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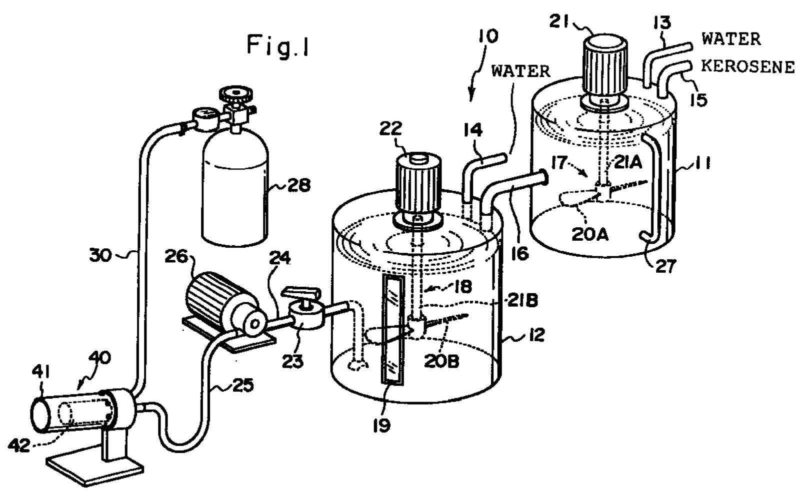
(54) **Emulsion fuel production method and apparatus, emulsion fuel combustion apparatus, and emulsion fuel production supply apparatus**

(57) A rotating means rotates a first member so as to have a gap of a predetermined thickness with respect to a second member. If water, kerosene, surfactant, and air are supplied to a bottom of the gap through a supply means, these are mixed by the rotation of the first member to a mixed liquid thereof so that the mixed liquid is raised in the gap. If the mixed liquid reaches a cylindrical portion of the first member, it is agitated by a plurality of protrusions provided on the cylindrical portion to produce emulsion fuel. The emulsion fuel has a high kinetic energy due to rotation. The emulsion fuel is supplied to an emulsion fuel combustion apparatus by this kinetic energy through a pipe path.

Fig.1



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to an emulsion fuel production method and apparatus and to an emulsion fuel combustion apparatus, and to an emulsion fuel production supply apparatus, more particularly to an emulsion fuel production method for producing oil-in-water emulsion or water-in-oil emulsion by mixing petroleum fuel, water, and a surfactant; an emulsion fuel production apparatus for realizing this emulsion fuel production method; and an emulsion fuel combustion apparatus for burning emulsion fuel, and an emulsion fuel production supply apparatus for producing and supplying emulsion fuel.

The emulsion fuel combustion apparatus of the present invention can be used for boilers, gas turbines, household heating apparatuses, agricultural greenhouse boilers, and the like.

Description of the Related Art

Conventionally, various methods have been proposed for burning emulsion fuel emulsified by mixing petroleum fuel with water and a small amount of a surfactant to reduce the consumption of petroleum fuels such as kerosene and light oil and to reduce NOx, smoke slag, and like emissions. Conventionally, it was considered that the practical limit for use of a mixing ratio of water in combustible emulsion fuel was about 1-10 weight percent because latent heat was absorbed by water, increasing the consumption of fuel.

Japanese Patent Application Laid-Open (JP-A) No. 7-313859 disclosed a method for producing an emulsion fuel having an oil particle diameter of about 0.5 μm by agitating oil and water in a single agitation bath. However, this method has a problem such that the emulsion fuel produced is destroyed by repeated agitation because a single agitation bath is used and a relatively fast agitation speed is employed. Although emulsion fuel is difficult to destroy by agitation at a low speed, thus solving this problem, it takes a long time to produce emulsion fuel.

Further, Japanese Patent Application Laid-Open (JP-A) No. 55-23812 has disclosed a liquid fuel combustion apparatus containing an air heating chamber in which air is heated to 200-400°C and the vaporized emulsion fuel is mixed with heated air to burn the mixed liquid.

However, the above conventional art requires an air heating chamber and evaporation portion. Therefore, the structure of the combustion apparatus becomes complicated.

Although Japanese Patent Application Laid-Open (JP-A) No. 7-313859 describes the above emulsion fuel production method, it disclosed nothing about the combustion apparatus.

Further, according to the prior art, the produced emulsion fuel is stored temporarily in a tank and is compressed, and the compressed emulsion fuel is supplied to the combustion apparatus. When the stored emulsion fuel is compressed as described above, it is destroyed because of the violent change in pressure which occurs. Destroyed emulsion fuel produces poor combustion efficiency and generates soot and black smoke when burned in a combustion apparatus.

Emulsion fuel produced by agitation possesses a high kinetic energy due to agitation. However, this kinetic energy is lost when the emulsion fuel is stored in a stationary condition in a tank. After that, the stored emulsion fuel is compressed and is supplied to the fuel apparatus, preventing the kinetic energy from being used. Thus, energy efficiency is poor.

SUMMARY OF THE INVENTION

The present invention has been proposed to solve the above problems. A first object of the present invention is to provide an emulsion fuel production method and apparatus for producing a stabilized emulsion fuel and an emulsion fuel combustion apparatus with a simple structure for burning emulsion fuel.

A second object of the present invention is to provide an emulsion fuel combustion apparatus with a simple structure for burning emulsion fuel.

