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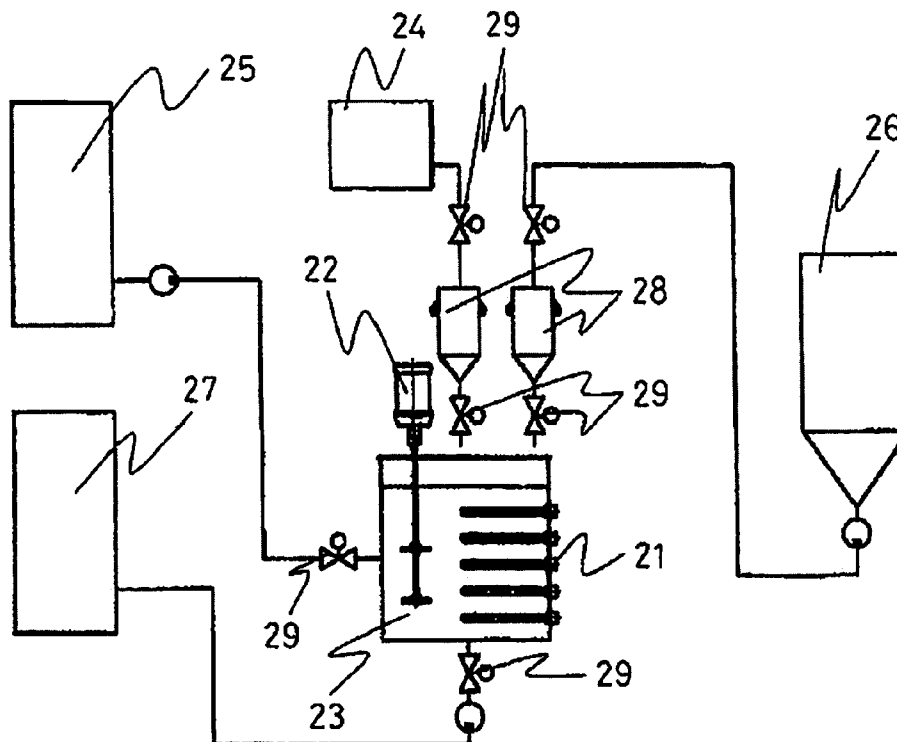


Fig. 1

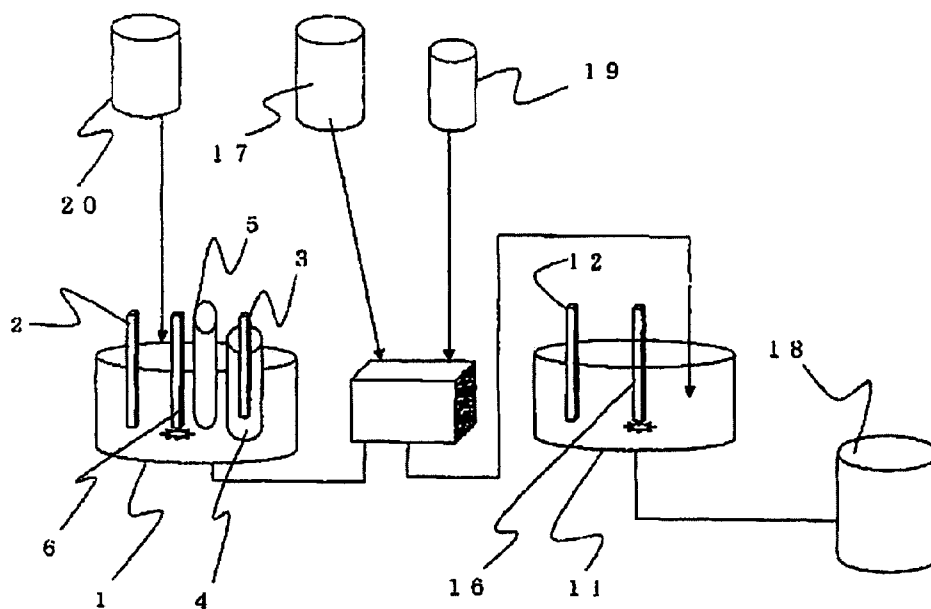
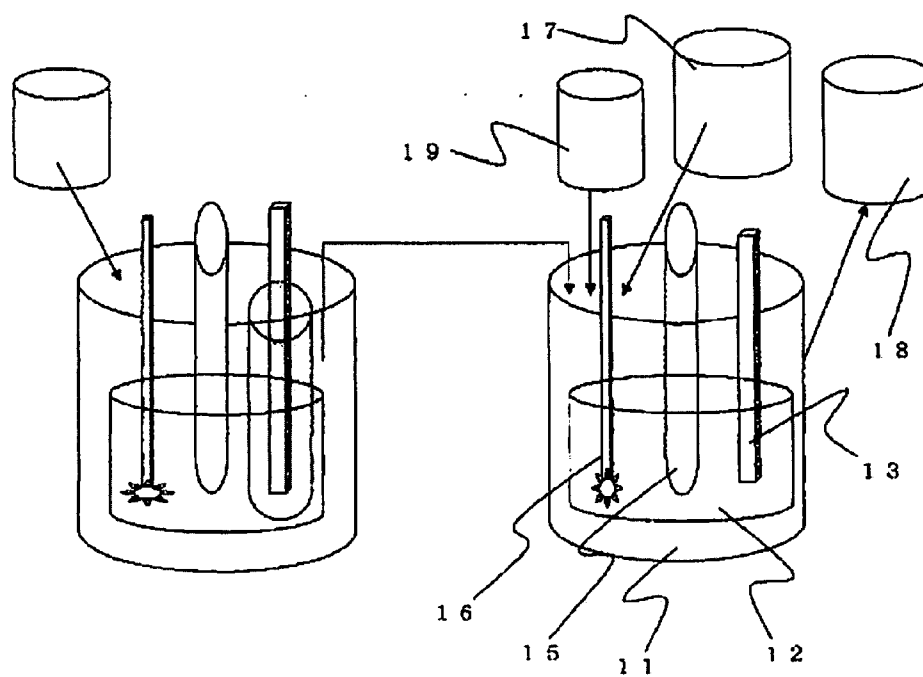
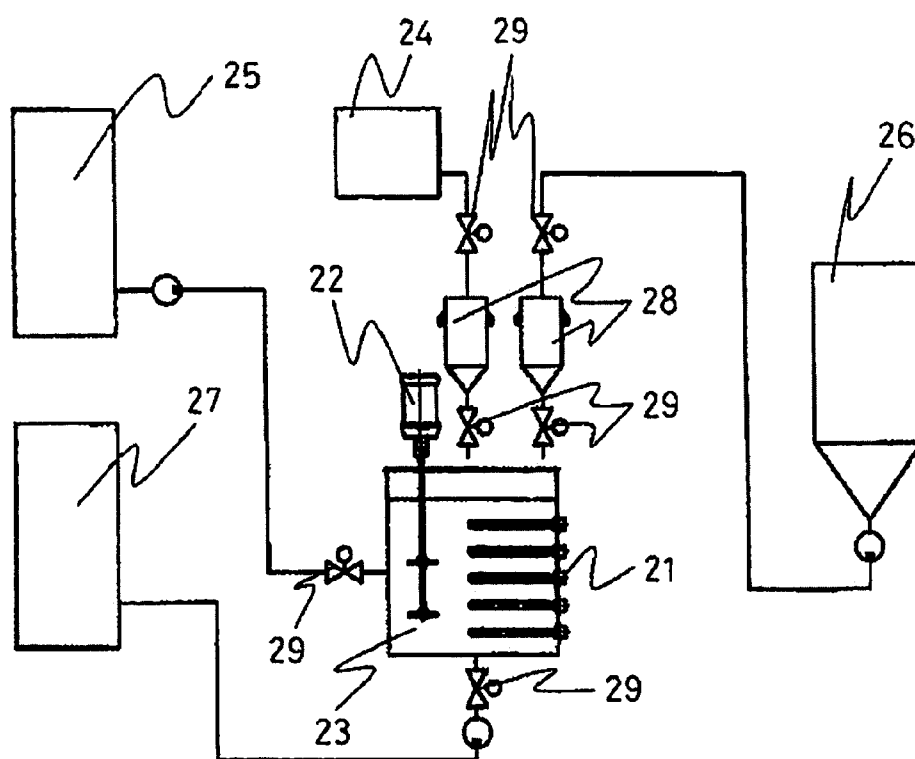


