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(54) **FUEL FOR FUEL CELL SYSTEM**

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(57) **ABSTRACT**

A fuel for a fuel cell system comprises wherein said fuel comprises 5 mol. % or more of hydrocarbons, 0.5-20 mass % of oxygenates therein in terms of an oxygen content based on the whole fuel and 5 mol. % or less of hydrocarbons having carbon numbers of 2 or less, 90 mol. % or more of hydrocarbons having carbon numbers of 3 and 4 in total, 5 mol. % or less of hydrocarbons having carbon numbers of 5 or more and is a gaseous phase under normal temperature and pressure. The fuel for a fuel cell system has a high power generation quantity per weight, a high power generation quantity per CO₂ emission, a low fuel consumption, a small evaporative gas (evapo-emission), small deterioration of a fuel cell system comprising such as a reforming catalyst, a water gas shift reaction catalyst, a carbon monoxide removal catalyst, fuel cell stacks and the like to maintain the initial performances for a long duration, good handling properties in view of storage stability and inflammability, and a low preheating heat quantity.

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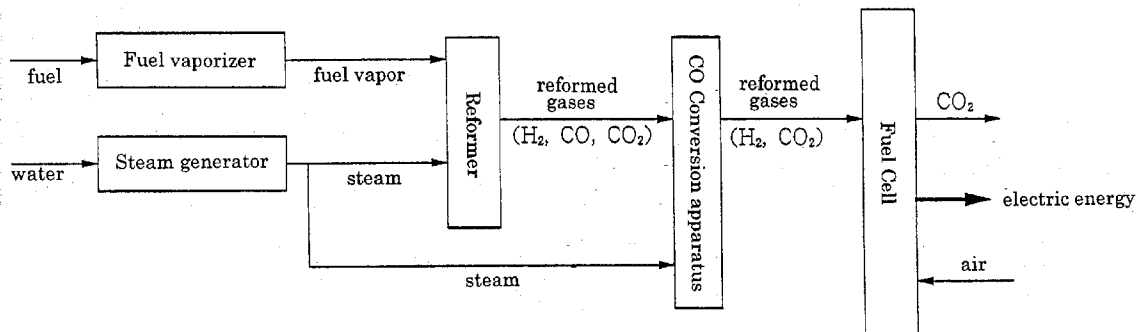


