a double wall tube so as to assure that heat recovery is carried out effectively, that the whole apparatus is constructed in smaller dimensions owing to the arrangement that each of the catalyzer filled tubes is designed in thin wall thickness so as to reduce thermal stress and assure light weight and manufacturing at an inexpensive cost whereby transportation of the apparatus constituted by a plurality of modules can be carried out with the aid of a trailer or the like vehicle and that in order to utilize residual heat contained in exhaust gas more effectively after it leaves the fluidized layer which serves as heating medium a gas turbine is mounted at the position located outside the fuel reforming system, said gas turbine being driven by exhaust gas delivered from the apparatus.

Figs. 12(a) and (b) schematically illustrate a fuel reforming apparatus in accordance with the fifth embodiment of the invention. In the drawings reference numeral 81 designates a fluidized layer which is built by fluidizing granular material such as sand, alumina or the like (of which grain size is generally in the range of 40 to 200 microns). Reference numeral 82 designages an outer tube constituting a double wall catalyzer filled tube and reference numeral 83 does a housing for the apparatus. Reference numeral 84 does an empty space located above the fluidized layer and reference numeral 85 does a combustion gas outlet duct. Reference numeral 86 designates an air chamber for a combustion air A to be delivered to the fluidized layer, reference numeral 87 does a gas chamber for gas G_1 to be delivered to the catalyzer filled tube, reference numeral 88 does an inner tube constituting the double wall catalyzer filled tube, reference numeral 89 does an outlet tube for reformed gas G_2 and reference numeral 90 does a reformed gas outlet manifold. Further, reference numeral 91 designates a reformed gas outlet duct and reference numeral 92 does a plurality of burners arranged in a spaced relation in the fluidized layer, said burners 92 being designed in the form of a pipe burner respectively.

Figs. 13(a) to (c) illustrate the detailed structure of the double wall catalyzer filled tube, wherein Fig. 13(a) is a vertical sectional view of the catalyzer filled tube, Fig. 13(b) is a cross-sectional view taken in line C—C in Fig. 13(a) and Fig. 13(c) is another cross-sectional view taken in line D—D in Fig. 13(a). In the drawings reference numeral 82 designates an outer tube constituting the double wall catalyzer filled tube and reference numeral 88 does an inner tube constituting the same so that catalyzer 93 is filled within an annular space as defined between both the inner and outer tubes 82 and 88. Vanadium-nickel based catalyzer is preferably employed as a typical catalyzer of which configuration is typically designed in the form of a tube having an inner diameter in the range of 5 to 6 mm, an outer diameter of 16 mm and a height of 19 mm. Reference numeral 94 designates a catalyzer holding porous plate or mesh-shaped plate fitted onto the inner tube, reference numeral 95 does a guide vane disposed at the top end part of the double wall tube and reference numeral 96 does a helically extending ribbon contained within the inner tube so as to promote heat transmission. Reference numeral 97 designates a support plate on which the outer tube is firmly mounted in the vertical direction and reference numeral 98 does another support plate on which the inner tube is firmly mounted in the same direction as that of the outer tube.

Next, operation and characterizing features of the fuel reforming apparatus as constructed in the above-described manner will be described below.

Referring to Fig. 12 again, air A delivered into the combustion air chamber 86 burns fuel blown out of the burners 92 and the thus produced combustion gas flows upward in the state of ascending current while building a fluidized layer 81 within the housing 81 so that generated heat is effectively transmitted to a number of catalyzer filled tubes 82 with a constant temperature being distributed across the fluidized layer 81. As is apparent from the drawing, an arrangement is made such that the fluidized layer 81 is built below the plane located in the proximity of the top end of the catalyzer filled tubes 82 whereby a cross-sectional area is abruptly enlarged within the hollow space 84 located above the fluidized layer 81, causing gas speed to be abruptly reduced therein. As a result an occurrence of so-called carry-over phenomenon can be minimized, said carry-over phenomenon referring to such a malfunction that fluidizing material is carried away together with ascending current. This means that additional supply of fluidizing material is minimized. A number of pipe burners 92 are arranged in the lower part of the fluidized layer 81 so as to allow the latter to become operative for a short period of time with the minimized temperature difference being distributed across the fluidized layer. Reference letter G_3 designates a combustion gas.