Fig. 2



F i g . 3



EMULSION FUEL, AND PROCESS AND APPARATUS FOR PRODUCTION THEREOF

TECHNICAL FIELD

[0001] The present invention relates to an emulsion fuel, a method for producing the same, and an apparatus used therefor, the emulsion fuel being of environmentally-adaptable type and being obtained by emulsifying water and fuel oil such as gasoline, light oil, kerosene, heavy oil, vegetable oil or waste oil.

BACKGROUND ART

[0002] An emulsion fuel obtained by mixing water with fuel oil such as gasoline, light oil, kerosene, heavy oil, vegetable oil or waste oil, generates less amounts of nitrogen oxide (NO_x) and soot at the time of combustion. Thus, the emulsion fuel is known to be an effective fuel for suppressing air pollution. For example, diesel engines, which are effectively utilized in many fields such as vehicles, ships, power generation, civil engineering and construction, etc, mainly use light oil as fuel. Recently, an uncombusted product, soot, and the like, such as nitrogen oxide and PM (Particulate Matter), which are included in exhaust gas from diesel engines, have caused air pollution. For this reason, various technological developments have been in progress for purification of exhaust gas from diesel engines. In order to reduce the amount of nitrogen oxide in exhaust gas, one of such technological developments proposes various types of emulsion-fuel supply apparatuses which supply, jet and combust an emulsion fuel including light oil and water. Moreover, various kinds of emulsifiers are also proposed to obtain a fuel achieving stable emulsion.

[0003] Patent Document 1: JP-A 6-346071

[0004] Patent Document 2: JP-A 11-263991

[0005] Patent Document 3: JP-A 2004-10765

[0006] Patent Document 4: JP-A 2002-226000

[0007] Patent Document 5: JP-A 2003-27074

[0008] Patent Document 6: JP-A 2004-123947

[0009] Furthermore, JP-A 2004-76608 proposes a fuel reforming device connected to a diesel engine. Its characteristics are stated as follows. Specifically, this reforming device applies a high-frequency vibration to a liquid mixture of a liquid fuel and water to produce an emulsion fuel of ultrafine particles and having a high mixture density. Then, this emulsion fuel is supplied to an engine body by a fuel-injection pump. The use of such a fuel in a diesel engine with its control system in operation suppresses a combustion temperature to a low level. Moreover, this hardly generates an uncombusted product, soot, and the like, such as nitrogen oxide and PM (Particulate Matter), by the following reason. Specifically, water in the fuel is vaporized, and then part of the vapor is separated, causing a phenomenon of small explosion. Its explosive force assists the mixing of the fuel with air to promote the combustion reaction. However, the invention in JP-A 2004-76608 only relates to a fuel reforming device mounted on a vehicle. Thus, the object thereof is achieved only when the fuel reforming device is used in combination with the control system during operation.

[0010] Patent Document 7: JP-A 2004-76608

[0011] Meanwhile, in fact, a system as follows is publicly recognized as a device certified by the Law concerning NO_x-PX. Specifically, the system is of in-vehicle type, and performs integrated processing by electronic control on a

combination of: an apparatus for producing, from light oil and water, an emulsion fuel optimum for a combustion condition from time to time; and a post-treatment filter. This system is known to bring about the following effects. Specifically, the water content in the fuel reduces the peak temperature at the time of combustion, significantly reducing the generation of nitrogen oxide. Moreover, at this point, the micro-explosion of the water promotes the mixing of the fuel with oxygen, and thereby causes more complete combustion. Thus, the generation of black smoke and soot can be suppressed.

[0012] As described above, heretofore various modifications and improvements have been attempted mainly on a fuel supply system that is directly connected to a diesel engine. However, also desired is development of a practical emulsion fuel itself which has a wider adaptable and applicable range, and which retains a favorable emulsion state of the fuel and water over a prolonged period of time.

[0013] The present inventor has already proposed an emulsion fuel, and a method and an apparatus for producing the same, the emulsion fuel being of environmentally-adaptable type and being obtained by stirring and mixing a liquid mixture of 50 vol % or more of a fuel and 50 vol % or less of an emulsifier aqueous solution, while applying an ultrasonic wave thereto (Patent Document 8). Although the emulsion fuel obtained by such a proposal is high in quality, further improvement has been desired in terms of the emulsion stability over a prolonged period of time.

[0014] Patent Document 8: JP-A 2006-28215

DISCLOSURE OF THE INVENTION

Problems To Be Solved By the Invention

[0015] An object and aim of the present invention is to develop an emulsion fuel of high quality, which can be handled and used in the same manner as for ordinary fuel oil, and which retains a very good emulsion state over a prolonged period of time.

Means For Solving the Problems

[0016] The present invention is an emulsion fuel including a liquid mixture of: 40 to 95 vol % of fuel oil; 60 to 5 vol % of reduced water having an oxidation-reduction potential (ORP) of +100 mV or below; and 0.1 to 10 wt % of an emulsifier relative to the fuel oil. As a preferable mixing ratio between the fuel oil and the reduced water, the fuel oil is 50 to 90 vol %, while the reduced water is 50 to 10 vol %.