A third object of the present invention is to provide an emulsion fuel production supply apparatus which minimizes changes in pressure when the produced emulsion fuel is supplied to a combustion apparatus, thereby improving energy use efficiency.

According to the first invention, an emulsion fuel production method is provided comprising: producing an initial-phase emulsion by mixing petroleum fuel, water, and a surfactant and then agitating the mixed liquid at a predetermined agitation speed; and producing emulsion fuel by mixing the produced initial-phase emulsion and water and then agitating the mixed liquid at an agitation speed lower than the previous agitation speed.

According to the second invention, there is provided an emulsion fuel production apparatus containing a first agitation bath for producing an initial-phase emulsion by mixing petroleum fuel, water, and a surfactant and then agitating the mixed liquid at a predetermined agitation speed, and a second agitation bath for producing emulsion fuel by mixing the initial-phase emulsion produced in the first agitation bath and water and then agitating the mixed liquid at an agitation speed lower than the previous agitation speed.

According to the above respective inventions, because the agitation speed for producing the initial-phase emulsion is higher than the agitation speed for producing a final emulsion fuel, the initial-phase emulsion can be produced quickly. Part of the produced initial-phase emulsion is destroyed, however. On the other hand, because a slow agitation speed is used to produce the final emulsion fuel, the produced initial-phase emulsion is not destroyed. Further, destroyed initial-phase emulsion is reproduced by a slow agitation speed and a new emulsion is produced by a slow agitation speed, so that, finally, a stabilized emulsion fuel is produced.

Because the agitation speed for producing the above initial-phase emulsion is higher, there is the worry that the produced emulsion may be destroyed, so it is preferable to reduce the mixing ratio of water relative to petroleum fuel. On the other hand, the agitation speed for producing the final emulsion fuel is slower, so that produced emulsion is difficult to destroy. Thus, it is possible to increase the mixing ratio of water relative to the initial-phase emulsion.

The above initial-phase emulsion can be produced by mixing and agitating petroleum fuel mixed beforehand with a lipophilic surfactant and water, petroleum fuel and water mixed beforehand with a hydrophilic surfactant, or petroleum fuel mixed beforehand with a lipophilic surfactant and water mixed beforehand with a hydrophilic surfactant.

As the lipophilic surfactant, sorbitan monolaurate, sorbitan monopalmitate, sorbitan monostearate, or sorbitan monooleate can be used. As the hydrophilic surfactant, polyoxyethylene sorbitan monolaurate, polyoxyethylene sorbitan monopalmitate, polyoxyethylene sorbitan monostearate, polyoxyethylene sorbitan monooleate, or polyoxyethylene sorbitan trioleate can be used.

Further, if any one of ethylene glycol or polyethylene glycol which is a surfactant for combining petroleum fuel with water is added in a small quantity, a further stabilized emulsion fuel can be produced.

According to the emulsion production method of the present invention, petroleum fuel and water are mixed at a maximum ratio of 1:1 so as to produce a microemulsion fuel in which an average particle diameter of liquid particles is 0.05-3 μm.

According to the emulsion production method of the present invention, although the emulsion fuel can be produced with a single agitation bath, it is possible to produce the emulsion fuel with two agitation baths.

According to a third invention of the present invention, there is provided an emulsion fuel combustion apparatus comprising: an emulsion fuel production apparatus for producing the emulsion in the above described method; a temperature maintaining means for maintaining a temperature of a position in which the emulsion fuel is injected at a temperature higher than the ignition temperature of the emulsion fuel; and a fuel injection means for injecting the emulsion fuel to a position maintained at a temperature higher than the ignition temperature of the emulsion fuel.

The emulsion fuel combustion apparatus may be constructed so as to contain a temperature maintaining means for maintaining a temperature of a position in which the emulsion fuel is injected at a temperature higher than the ignition temperature of the emulsion fuel; and a fuel injection means for injecting the emulsion fuel to the position maintained at a temperature higher than the ignition point of the emulsion fuel.

According to the present invention, because a temperature of the position in which the emulsion fuel is injected is maintained at a temperature higher than the ignition point of emulsion fuel by the temperature maintaining means, the emulsion fuel is burned by injecting the emulsion fuel from the fuel injection means to this point.

This temperature maintaining means is so constructed that a gas injection means for injecting combustion gas is provided in a position in which the emulsion fuel is injected to burn the combustion gas injected from the gas injection means to maintain a temperature of the position in which the emulsion fuel is injected at a temperature higher than the ignition point of the emulsion fuel. In this case, the gas injection means is so constructed that a plurality of combustion gas injection holes is arranged on a circumference so as to converge the combustion gas injected from the plurality of combustion gas injection holes to the position in which the emulsion fuel is injected.

This emulsion fuel can be produced by mixing petroleum fuel, water, and a surfactant in weight ratio of 1:1 to 0.5:0.004 to 0.008. As the surfactant, $C_{12}H_{25}(CH_2CH_2O)_6H$ can be used. It is effective if the average particle diameter of the liquid particle of the emulsion fuel is 0.05-3 μm.

According to a fourth invention, there is provided an emulsion fuel production supply apparatus comprising: a first member having, an expanding portion which expands in diameter around a spindle as the height is increased; a second member which is arranged so as to surround the first member and in which the inner face thereof corresponding to the expanding portion has a gap with respect to the expanding portion and the shape of the inner face corresponds to the shape of the expanding portion and which seals the gap; a rotating means for rotating one of the first member and the second member around the spindle; a supply means for supplying petroleum fuel, water, and a surfactant to a first position located at the front end of the expanding portion of the gap; a pipe path which is located at a second position above the first position of the gap and in which one end thereof is connected to the second position and the other end is connected to an emulsion fuel combustion apparatus; and a plurality of protrusions which is provided on at least one of the first member and the second member which form the gap and in a range above the first position and below the second position.