Figs. 13(a) to (c) illustrate the detailed inner structure of the double wall catalyzer filled tube, wherein the annular space as defined between the outer tube 82 and the inner tube 88 is filled with catalyzer 93 and raw material gas G_1 to be reformed is caued to flow upward via the gas inlet piping in the form of ascending current. While raw material gas flows upward through the layer of filled catalyzer, heat is transmitted to the outer tube 88 from the fluidized layer 81 so that the layer of catalyzer is maintained at an elevated temperature required for practicing reforming reaction. When a fluidized layer is employed for the apparatus, it is expected that a heat conduction coefficient is in the range of 200 to 250 Kcal/m^{2}h°C which means that a tube length required for heat conduction can be reduced substantially.

As hydrocarbon based fuel gas passes through the layer of catalyzer, it is reformed to gas containing hydrogen and carbon monoxide as main components until it reaches the top end of the double wall catalyzer filled tube. As is apparent from Fig. 13(c), a plurality of guide vanes 95 are bridged between the inner wall of the outer tube and the upper end part of the inner tube in the radial direction so that hydrogen rich gas flowing upward through the annular space with catalyzer filled therein smoothly changes the direction of flowing by 180 degrees to enter the inner tube. To assure that an effect of heat conduction is maximized by way of the repeated steps of collision and changing of the direction of gas flow a number of fillets (not shown) may be fixedly secured to the inner wall of the outer tube and/or the outer wall of the inner tube so that heat conduction area is increased substantially.

After completion of reforming to hydrogen rich reaction gas G_2 it folows downward through the interior of the inner tube 88 in the form of descending current. In view of the fact that hydrogen rich gas has a heat conduction coefficient higher than that of hydrocarbon based gas a heat conduction promoting ribbon 96 made of heat resistant metallic material such as SUS 304 according to JIS or the like is disposed in the inner tube so as to maximize the advantageous feature of hydrogen rich gas whereby increased heat conduction area as well as increased heat conduction rate are achieved. Reference numeral 94 designates a catalyzer holding plate in the form of a perforated plate with a number of small holes opened thereon or a mesh-shaped plate. As catalyzer is used for many years, it becomes deteriorated gradually and it tends to be partially broken or pulverized. Fractured or pulverized catalyzer falls down on the bottom of the double wall catalyzer filled tubes to accumulate thereon and thereby there is fear of causing troubles such as inhibition of smooth flowing of reformed gas, interruption of flowing of the same or the like. However, the arrangement of the catalyzer holding porous plate prevents an occurrence of troubles as described above. When the layer of catalyzer is to be inspected or replaced with new one, the inner tube holding plate 98 is first disconnected and then the inner tube 88 is removed by drawing it downward.

Fig. 14 is a diagram illustrating how temperature is distributed over the double wall catalyzer filled tubes, wherein temperature A in the fluidized layer, temperature B in ascending current and temperature C in descending current are shown as a function of the position in the catalyzer filled tube. As will be apparent from the diagram, reaction gas has a temperature of 850°C at the top end part of the catalyzer filled tube, whereas it has a temperature of 700°C at the outlet and this means that the catalyzer filled tube functions also as an effective heat conductor for preheating incoming fluid at the same time as reforming of the latter.

As described above, each of the double wall catalyzer filled tubes is arranged in such a manner that the lower end part is fixedly mounted while the upper end part is kept free. Alternatively, the arrangement may be inverted by 180 degrees, that is, each of the catalyzer filled tubes is suspended from the above and the lower end part thereof is kept free.