[0017] Generally, the oxidation-reduction potential of oxygen is approximately +850 mV, and the oxidation-reduction potential of hydrogen is approximately -420 mV. It is said that the oxidizing power and the reducing power are in equilibrium at approximately +200 mV. Accordingly, reduced water means water having an oxidation-reduction potential lower than approximately +200 mV. It is known that, the lower the oxidation-reduction potential, the higher the reducing power. In this specification also, the reduced water means water having an oxidation-reduction potential lower than approximately +200 mV. The reduced water used in the present invention is one having an oxidation-reduction potential of approximately +100 mV or below. Moreover, the reduced water is further preferably electrolyzed-reduced water obtained by electrolysis of water. Among various types of electrolyzed-reduced water, preferable is electrolyzed-reduced water having an oxidation-reduction potential of +50 mV or below.

[0018] As the electrolyzed-reduced water used in the present invention, preferably used is electrolyzed-reduced water obtained by electrolysis of water, while an ultrasonic wave is being applied thereto with ultrasonic wave-generating means, using a diaphragm cell with an anode and a cathode separated from each other. Moreover, in the electrolysis of water, water is electrolyzed appropriately when a hydrogen storage metal or alloy is used as the cathode.

[0019] Another aspect of the present invention relates to an apparatus for producing the emulsion fuel of the present invention as described above. The apparatus for producing an emulsion fuel includes: an electrolytic cell; an emulsion forming cell; and a fuel oil tank and an emulsion fuel tank which are connected to the emulsion forming cell. The electrolytic cell includes: an anode and a cathode separated from each other by a diaphragm; ultrasonic wave-generating means; and stirring means. The emulsion forming cell includes stirring means. It is needless to say that, in such an apparatus of the present invention, ordinarily-used publicly-known pipes, pumps, measurement devices, controllers, and the like can be disposed or incorporated as appropriate. Meanwhile, in the present invention, no dedicated equipment for emulsifier storage means, weighing means, and adding-mixing means is necessary, and publicly-known equipment may be disposed or installed at any position.

[0020] In the production apparatus, the cathode of the electrolytic cell is preferably an electrode formed of a hydrogen storage metal or alloy. Additionally, an electrode formed of a hydrogen storage metal or alloy is preferably disposed in the emulsion forming cell. In this case, it is convenient that the electrode of the electrolytic cell and the electrode of the emulsion forming cell be disposed interchangeably with each other, both of the electrodes being formed of the hydrogen storage metal or alloy.

[0021] In the production apparatus, an anode and a cathode which is formed of a hydrogen storage metal or alloy may be disposed in the emulsion forming cell. Moreover, ultrasonic wave-generating means may be disposed in the emulsion forming cell.

[0022] Still another aspect of the present invention relates to a method for producing the emulsion fuel of the present invention as described above. The method for producing an emulsion fuel includes the step of stirring and mixing, in an emulsion forming cell: 40 to 95 vol % of fuel oil (A); 60 to 5 vol % of electrolyzed-reduced water (B) obtained by electrolysis of water, while an ultrasonic wave is being applied thereto with ultrasonic wave-generating means, using a diaphragm cell with an anode and a cathode separated from each other; and 0.1 to 10 wt % of an emulsifier (C) relative to the fuel oil.

[0023] In the method, the water is electrolyzed preferably using an electrode formed of a hydrogen storage metal or alloy as the cathode. Moreover, the fuel oil (A), the electrolyzed-reduced water (B) and the emulsifier (C) are preferably stirred and mixed with one another in the presence of the electrode formed of the hydrogen storage metal or alloy, the electrode being used in the electrolysis of the water.

[0024] Furthermore, in the method, the fuel oil (A), the electrolyzed-reduced water (B) and the emulsifier (C) may be stirred and mixed with one another, while a current is being passed through an anode and a cathode (electrode) formed of a hydrogen storage metal or alloy, the anode and the cathode being provided in the emulsion forming cell. In addition, the

stirring and mixing may be performed, while an ultrasonic wave is being applied with ultrasonic wave-generating means.

Effects of the Invention

[0025] An emulsion fuel obtained according to the present invention is an environmentally-friendly fuel causing less pollution, and retains a very good emulsion state over a prolonged period of time. Thus, the emulsion fuel can be handled and used in the same manner as for ordinary fuel oil. Moreover, the emulsion fuel of the present invention can be used directly in presently-known engines, combustion apparatuses and facilities, and thus no dedicated equipment is necessary to be installed additionally. Besides, the emulsion fuel is superior in gas mileage and quality, also. Moreover, when the emulsion fuel of the present invention including, for example, light oil and water containing an emulsifier is used in a diesel engine, the generation amounts of nitrogen oxide and PM including black smoke particles are reduced considerably. Furthermore, the following merits are obtained: the gas mileage of a vehicle is improved, and the lifetime of engine oil is extended.

Best Modes For Carrying Out the Invention

First Embodiment

[0026] An emulsion fuel according to a first embodiment of the present invention is obtained by mixing, stirring and then emulsifying: 40 to 95 vol % of fuel oil; 60 to 5 vol % of reduced water having an oxidation-reduction potential (ORP) of +100 mV or below; and 0.1 to 10 wt % of emulsifier relative to the fuel oil. The method and means for the mixing, stirring or emulsifying are not particularly limited. Any publicly known method, means and device can be used. As a preferable mixing ratio between the fuel oil and the reduced water, the fuel oil is 50 to 90 vol %, while the reduced water is 50 to 10 vol %.

[0027] The emulsifier used in the first embodiment is in a liquid or solid state. However, a way of adding the emulsifier to and mixing the emulsifier with the fuel oil and/or the reduced water is not limited at all. The emulsifier may be added and mixed in the form of an aqueous solution, or may be directly added to and mixed with the fuel oil and/or the reduced water. It is only necessary that the amount of the emulsifier added be 0.1 to 10 wt %, and preferably 1 to 5 wt %, relative to the fuel oil in the liquid mixture of the fuel oil and the reduced water in the end.

[0028] As the emulsifier used in the first embodiment, any of nonionic surfactants, anionic surfactants, cationic surfactants and amphoteric surfactants can be used. However, preferable are nonionic surfactants including: fatty acid esters of polyvalent alcohols such as sorbitol, sorbitan and sorbide; alkylene oxide adducts of alcohols; and the like. A single kind of the emulsifier can be used, or two or more kinds thereof can be used in mixture.

[0029] The reduced water used in the first embodiment has an oxidation-reduction potential of +100 mV or below. Generally, reduced water means water having an oxidation-reduction potential lower than approximately +200 mV. It is known that, the lower the oxidation-reduction potential, the higher the reducing power. Incidentally, it is said that the oxidation-reduction potential of tap water is +200 to +700 mV. The oxidation-reduction potential of natural water such as well

water is lower than that of tap water. Some kind of natural water has a negative oxidation-reduction potential.

[0030] The reduced water in the first embodiment is preferably electrolyzed-reduced water obtained by electrolysis of water. Among various types of electrolyzed-reduced water, preferable is electrolyzed-reduced water having an oxidation-reduction potential of +50 mV or below, and further preferably -100 mV or below. The electrolyzed-reduced water refers to cathode water generated on the cathode side when water is electrolyzed. The electrolyzed-reduced water may be called alkali ion water. Although the oxidation-reduction potential thereof varies depending on the production method, the electrolyzed-reduced water having an oxidation-reduction potential of approximately -200 mV or below can be obtained by some production methods.

