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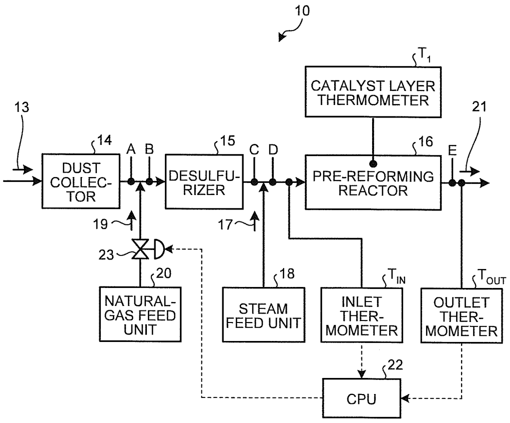
(54) BIOMASS GASIFICATION GAS PURIFICATION SYSTEM AND METHOD, AND METHANOL PRODUCTION SYSTEM AND METHOD

(57) A biomass gas purification system comprises: dust removal equipment (14) that filters soot and dust in biomass gasification gas (including tar components) (13) obtained through the gasification of biomass using a biomass gasification furnace; desulfurization equipment (15) that removes sulfur oxide components in the filtered biomass gasification gas (13); a pre-reforming reactor (16) that reforms the tar components in the biomass gasification gas (13) after desulfurization; a vapor supply means (18) that supplies vapor (17) at the upstream side of the pre-reforming reactor (16); and a natural gas supply means (20) that supplies natural gas (19) at the upstream side of the desulfurization equipment (15).

FIG.1



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Description

Field

[0001] The present invention relates to a biomass gasification gas purification system, a biomass gasification gas purification method, a methanol production system, and a methanol production method.

Background

[0002] The present invention relates to a biomass gasification gas purification system, a biomass gasification gas purification method, a methanol production system, and a methanol production system method that can efficiently use biomass as a feedstock and can acquire a clean gas feedstock usable for fuels or for producing liquid fuels such as alcohol.

[0003] Generally, biomass refers to organisms (for example, agricultural products or by-products, wood, or plants) that can be used as an energy source or an industrial material, and is generated by an action of solar energy, air, water, soil, and the like. Therefore, biomass can be reproduced unlimitedly.

[0004] Use of the biomass enables production of a clean energy source such as gas and methanol for fuels. Furthermore, biomass as waste can be treated, which contributes also to environmental cleanup, and biomass to be newly produced can be grown by photosynthesis while fixing CO_2. Because CO_2 in the air does not increase, the use of biomass leads to suppression of CO_2, and thus it is a favorable technique.

[0005] As biomass to be fed, it is preferable to feed produced or discarded biomass after being pulverized and dried. In the present invention, biomass refers to biological resources (for example, agricultural products or by-products, wood, or plants) that can be used as an energy source or an industrial material and, for example, plants such as sorghum, Napier grass, and Spirulina, and wood such as Japanese cedar, broad-leaved tree, and bark are used (Patent Literatures 1 and 2, and Non Patent Literature 1).

[0006] Meanwhile, gas produced by using the biomass as a feedstock contains fine particles, tar components, hydrogen sulfide, chlorine, and the like, and thus it is not suitable to use the gas as it is as gas for synthesizing a liquid fuel using a synthetic catalyst or an energy source for fuel cells. Accordingly, a method of removing minor components such as the fine particles, the tar components, the hydrogen sulfide, and the chlorine has been devised by using a separation device and a gas purification device.

As a source gas for acquiring the liquid fuel and the energy source for fuel cells, for practical operation, the minor components need to be reduced to allowable content limits of tar, which is less than 1 mg/Nm^3, and of sulfur content, which is less than 0.1 ppm. However, in the existing biomass gasification system, sufficient reduction of the minor components has not been realized yet.

[0007] Furthermore, the processing volume of the biomass gasification system is several hundred tons per day, which corresponds to a small-sized or medium-sized plant as compared to a typical gasification system using fossil fuels. In such a small-sized or medium-sized gasification system, it is preferable to include a simple and inexpensive gas purification line, which is an essential requirement in a so-called decentralized plant. Also in this regard, the existing biomass gasification system has not realized a simple and inexpensive gas purification line yet.

[0008] Conventionally, therefore, a biomass gasification system including a separation unit such as a cyclone that removes dust in produced gas gasified by a biomass gasification furnace, a cooler that cools dust-removed gas, and a gas purification device that purifies the cooled gas has been proposed (Patent Literature 3).

In the conventional gas purification device for biomass gasification gas, biomass is temporarily stored, and cooled produced gas having passed through the cooler is caused to pass through the gas purification device, where tar components contained in the cooled produced gas are adsorbed. Tar-adsorbed biomass from which the tar has been adsorbed is carried to a biomass feed unit by a carrier unit as purified gas.

[0009] There is another proposal of a fixed-bed removal device to which a remover layer for removing tar components is fixed (Patent Literature 4).

Citation List

Patent Literatures

[0010]

Patent Literature 1: Japanese Patent Application Laid-open No. 2001-240877
Patent Literature 2: Japanese Patent Application Laid-open No. 2001-240878
Patent Literature 3: Japanese Patent Application Laid-open No. 2004-346285
Patent Literature 4: Japanese Patent Application Laid-open No. 2006-016470

Non Patent Literature

[0011] Non Patent Literature 1: "Biomass fuel for the 21st Century", Masayasu SAKAI, Morikita Publishing Co., Ltd., published on 28th October, 1998

Summary

Technical Problem

[0012] However, in the proposal described in Patent Literature 3, at the time of removing tar components by the gas purification device, the tar components cannot be removed or reduced to a level allowable for a synthetic catalyst.

[0013] Furthermore, in the proposal described in Patent Literature 4, treatment of activated carbon as a remover having adsorbed tar components is required separately.