Fluidized layer may be operated either at normal pressure or under particularly pressurized atmosphere.

Further, it should be noted that the present invention should not be limited only to a fuel reforming apparatus but it may be applied to a fluidized layer type heat exchanger or the like device.

Finally, description will be made as to a fuel reforming apparatus in accordance with the sixth embodiment of the invention with reference to Fig. 15.

In the drawing reference numeral 121 designates a housing for the fuel reforming apparatus, reference numeral 122 does a fluidized layer, reference numeral 123 does a hollow space located above said fluidized layer 122, reference numeral 124 does an outer tube constituting a double wall catalyzer filled tube and reference numeral 125 does an inner tube constituting the same. Further, reference numeral 126 designates a combuston gas outlet duct, reference numeral 127 does a gas turbine, reference numeral 128 does a gas turbine exhaust gas duct, reference numeral 129 does an exhaust gas heat recovery boiler and reference numeral 130 does a chimney.

Reference numeral 131 designates a delivery tube for delivering hydrocarbon based fuel therethough, reference numeral 132 does a fuel tube for burners and reference numeral 132′ does a plurality of burners which are designed in the form of a pipe nozzle. Reference numeral 133 designates a delivery tube for raw material gas to be reformed, reference numeral 134 does a raw material gas-stream mixer and reference numeral 138 does a delivery tube for the mixture gas of raw material gas and steam. Reference numeral 135 designates a feed water tube for the boiler, reference numeral 136 does a feed water pump for the same and reference numeral 137 does a steam tube for reforming fuel. Reference numeral 139 designates a reaction product gas tube, reference numeral 140 does a heat exchanger, reference numeral 141 does a CO shift converter inlet tube and reference numeral 142 does a CO shift converter. Further, reference numeral 143 designates a compressor for combustion air A, reference numeral 144 does a combustion air duct, reference numeral 145 does a combustion air chamber and reference numeral 146 does a power generator.

Next, operation of the fuel reforming apparatus as constructed in the above-described manner will be described below.

Fuel mixed with pressurized air coming via the piping 144 is burnt with the aid of the burners 132′ so that a fluidized heating layer 122 is built in the pressurized state by causing fluidized material to float up. Thus built fluidized layer 122 heats a plurality of double wall catalyzer filled tubes constituted by both the outer and inner tubes 124 and 125 uniformly to a predetermined elevated temperature whereby the mixture gas of raw material gas and steam delivered via the tube 138 is reformed while passing through the layer of catalyzer filled in the double wall tubes until reformed gas containing hydrogen and carbon dioxide as main components are produced. After completion of reforming reaction product gas is taken out of the reforming system via the piping 139. Reaction product gas enters the heat exchanger 140 in which it is cooled down to a previously determined temperature by way of heat exchanging and thereafter it is delivered to the CO shift converter 142 in which carbon dioxide is reformed to hydrogen in accordance with the chemical formula ($CO + H_2O \rightarrow CO_2 + H_2$) so that hydrogen rich gas H is obtained.

Exhaust gas produced after combustion in the fluidized layer enters the gas turbine 127 via the hollow space 123 located above the fluidized layer and the combustion gas duct 126. The gas turbine 127 is operatively connected to the compressor 143 and the power generator 146 so that combustion air is compressed to a required pressure and it is then delivered to the fluidized layer via the combustion air duct 144 and the combustion air chamber 145.

In addition to operation of the compressor 143 extra power is consumed for rotating the power generator 146 so that it is converted to electricity. After leaving the gas turbine exhaust gas flows into the exhaust gas heat recovery boiler 129 in which heat exchanging is effected for recovering waste heat and thereafter it is discharged into the outside atmosphere via the chimney 130. Feed water for the exhaust gas heat recovery boiler 129 is delivered from the feed water pump 136 so that it is vaporized in the former and the thus generated steam is mixed with fuel in the raw material gas-stream mixer 134.