[0031] As the electrolyzed-reduced water used in the first embodiment, preferably used is electrolyzed-reduced water (electrolyzed water on the cathode side) obtained by electrolysis of water, while applying an ultrasonic wave thereto with ultrasonic wave-generating means, using a diaphragm cell with an anode and a cathode separated from each other. In the electrolysis of water, it is appropriate to electrolyze water by using a hydrogen storage metal or alloy as the cathode. By such a method and an apparatus, it is possible to obtain water having an oxidation-reduction potential as low as -300 mV to -750 mV depending on the conditions. Normally, water having an oxidation-reduction potential of -100 mV or below is preferable; particularly, water having an oxidation-reduction potential of around -300 mV is appropriate. The conditions for electrolyzing water can be easily set as appropriate in accordance with a desired oxidation-reduction potential of electrolyzed-reduced water.

[0032] In the electrolysis of water, used is a diaphragm cell that separates an anode (compartment) and a cathode (compartment) from each other. Examples of a diaphragm thereof include an ion exchange membrane, an organic or inorganic microporous membrane, and the like. Among these, an appropriate diaphragm can be selected easily in consideration of the corrosion resistance, mechanical strength, pore diameter and distribution, electric resistance, and so forth. The shape thereof is not particularly limited, as long as the diaphragm prevents substances that are generated and exist at the anode and the cathode, and are dissolved in an electrolytic solution from being mixed through diffusive convection. A practically-convenient diaphragm cell has a form in which the anode in the electrolytic cell is covered with a cylindrical anion exchange membrane.

[0033] Emulsion fuels obtained by emulsion are categorized into O/W (Oil in Water) type and W/O (Water in Oil) type according to the proportions of fuel oil and water. In the first embodiment, any type can be adopted. Generally, the W/O type in which water micro-particles are dispersed in fuel oil is superior in stability. Moreover, the W/O type has less properties as water, and does not cause a problem of oxidizing machineries that come into contact with this. Thus, the W/O type is preferable. The size of the water micro-particle in the fuel oil is appropriately 20 μ m or smaller, and more preferably 5 μ m or smaller. Furthermore, the emulsion fuel of the first embodiment can be blended with a necessary publicly-known additive, for example, antirust, pour-point depressant and corrosion inhibitor, depending on the purpose and usage thereof.

[0034] In the first embodiment, better effect can be obtained when ultrasonic wave-generating means is also used

in the electrolysis of water to obtain the electrolyzed-reduced water. Although the detailed principle and operations are not known, the followings are assumed. Specifically, when an ultrasonic wave is applied to water with the ultrasonic wave-generating means during the electrolysis, microbubbles are formed in the water. Simultaneously, the ultrasonic wave causes the cavitation effect to occur, which is said to create a vacuum condition of 1000 atm and 5000° C. under normal temperature and normal pressure. Accordingly, electrolyzed-reduced water is obtained considerably efficiently. In this case, when the hydrogen storage metal or alloy is used as the cathode, generated hydrogen is absorbed by and adsorbs to the cathode. This hydrogen can be used in the emulsion forming process as described later. By such electrolysis of water, water having an oxidation-reduction potential as low as approximately -500 mV can be obtained.

[0035] In the first embodiment, as the ultrasonic wave-generating means, for example, a publicly-known or commercially-available ultrasonic wave-generator can be used. The power of the ultrasonic wave is approximately 1 to 100 W, and preferably 5 to 40 W, per liter of water, or per liter of the liquid mixture of the fuel oil and the reduced water in the emulsion forming process to be described later. Note that, in the first embodiment, the ultrasonic wave-generating means does not include high frequency wave-generating means, but includes means for imparting oscillation to an object by use of frequencies, such as microwaves, other than what is called an ultrasonic wave. The ultrasonic wave-generating means may be of any type as long as the cavitation effect can act on treatment liquid. In an appropriate type thereof, an ultrasonic wave-oscillating rod connected to an ultrasonic wave-generating unit is inserted into the liquid mixture. As stirring means, a publicly-known or commercially-available stirrer may be utilized. As a mixing container used for stirring and mixing in the electrolysis or in the emulsion forming process to be described below, a dedicated container does not need to be used. For example, generally-available container or device made of stainless steel, glass or vinyl chloride, can be used in practice.

[0036] The emulsion formed of the reduced water or electrolyzed-reduced water and the fuel oil as described above is assumed to serve as a novel emulsion fuel to which hydrogen is added. This emulsion fuel is superior in combustibility, gas mileage and quality without the water and the fuel oil separated from each other over a longer period of time. The emulsion fuel of the first embodiment is speculated to be combusted completely in a way that: at first, the fuel oil is combusted, causing micro-explosion of the water in the emulsion; the combustion area of the fuel oil is thus markedly increased.

[0037] A method and an apparatus for producing an emulsion fuel of the first embodiment will be described by use of the drawings. FIG. 1 is a schematic view of an example of the apparatus for producing an emulsion fuel of the first embodiment. In FIG. 1, reference numeral 1 denotes an electrolytic cell used for electrolysis of water. The electrolytic cell 1 includes: an anode 3 and a cathode 2 separated from each other by a diaphragm 4 such as an ion membrane; ultrasonic wave-generating means 5 such as an ultrasonic wave-oscillating rod; and stirring means 6 such as a stirrer. Reference numeral 11 denotes an emulsion forming cell. The emulsion forming cell 11 includes stirring means 16. This emulsion forming cell 11 is connected to a fuel oil tank 17 and to an emulsion fuel tank 18. In such an apparatus of the first

embodiment, ordinarily-used publicly-known pipes, pumps, measurement devices, controllers, and the like can be disposed or incorporated as appropriate (unillustrated). Reference numeral **19** denotes an emulsifier storage tank, and the storage tank is connected to, for example, the emulsion forming cell **11** via a pump or measurement means (unillustrated). Moreover, the electrolytic cell **1** is connected to a water tank **20**.

[0038] In the first embodiment, as the anode **3**, for example, platinum, titanium or carbon is used. As the cathode **2**, for example, a metal such as palladium or titanium or alloy thereof is used. The ultrasonic wave-generating means **5** may be of any type as long as a liquid mixture can be sufficiently emulsified by the emulsion effect and the cavitation effect. In an appropriate type thereof, an ultrasonic wave-oscillating rod connected to an ultrasonic wave-generating unit is inserted into the treatment liquid. As the stirring means **6**, **16**, publicly-known or commercially-available stirrers may be utilized. As described above, as the electrolytic cell **1** and the emulsion forming cell **11**, dedicated cells do not need to be used.