[0014] As a method of removing (decomposing) tar (a hydrocarbon component having a high boiling point), a method of performing decomposition by a reforming reaction shown by the following formula (1) by using a pre-reforming catalyst (for example, Ni catalyst or Ru catalyst) can be considered. However, in biomass gasification gas, a concentration of CO components is quite high, and when a reaction is caused at a pressure of about 1 MPaG or less and at a temperature from 400°C to 550°C, which is an optimum reaction temperature of the catalyst, there is a problem that a methanation reaction as shown in the following formulae (3) and (4) occurs as a side reaction.
The formula (2) is a combination of the formulae (3) and (4), which is referred to as a shift reaction.

[0015]

$$C_nH_{2n+2}+nH_2O\rightarrow nCO+(3n+2)H_2 \qquad (1)$$

$$CO+H_2O\rightarrow CO_2+H_2 \qquad (2)$$

$$CO+3H_2\rightarrow CH_4+H_2O \qquad (3)$$

$$CO_2+4H_2\rightarrow CH_4+2H_2O \qquad (4)$$

[0016] As the pre-reforming catalyst, for example, "ReforMax 100" (trade name) and "ReforMax 100RS, N. E" (trade name) manufactured by Süd-Chemie AG, "E Catalyst" (trade name) and "NI-3266E" (trade name) manufactured by N. E. Chemcat Corporation, and "RKNGR, AR-401" (trade name) manufactured by Haldor Topsøe A/S are commercially available.

[0017] The methanation reaction shown by the formulae (3) and (4) is an exothermic reaction. Therefore, when a pre-reforming reactor including an insulated pre-reforming catalyst is used, the reaction occurs at a temperature of 550°C higher than an appropriate temperature for the pre-reforming catalyst. Accordingly, sintering or coking occurs and also thermal runaway may occur, which prevents satisfactory gas purification from being stably performed.

[0018] The present invention has been achieved to solve the above problems, and an object of the present invention is to provide a biomass gasification gas purification system, a biomass gasification gas purification method, a methanol production system, and a methanol production method in which tar components in gas produced by biomass gasification are efficiently reformed, and thermal runaway does not occur.

Solution to Problem

[0019] According to a first aspect of the present invention in order to solve the above problems, there is provided a biomass gasification gas purification system including: a dust collector that collects to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace; a desulfurizer that removes sulfur oxide components in dust-removed biomass gasification gas; a pre-reforming reactor that reforms tar components in desulfurized biomass gasification gas; and a natural-gas feed unit that feeds natural gas on an upstream side of the desulfurizer or the pre-reforming reactor.

[0020] According to a second aspect of the present invention, there is provided a biomass gasification gas purification system including: a dust collector that collects to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace; a desulfurizer that removes sulfur oxide components in dust-removed biomass gasification gas; and a pre-reforming reactor that reforms tar components in desulfurized biomass gasification gas; and a steam feed unit that feeds steam to an upstream side of the pre-reforming reactor.

[0021] According to a third aspect of the present invention, there is provided a biomass gasification gas purification system including: a dust collector that collects to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace; a desulfurizer that removes sulfur oxide components in dust-removed biomass gasification gas; a pre-reforming reactor that reforms tar components in desulfurized biomass gasification gas; and a steam feed unit that feeds steam to an upstream side of the pre-reforming reactor; and a natural-gas feed unit that feeds natural gas on an upstream side of the desulfurizer or the pre-reforming reactor.

[0022] According to a fourth aspect of the present invention, there is provided a methanol production system including: the biomass gasification gas purification system according to any one of the first to third aspects; a boosting device that boosts pre-reformed biomass gasification gas; and a methanol synthesis apparatus that synthesizes methanol by using boosted gas.

[0023] According to a fifth aspect of the present invention, there is provided the methanol production system according to the fourth aspect, including a reforming reactor that reforms the boosted gas.

[0024] According to a sixth aspect of the present invention, there is provided a biomass gasification gas purification method including: collecting to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace; desulfurizing sulfur oxide components in dust-removed biomass gasification gas; and feeding natural gas to a pre-reforming reactor at a time of reforming tar components in desulfurized biomass gasification gas by the pre-reforming reactor.

[0025] According to a seventh aspect of the present invention, there is provided a biomass gasification gas purification method including: collecting to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace; desulfurizing sulfur oxide components in dust-removed biomass gasification gas; and reforming tar components in desulfurized biomass gasification gas by a pre-reforming reactor while feeding steam.

[0026] According to an eighth aspect of the present invention, there is provided a biomass gasification gas purification method including: collecting to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace; desulfurizing sulfur oxide components in dust-removed biomass gasification gas; and feeding natural gas to a pre-reforming reactor at a time of reforming tar components in desulfurized biomass gasification gas by the pre-reforming reactor while feeding steam.

[0027] According to a ninth aspect of the present invention, there is provided a methanol production method including: purifying biomass gasification gas by the biomass gasification gas purification method according to any one of the sixth to eighth aspects; boosting pre-reformed biomass gasification gas; and synthesizing methanol by using boosted gas.

[0028] According to a tenth aspect of the present invention, there is provided the methanol production method according to the ninth aspect, including reforming the boosted gas.

Advantageous Effects of Invention

[0029] According to the present invention, the methanation reaction as a side reaction is suppressed and thermal runaway of the reforming reactor is suppressed by introducing at least one of natural gas and steam or both thereof at the time of reforming tar components in the biomass gasification gas having a high concentration of CO components, thereby enabling stabilized gas purification of biomass gasification gas.

Brief Description of Drawings

[0030]

FIG. 1 is a schematic diagram of a biomass gasification gas purification system.

FIG. 2 is a relationship diagram between a reaction temperature and an equilibrium constant in a methanation occurrence region and a reforming occurrence region of CO.

FIG. 3 is a schematic diagram of a methanol production system according to a second embodiment of the present invention.