Here, the first member has an expanding portion which expands in diameter as height is increased. The second member is arranged so as to surround the first member. A gap is provided between the inner face of the second member corresponding to the expanding portion of the first member and the expanding portion.

The shape of the inner face corresponds to the expanding portion. Further, the gap is sealed.

Petroleum fuel, water, and surfactant are supplied to a first position on the front end side of the gap on the above expanding portion by means of the supply means. The gap serves as a path for petroleum, water, and surfactant, and petroleum, water, and a surfactant are raised through this gap.

On the other hand, the rotating means rotates one of the first member or the second member around the spindle.

Accordingly, petroleum fuel, water, and surfactant supplied by the supply means are raised through the gap and rotated by the viscosity of the petroleum fuel accompanied by rotation of one of the first member or the second member. As a result of such rotation, petroleum fuel, water, and a surfactant are mixed into a mixed liquid. Centrifugal force in the direction of the radius is applied to this mixed liquid by rotation.

This centrifugal force can be broken down into a rising direction along the gap and a direction perpendicular to this rising direction. Although friction force is applied to the mixed liquid by the force of a direction perpendicular to the rising direction, the mixed liquid is further raised by the force of the rising direction along the gap.

The first member may have a cylindrical portion which is located continuous with and above the expanding portion and formed around the spindle.

Further, a plurality of protrusions is provided in a gap in which the mixed liquid is raised. The plurality of protrusions may be provided on the expanding portion of the first member, the inner face of the second member corresponding to the expanding portion, or both the expanding portion of the first member and the inner face. Further, the plurality of protrusions may be provided on a cylindrical portion of the first member, the inner face of the second member corresponding to the cylindrical portion, or both the cylindrical portions and the inner face.

The mixed liquid is agitated by these plural protrusions while rotated so as to produce an emulsion fuel. Because this emulsion fuel continues to be rotated as described above, it has a high kinetic energy. If the above cylindrical portion is provided, the emulsion fuel which reaches the cylindrical portion of the gap has the highest kinetic energy so that it can rotate emulsion fuel with possessing high kinetic energy.

If the emulsion fuel reaches the second position in which one end of the pipe path is connected, the emulsion fuel enters the pipe path so that the emulsion fuel is supplied to the emulsion fuel combustion apparatus through the pipe path.

As described above, the produced emulsion fuel is supplied to the emulsion fuel combustion apparatus immediately. Thus, it is possible to minimize changes in pressure which occur in the emulsion fuel when the produced emulsion fuel is supplied to the emulsion fuel combustion apparatus.

Thus, the emulsion fuel can be burned as an emulsion fuel composition so that the combustion efficiency can be improved. Further, it is possible to prevent the occurrence of soot, black smoke, or the like.

Because the emulsion fuel is supplied to the emulsion fuel combustion apparatus by using the kinetic energy of the emulsion fuel just produced even if a pressure feed pump is not operated, the energy use efficiency can be improved.

If the above second position is located at a position corresponding to the cylindrical portion of the gap, the emulsion fuel can be supplied to the combustion apparatus by using high kinetic energy and further emulsion fuel can be supplied to the combustion apparatus forcefully.

It is permissible to form a path to be connected below the second position of the gap in the pipe path. Consequently, when the emulsion fuel combustion apparatus is not actuated, the emulsion fuel is returned to the gap again. The emulsion fuel returned to the gap is supplied with kinetic energy by the above rotation. Thus, it is possible to store the emulsion fuel while maintaining kinetic energy. Thus, if the combustion apparatus is started, the emulsion fuel can be supplied to the emulsion fuel combustion apparatus immediately.

Further, it is permissible to raise the petroleum fuel, water, and surfactant supplied by the supply means by means of raising means located at the front end side of the expanding portion of the gap. Consequently, petroleum fuel, water, and surfactant can be sent to the above gap forcefully and smoothly.

The raising means may be structured with at least one blade disposed at an angle larger than 0° and smaller than 90° with respect to the direction opposite to the direction of the rotation.

If air is supplied to the above gap or air is produced as bubbles from water, an air layer may be formed in the gap. If an air layer is formed in the gap, it may obstruct the raising of the mixed liquid. If at least one baffle plate is provided at a position above the first position and lower than the second position on at least one face of the first member and the second member which form the gap, the air layer can be destroyed so that resistance to the emulsion fuel can be reduced.

Petroleum fuel has various viscosities, depending on the type. If the thickness of the gap is constant, a large resistance may be generated by the petroleum fuel. However, if the rotating means is structured such that the thickness of the above gap can be changed, the thickness of the gap can be adjusted depending on viscosity determined by the type of petroleum fuel to be used, thereby reducing the above resistance.

If a section of the above protrusion is formed in rectangular shape, it is possible to prevent the occurrence of Karman's vortex street. Thus, it is possible to prevent the protrusions from being damaged by Karman's vortex street.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a first embodiment.

FIG. 2 is a sectional view of an emulsion fuel combustion apparatus according to the present embodiment.