[0039] In the production apparatus, the cathode **2** of the electrolytic cell **1** is preferably an electrode formed of a hydrogen storage metal or alloy. When a hydrogen storage metal such as palladium or hydrogen storage alloy such as titanium-iron alloy is used as the cathode, hydrogen generated by electrolysis is occluded in the cathode. Then, the hydrogen thus released can be effectively used in the emulsion forming cell. Moreover, an electrode **12** formed of the hydrogen storage metal or alloy is preferably disposed in the emulsion forming cell **11** as well. In this case, it is convenient that the electrode of the electrolytic cell and the electrode of the emulsion forming cell be disposed interchangeably with each other, both of the electrodes being formed of the hydrogen storage metal, or alloy. Specifically, it is preferable to structure and dispose the electrodes so that the cathodes can be transferred from the electrolytic cell to the emulsion forming cell, and from the emulsion forming cell to the electrolytic cell, for each batch. The cathode formed of the hydrogen storage metal or alloy which has absorbed and occluded hydrogen in the electrolytic cell is transferred to the emulsion forming cell, and demonstrate the operation and effect of adding the hydrogen to the emulsion. In the electrolysis of water, salts of electrolytes such as a hydroxide and chloride of alkali metal or alkaline earth metal may be put in the electrolytic cell **1**.

[0040] FIG. **2** is a schematic view showing another example of the apparatus for producing an emulsion fuel of the first embodiment. In FIG. **2**, reference numeral **11** denotes an emulsion forming cell; **12** denotes a cathode (annular cathode) formed of a hydrogen storage metal or alloy; **13** denotes an anode; **15** denotes ultrasonic wave-generating means; and **16** denotes stirring means. In the first embodiment, an emulsion may be formed, while a current is being passed through the anode **13** and the cathode **12**. Moreover, the stirring and mixing may be performed, while an ultrasonic wave is being applied with the ultrasonic wave-generating means **15**. In this manner, the effect of further improving the emulsion stability can be obtained.

[0041] In FIG. **1**, a predetermined amount of water, for example, tap water, is supplied from a water tank **20** to an electrolytic cell **1**, and electrolyzed while an ultrasonic wave is being applied thereto. Then, electrolyzed-reduced water thus produced at the cathode (compartment) of the electro-

lytic cell **1** is transferred to the emulsion forming cell **11** through a liquid feed pipe or the like. An emulsifier is stored in the form of powder, liquid or aqueous solution. The emulsifier may be added to and mixed with the electrolyzed-reduced water when passing through a liquid feed pump from a storage tank **19**, may be mixed with fuel oil in advance, or may be directly supplied to the emulsion forming cell **11**.

[0042] Next, the electrode formed of the hydrogen storage metal or alloy used as a cathode **2** for electrolysis in the electrolytic cell **1** is transferred to the emulsion forming cell **11**. A liquid mixture of the electrolyzed-reduced water, the fuel oil and the emulsifier in the emulsion forming cell is stirred and emulsified, while hydrogen is released from the electrode (**12** in FIG. **2**) to the liquid mixture. At this time, if necessary, an ultrasonic wave is applied to the liquid mixture with the ultrasonic wave-generating means (**15** in FIG. **2**). The duration, temperature, atmosphere, and the like for the emulsification are not particularly limited. When the emulsion formation is completed, the electrode (**12** in FIG. **2**) formed of the hydrogen storage metal or alloy is transferred to the electrolytic cell **1**, and used as the cathode **2** for the electrolysis of water again.

[0043] Thereafter, the emulsion fuel which has been emulsified by the emulsifier, and which includes 40 to 95 vol % of the fuel oil and 60 to 5 vol % of the electrolyzed-reduced water, is transferred to and stored in an emulsion fuel tank **18**. Note that, for example, when the first embodiment is employed to a combustion apparatus of a type installed at a certain position in a factory or the like, an emulsion fuel can be directly supplied to the combustion apparatus from the emulsion fuel tank **18** in corporation with appropriate control means. Meanwhile, the water tank **20** does not necessarily have to be what is called a tank for storing water temporarily, and may be directly connected to a water supply source such as a water pipe. In the first embodiment, the concept of the water tank includes such a water tank.

[0044] Hereinbelow, the first embodiment will be described on the basis of Examples, but the present invention is not limited to these. Note that the temporal stability of an emulsion was evaluated as follows. Specifically, 250 ml of an emulsion fuel was put into a graduated cylinder of 250 ml capacity. After the emulsion fuel was left to stand in a hermetically-closed system at 25° C. for 1 to 3 months, the appearance was observed according to the following evaluation criteria. ○: no change in appearance, Δ: slightly changed, ×: emulsion was separated.

EXAMPLE 1

[0045] 20 L of tap water (oxidation-reduction potential: approximately +200 mV) was put into a cathode compartment of an electrolytic cell (treatment cell was made of stainless steel) of FIG. **1**. Meanwhile, 20 L of an aqueous solution including 100 g of sodium hydroxide was put into an anode compartment thereof. As the power source, a direct current of a three-phase power supply was used. While an ultrasonic wave was being applied, the electrolysis was carried out under normal temperature and normal pressure for 30 minutes. As the cathode, an electrode made of palladium (hydrogen storage metal) was used. The electrolysis was carried out at an average voltage of 20 V and an average current of 50 A. As a radio wave rod that served as ultrasonic wave-generating means, used was a metal rod with a diameter of 45 mm and a length of 35 cm. An ultrasonic wave of 20 KHz was applied to the radio wave rod. The power of the ultrasonic wave was 255

W on average. Note that, although the voltage applied in the electrolysis was substantially constant for 30 minutes, the powers of the current and the ultrasonic wave were gradually increased. The water in the cathode compartment was stirred using a commercially-available mixer at a rate of 1400 times/m. The electrolyzed-reduced water obtained in the cathode compartment had an oxidation-reduction potential of approximately -300 mV.

[0046] 12 L of light oil (specific gravity: 0.85), 204 g (2 wt % relative to the light oil) of a nonionic surfactant (emulsifier) mainly composed of polyoxyethylene alkyl ether, and 8 L of the electrolyzed-reduced water obtained as described above were put into an emulsion forming cell (made of stainless steel) of FIG. 1 to prepare a liquid mixture (with 60 vol % of fuel oil and 40 vol % of reduced water). Then, the cathode (electrode) used for the electrolysis in the electrolytic cell was transferred to the emulsion forming cell, and immersed into the liquid mixture. Thereafter, the liquid mixture was stirred under normal temperature and normal pressure for 30 minutes. The stirring was performed using a commercially-available mixer at a rate of 1400 times/m. An emulsion fuel thus obtained had a homogeneous emulsion state. As a result of the evaluation of the temporal stability of this emulsion, it was found out that even after the emulsion was left to stand at 25° C. for 1 month and subsequent 3 months, the appearance of the emulsion state was not changed ($\circ$: no change in appearance).

COMPARATIVE EXAMPLE 1

[0047] An emulsion fuel was obtained by stirring and mixing a liquid mixture of light oil, an emulsifier and tap water in an emulsion forming cell in the same manner as in the case of Example 1 above except that a cathode (electrode) was immersed into the liquid mixture in the emulsion forming cell, using ordinary tap water (oxidation-reduction potential: approximately $+200$ mV). In this case, after the emulsion was left to stand at 25° C. for 1 day, the emulsion state was changed (Δ : slightly changed). After 1 week, most of the emulsion was separated ($\times$: emulsion was separated).