Fig. 1

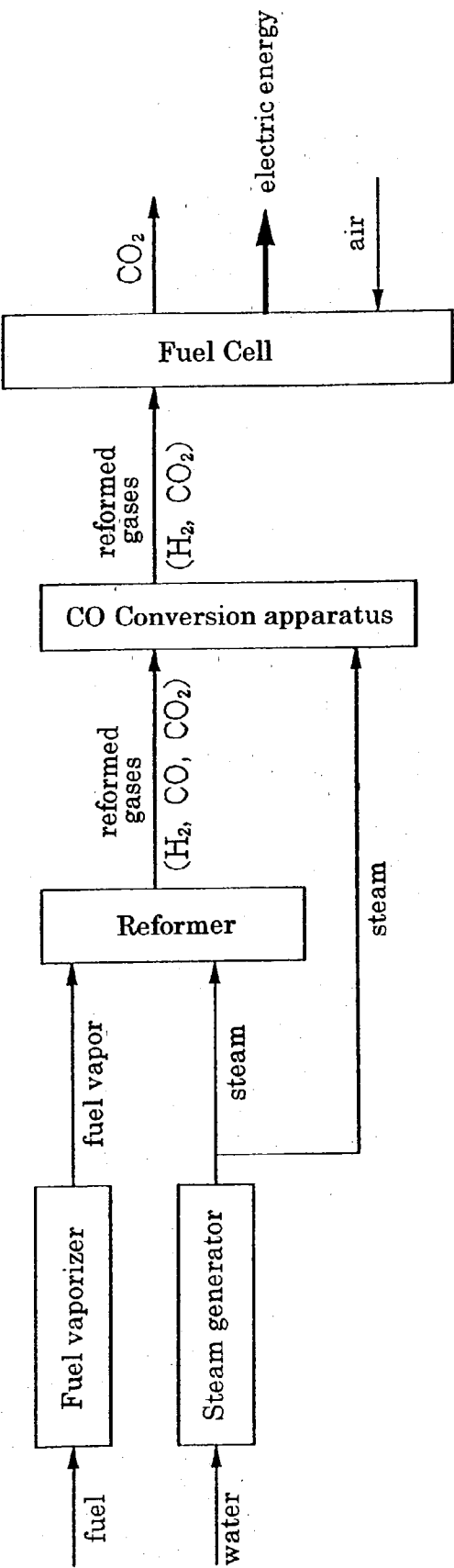
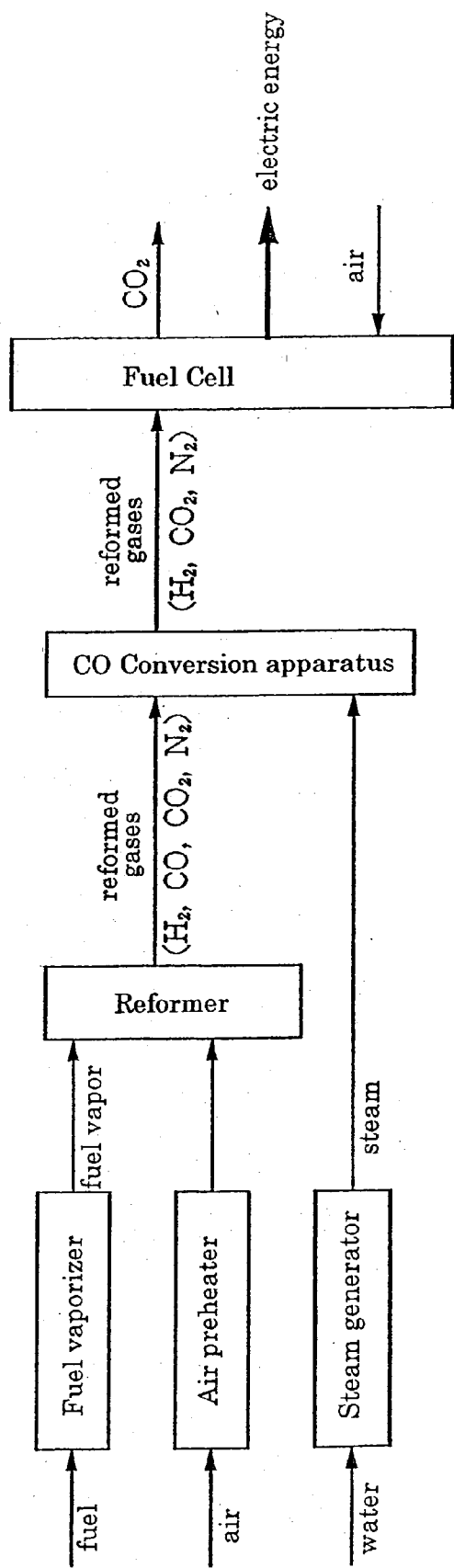


Fig. 2



FUEL FOR FUEL CELL SYSTEM

TECHNICAL FIELD

[0001] The present invention relates to a fuel to be used for a fuel cell system.

BACKGROUND ART

[0002] Recently, with increasing awareness of the critical situation of future global environments, it has been highly expected to develop an energy supply system harmless to the global environments. Especially urgently required are to reduce CO₂ to prevent global warming and reduce harmful emissions such as THC (unreacted hydrocarbons in an exhaust gas), NO_x, PM (particulate matter in an exhaust gas: soot, unburned high boiling point and high molecular weight fuel and lubricating oil). Practical examples of such a system are an automotive power system to replace a conventional Otto/Diesel engine and a power generation system to replace thermal power generation.

[0003] Hence, a fuel cell, which has high energy efficiency and emits only H₂O and CO₂, has been regarded as a most expectative system to response to respond to social requests. In order to achieve such a system, it is necessary to develop not only the hardware but also the optimum fuel.

[0004] Conventionally, as a fuel for a fuel cell system, hydrogen, methanol, and hydrocarbons have been candidates.

[0005] As a fuel for a fuel cell system, there is methanol except for hydrogen. Methanol is advantageous in a point that it is relatively easy to reform, however power generation quantity per weight is low and owing to its toxicity, handling has to be careful. Further, it has a corrosive property, special facilities are required for its storage and supply.

[0006] Like this, a fuel to sufficiently utilize the performances of a fuel cell system has not yet been developed. Especially, as a fuel for a fuel cell system, the following are required: power generation quantity per weight is high; power generation quantity per CO₂ emission is high; a fuel consumption is low in a fuel cell system as a whole; an evaporative gas (evapo-emission) is a little; deterioration of a fuel cell system comprising such as a reforming catalyst, a water gas shift reaction catalyst, a carbon monoxide conversion catalyst, fuel cell stacks and the like is scarce to keep the initial performances for a long duration; a starting time for the system is short; and storage of the system, storage stability and handling easiness are excellent.