FIG. 3 is a side view of the emulsion fuel combustion apparatus according to the present embodiment.

FIG. 4 is a sectional view of a gas-injection hole of the emulsion fuel combustion apparatus according to the present embodiment.

FIG. 5 is a side view of another example of a pressure feed pump.

FIG. 6 is a perspective view of a second embodiment.

FIG. 7 is a construction diagram of an emulsion fuel production combustion system according to a third embodiment.

FIG. 8 is a sectional view of the emulsion fuel production supply apparatus according to the present embodiment.

FIG. 9 is a vertical sectional view of a supply portion of the emulsion fuel production supply apparatus.

FIG. 10 is a horizontal sectional view of space at the front end of an expanding portion of a spindle.

FIG. 11 is a view of space supplied with air, water, kerosene, and surfactant.

FIG. 12 is a sectional view of a rotation supporting portion of the emulsion fuel production supply apparatus.

FIG. 13A is a view showing an inner condition of a fixed body corresponding to a cylindrical portion.

FIG. 13B is a sectional view taken along lines A-A.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A first embodiment of the present invention will be described with reference to the accompanying drawings.

As shown in Fig. 1, the emulsion fuel combustion system according to the present embodiment comprises an emulsion fuel producing apparatus 10 for producing emulsion fuel by mixing and agitating water, kerosene which is a petroleum fuel, and a surfactant, and an emulsion fuel combustion apparatus 40 for burning the emulsion fuel.

The emulsion fuel producing apparatus 10 comprises a first agitation tank 11 for producing the initial-phase emulsion by mixing kerosene mixed beforehand with sorbitan monooleate, which is a lipophilic surfactant, with water mixed beforehand with polyoxyethylene sorbitan trioleate, which is a hydrophilic surfactant, and then agitating quickly, and a second agitation tank 12 in which the initial-phase emulsion produced in the first agitation tank is mixed with water and agitated slowly to produce a final emulsion.

The first agitation tank 11 contains a water supply pipe 13 for supplying water in which the hydrophilic surfactant is mixed beforehand and a kerosene supply pipe 15 for supplying kerosene in which the lipophilic surfactant is mixed beforehand, these pipes being provided on the top thereof.

The first agitation tank 11 contains an agitation unit 17 which passes through the top surface of the agitation tank 11. The agitation unit 17 comprises a spindle 21A which passes through the top surface of the first agitation tank 11, agitation fans 20A fixed to one end of the spindle 21A inside of the first agitation tank 11, and a high-speed motor 21 fixed to the other end of the spindle 21A outside of the first agitation tank 11 for rotating the agitation fan 20A. Reference numeral 27 designates a level gauge for visually recognizing the amount of liquid inside.

The second agitation tank 12 comprises a water supply pipe 14 for supplying water and an emulsion supply pipe 16 for supplying the initial-phase emulsion generated in the first agitation tank.

The second agitation tank 12 contains an agitation unit 18 which passes through a top surface of the second agitation tank 12 in the same manner as the first agitation tank 11. The agitation unit 18 comprises a spindle 21B which passes through the top surface of the second agitation tank 12, an agitation fan 20B fixed to one end of the spindle 21B inside of the second agitation tank 12 and a low-speed motor 22 fixed to the other end of the spindle 21B outside of the second agitation tank 12 for rotating the agitation fan 20B. Reference numeral 19 designates a confirmation window for confirming the amount of emulsion fuel in the second agitation tank 12.

A diaphragm valve 23 is installed on a side face on the bottom side of the second agitation tank 12 and the end of a fuel supply pipe 24 for supplying the emulsion fuel is connected to this diaphragm 23. The other end of this fuel supply pipe 24 is connected to a pressure feed pump 26 for supplying the emulsion fuel under pressure. The pressure feed pump 26 is connected to the emulsion fuel combustion apparatus 40 through a fuel supply pipe 25.

An LPG cylinder 28 in which LPG, a material for combustion gas, is stored is connected to the emulsion fuel combustion apparatus 40 through an LPG supply pipe 30.

As shown in Figs. 2 and 3, the emulsion fuel combustion apparatus 40 comprises a cylindrical frame holder 42 formed of ceramic or metal. The frame holder 42 has an outer diameter of about 60 mm and a length of about 135 mm. A guard holder 41 (see Fig. 1) is attached to an external circumference of the frame holder 42.

Inside the proximal end of the frame holder 42 is installed a gas injection unit 44 which injects the combustion gas in which LPG and air are mixed toward a point O in the vicinity of the center inside of the frame holder 42. This gas injection unit 44 is installed through fins 46. This gas injection unit 44 is formed of casting or the like in the shape of a substantially cylindrical structure of about 50 mm in outer diameter, about 15 mm in diameter of the center hole and about 20 mm in height. An end of the LPG supply pipe 34 passes through a bottom 44A of the gas injection unit 44 and this gas injection unit 44 is installed at the frame holder 42 such that the bottom 44A is located about 15 mm from the proximal end of the frame holder 42. The other end of the LPG supply pipe 34 projecting from the bottom 44A is connected to the LPG supply pipe 30 through an air introduction portion 32 provided with an air intake port for mixing supplied LPG with air introduced from the air introduction port.