EXAMPLE 2

[0048] 12 L of kerosene, 200 g of a nonionic surfactant mainly composed of polyoxyethylene alkyl ether, and either 8 L of natural groundwater (oxidation-reduction potential: approximately $+80$ mV) or 8 L of alkali ion water (oxidation-reduction potential: approximately -50 mV) produced with a commercially-available device were put into an emulsion forming cell to prepare liquid mixtures. Then, each of the liquid Mixtures was stirred with a stirrer, while 20 KHZ of an ultrasonic wave was applied thereto. The stirring was performed using a commercially-available mixer at a speed of 1400 times/m for 20 minutes.

[0049] In either case where the natural groundwater was used or where the alkali ion water produced using the commercially-available device was used, an emulsion fuel of the first embodiment having a homogeneous emulsion state was obtained. In either case, the emulsion was left to stand for 1 month, but no dissociation phenomena occurred between the kerosene and the water, and the emulsion state was retained

perfectly ($\circ$: no change in appearance). However, after three months elapsed, slight separation was observed in the emulsion (Δ : slightly changed).

COMPARATIVE EXAMPLE 2

[0050] An emulsion fuel was obtained in the same manner as that in Example 2, using ordinarily tap water (oxidation-reduction potential: approximately $+200$ mV). This emulsion was far more stable than that in Comparative Example 1, but inferior in stability to that in Example 2.

EXAMPLE 3

[0051] A combustion experiment was conducted using a boiler with an emulsion fuel of the first embodiment, whereby the thermal energy efficiency was examined. As the emulsion fuel, used was a liquid mixture of electrolyzed-reduced water (40 vol %) having an oxidation-reduction potential of approximately -300 mV, heavy oil A (60 vol %), and a non-ionic surfactant (emulsifier: 2 wt % relative to the heavy oil). The liquid mixture was obtained according to the method in Example 1. For comparison, fuel oil of 100% heavy oil A was used.

[0052] A commercially-available ordinary boiler was used to conduct the combustion experiment. The results were as shown below.

[0053] Emulsion fuel of the first embodiment: an exhaust gas temperature: 410° C. at a combustion rate of 200 L per hour.

[0054] Heavy oil A (for comparison): an exhaust gas temperature: 450° C. at a combustion rate of 200 L per hour.

[0055] Although the emulsion fuel of the first embodiment contains 40% of water, the thermal efficiency of 91% ($(410/450) \times 100$) was obtained, compared with that of the 100% heavy oil A. This means that the gas mileage was improved by approximately 50%, compared with that of 60% heavy oil A ($410/(450 \times 0.6)$). Note that, the boiler used in the experiment is a device having a complete-combustion rate of 99.7% with 100% heavy oil A. Thus, the boiler achieves complete combustion when combusting only heavy oil A. Accordingly, it is assumed that the comparison was made between the fuel only of heavy oil A and the emulsion fuel both of which were completely combusted.

[0056] When the emulsion fuel including 60% of the fuel oil and 40% of the water is produced as described above, it is totally nonsense, from the viewpoint of fuel cost reduction, to maintain the heat calorie by using the emulsion fuel with its quantity increased by 40%. This merely helps to obtain a merit of using an environmentally-adaptable type fuel. It is important to increase the thermal efficiency using the fuel with water compared with the case of using fuel oil only. It can be seen that the emulsion fuel of the first embodiment achieved such a demand as described above.

[0057] It is assumed that the water in the emulsion fuel sprayed in the boiler is rapidly heated to approximately 700° C., successively subjected to micro-explosion, and rapidly expands by approximately 3200 times. The fuel oil in the emulsion reacts with the water vapor through the water-gas reaction as described below, and the carbon in the fuel oil reacts with the water vapor to produce CO and H_2 . Then, the CO, CO_2 and H_2 produced through the water-gas reaction are completely combusted in the theoretical air, since their areas that come into contact with the air is increased. Thus, the

combustion efficiency is assumed to be improved. This is a phenomenon that cannot be observed by simply spraying water vapor.

[0058] The water-gas reaction starts at approximately 700° C. ($C+H_2O=CO+H_2$). Then, it is assumed that the reaction of: $C_nH_{2n+2}+nH_2O+n/2O_2 \rightarrow nCO_2+(2n+1)H_2$ takes place at approximately 700° C. or higher.

EXAMPLE 4

[0059] A combustion state check test was conducted on an emulsion fuel of the first embodiment used in Example 3. As a result, the following facts were found out: the air amount equal to 30% of the theoretical air amount or smaller brought incomplete combustion; the air amount equal to 70% of the theoretical air amount or larger brought an excessive air region. It was found out, in the case of this emulsion fuel, that a preferable range of the air amount was 35% to 65%, and that the air had a uniform oxygen concentration, when especially around 50%.

[0060] Normally, in order to achieve complete combustion in a boiler, an excessive amount of air (having a temperature far lower than the combustion gas has) larger than the theoretical air amount by 1.2 to 1.5 times is sent into the boiler. The exhaust heat loss through flue gas takes up 15 to 40% of the energy the fuel oil has, and causes a loss of gas mileage.

[0061] Since the emulsion fuel of the first embodiment can be combusted completely with a significantly small amount of air, the exhaust heat loss can be prevented. This is assumed to be due to the following phenomena. Specifically, water particles dispersed in the emulsion fuel oil are instantaneously exploded and gasified in the combustion chamber of the boiler. Then, the water particles thus exploded and gasified divide fuel oil particles into finer particles and disperse them, thereby assisting the fuel oil particles to come into contact with oxygen. The emulsion fuel of the first embodiment is capable of suppressing such an excessive amount of air to half or smaller of the air amount in the case of ordinary general combustion.

Second Embodiment

[0062] In a second embodiment of the present invention, fuel oil is emulsified by stirring and mixing, while applying an ultrasonic wave to, a liquid mixture of: 50 vol % or more, and preferably 60 vol % or more, of fuel oil; and 50 vol % or less, and preferably 40 vol % or less, of an emulsifier aqueous solution. The liquid mixture particularly preferably includes: 80 to 90 vol % of fuel oil; and 20 to 10 vol % of an emulsifier aqueous solution. In the second embodiment, the emulsifier aqueous solution does not necessarily mean only a solution with an emulsifier dissolved in water from the beginning, but includes a solution as a liquid mixture of: 50 vol % or more of fuel oil; and 50 vol % or less of an emulsifier and water in the end regardless of the order of mixing and dissolving. Thus, the order of adding and mixing the fuel oil, the water and the emulsifier is not particularly limited, also. The fuel oil, the water and the emulsifier may be mixed with one another at once. The emulsifier may be first mixed with and dissolved into the water, and then added to the fuel oil. Alternatively, the emulsifier may be first mixed with and dissolved into the fuel oil, and then the water may be gradually added thereto.