[0007] Incidentally, in a fuel cell system, it is required to keep a fuel and a reforming catalyst at a proper temperature, the net power generation quantity of the entire fuel cell system is equivalent to the value calculated by subtracting the energy necessary for keeping the temperature (the energy for keeping balance endothermic and exothermic reaction following the preheating energy) from the actual power generation quantity. Consequently, if the temperature for the reforming is lower, the energy for preheating is low and that is therefore advantageous and further the system starting time is advantageously shortened. In addition, it is also

necessary that the energy for preheating per fuel weight is low. If the preheating is insufficient, unreacted hydrocarbon (THC) in an exhaust gas increases and it results in not only decrease of the power generation quantity per weight but also possibility of becoming causes of air pollution. To say conversely, when some kind of fuels are reformed by the same reformer and the same temperature, it is more advantageous that THC in an exhaust gas is lower and the conversion efficiency to hydrogen is higher.

[0008] The present invention, taking such situation into consideration, aims to provide a fuel suitable for a fuel cell system satisfying the above-described requirements in good balance.

DISCLOSURE OF THE INVENTION

[0009] Inventors of the present invention have extensively investigated to solve the above-described problems and found that a fuel comprising a specific amount of oxygenates (oxygen-containing compounds) and hydrocarbons with specific compositions of respective carbon atoms is suitable for a fuel cell system.

[0010] That is, the fuel for a fuel cell system according to the present invention comprises:

[0011] (1) 5 mol. % or more of hydrocarbons, 0.5-20 mass % of oxygenates therein in terms of an oxygen content based on the whole fuel and 5 mol. % or less of hydrocarbons having carbon numbers of 2 or less, 90 mol. % or more of hydrocarbons having carbon numbers of 3 and 4 in total, 5 mol. % or less of hydrocarbons having carbon numbers of 5 or more and being a gaseous phase under normal temperature and pressure.

[0012] The fuel comprising the specific amount of oxygenates described above and hydrocarbons with specific compositions is preferable to satisfy the following additional requirements;

[0013] (2) a sulfur content is 50 ppm by mass or less;

[0014] (3) said hydrocarbons comprises 60 mol. % or more of saturates, 40 mol. % or less of olefins, 0.5 mol. % or less of butadiene, 0.1 mol. % or more of isoparaffin in saturates having carbon atoms of 4 or more.

[0015] (4) vapor pressure at 40° C. is 1.55 MPa or less;

[0016] (5) density of hydrocarbons at 15° C. is 0.500 to 0.620 g/cm³;

[0017] (6) corrosiveness to copper at 40° C. for 1 hour is 1 or less;

[0018] (7) heat capacity of the fuel is 1.7 kJ/kg ° C. or less at 15° C. in gaseous phase.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 shows a flow chart of a steam reforming type fuel cell system employed for evaluation of a fuel for a fuel cell system of the invention. FIG. 2 is a flow chart of a partial oxidation type fuel cell system employed for evaluation of a fuel for a fuel cell system of the invention.

BEST MODE FOR CARRYING OUT THE INVENTION

[0020] Hereinafter, the contents of the invention will be described further in detail.

[0021] In the present invention, the oxygenates contained the specific amount in the fuel mean alcohols having carbon numbers of 2 to 4, ethers having carbon numbers of 2 to 8 and the like. More particularly, the oxygenates include methanol, ethanol, dimethyl ether, methyl tertiary butyl ether (MTBE), ethyl tertiary butyl ether, tertiary amyl methyl ether (TAME), tertiary amyl ethyl ether and the like.

[0022] The content of these oxygenates is required to be 0.5 mass % or more in terms of an oxygen content based on the whole fuel in view of a low fuel consumption of a fuel cell system as a whole, a small THC in an exhaust gas, short starting time of a system and the like, and further is required to be 20 mass % or below taking into consideration of a balance of a power generation quantity per weight.

[0023] The fuel for a fuel cell system of the invention, in addition to the oxygenates mentioned-above, is a mixture of the oxygenates and the hydrocarbons in view of a high power generation quantity per weight, a high power generation quantity per CO₂ emission and the like and an amount of formulation for hydrocarbons is 5 mol. % or more based on the whole fuel.