The top face 44B of the gas injection unit 44 is inclined so as to descend to the center of the gas injection unit 44 and this top face 44B contains a plurality of gas injection ports 44C (8 ports in this embodiment) in which the direction of gas injection is substantially perpendicular to the top face 44B. Thus, the combustion gas injected from the respective gas injection ports 44C converges at point O in the vicinity of the center of the frame holder 42 inside thereof. Angle θ formed by axis C of the frame holder 42 and the injected combustion gas is preferably about 20-23 degrees.

These gas injection ports 44C are, as shown in Fig. 3, formed in the shape of a frustum projecting from the top face of the gas injection unit 44. As shown in Fig. 4, inside of the gas injection port are provided a large-diameter cylindrical hole 44D located on its gas injection side and a small-diameter cylindrical hole 44E, located inside of the gas injection unit 44, which communicate with each other. The height of the frustum portion of this gas injection port 44C is 2-3 mm, the outer diameter on the top face is 4-5 mm and the inner diameter of the large-diameter cylindrical hole 44D is 2.5 mm and that of the small-diameter cylindrical hole 44E is about 1 mm.

As shown in Fig. 2, the tip of a cylindrical emulsion fuel injection nozzle 50 is inserted into the center hole of the gas injection unit 44 such that it can be moved in the axial direction of the gas injection unit 44. A rack 50A is formed on a side of the emulsion fuel injection nozzle 50 and a pinion 50B driven by a motor (not shown) meshes with this rack. Thus, by driving this pinion 50B, the emulsion fuel injection nozzle 50 is moved in the axial direction of the gas injection unit 44.

A temperature sensor 54 for detecting the temperature of the flame produced by burning the emulsion fuel is installed on the inner circumference of the front end of the frame holder 42. Forward from the gas injection unit 44 inside of the frame holder 42 is installed a temperature sensor 56 for detecting the temperature of the flame produced by burning LPG.

An operation of the present invention is described below. First, the emulsion fuel can be produced in the ratio below if the total weight is assumed to be 750 g. In this case, the weight ratio between kerosene and water is 2:1.

Kerosene: 494 g
Water: 247 g
Sorbitan monooleate: 4.5 g
Polyoxyethylene sorbitan trioleate: 4.5 g
Ethylene glycol: small amount

Water mixed beforehand with a hydrophilic surfactant and kerosene mixed beforehand with a lipophilic surfactant are supplied to a first agitation tank 11 at a weight ratio of, for example, 1:6 and then a small amount of ethylene glycol is added. These materials are agitated at high speed by means of the agitation unit 17 to generate the initial-phase emulsion.

This generated initial-phase emulsion is supplied to the second agitation tank 12 through an emulsion supply pipe 16. Water is supplied to the second agitation tank 12 through a water supply pipe 14 and these materials are agitated at low speed by means of the agitation unit 18 to generate the emulsion fuel. The ratio between water and the initial-phase emulsion to be supplied to the second agitation tank is, for example, 1:3 in terms of the weight ratio.

Consequently, an emulsion fuel in which the mixed liquid ratio between water and kerosene is 1:2 in terms of the weight ratio and the average diameter of particles is 0.05-3 μm is generated.

If LPG is supplied from an LPG cylinder 28, LPG and air are mixed in the air introduction portion 32 to generate a combustion gas, and the combustion gas is injected from the gas injection port 44C of the gas injection unit 44 so as to converge at point O in the vicinity of the center inside of the frame holder 42. If this combustion gas is ignited by an electric ignition device (not shown), a flame is produced. This flame is detected by a temperature sensor 56 and then at least one of the LPG supply amount and the intaken air amount is controlled so as to maintain the temperature of the flame higher than the ignition point of the emulsion fuel, for example, 400°C or more. If the temperature of the flame is maintained at about 400°C, the amount of consumption of LPG is about 12-15 g/hour.

Under this condition, the diaphragm valve 23 provided on the agitation tank 12 is opened and the pressure feed pump 26 is driven to inject emulsion fuel from an emulsion injection nozzle 50. Then, the injected emulsion fuel is ignited by the flame and burned. The temperature of the flame of the burned emulsion fuel is detected by the temperature sensor 54 and controlled to the target temperature by adjusting the amount of the emulsion fuel fed by the pressure feed pump 26 and adjusting the amount of projection of the emulsion fuel injection nozzle 50.

If the emulsion fuel is injected under pressure, emulsion particles, which are liquid fine particles, may collect to increase the particle diameter. Thus, it is preferable to utilize an emulsion fuel feeder instead of the above pressure feed pump. The emulsion fuel feeder comprises, as shown in Fig. 5, a spindle-shaped rubber tube 60 and a rotating body 62 having a plurality of projections whose front end is spherical or cylindrical and which supplies emulsion fuel by deforming the rubber tube 60 periodically by rotating the rotating body.

The emulsion production method and apparatus described above have the effect that stabilized supply of the emulsion is made possible because the initial-phase emulsion is generated by high-speed agitation and then it is agitated at low speed to produce the emulsion fuel.

Next, a second embodiment of the present invention will be described. This embodiment has the same components as in the first embodiment, and therefore the same reference numerals are applied to the same components and a description thereof is omitted, while only different components are described.

As shown in Fig. 6, an emulsification unit 10A for producing the emulsion fuel by mixing and agitating water, kerosene, which is a petroleum fuel, and surfactant is connected to the emulsion fuel combustion apparatus 40 according to the present embodiment.