[0063] The amount of the emulsifier used is appropriately 0.1 to 10 wt %, and preferably 1 to 5 wt %, relative to the fuel oil. As the emulsifier, any of nonionic surfactants, anionic

surfactants, cationic surfactants and amphoteric surfactants can be used. However, preferable are nonionic surfactants including: fatty acid esters of polyvalent alcohols such as sorbitol, sorbitan and sorbide; alkylene oxide adducts of alcohols; and the like. A single kind of the emulsifier can be used, or two or more kinds thereof can be used in mixture.

[0064] Environmentally-adaptable type emulsion fuels obtained by emulsion are categorized into O/W (Oil in Water) type and W/O (Water in Oil) type according to the proportions of fuel oil and water. In the second embodiment, any type can be adopted. Generally, the W/O type in which water micro-particles are dispersed in fuel oil is superior in stability. The size of the water micro-particle in the fuel oil is appropriately 20 μ or smaller, and more preferably 5 μ or smaller. Furthermore, the environmentally-adaptable type emulsion fuel of the second embodiment can be blended with a necessary publicly-known additive, for example, antirust, pour-point depressant and corrosion inhibitor, depending on the purpose and usage thereof.

[0065] In the second embodiment, an ultrasonic wave is applied to the fuel oil and the emulsifier aqueous solution with ultrasonic wave-generating means that are easier to handle and safer than a method and an apparatus using a high frequency wave, i.e., electromagnetic wave. The method and the apparatus are disclosed in the prior patent. When an ultrasonic wave is applied to the fuel oil and the emulsifier aqueous solution with the ultrasonic wave-generating means, the fuel oil and the emulsifier aqueous solution are emulsified. Simultaneously, the ultrasonic wave causes the cavitation effect to occur, which is said to create a vacuum condition of 1000 atm and 5000° C. under normal temperature and normal pressure. By the emulsification, cavitation effect together with stirring of the liquid by stirring and mixing means, a considerably stable environmentally-adaptable type emulsion fuel is obtained.

[0066] In the second embodiment, as the ultrasonic wave-generating means, the ultrasonic wave-generating means in the first embodiment can be used. The power of the ultrasonic wave is approximately 1 to 100 W, and preferably 10 to 40 W, per liter of the liquid mixture of the fuel oil and the emulsifier aqueous solution.

[0067] A method for producing an environmentally-adaptable type emulsion fuel, the second embodiment and an apparatus used therefor will be described by use of the drawing. FIG. 3 shows an example thereof, and is a schematic view of the apparatus (apparatus for producing an environmentally-adaptable type emulsion fuel). The apparatus includes: a mixing container 23 provided with ultrasonic wave-generating means 21 and stirring means 22; as well as a water tank 24, a fuel oil tank 25, an emulsifier tank 26 and an environmentally-adaptable type emulsion fuel tank 27 which are connected to the mixing container 23. Reference numeral 28 denotes a gauge, and 29 denotes a valve. Predetermined amounts of fuel oil, emulsifier and water are supplied from the respective tanks to the mixing container 23. The emulsifier may be in the form of powder, liquid or aqueous solution, depending on the kinds thereof. Moreover, the emulsifier having been mixed with the fuel oil or the water in advance maybe supplied to the mixing container 23. The ultrasonic wave-generating means (oscillating rods) 21 for applying an ultrasonic wave to the fuel oil and the emulsifier aqueous solution are inserted into the mixing container 23. The stirring means 22 is also placed in the mixing container 23. Using such a mixing container, the fuel oil is stirred, while an ultrasonic wave is being applied

thereto, and thereby emulsified. The duration, temperature, atmosphere, and the like for the emulsification are not particularly limited. Thereafter, the environmentally-adaptable type emulsion fuel including 50 vol % or more of the fuel oil and 50 vol % or less of the emulsifier aqueous solution thus obtained is introduced and stored in the environmentally-adaptable type emulsion fuel tank 27. Note that, for example, when the second embodiment is employed to a combustion apparatus of a type installed at a certain position in a factory or the like, an environmentally-adaptable type emulsion fuel can be directly supplied to the combustion apparatus from the environmentally-adaptable type emulsion fuel tank 27 in corporation with appropriate control means. Meanwhile, the water tank 24 does not necessarily have to be what is called a tank for storing water temporarily, and may be directly connected to a water supply source such as a water supply. In the second embodiment, the concept of the water tank includes such a water tank.

[0068] Hereinbelow, the second embodiment will be described on the basis of Examples, but the present invention is not limited to these. Note that the temporal stability of an emulsion was evaluated as follows. Specifically, 250 ml of an emulsion fuel was put into a graduated cylinder of 250 ml capacity. After the emulsion fuel was left to stand in a hermetically-closed system at 25° C. for 1 month, the appearance was observed according to the following evaluation criteria. ○: no change in appearance, Δ: slightly changed, ×: emulsion was separated.

EXAMPLE 5

[0069] Prepared is a liquid mixture (with 77 vol % of fuel oil and 23 vol % of water) of 8 L of light oil (specific gravity: 0.85) and 2 L of water containing 136 g (2 wt % relative to the light oil) of a nonionic surfactant mainly composed of polyoxyethylene alkyl ether. A mixing container (made of stainless steel) of FIG. 3 was used, and the liquid mixture was put thereinto and stirred under normal temperature and normal pressure for 30 minutes, while an ultrasonic wave was being applied thereto. As radio wave rods that served as ultrasonic wave-generating means, used were metal rods each with a diameter of 45 mm and a length of 35 cm. An ultrasonic wave of 20 KHz was applied to the radio wave rods. The power of the ultrasonic wave was 255 W on average. The stirring was performed using a commercially-available mixer at a rate of 1400 times/m. An environmentally-adaptable type emulsion fuel thus obtained had a homogeneous emulsion state. As a result of the evaluation of the temporal stability of this emulsion, it was found out that even after the emulsion was left to stand at 25° C. for 1 month, the appearance of the emulsion state was not changed (○: no change in appearance).

COMPARATIVE EXAMPLE 3

[0070] An emulsion fuel was obtained in the same manner as that in Example 5 except that no ultrasonic wave was applied. In this case, after the emulsion was left to stand at 25° C. for 1 day, the emulsion state was changed (Δ: slightly changed). After 1 week, most of the emulsion was separated (×: emulsion was separated).

EXAMPLE 6

[0071] Prepared was a liquid mixture of 12 L of kerosene and 8 L of water containing 200 g of a nonionic surfactant mainly composed of polyoxyethylene alkyl ether. As in the

case of Example 5, the liquid mixture was put into a container made of stainless steel. The liquid mixture was applied with an ultrasonic wave of 20 KHz, and simultaneously stirred with a stirrer. After the 20-minute treatment, the treatment solution was left to stand for 1 month, but no dissociation phenomena occurred between the kerosene and the water, and the emulsion state was retained perfectly (○: no change in appearance).