FIG. 4 is a schematic diagram of another methanol production system according to the second embodiment. Description of Embodiments

[0031] The present invention will be explained below in detail with reference to the accompanying drawings. The present invention is not limited to the following embodiments. In addition, constituent elements in the following embodiments include those that can be easily anticipated by persons skilled in the art or that are substantially equivalent.

First embodiment

[0032] A biomass gasification gas purification system according to a first embodiment of the present invention is explained with reference to the drawings. FIG. 1 is a schematic diagram of the biomass gasification gas purification system. As shown in FIG. 1, a biomass gasification gas purification system 10 includes a dust collector (cyclone, scrubber, or the like) 14 that collects to remove dust in biomass gasification gas (containing tar components) 13 acquired by gasifying biomass by a biomass gasification furnace, a desulfurizer 15 that removes sulfur oxide components in the dust-removed biomass gasification gas 13, a pre-reforming reactor 16 that reforms the tar components in the desulfurized biomass gasification gas 13, a steam feed unit 18 that feeds steam 17 to an upstream side of the pre-reforming reactor 16, and a natural-gas feed unit 20 that feeds natural gas (main component: methane) 19 on an upstream side of the desulfurizer 15. In FIG. 1, reference numeral 21 denotes synthesis gas, 22 denotes a controller (CPU), 23 denotes an adjustment valve that adjusts an introduced amount of the natural gas, and reference character T_{IN} denotes an inlet thermometer that measures a temperature on an inlet side of the pre-reforming reactor 16, T_{OUT} denotes an outlet thermometer that measures a temperature on an outlet side of the pre-reforming reactor 16, T_1 denotes a catalyst layer thermometer that measures a temperature of a catalyst layer, and A to E denote measurement positions.

[0033] Because progress of the methanation reaction is caused by a large amount of CO components in the biomass gasification gas 13, methanation can be suppressed by calculating an equilibrium composition in each temperature range in the following formula (3). Therefore, either the steam or the natural gas (main component: methane) is introduced to achieve suppression of methanation.

$$CO+3H_2 \rightarrow CH_4+H_2O \qquad (3)$$

[0034] The introduced amount of natural gas (main component: methane) can be calculated from an equilibrium constant to keep the temperature at equal to or lower than 550°C, which is an upper temperature limit of the catalyst of the pre-reforming reactor 16.

[0035] Results obtained by measuring the concentration of components at the respective measurement positions (A to E) when the natural gas 19 is introduced on the upstream side of the desulfurizer 15 as in the present invention are shown in Table 1.

As shown in Table 1, under the condition of S/C=3, which is a ratio between steam (H_2O) in source gas and an amount of carbon in carbon hydride in the source gas, a feed rate of steam (44.5 kgmol/h) and a feed rate of natural gas (main component: methane) (11.3 kgmol/h) are obtained from the respective components, and then the steam 17 is fed by the steam feed unit 18 and the natural gas 19 is fed by the natural-gas feed unit 20.

In Table 1, C2+ denotes a total of hydrocarbon components such as ethane, propane, and butane contained in natural gas.

[0036] As the respective measurement positions in Table 1, the position A is at an outlet of the dust collector 14 and before feed of the natural gas 19. The position B is at an outlet of the dust collector 14 and after the feed of the natural gas 19. The position C is at an outlet of the desulfurizer 15 and before feed of the steam 17. The position D is at an outlet of the desulfurizer 15 and after the feed of the steam 17. The position E is at an outlet of the pre-reforming reactor 16.

[0037]

Table 1

<S/C=3, with introduction of natural gas>										
POS.	A		B		C		D		E	
Phase	Vapor		Vapor		Vapor		Vapor		Vapor	
Temp(°C)	40		300		300		400		550	
Pressure (kg/cm^{2}G)	0.3		4.8		4.4		4.2		4.0	
Mole Weight	23.19		22.23		22.23		20.54		21.10	
COMP.	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%
CO	11.5	21.1	11.5	17.4	11.5	17.4	11.5	10.4	3.4	3.1
CO_2	16.8	30.9	17.2	26.0	17.2	26.0	17.2	15.6	24.3	22.6
METHANE	2.4	4.3	13.7	20.7	13.7	20.7	13.7	12.4	17.4	16.1
H_2	18.6	34.1	18.6	28.1	18.6	28.1	18.6	16.8	20.0	18.6
H_2O	2.7	4.9	2.0	3.1	2.0	3.1	46.5	42.0	40.5	37.6
C2+	0.0	0.0	0.6	0.9	0.6	0.9	0.6	0.5	0.0	0.0
	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm
Tar components	0.3	6968.6	0.3	5744.1	0.3	5744.3	0.3	3434.4	0.0	0.0

[0038] On the other hand, as shown in Table 2, when natural gas (methane) is not fed under the condition of S/C=3, methanation cannot be suppressed, and the temperature rises up to 640°C largely exceeding the upper temperature limit (for example, 550°C) of the catalyst of the pre-reforming reactor 16, resulting in a temperature higher than an allowable catalyst temperature.

[0039]

Table 2

<S/C=3, without introduction of natural gas>										
POS.	A		B		C		D		E	
Phase	Vapor		Vapor		Vapor		Vapor		Vapor	
Temp(°C)	40		300		300		400		640	
Pressure (kg/cm^{2}G)	0.3		4.8		4.4		4.2		4.0	
Mole Weight	23.19		23.25		23.25		22.68		24.54	
COMP.	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%
CO	11.5	21.1	11.5	21.4	11.5	21.4	11.5	19.1	9.3	16.6
CO_2	16.8	30.9	16.8	31.3	16.8	31.3	16.8	27.9	17.2	30.8
METHANE	2.4	4.3	2.4	4.4	2.4	4.4	2.4	3.9	5.5	9.9
H_2	18.6	34.1	18.6	34.6	18.6	34.6	18.6	30.8	11.6	20.8
H_2O	2.7	4.9	2.0	3.8	2.0	3.8	8.6	14.2	10.1	18.1
C2+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm
Tar components	0.3	6969.1	0.3	7055.8	0.3	7057.5	0.3	6292.3	0.0	0.0

[0040] As shown in Table 3, when only steam is fed, thermal runaway due to methanation can be suppressed by introducing steam excessively (74.9 kgmol/h) and setting S/C to "27".
In this case, however, while the gas reforming proceeds further than that in a conventional case, the feed rate of steam increases and thus the system efficiency decreases, which is not desirable.