[0024] In the fuel according to the invention, the composition of respective carbon atoms means that a content of hydrocarbons having carbon numbers of 2 or less is 5 mol. % or less, a content of hydrocarbons having carbon numbers of 3 and 4 in total is 90 mol. % or more, and a content of hydrocarbons having carbon numbers of 5 or more is 5 mol. % or less.

[0025] The content of hydrocarbons having carbon numbers of 2 or less is preferably 5 mol. % or less and more preferably 3 mol. % or less in relation to the storage, inflammability and evapo-emission and the like. The content of hydrocarbons having carbon numbers of 3 and 4 in total is 90 mol. % or more and more preferably 95 mol. % or more in view of a high power generation quantity per weight, a high power generation quantity per CO₂ emission, a low fuel consumption of a fuel cell system as a whole, a low THC in an exhaust gas, short starting time of a system, small deterioration of a reforming catalyst to maintain the initial performances for a long duration, and the like. The content of hydrocarbons having carbon numbers of 5 or more is 5 mol. % or less and more preferably 2 mol. % or less in view of a high power generation quantity per weight, a high power generation quantity per CO₂ emission, a low fuel consumption of a fuel cell system as a whole, a low THC in an exhaust gas, short starting time of a system, small deterioration of a reforming catalyst to maintain the initial performances for a long duration, and the like.

[0026] Incidentally, the compositions of respective carbon atoms mentioned above are values measured by JIS K 2240, "Liquefied Petroleum Gases 5.9 Methods for Chemical Composition Analysis".

[0027] Further, the content of sulfur in a fuel of the invention is not particularly restricted, however; because deterioration of a fuel cell system comprising such as a reforming catalyst, a water gas shift reaction catalyst, a

carbon monoxide removal catalyst, fuel cell stacks, and the like can be suppressed to low and the initial performances can be maintained for a long duration, the content is preferably 50 ppm by mass or less, more preferably 10 ppm by mass or less, further more preferably 1 ppm by mass or less.

[0028] Here, sulfur content means sulfur measured by JIS K. 2240, "Liquefied Petroleum Gases 5.5 or 5.6 Determination of sulfur content".

[0029] In the present invention, the compositions for hydrocarbons are not particularly restricted, however, saturates (M(S)) is preferably 60 mol. % or more, olefins (M(O)) is preferably 40 mol. % or less, butadiene (M(B)) is 0.5 mol. % or less, isoparaffin (M(IP)) in saturates having carbon atoms of 4 or more is preferably 0.1 mol. % or more. Hereinafter, these compositions are explained separately.

[0030] The saturates (M(S)) is preferably 60 mol. % or more, more preferably 80 mol. % or more, further more preferably 95 mol. % or more and most preferably 99 mol. % or more in view of a high power generation quantity per weight, a high power generation quantity per CO₂ emission, a low fuel consumption of a fuel cell system as a whole, a low THC in an exhaust gas, short starting time of a system, and the like.

[0031] The olefins (M(O)) is preferably 40 mol. % or less, more preferably 10 mol. % or less and most preferably 1 mol. % or less in view of a high power generation quantity per weight, a high power generation quantity per CO₂ emission, a low fuel consumption of a fuel cell system as a whole, a low THC in an exhaust gas, short starting time of a system, small deterioration of a reforming catalyst to maintain the initial performances for a long duration, a good storage stability, and the like.

[0032] The butadiene (M(B)) is preferably 0.5 mol. % or less and most preferably 0.1 mol. % or less in view of a high power generation quantity per weight, a high power generation quantity per CO₂ emission, a low fuel consumption of a fuel cell system as a whole, a low THC in an exhaust gas, short starting time of a system, small deterioration of a reforming catalyst to maintain the initial performances for a long duration, a good storage stability, and the like.

[0033] The isoparaffin (M(IP)) in saturates having carbon atoms of 4 or more is preferably 0.1 mol. % or more, more preferably 1 mol. % or more, furthermore preferably 10 mol. % or more, much more preferably 20 mol. % or more and most preferably 30 mol. % or more in view of a low fuel consumption of a fuel cell system as a whole, a low THC in an exhaust gas, short starting time of a system, small deterioration of a reforming catalyst to maintain the initial performances for a long duration, and the like.

[0034] Incidentally, the above-described (M(S)), (M(O)), (M(B)) and (M(IP)) are values measured by JIS K 2240, "Liquefied Petroleum Gases 5.9 Methods for Chemical Composition Analysis".