While the above described emulsification unit according to the first embodiment contains the first agitation tank and the second agitation tank, this emulsification unit 10A according to the second embodiment has an agitation tank 12A having a water supply pipe 14 for supplying water mixed beforehand with a surfactant and a kerosene supply pipe 16A for supplying kerosene, which is an emulsion material mixed beforehand with a surfactant, these pipes being attached to the top face of the emulsification unit 10A.

The agitation tank 12A contains an agitation unit 18A which passes through the top face the agitation tank 12A. The agitation unit 18A comprises a spindle 21A which passes through the top face of the agitation tank 12A, an agitation fan 20A fixed to one end of the spindle 21A inside of the agitation tank 12A and a motor 22A which is fixed to the other end of the spindle 21A outside of the agitation tank for rotating the agitation fan 20A.

The diaphragm valve 23 is installed at a side face of the bottom of the agitation tank 12A and one end of the fuel supply pipe 24 for supplying the emulsion fuel is connected to the diaphragm valve 23. The other end of this fuel supply pipe 24 is connected to the pressure feed pump 26 for feeding the emulsion fuel under pressure. The pressure feed pump 26 is connected to the emulsion fuel combustion apparatus 40 through the fuel supply pipe 25. Meanwhile, the emulsion fuel combustion apparatus 40 of this embodiment is the same as that of the first embodiment; therefore, a description thereof is omitted.

Next, the operation of the second embodiment will be described. After water, kerosene, and a surfactant are supplied to the agitation tank 12A at a weight ratio of 1:1 to 0.5:0.004 to 0.008, these materials are agitated by means of the agitation unit 18A to produce the emulsion fuel. Consequently, an emulsion having an average particle diameter of about 0.05-3 μm is produced.

Because the weight ratio of kerosene relative to water is 1-0.5, that is, 50-33 weight% according to the present embodiment, it is possible to greatly reduce the consumption of kerosene.

As the above surfactant, $C_{12}H_{25}(CH_2CH_2O)_6H$ can be used. As the material for the emulsion, heavy oil (A heavy oil, B heavy oil, C heavy oil) and petroleum fuel such as gasoline can be used as well as kerosene.

Because the combustion action of the emulsion fuel is the same as in the above described first embodiment, a description thereof is omitted.

As described above, because the emulsion fuel combustion apparatuses according to the first and second embodiments are structured so as to burn the emulsion fuel by maintaining the temperature of a portion from which the emulsion fuel is to be injected at a temperature above the ignition point of the emulsion fuel, it is possible to provide an emulsion fuel combustion apparatus having a simple structure.

Although, according to the above first and second embodiments, the agitation tank is already supplied with water mixed beforehand with a surfactant and kerosene or the like mixed beforehand with a surfactant, the present invention is not restricted to this. It is permissible to supply surfactant through a lid provided on the agitation tank and water through a water supply pipe and kerosene through a kerosene supply pipe. That is, it is permissible to supply a surfactant, water, and kerosene to the agitation tank separately.

Next, a third embodiment of the present invention will be described with reference to the accompanying drawings.

Fig. 7 shows an emulsion fuel supply combustion system. The emulsion fuel supply combustion system comprises an emulsion fuel production supply unit (mixer feeder) 100 for generating and supplying emulsion fuel and an emulsion fuel combustion unit 40 for burning the emulsion fuel supplied from the emulsion fuel production supply unit 100.

To the emulsion fuel production supply unit 100 are connected a water tank 104 through a water supply pipe 112, a kerosene tank 102 through a kerosene supply pipe 108, a surfactant tank 106 through a surfactant supply pipe 114, and an air tank (not shown) through an air supply pipe 115 (see Fig. 7).

The water supply pipe 112, the kerosene supply pipe 108, the surfactant supply pipe 114, and the air supply pipe 115 are each provided with a control valve 113 and a flow meter (FM) 116. Further, the water supply pipe 112 and the kerosene supply pipe 108 are each provided with a thermometer 118. Further, the kerosene supply pipe is provided with a heater 110.

The emulsion fuel combustion apparatus 40 is connected to the emulsion fuel production supply unit 100 through an emulsion fuel supply pipe 126, a three-way cock 130, and a fuel supply pipe 25. The emulsion fuel production supply unit 100 is connected to the three-way cock 130 through an emulsion fuel return pipe 128. The emulsion fuel supply pipe 126 is provided with a thermometer 118 and a flow meter 116. A pressure gauge 120 is connected to the fuel supply pipe 25.

The emulsion fuel production supply unit 100 has, as shown in Fig. 8, an emulsion fuel production portion 134 within a case 132. This emulsion fuel production portion 134 comprises a rotating body 138 which can be rotated relative to a spindle 144 and a fixed body having an inner structure corresponding to that of the rotating body 138. The rotating body 138 comprises an expanding portion 140 which expands in diameter upward in a conical shape around the spindle 144 and a cylindrical portion 142 which is located at a proximal portion of the expanding portion 140 and has a plurality of protrusions (pins) 148 having a rectangular section each on a circumference thereof around the spindle 144.

The tilt angle of the expanding portion 140 with respect to a horizontal plane is assumed to be 60° (this is not restricted to 60°). The outer face of the expanding portion 140 has a plurality of baffle plates 141. A ceiling 146 is formed on top of the fixed body 136 and the fixed body 136 accommodates the rotating body 138 under an airtight condition.