[0041]

Table 3

<S/C=27, with excessive steam>										
POS.	A		B		C		D		E	
Phase	Vapor		Vapor		Vapor		Vapor		Vapor	
Temp(°C)	40		300		300		400		550	
Pressure (kg/cm^{2}G)	0.3		4.8		4.4		4.2		4.0	
Mole Weight	23.19		23.25		23.25		20.21		20.79	
COMP.	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%	kgmol/h	MOL%
CO	11.5	21.1	11.5	21.4	11.5	21.4	11.5	9.0	2.1	1.6
CO_2	16.8	30.9	16.8	31.3	16.8	31.3	16.8	13.1	24.9	19.9
METHANE	2.4	4.3	2.4	4.4	2.4	4.4	2.4	1.8	5.1	4.1
H_2	18.6	34.1	18.6	34.6	18.6	34.6	18.6	14.5	20.7	16.6
H_2O	2.7	4.9	2.0	3.8	2.0	3.8	76.9	59.7	70.2	56.2
C2+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm	kgmol/h	ppm
Tar components	0.3	6970.1	0.3	7062.1	0.3	7056.9	0.3	1027.8	0.0	0.0

[0042] FIG. 2 is a relationship diagram between a reaction temperature and an equilibrium constant in a methanation occurrence region and a reforming occurrence region of CO. In FIG. 2, a region below an equilibrium constant curve is the methanation occurrence region, and a region above the equilibrium constant curve is the reforming occurrence region. In FIG. 2, a black triangular plot corresponds to Table 1, black circular plots correspond to Table 2, and black square plots correspond to Table 3.

[0043] The equilibrium constant (Kp) corresponding to a relational expression of FIG. 2 is shown by the following formula (5).

$$\text{Equilibrium constant (Kp)} = ([CH_4] \times [H_2O]) / ([CO] \times [H_2]^3) \qquad (5)$$

where [] denotes a partial pressure of gas components.

[0044] An equilibrium constant value (Kp=12) corresponding to the allowable catalyst temperature (for example, 550°C) is obtained from FIG. 2, and a feedstock composition at the inlet of the reactor required for achieving the equilibrium constant value at the outlet of the reactor can be obtained based on the formula (5) and reaction calculation and calculation of a heat generation amount and a heat absorption amount of formulae (1) to (4). The introduced amounts of natural gas (main component: methane) and steam are determined to realize the feedstock composition.

[0045] Even if natural gas (methane) is fed beforehand, occurrence of methanation changes in some reaction conditions. Therefore, the allowable temperature (Tmax: 550°C) of the pre-reforming reactor 16 is monitored by the outlet thermometer T_{OUT} and the catalyst layer thermometer T_1, and when the temperature approaches the allowable temperature (Tmax: 550°C), the controller (CPU) 22 executes a control to adjust the adjustment valve 23 to increase natural gas (main component: methane), thereby increasing the introduced amount of the natural gas 19.

[0046] In this way, the concentration of natural gas (main component: methane) in the gas is increased by feeding natural gas (main component: methane) on the upstream side of the pre-reforming reactor 16, thereby suppressing the methanation reaction and an increase in temperature. Accordingly, the temperature does not rise to the upper temperature limit of the catalyst of the pre-reforming reactor 16 or higher, deterioration (sintering or the like) of the catalyst does not occur, and satisfactory tar reforming can be performed.

[0047] In the present embodiment, the natural gas 19 is introduced on the upstream side of the desulfurizer 15. However, when the natural gas 19 contains fewer S (sulfur) components, the natural gas 19 can be introduced from the same position as that of the steam 17 on the upstream side of the pre-reforming reactor 16 because there is no poisoning of the catalyst.

[0048] Furthermore, there may be a surplus of steam in some biomass gasification plants. In this case, only steam can be introduced. When natural gas can be acquired at a low cost, only natural gas can be introduced without introducing steam.

[0049] The acquired synthesis gas 21 can be directly used as fuel gas for a gas turbine. By adjusting compositions of H_2 and CO gas in the synthesis gas, the synthesis gas 21 can be used also as gas for producing chemical products such as ammonia and methanol (or dimethyl ether). A system using the acquired gas for methanol synthesis is explained below.

Second embodiment

[0050] A methanol production system according to a second embodiment of the present invention is explained with reference to the drawings. FIG. 3 is a schematic diagram of the methanol production system according to the second embodiment. FIG. 4 is a schematic diagram of another methanol production system according to the second embodiment. As shown in FIG. 3, a methanol production system 30A includes a biomass gasification furnace 12 that gasifies biomass 11, the dust collector 14 that collects to remove dust in the biomass gasification gas (containing tar components) 13 acquired by gasification, the desulfurizer 15 that removes sulfur oxide components in the dust-removed biomass gasification gas 13, the pre-reforming reactor 16 that reforms the tar components in the desulfurized biomass gasification gas 13, the steam feed unit 18 that feeds the steam 17 to the upstream side of the pre-reforming reactor 16, the natural-gas feed unit 20 that feeds the natural gas 19 on the upstream side of the desulfurizer 15, a boosting device 31 that boosts the synthesis gas 21 of the pre-reformed biomass gasification gas, and a methanol synthesis apparatus 34 that synthesizes methanol 33 by using boosted gas 32.