[0035] Then, it is most preferably to satisfy the above-described preferable ranges of sulfur and the above-described preferable ranges of compositions since deterioration of a fuel cell system comprising such as a reforming catalyst, a water gas shift reaction catalyst, a carbon monoxide removal catalyst, fuel cell stacks, and the like can be

suppressed to low and the initial performances can be maintained for a long duration.

[0036] Further, vapor pressure of a fuel of the invention is not particularly restricted, however, it is preferably 1.55 MPa or less and more preferably 1.53 MPa or less at 40° C. in relation to the storage, inflammability and evapo-emission and the like.

[0037] Incidentally, the vapor pressure at 40° C. is measured by JIS K 2240, "Liquefied Petroleum Gases 5.4 Calculation method for density and vapor pressure".

[0038] Further, density of hydrocarbons contained in a fuel of the invention is not particularly restricted, however, it is preferably 0.620 g/cm³ or less at 15° C. in view of a high power generation quantity per weight, a high power generation quantity per CO₂ emission, a low fuel consumption of a fuel cell system as a whole, a low THC in an exhaust gas, short starting time of a system, small deterioration of a reforming catalyst to maintain the initial performances for a long duration, and the like, and more preferably 0.500 g/cm³ or less to exhibit the effects of the invention.

[0039] Incidentally, the density at 15° C. is measured by JIS K 2240, "Liquefied Petroleum Gases 5.7 or 5.8 Calculation method for density and vapor pressure".

[0040] Further, the corrosiveness to copper of a fuel according to the invention is not particularly restricted, however, the corrosiveness thereof is preferable to 1 or less at 40° C. for 1 hour because deterioration of a fuel cell system comprising such as a reforming catalyst, a water gas shift reaction catalyst, a carbon monoxide removal catalyst, fuel cell stacks, and the like can be suppressed to low and the initial performances can be maintained for a long duration.

[0041] Incidentally, the corrosiveness to copper at 40° C. for 1 hour is measured by JIS K 2240, "Liquefied Petroleum Gas 5.10 Testing Method for Corrosiveness to copper".

[0042] Further, in the invention, heat capacity of a fuel is not particularly restricted, however, the heat capacity is preferably 1.7 kJ/kg·° C. or less at 15° C. and in gaseous phase in view of a low fuel consumption of a fuel cell system as a whole.

[0043] The heat capacity is measured by means of calorimeters such as water calorimeter, ice calorimeter, vacuum calorimeter, adiabatic calorimeter and the like.

[0044] A production method for the fuel of the invention is not particularly restricted. As a practical method, for example, the fuel can be prepared by including the specific amount of oxygenates defined in the invention in one or more of the following hydrocarbon base materials. The hydrocarbons can be produced, for example, by the following hydrocarbon base materials; a straight-run propane fraction containing propane as a main component obtained by treating heavy oils with a distillation apparatus, naphtha reforming apparatus and the like, a straight-run desulfurized propane fraction obtained by desulfurizing the straight-run propane fraction, a straight-run butane fraction containing butane as a main component obtained by treating heavy oils with a distillation apparatus, naphtha reforming apparatus, alkylation apparatus and the like, a straight-run desulfurized butane fraction obtained by desulfurizing the straight-run butane fraction, a cracked propane fraction containing propane and propylene as main components obtained by crack-

ing heavy oils with a fluid catalytic cracking apparatus (FCC) and the like, a cracked butane fraction containing butane and butene as main components obtained by treating heavy oils with a fluid catalytic cracking apparatus (FCC) and the like.

[0045] Among them, preferable materials as the base materials for the production of the fuel of the invention are the straight-run desulfurized propane fraction, the straight-run desulfurized butane fraction and the like, and dimethylether and methanol.

[0046] A fuel of the invention is to be employed as a fuel for a fuel cell system. A fuel cell system mentioned herein comprises a reformer for a fuel, a carbon monoxide conversion apparatus, fuel cells and the like, however, a fuel of the invention may be suitable for any fuel cell system.