The rotating body 138 is rotatably supported around the spindle 144. Under this condition, the outer face of the expanding portion 140 opposes the inner face of the fixed body 136 correspondingly with a predetermined gap. Thus, a passage 154 is formed between the outer face of the rotating body 138 and the inner face of the fixed body 136.

A supply portion 152 is formed below the emulsion fuel production portion 134 and a rotation supporting portion 150 is formed on top thereof.

The supply portion 152 contains a space 173 which is formed on a side of the front end of the expanding portion 140 so as to communicate with the above passage 154 and sealed by a sealing member 162 as shown in Figs. 9-11. The sealing member 162 is fixed to a mounting plate 160 provided below the case 132.

The space 173 contains a connecting member 176 connected to the spindle 144. The connecting member 176 is rotatably supported by a rouleau(spindle receiving member) 168 disposed therearound. The space 173 includes a connecting portion to which the air supply pipe 115, the water supply pipe 112, the kerosene supply pipe 108, and the surfactant supply pipe 114 are connected. Fig. 9 shows only connecting portions 164, 166 to which the water supply pipe 112 and the kerosene supply pipe 108 are connected. This space 173 is supplied with air, water, kerosene, and surfactant through the air supply pipe 115, the water supply pipe 112, the kerosene supply pipe 108, and the surfactant supply pipe 114.

Four (not restricted to four but permissible if at least one is present) blades 180 for raising air, petroleum fuel, water, and surfactant supplied in the above manner are connected to the connecting member 176 by bolts 178. The blades 180 are disposed so as to intersect a direction of the spindle 144 at a predetermined angle (more than 0°to less than 90° (e.g., 30°)) with respect to the direction opposite to the rotation direction of the rotating body 138.

The expanding portion 140 is connected to the spindle 144 by bolts 158 and pins 156.

As shown in Fig. 12, the rotation supporting portion 150 is connected to the spindle 144 by pins 202 and contains a connecting member 204 which passes through the fixed body 136 and the case 132. A rotating member 214 is connected to the top of the connecting member 204 and the bottom end of the connecting member 204 reaches the cylindrical portion 142 and is coupled to the cylindrical portion 142 by bolts. A belt applied to a motor (not shown) is wound around the rotating member 214. The connecting member 204 is rotatably supported by the rouleau 216.

The connecting member 204 has three holes with a predetermined distance in the direction of the spindle for adjusting a distance between the rotating body 138 and the fixed body 136, that is, the width of the passage 154, depending on the type of petroleum fuel for use. Fig. 12 shows a case in which a pin 211 is inserted into one hole such that the width of the passage 154 is determined depending on the viscosity of kerosene.

Accompanied by rotations of the rotating member 214 driven by the aforementioned motor, the connecting member 204, the spindle 144, the rotating body 138, the connecting member 176, and the blades 180 are rotated with the outer face of the expanding portion 140 of the rotating body 138 opposing the inner face of the fixed body 136 correspondingly with a distance determined depending on the aforementioned viscosity.

As shown in Figs. 13A, 13B, a first hole 224 is provided on the upper portion of the inner face of the fixed body 136 corresponding to the cylindrical body 142 and a second hole 225 is provided on a lower portion thereof.

One end of a connecting pipe 220 is connected to the first hole 224 and an emulsion fuel supply pipe 126 is connected to the other end of the connecting portion 226 of the connecting pipe 220. The connecting pipe 220 is stretched in the direction of a tangent line of the inner face of the fixed body 136 at a position of the first hole 224 and in the direction of rotation of the rotating body 138.

One end of a connecting pipe 222 is connected to the second hole 225 and an emulsion fuel return pipe 128 is connected to the other end of the connecting portion 228 of the connecting pipe 222. The connecting pipe 222 is stretched in the direction of a tangent line of the inner face of the fixed body 136 at a position of the second hole 225 and in a direction opposite to the direction of rotation of the rotating body 138.

Meanwhile, the emulsion fuel combustion apparatus 40 is the same as the above described first and second embodiments; therefore, a description thereof is omitted.

Next, an operation of this embodiment will be described. First, the emulsion fuel is generated with the above-mentioned ratio.

The aforementioned flow meter 116 is connected to a control circuit (not shown). Based on flow rates detected by the respective flow meters 116, the control circuit controls the control valves 115 provided on the air supply pipe 113, the water supply pipe 112, the kerosene supply pipe 108, and the surfactant supply pipe 114 so that air, water, kerosene, and surfactant are supplied to the emulsion fuel production supply unit 100 at their respective predetermined ratios.

This control circuit controls the heater 110 such that kerosene becomes a predetermined temperature based on the temperature of the kerosene detected by the thermometer 118.

This control circuit rotates the aforementioned motor to rotate the rotating member 214 so that the rotating body 138 is rotated, together with the spindle 144, around the spindle 144.

Air, water, kerosene, and surfactant supplied from the air supply pipe 115, the water supply pipe 112, the kerosene supply pipe 108, and the surfactant supply pipe 114 with the aforementioned predetermined ratios are mixed mutually and raised gradually through the passage 154 by the supply pressures from the water tank 104, the kerosene tank 102, the surfactant tank 106, and the air tank, and by a raising pressure by the blades 180 rotating together with the spindle 144. Because blades 180 are provided rotating with the rotation of the spindle 144, it is possible to feed air, water, kerosene, and a surfactant smoothly and forcefully into the passage 154 and increase a raising force along the passage 154.