The biomass gasification gas purification system 10 according to the first embodiment shown in FIG. 1 corresponds to components from the dust collector 14 to the pre-reforming reactor 16.

According to the present embodiment, when the tar components in the biomass gasification gas 13 are reformed in the biomass gasification gas purification system 10, the natural gas 19 can be introduced to stably perform reforming of tar components. Accordingly, stable methanol synthesis can be performed for gas from which the tar components have been removed, without deteriorating the methanol synthesis catalyst.

[0051] In the present invention, it is preferable to feed produced or discarded biomass after being pulverized and dried, as the biomass 11 to be fed into the biomass gasification furnace 12. Biomass in the present invention refers to biological resources (for example, agricultural products or by-products, wood, or plants) that can be used as an energy source or an industrial material, and plants such as sorghum, Napier grass, and Spirulina, and wood such as Japanese cedar, broad-leaved tree, and bark can be cited as examples. In the present invention, it is preferable that an average grain diameter (D) of the pulverized biomass 11 is 0.05 mm≤D≤5 mm. This is because when the average grain diameter is smaller than 0.05 millimeter, the pulverization efficiency of biomass decreases, which is not desirable. On the other hand, when the average grain diameter exceeds 5 millimeters, satisfactory burning does not proceed up to the inside of biomass, any reaction is not accelerated, and highly efficient gasification becomes difficult. In the present invention, a combustion oxidizer to be fed to the biomass gasification furnace is preferably a mixture of air and steam or oxygen and steam.

[0052] Furthermore, because the natural gas (main component: methane) 19 is introduced in the biomass gasification gas purification system 10, a reforming reactor 36 that reforms the boosted gas 32 is provided in a methanol production system 30B according to a modification of the second embodiment as shown in FIG. 4 to perform gas reforming and decrease the concentration of methane, which does not contribute to methanol synthesis, thereby improving methanol synthesis yields.

Reference Signs List

10	biomass gasification gas purification system
11	biomass
12	biomass gasification furnace
13	biomass gasification gas (containing tar components)
14	dust collector
15	desulfurizer
16	pre-reforming reactor
17	steam
19	natural gas

Claims

1. A biomass gasification gas purification system comprising:

a dust collector that collects to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace;
a desulfurizer that removes sulfur oxide components in dust-removed biomass gasification gas;
a pre-reforming reactor that reforms tar components in desulfurized biomass gasification gas; and
a natural-gas feed unit that feeds natural gas on an upstream side of the desulfurizer or the pre-reforming reactor.

2. A biomass gasification gas purification system comprising:

a dust collector that collects to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace;
a desulfurizer that removes sulfur oxide components in dust-removed biomass gasification gas;
a pre-reforming reactor that reforms tar components in desulfurized biomass gasification gas; and
a steam feed unit that feeds steam to an upstream side of the pre-reforming reactor.

3. A biomass gasification gas purification system comprising:

a dust collector that collects to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace;
a desulfurizer that removes sulfur oxide components in dust-removed biomass gasification gas;
a pre-reforming reactor that reforms tar components in desulfurized biomass gasification gas;
a steam feed unit that feeds steam to an upstream side of the pre-reforming reactor; and
a natural-gas feed unit that feeds natural gas on an upstream side of the desulfurizer or the pre-reforming reactor.

4. A methanol production system comprising:

the biomass gasification gas purification system according to any one of claims 1 to 3;
a boosting device that boosts pre-reformed biomass gasification gas; and
a methanol synthesis apparatus that synthesizes methanol by using boosted gas.

5. The methanol production system according to claim 4, comprising a reforming reactor that reforms the boosted gas.

6. A biomass gasification gas purification method comprising:

collecting to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace;
desulfurizing sulfur oxide components in dust-removed biomass gasification gas; and
feeding natural gas to a pre-reforming reactor at a time of reforming tar components in desulfurized biomass gasification gas by the pre-reforming reactor.

7. A biomass gasification gas purification method comprising:

collecting to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace;
desulfurizing sulfur oxide components in dust-removed biomass gasification gas; and
reforming tar components in desulfurized biomass gasification gas by a pre-reforming reactor while feeding steam.

8. A biomass gasification gas purification method comprising:

collecting to remove dust in biomass gasification gas acquired by gasifying biomass by a biomass gasification furnace;
desulfurizing sulfur oxide components in dust-removed biomass gasification gas; and
feeding natural gas to a pre-reforming reactor at a time of reforming tar components in desulfurized biomass gasification gas by the pre-reforming reactor while feeding steam.

9. A methanol production method comprising:

purifying biomass gasification gas by the biomass gasification gas purification method according to any one of claims 6 to 8;
boosting pre-reformed biomass gasification gas; and
synthesizing methanol by using boosted gas.