[0047] The reformer is an apparatus for obtaining hydrogen, by reforming a fuel. Practical examples of the reformer are:

[0048] (1) a steam reforming type reformer for obtaining products of mainly hydrogen by treating a heated and vaporized fuel and steam with a catalyst such as copper, nickel, platinum, ruthenium and the like;

[0049] (2) a partial oxidation type reformer for obtaining products of mainly hydrogen by treating a heated and vaporized fuel and air with or without a catalyst such as copper, nickel, platinum, ruthenium and the like; and

[0050] (3) an auto thermal reforming type reformer for obtaining products of mainly hydrogen by treating a heated and vaporized fuel, steam and air, which carries out the partial oxidation of (2) in the prior stage and carries out the steam type reforming of (1) in the posterior stage while using the generated heat of the partial oxidation reaction with a catalyst such as copper, nickel, platinum, ruthenium and the like.

[0051] The carbon monoxide conversion apparatus is an apparatus for removing carbon monoxide which is contained in a gas produced by the above-described reformer and becomes a catalyst poison in a fuel cell and practical examples thereof are:

[0052] (1) a water gas shift reactor for obtaining carbon dioxide and hydrogen as products from carbon monoxide and steam by reacting a reformed gas and steam in the presence of a catalyst of such as copper, nickel, platinum, ruthenium and the like; and

[0053] (2) a preferential oxidation reactor for converting carbon monoxide into carbon dioxide by reacting a reformed gas and compressed air in the presence of a catalyst of such as platinum, ruthenium and the like, and these are used singly or jointly.

[0054] As a fuel cell, practical examples are a proton exchange membrane type fuel cell (PEFC), a phosphoric acid type fuel cell (PAFC), a molten carbonate type fuel cell (MCFC), a solid oxide type fuel cell (SOFC) and the like.

[0055] Further, the above-described fuel cell system can be employed for an electric automobile, a hybrid automobile comprising a conventional engine and electric power, a

portable power source, a dispersion type power source, a power source for domestic use, a cogeneration system and the like.

EXAMPLES

[0056] The properties of base materials (LPG) employed for the respective fuels for examples and comparative examples are shown in Table 1.

[0057] Also, the compositions and properties of the respective fuels employed for examples and comparative examples are shown in Table 2.

TABLE 1

		straight-run C3 fraction *1	straight-run desulfurized C4 fraction *2	FCC-C3 fraction *3	FCC-C4 fraction *4	DME *5
sulfur	mass ppm	7	<1	5	34	<1
density @ 15° C.	g/m ³	0.509	0.577	0.518	0.591	0.600
vapor pressure @ 40° C.	Mpa	1.33	0.34	1.50	0.39	0.88
corrosiveness to copper		1a	1a	1a	1	—
carbon number C ₂₋	mol. %	2.5	0.0	0.0	0.0	—
carbon number C ₃	mol. %	96.6	0.0	99.8	2.4	—
carbon number C ₄	mol. %	0.9	99.9	0.29	92.4	—
carbon number C _{S+}	mol. %	0.0	0.1	0.0	5.2	—
saturates	mol. %	99.9	99.9	19.7	53.9	—
olefins	mol. %	0.1	0.1	80.3	46.1	—
butadiene	mol. %	0.0	0.0	0.0	0.2	—
isoparaaffines in saturates having carbon numbers of 4 or more	mol. %	78.2	35.8	100.0	81.4	—

*1: fractions containing propane as a main component obtained by treating heavy oils with a distillation apparatus, naphtha reforming apparatus and the like
*2: those obtained by desulfurization of fractions containing butane as a main component obtained by treating heavy oils with a distillation apparatus, naphtha reforming apparatus, alkylation apparatus and the like
*3: fractions containing propane and propylene as main components obtained by treating heavy oils with a fluid catalytic cracking apparatus (FCC) and the like
*4: fractions containing butane and butene as main component obtained by treating heavy oils with a fluid catalytic cracking apparatus (FCC) and the like
*5: dimethylether

[0058]

TABLE 2

		Ex. 1	Ex. 2
Mixing ratio (vol. %)			
straight-run C3 fraction		20	
straight-run desulfurized C4 fraction		90	75
FCC-C3 fraction			
FCC-C4 fraction			
DME		10	5
methanol			
Analytical results of properties			
sulfur	mass ppm	<1	1
density	g/cm ³	0.509	0.563
vapor pressure	Mpa	0.40	0.57
distribution of carbon numbers (hydrocarbon moieties)			
carbon number: C ₂₋	mol. %	2.5	0.6
carbon number: C ₃	mol. %	96.6	23.0