By employing the fluidized layer in the pressurized state for the apparatus the following advantageous features are obtainable.

(1) Moving speed in the hollow space can be reduced lower than that in operation at a normal pressure. Provided that moving speed in the hollow space is determined same to that in operation at a normal pressure, it results that space required for the fluidized layer can be reduced and therefore the whole apparatus can be constructed in smaller dimensions.

(2) Provided that moving speed in the hollow space is selectively determined to a lower level, a grain size of fluidizing material can be reduced correspondingly. As a result a number of catalyzer filled tubes disposed in the fluidized layer wear little and moreover carry-over occurs rarely in the hollow space located above the fluidized layer.

(3) Since fluidizing is effected in the pressurized state, the fludized layer obtains a heat conduction coefficient higher than that in operation at a normal pressure.

(4) Thermal energy contained in exhaust gas at an elevated temperature is recovered in the form of mechanical force which is utilized for rotating both the gas turbine and the compressor. In addition to this extra force is utilized for rotating a power generator. This makes it possible to design the exhaust gas heat recovery boiler in a smaller size in proportion to utilization of recovered heat in that way.

(5) Since the housing for the fuel reforming apparatus constituting the heaviest article can be designed in smaller dimensions, it results that transportation and installation are carried out very easily. Moreover, when the apparatus is constituted by a plurality of modules, transportation is carried out easier with the aid of a trailer or the like vehicle.

(6) A fluidized layer has a constant temperature distributed uniformly thereacross. Thus, by properly controlling operation of the fluidized layer it is assured that a number of catlyzer filled tubes exposed to severe temperature condition in the fluidized layer are protected from an occurrence of trouble such as rupture, leakage or the like. Further, another advantageous feature of the fluidized layer such as operational characteristics under partial loading, excellent adapatability to changing in load at a high speed and others can be utilized satisfactorily.

While the present invention has been described above with respect to several preferred embodiments, it should be of course understood that it should not be limited only to them but various changes and modifications may be made in a suitable manner without any departure from the spirit and scope of the invention.

CLAIMS

1. Fuel-reforming apparatus of the type including a plurality of catalyzer filled tubes adapted to be heated up to an elevated temperature by heating from the outside so as to reform fuel to gas containing hydrogen as a main component, said fuel passing through each of said catalyzer filled tubes, wherein the catalyzer filled tubes are arranged in a fluidized layer.

2. Fuel-reforming apparatus as claimed in claim 1, wherein a heat exchanger is provided so that heat exhanging is effected between outgoing combustion gas and incoming combustion air.

3. Fuel-reforming apparatus as claimed in claim 1 or 2, wherein a recirculating passage is provided through which a part of combustion gas extracted from a flue is caused to recirculate in the pressurized state.

4. Fuel-reforming apparatus as claimed in claim 1, 2 or 3, wherein the fluidized layer comprises non-combustible fluidizing material, and a plurality of pipe burners are disposed above the bottom floor of the fluidized layer.

5. Fuel-reforming apparatus as claimed in any one of the preceding claims, wherein each of the catalyzer-filled tubes is constructed in the form of a double wall tube.

6. Fuel-reforming apparatus as claimed in claim 5, wherein each of the double wall catalyzer-filled tubes has an annular space defined between the outer tube and the inner tube and containing catalyzer therein and includes a catalyzer-holding porous plate fixedly secured to the outer wall surface of the inner tube, a plurality of guide vanes attached at a top end to change the direction of gas flow and promote heat conduction, and a heat conduction promoting ribbon disposed within the inner tube.

7. Fuel-reforming apparatus as claimed in any one of the preceding claims, wherein the fluidized layer is constructed in the form of a fluidized layer

operating in a pressurized state, and a gas turbine is provided and is driven by combustion gas.

8. Fuel-reforming apparatus substantially as herein described with reference to any one of the embodiments shown in the accompanying drawings.

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