10. The methanol production method according to claim 9, comprising reforming the boosted gas.

FIG.1

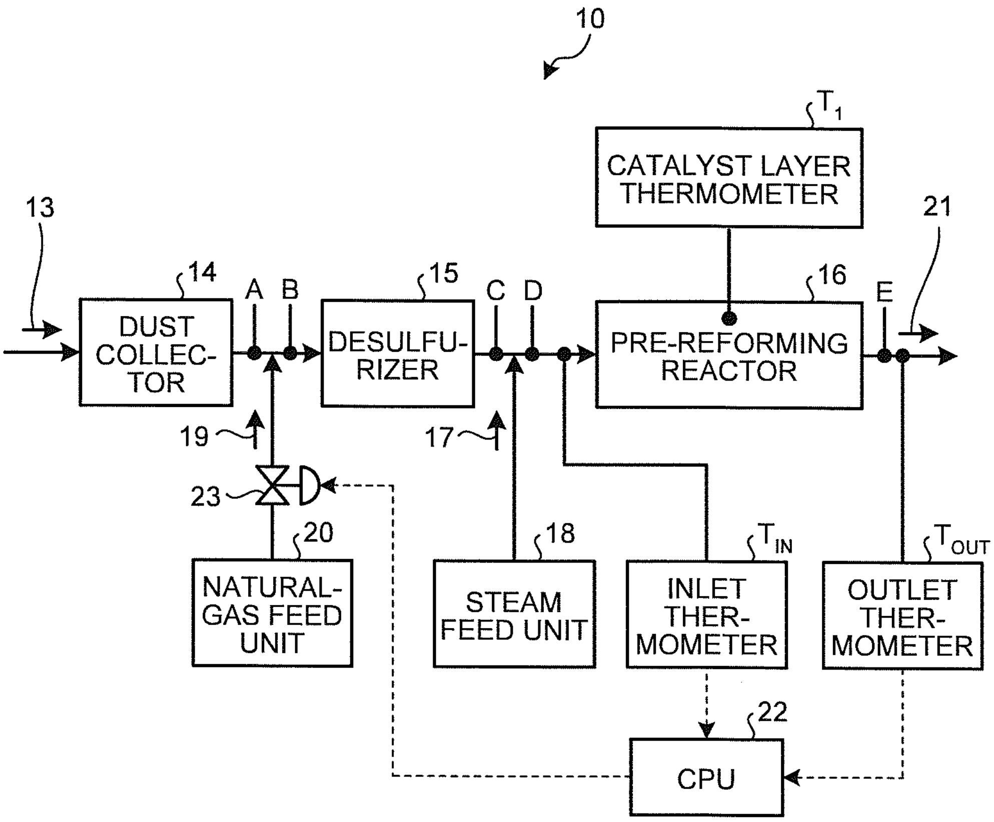
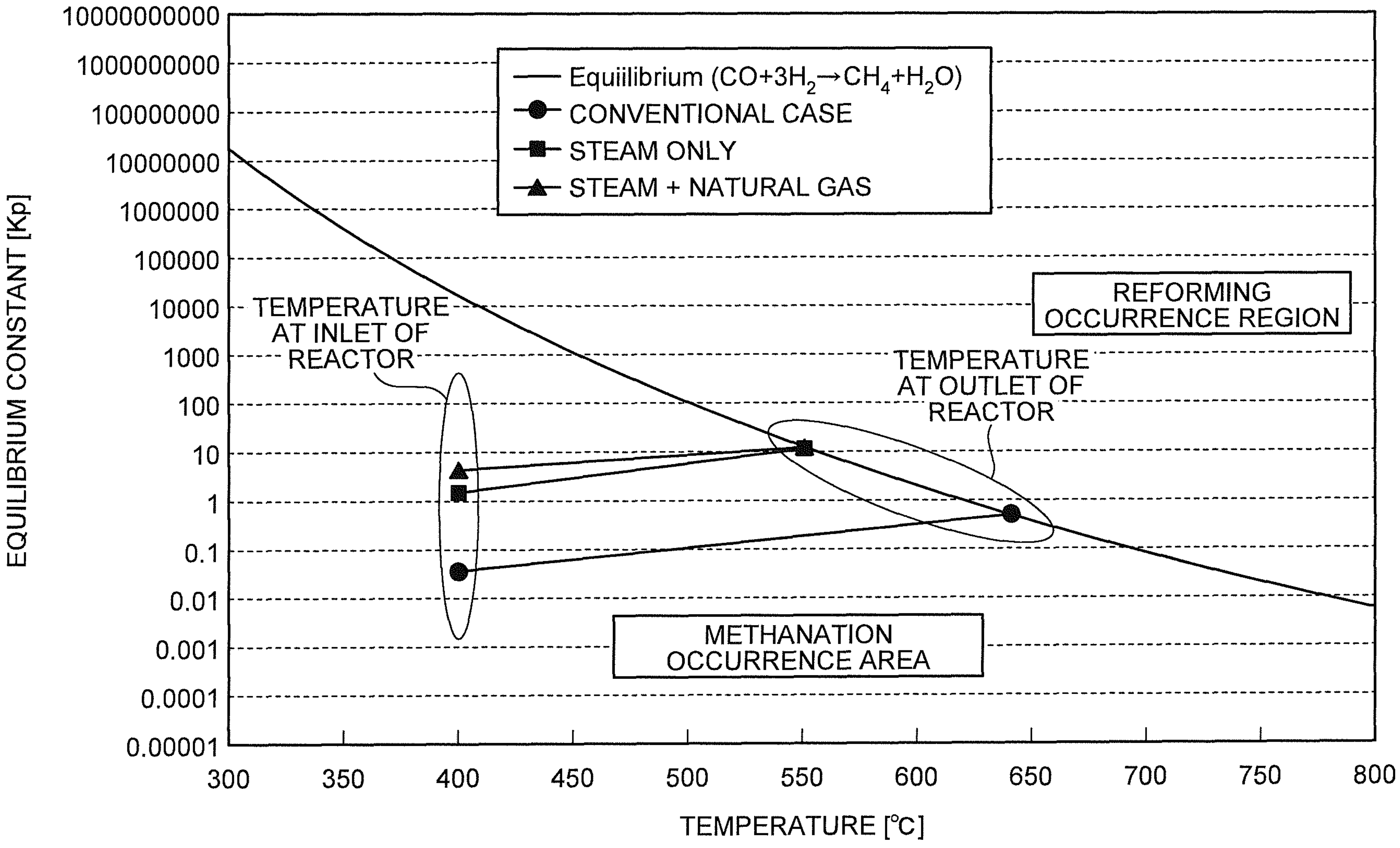

10
T1
CATALYST LAYER THERMOMETER
13
21
14
DUST COLLECTOR
A
B
15
DESULFURIZER
C
D
16
PRE-REFORMING REACTOR
E
19
17
23
20
NATURAL-GAS FEED UNIT
18
STEAM FEED UNIT
TIN
INLET THERMOMETER
TOUT
OUTLET THERMOMETER
22
CPU