TABLE 2-continued

carbon number: C ₄	mol. %	0.9	76.4
carbon number: C _{S+}	mol. %	0.0	0.1
composition			
saturates	mol. %	99.9	99.9
olefins	mol. %	0.1	0.1
butadiene	mol. %	0.0	0.0
isoparaaffines in saturates having carbon numbers of 4 or more	mol. %	78.2	35.9
oxygen ratio	mass %	4.0	2.1

TABLE 2-continued

corrosiveness to copper		1a	1a
net heat of combustion	kJ/kg	43750	44800
heat capacity	kJ/kg · ° C.	1.60	1.61
gas			
Comp. 1 Comp. 2			
Mixing ratio (mol. %)			
straight-run C3 fraction			
straight-run desulfurized C4 fraction			
FCC-C3 fraction			
FCC-C4 fraction			100
DME			
methanol		100	
Analytical results of properties			
sulfur	mass ppm	<1	34
density	g/cm ³	0.796	0.591
vapor pressure	Mpa	0.03	0.36

TABLE 2-continued

distribution of carbon numbers (hydrocarbon moieties)			
carbon number: C ₂ -	mol. %	—	0.0
carbon number: C ₃	mol. %	—	2.4
carbon number: C ₄	mol. %	—	92.4
carbon number: C ₅ +	mol. %	—	5.2
composition			
saturates	mol. %	—	53.9
olefins	mol. %	—	46.1
butadiene	mol. %	—	0.2
isoparaffines in saturates having carbon numbers of 4 or more	mol. %	—	80.6
oxygen ratio	mass %	49.9	0.0
corrosiveness to copper		—	1
net heat of combustion	kJ/kg	19920	45440
heat capacity	kJ/kg · ° C.	1.34	1.55
gas			

[0059] These respective fuels were subjected to evaluation tests for a fuel cell system.

[0060] Fuel Cell System Evaluation Test

[0061] (1) Steam Reforming

[0062] A fuel and water were evaporated by electric heating and led to a reformer filled with a noble metal type catalyst and kept at a prescribed temperature by an electric heater to generate a reformed gas enriched with hydrogen.

[0063] The temperature of the reformer was adjusted to be the minimum temperature (the minimum temperature at which no THC was contained in a reformed gas) at which reforming was completely carried out in an initial stage of the test.

[0064] Together with steam, a reformed gas was led to a carbon monoxide conversion apparatus (a water gas shift reaction) to convert carbon monoxide in the reformed gas to carbon dioxide and then the produced gas was led to a solid polymer type fuel cell to carry out power generation.

[0065] A flow chart of a steam reforming type fuel cell system employed for the evaluation was illustrated in FIG. 1.

[0066] (2) Partial Oxidation

[0067] A fuel is evaporated by electric heating and together with air, the evaporated fuel was led to a reformer filled with a noble metal type catalyst and kept at a 1100° C. by an electric heater to generate a reformed gas enriched with hydrogen.

[0068] Together with steam, a reformed gas was led to a carbon monoxide conversion apparatus (a water gas shift reaction) to convert carbon monoxide in the reformed gas to carbon dioxide and then the produced gas was led to a solid polymer type fuel cell to carry out power generation.

[0069] A flow chart of a partial oxidation type fuel cell system employed for the evaluation was illustrated in FIG. 2.

[0070] (3) Evaluation Method

[0071] The amounts of H₂, CO, CO₂ and THC in the reformed gas generated from a reformer were measured

immediately after starting of the evaluation test. Similarly, the amounts of H₂, CO, CO₂ and THC in the reformed gas generated from a carbon monoxide conversion apparatus were measured immediately after starting of the evaluation test.

[0072] The power generation quantity, the fuel consumption, and the CO₂ amount emitted out of a fuel cell were measured immediately after starting of the evaluation test and 100 hours later from the starting.

[0073] The energy (preheating quantities) necessary to heat the respective fuels to a prescribed reforming temperature were calculated from the heat capacities and the heat of vaporization.

[0074] Further, these measured values, calculated values and the heating values of respective fuels were employed for calculation of the performance deterioration ratio of a reforming catalyst (the power generation amount after 100 hours later from the starting divided by the power generation amount immediately after the starting), the thermal efficiency (the power generation amount immediately after the starting divided by the net heat of combustion of a fuel), and the preheating energy ratio (preheating energy divided by the power generation amount).

[0075] The respective measured values and the calculated values are shown in Table 3.