INDUSTRIAL APPLICABILITY

[0072] Since an emulsion fuel obtained according to the present invention retains a very good emulsion state over a prolonged period of time, the emulsion fuel can be handled and used in the same manner as for ordinary fuel oil. Moreover, the emulsion fuel is of high quality, and improves gas mileage. Thus, the emulsion fuel is environmentally friendly, and allows the saving in the fuel cost greatly. Furthermore, an emulsion fuel obtained by using water and fuel oil such as light oil, kerosene, heavy oil or gasoline generates less amounts of nitrogen oxide (NO_x) and soot at the time of combustion. Thus, the emulsion fuel is utilizable, for example, in fuels for factories, agricultural machinery, fishing vessels, ships, and vehicles, as an effective fuel for suppressing air pollution. Additionally, an emulsion fuel of, particularly, light oil and water containing an emulsifier is effectively usable as a fuel for a diesel engine.

BRIEF DESCRIPTION OF THE DRAWINGS

[0073] FIG. 1 is a schematic view of an example of an apparatus for producing an emulsion fuel of a first embodiment.

[0074] FIG. 2 is a schematic view of another example of the apparatus for producing an emulsion fuel of the first embodiment.

[0075] FIG. 3 is a schematic view of an example of an apparatus for producing an environment-adaptive type emulsion fuel of a second embodiment.

EXPLANATION OF REFERENCE NUMERALS

- [0076] 1 electrolytic cell
- [0077] 2, 12 cathode (rod-shaped or annular-shaped)
- [0078] 3, 13 anode (rod-shaped)
- [0079] 4 ion diaphragm
- [0080] 5, 15 ultrasonic wave-oscillating rod
- [0081] 6, 16 stirrer
- [0082] 11 emulsion forming cell
- [0083] 17 fuel oil tank
- [0084] 18 emulsion fuel tank
- [0085] 19 emulsifier tank
- [0086] 20 water tank
- [0087] 21 ultrasonic wave-generating means
- [0088] 22 stirring means
- [0089] 23 mixing container
- [0090] 24 water tank
- [0091] 25 fuel oil tank
- [0092] 26 emulsifier tank
- [0093] 27 environmentally-adaptable type emulsion fuel tank
- [0094] 28 gauge
- [0095] 29 valve

- 1. An emulsion fuel comprising a liquid mixture of:
 - 40 to 95 vol % of fuel oil;
 - 60 to 5 vol % of reduced water having an oxidation-reduction potential (ORP) of +100 mV or below; and
 - 0.1 to 10 wt % of an emulsifier relative to the fuel oil.

2. The emulsion fuel according to claim 1, wherein the content of the fuel oil is 50 to 90 vol %, and the content of the reduced water is 50 to 10 vol %.
3. The emulsion fuel according to claim 1, wherein the reduced water is electrolyzed-reduced water.
4. The emulsion fuel according to claim 3, wherein the electrolyzed-reduced water has an oxidation-reduction potential (ORP) of +50 mV or below.
5. The emulsion fuel according to claim 3, wherein the electrolyzed-reduced water is obtained by electrolysis of water, while an ultrasonic wave is being applied thereto with ultrasonic wave-generating means, using a diaphragm cell with an anode and a cathode separated from each other.
6. The emulsion fuel according to claim 3, wherein the electrolyzed-reduced water is obtained by electrolysis of water using any of a hydrogen storage metal and alloy as the cathode.
7. An apparatus for producing an emulsion fuel, the apparatus comprising:
 - an electrolytic cell including
 - an anode and a cathode separated from each other by a diaphragm,
 - ultrasonic wave-generating means, and
 - stirring means;
 - an emulsion forming cell including stirring means; and
 - a fuel oil tank and an emulsion fuel tank which are connected to the emulsion forming cell.
8. The apparatus for producing an emulsion fuel according to claim 7, wherein
 - the cathode of the electrolytic cell is an electrode formed of any of a hydrogen storage metal and alloy.
9. The apparatus for producing an emulsion fuel according to claim 7, wherein
 - an electrode formed of any of a hydrogen storage metal and alloy is disposed in the emulsion forming cell.
10. The apparatus for producing an emulsion fuel according to claim 8, wherein
 - the electrode of the electrolytic cell and the electrode of the emulsion forming cell are disposed interchangeably with each other, both of the electrodes being formed of any of the hydrogen storage metal and alloy.
11. The apparatus for producing an emulsion fuel according to claim 7, wherein
 - an anode and a cathode which is formed of any of a hydrogen storage metal and alloy are disposed in the emulsion forming cell.
12. The apparatus for producing an emulsion fuel according to claim 7, wherein
 - ultrasonic wave-generating means is disposed in the emulsion forming cell.
13. A method for producing an emulsion fuel comprising the step of stirring and mixing, in an emulsion forming cell:
 - 40 to 95 vol % of fuel oil (A);
 - 60 to 5 vol % of electrolyzed-reduced water (B) obtained by electrolysis of water, while an ultrasonic wave is being applied thereto with ultrasonic wave-generating means, using a diaphragm cell with an anode and a cathode separated from each other; and
 - 0.1 to 10 wt % of an emulsifier (C) relative to the fuel oil.
14. The method for producing an emulsion fuel according to claim 13, wherein
 - the water is electrolyzed using an electrode formed of any of a hydrogen storage metal and alloy as the cathode.
15. The method for producing an emulsion fuel according to claim 13, wherein
 - the fuel oil (A), the electrolyzed-reduced water (B) and the emulsifier (C) are stirred and mixed with one another in presence of the electrode formed of any of the hydrogen storage metal and alloy, the electrode being used in the electrolysis of the water.
16. The method for producing an emulsion fuel according to claim 15, wherein
 - the fuel oil (A), the electrolyzed-reduced water (B) and the emulsifier (C) are stirred and mixed with one another, while a current is being passed through an anode and a cathode (electrode) formed of any of a hydrogen storage metal and alloy, the anode and the cathode being provided in the emulsion forming cell.
17. The method for producing an emulsion fuel according to claim 13, wherein
 - the fuel oil (A), the electrolyzed-reduced water (B) and the emulsifier (C) are stirred and mixed with one another, while an ultrasonic wave is being applied thereto with ultrasonic wave-generating means.
18. The apparatus for producing an emulsion fuel according to claim 8, wherein
 - an electrode formed of any of a hydrogen storage metal and alloy is disposed in the emulsion forming cell.
19. The apparatus for producing an emulsion fuel according to claim 18, wherein
 - the electrode of the electrolytic cell and the electrode of the emulsion forming cell are disposed interchangeably with each other, both of the electrodes being formed of any of the hydrogen storage metal and alloy.
20. The apparatus for producing an emulsion fuel according to claim 9, wherein
 - the electrode of the electrolytic cell and the electrode of the emulsion forming cell are disposed interchangeably with each other, both of the electrodes being formed of any of the hydrogen storage metal and alloy.

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