FIG.2


Equilibrium ($CO+3H_2 \rightarrow CH_4+H_2O$)
CONVENTIONAL CASE
STEAM ONLY
STEAM + NATURAL GAS
REFORMING OCCURRENCE REGION
METHANATION OCCURRENCE AREA
TEMPERATURE AT INLET OF REACTOR
TEMPERATURE AT OUTLET OF REACTOR
EQUILIBRIUM CONSTANT [Kp]
10000000000
1000000000
100000000
10000000
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
TEMPERATURE [℃]
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350
400
450
500
550
600
650
700
750
800

FIG.3

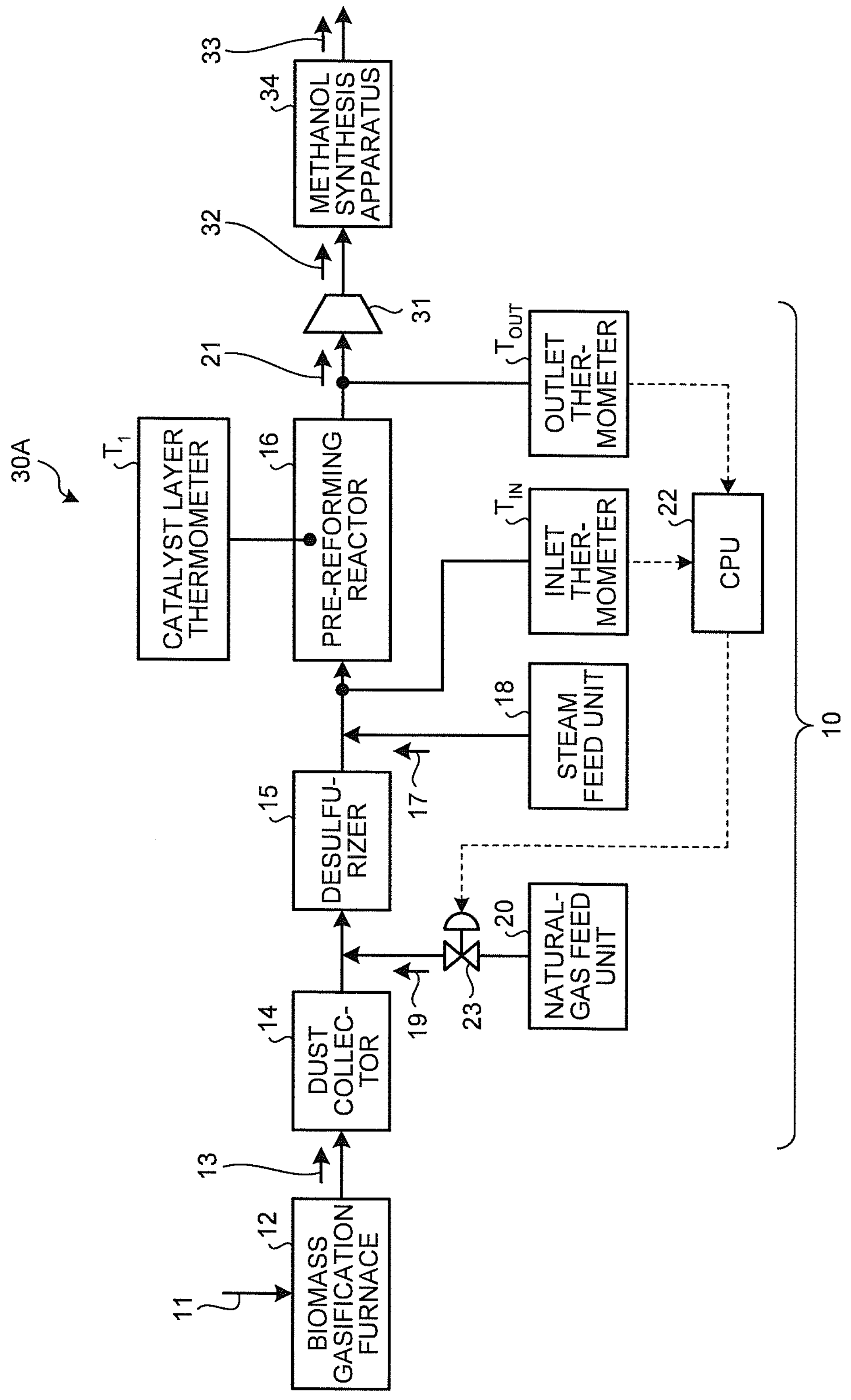
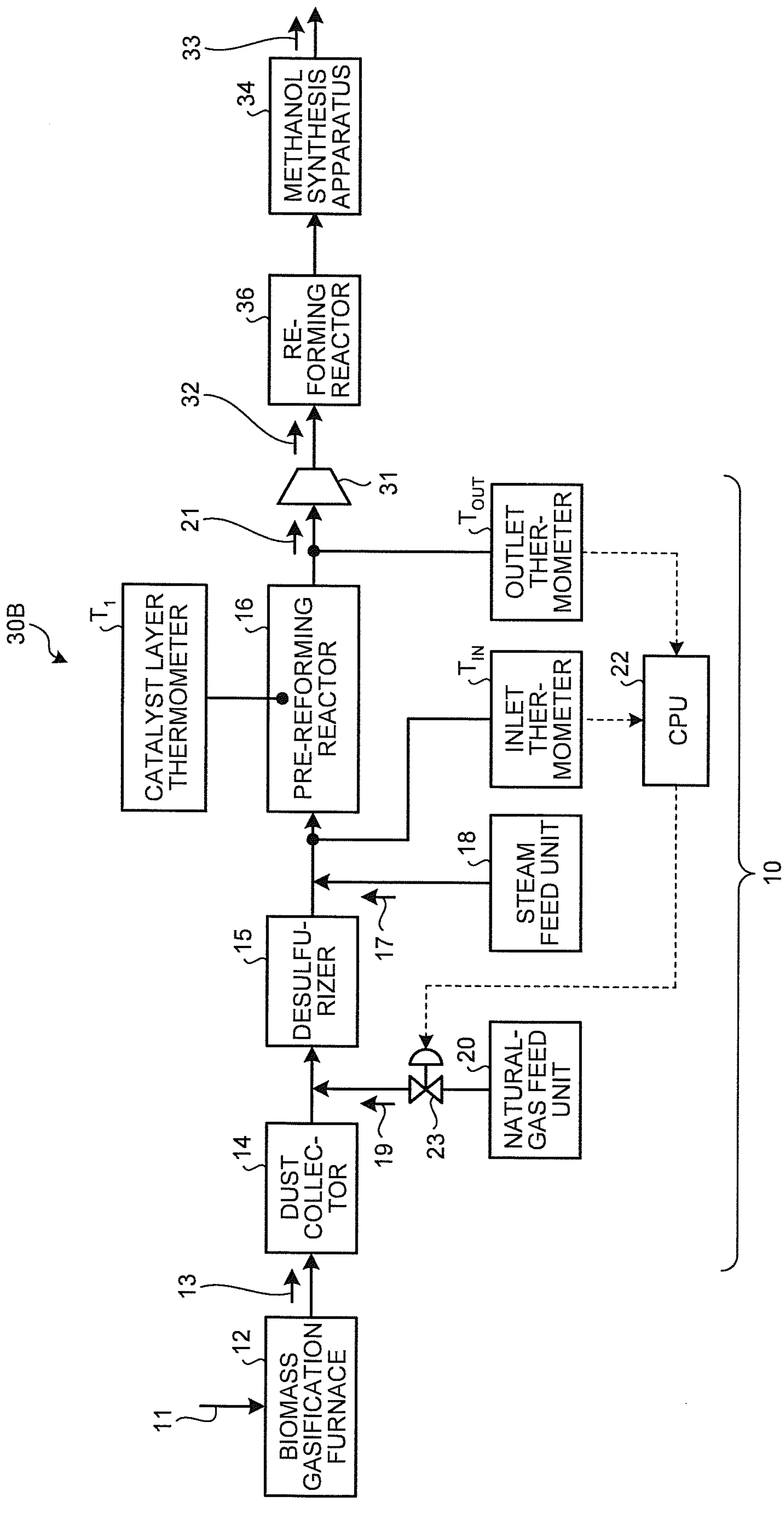