TABLE 3

	Ex. 1	Ex. 2
Evaluation results		
Electric power generation by steam reforming method (reforming temperature = optimum reforming temperature 1))		
Optimum reforming temperature ° C.	540	590
Electric energy kJ/fuel kg		
initial performance	29580	30200
100 hours later	29580	30190
performance deterioration ratio	0.00%	0.03%
100 hours later		
Thermal efficiency 2)	68%	67%
initial performance		
CO ₂ generation kg/fuel kg	2.901	2.956
initial performance		
Energy per CO ₂ KJ/CO ₂ -kg	10196	10217
initial performance		
Preheating energy 3) kJ/fuel kg	830	910
Preheating energy ratio 4)	2.8%	3.0%
Electric power generation by partial oxidation reforming method (reforming temperature 1100° C.)		
Electric energy kJ/fuel kg		
initial performance	15100	15440
100 hours later	15100	15430
performance deterioration ratio	0.00%	0.06%
100 hours later		
Thermal efficiency 2)	35%	34%
initial performance		
CO ₂ generation kg/fuel kg	2.900	2.955
initial performance		
Energy per CO ₂ KJ/CO ₂ -kg	5207	5225
initial performance		
Preheating energy 3) kJ/fuel kg	1720	1729
Preheating energy ratio 4)	11.4%	11.2%

TABLE 3-continued

	Comp. 1	Comp. 2
Evaluation results		
Electric power generation by steam reforming method (reforming temperature = optimum reforming temperature 1))		
Optimum reforming temperature ° C.	360	670
Electric energy kJ/fuel kg		
initial performance	17140	29460
100 hours later	17140	28520
performance deterioration ratio 100 hours later	0.00%	3.19%
Thermal efficiency 2)	86%	65%
initial performance		
CO ₂ generation kg/fuel kg	1.374	3.079
initial performance		
Energy per CO ₂ KJ/CO ₂ -kg	12475	9568
initial performance		
Preheating energy 3) kJ/fuel kg	1590	1000
Preheating energy ratio 4)	9.3%	3.4%
Electric power generation by partial oxidation reforming method (reforming temperature 1100° C.)		
Electric energy kJ/fuel kg		
initial performance	10280	14420
100 hours later	10280	14220
performance deterioration ratio 100 hours later	0.00%	1.39%
Thermal efficiency 2)	52%	32%
initial performance		
CO ₂ generation kg/fuel kg	1.373	3.077
initial performance		
Energy per CO ₂ KJ/CO ₂ -kg	7487	4686
initial performance		
Preheating energy 3) kJ/fuel kg	2590	1670
Preheating energy ratio 4)	25.2%	11.6%

1) the minimum temperature at which no THC is contained in a reformed gas
2) electric energy/net heat of combustion of fuel
3) energy necessary for heating a fuel to a reforming temperature
4) preheating energy/electric energy

[0076] Industrial Applicability

[0077] As described above, a fuel of the invention comprising a specific amount of oxygenates and hydrocarbons with specific compositions of respective carbon atoms has performances with small deterioration by using in a fuel cell system and can provide high output of electric energy and other than that, the fuel can satisfy a variety of performances for a fuel cell system.

1. A fuel for use in a fuel cell system, wherein said fuel comprises 5 mol. % or more of hydrocarbons, 0.5-20 mass % of oxygenates therein in terms of an oxygen content based on the whole fuel and 5 mol. % or less of hydrocarbons having carbon numbers of 2 or less, 90 mol. % or more of hydrocarbons having carbon numfbers of 3 and 4 in total, 5 mol. % or less of hydrocarbons having carbon numbers of 5 or more and is a gaseous phase under normal temperature and pressure.

2. A fuel according to claim 1, wherein a sulfur content is 50 ppm by mass or less.

3. A fuel according to claims 1 or 2, wherein said hydrocarbons comprises 60 mol. % or more of saturates, 40 mol. % or less of olefins, 0.5 mol. % or less of butadione, 0.1 mol. % or more of isoparaffin in saturates having carbon atoms of 4 or more, and is a gaseous phase under normal temperature and pressure.

4. A fuel according to any one of claims 1 to 3, wherein vapor pressure at 40° C. is 1.55 MPa or less.

5. A fuel according to any one of claims 1 to 4, wherein density at 15° C. is 0.500 to 0.620 g/cm³.

6. A fuel according to any one of claims 1 to 5, wherein corrosiveness to copper at 40° C. for 1 hour is 1 or less,

7. A fuel according to any one of claims 1 to 6, wherein heat capacity of the fuel is 1.7 kJ/kg ° C. or less at 15° C. in gaseous phase.

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