30A
11
BIOMASS GASIFICATION FURNACE
12
13
DUST COLLECTOR
14
19
23
NATURAL-GAS FEED UNIT
20
DESULFURIZER
15
17
STEAM FEED UNIT
18
PRE-REFORMING REACTOR
16
CATALYST LAYER THERMOMETER
T1
INLET THERMOMETER
TIN
CPU
22
OUTLET THERMOMETER
TOUT
21
31
32
METHANOL SYNTHESIS APPARATUS
34
33
10

FIG.4


30B
11
12
BIOMASS GASIFICATION FURNACE
13
14
DUST COLLECTOR
19
23
20
NATURAL-GAS FEED UNIT
15
DESULFURIZER
17
18
STEAM FEED UNIT
16
PRE-REFORMING REACTOR
T_1
CATALYST LAYER THERMOMETER
T_{IN}
INLET THERMOMETER
22
CPU
T_{OUT}
OUTLET THERMOMETER
21
31
32
36
REFORMING REACTOR
34
METHANOL SYNTHESIS APPARATUS
33
10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/067798

A. CLASSIFICATION OF SUBJECT MATTER
C10K3/02(2006.01)i, *C10K1/02*(2006.01)i

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)
C10K3/02, C10K1/02

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2011
Kokai Jitsuyo Shinan Koho	1971-2011	Toroku Jitsuyo Shinan Koho	1994-2011

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 2010-111779 A (Takuma Co., Ltd.), 20 May 2010 (20.05.2010), claims; paragraphs [0014], [0018], [0029], [0032] to [0058]; fig. 1 to 3 (Family: none)	2,4-5,7,9-10 1,3,6,8
Y	JP 2009-536262 A (Plasco Energy IP Holdings, S.L., Bilbao, Schaffhausen Branch), 08 October 2009 (08.10.2009), claims; paragraphs [0005], [0057], [0060], [0082] to [0088], [0117] to [0125] & WO 2007/131240 A2 & EP 2015859 A2 & AU 2007247899 A1 & CN 101479020 A & CA 2651406 A1 & KR 2009019816 A	2,4-5,7,9-10

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

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“A” document defining the general state of the art which is not considered to be of particular relevance

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“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search 25 August, 2011 (25.08.11)	Date of mailing of the international search report 06 September, 2011 (06.09.11)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/067798

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2007-204558 A (National Institute of Advanced Industrial Science and Technology), 16 August 2007 (16.08.2007), claims; paragraph [0044] (Family: none)	4-5,9-10
A	JP 2006-348155 A (Yanmar Co., Ltd.), 28 December 2006 (28.12.2006), claims; paragraphs [0019] to [0020], [0024] to [0025], [0027], [0044] (Family: none)	1-10
A	JP 2009-040862 A (IHI Corp.), 26 February 2009 (26.02.2009), claims (Family: none)	1-10
A	JP 2010-077219 A (Nippon Steel Corp.), 08 April 2010 (08.04.2010), claims; paragraphs [0014], [0047] (Family: none)	1-10

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2001240878 A **[0010]**
- JP 2004346285 A **[0010]**
- JP 2006016470 A **[0010]**

Non-patent literature cited in the description

- **MASAYASU SAKAI.** Biomass fuel for the 21st Century. Morikita Publishing Co., Ltd, 28 October 1998 **[0011]**