When the mixed liquid of air, water, kerosene, and a surfactant is raised with their mixing successively along the passage 154, it is rotated at a speed lower than the rotation speed of the rotating body 138 in a circumferential direction by the viscosity of the kerosene, accompanied by the rotation of the outer face of the expanding portion 140 of the rotating body 138. When the mixed liquid is rotated in a circumferential direction, a centrifugal force in the direction of the radius is applied to the mixed liquid. If this centrifugal force is broken down into vectors, it is broken down into a direction along the passage 154 and a direction perpendicular to the passage 154. Because a force in the direction along the passage 154 is applied to the mixed liquid, the mixed liquid is raised further with accelerated mixing, even though friction by a force perpendicular to the passage 154 exists. When raising is continued, the circumferential length on the horizontal section is increased because the expanding portion 140 expands as height increases along the spindle 144, so that speed is increased.

Because air is also supplied as described previously or air is produced as bubbles from water, there is the worry that an air layer may form in the passage 154. However, because baffle plates 141 are provided on at least one of the expanding portion 140 and an inner face corresponding to the expanding portion 140 of the fixed body 136 (the expanding portion 140 in this embodiment), the air layer can be destroyed.

Then, if the mixed liquid reaches the proximal portion of the expanding portion 140, its kinetic energy is maximized.

Even if the mixed liquid reaches the proximal portion of the expanding portion 140, the mixed liquid is successively raised, so that the passage 154 at the position of the cylindrical portion 142 is further raised. On the other hand, because a plurality of pins 148 is projected in the radius direction from the cylindrical portion 142, the mixed liquid is agitated by the plurality of pins 148 so as to produce an emulsion fuel. Because each of the plurality of pins 148 has a rectangular section, it is possible to prevent an occurrence of Karman's vortex street, thereby preventing pins 148 from being damaged.

Then, the emulsion fuel which reaches the position of the first hole 224 provided on the top portion inside corresponding to the cylindrical portion 142 of the fixed body 136 is supplied to the emulsion fuel combustion apparatus 40 through the connecting pipe 220 and the emulsion fuel supply pipe 126. The connecting pipe 220 is stretched in the direction of the tangent line for the inner face of the fixed body 136 at the position of the first hole 224 and in the direction of rotation. Thus, the emulsion fuel which reaches the first hole 224 enters into the connecting pipe 220 at the same speed as it reaches that hole. Thus, it is possible to use kinetic energy without reducing the kinetic energy possessed by the emulsion fuel and to supply the emulsion fuel to the emulsion fuel combustion apparatus 40.

The combustion action of the emulsion fuel is the same as the above described first embodiment, and therefore a description thereof is omitted.

When the emulsion fuel combustion apparatus 40 is not activated, the emulsion fuel is returned to the above passage 154 through the emulsion fuel return pipe 128, the connecting pipe 222, and the hole 225 on the inner face bottom of the fixed body 136 corresponding to the cylindrical portion 142. Therefore, the emulsion fuel can be supplied again to the emulsion fuel combustion apparatus 40 without being stored in a static condition and compressed. Thus, energy use efficiency can be improved. Meanwhile, it is permissible to return the emulsion to the expanding portion 140 of the fixed body 136.

As described above, because the produced emulsion fuel is supplied to the emulsion fuel combustion apparatus 40 immediately, changes in pressure for supplying the produced emulsion fuel to the emulsion fuel combustion apparatus 40 can be reduced.

Thus, under a condition in which the emulsion fuel composition is maintained, that is, the surfactant is not separated out, the emulsion fuel can be burned. Therefore, it is possible to improve the combustion efficiency and prevent the occurrence of black smoke or the like.

Because the emulsion fuel can be sent to the emulsion fuel combustion apparatus without activating the pressure feed pump, the kinetic energy of the emulsion fuel is used as energy for sending and injecting the emulsion fuel to the emulsion fuel combustion apparatus 40. Thus, it is possible to improve energy use efficiency.

Depending on the viscosity determined by the type of petroleum fuel, any one of the three holes provided on the connecting member 204 at each predetermined distance in the direction of the spindle is selected and the pin 211 is inserted thereinto to support the supporting member 208. Consequently, the distance between the rotating body 138 and the fixed body 136 is adjusted to reduce resistance. Thus, it is possible to reduce energy loss.

Although depending on the petroleum fuel for use, any one of the three holes can be used to insert the pin thereinto and support the pin to a distance between the outer face of the expanding portion of the rotating body and the inner face of the fixed body corresponding to that outer face, the present invention is not restricted to this manner, and it is permissible to move the rotating body by means of a moving means such as a rack and pinion means or the like to adjust that distance therebetween.

Although the rotating body contains an expanding portion in the examples above, the present invention is not restricted to this concept, and any shape expanding in diameter as height is increased may be applied. Although in the above example, the rotating body contains the expanding portion and the cylindrical portion, and the expanding portion has a plurality of pins, the present invention is not restricted to this concept but it is permissible to eliminate the cylindrical portion from the rotating body and provide at least one of the rotating body and the fixed body with protrusions. In this case, the emulsion fuel supply pipe is connected to the top portion of the expanding portion and the emulsion fuel return pipe is connected to a position lower than the position in which the emulsion fuel supply pipe is connected.

Further, although kerosene, water, and surfactant are supplied to the above space through different paths, the present invention is not restricted to this, and it is permissible to supply kerosene and surfactant and water and surfactant in a mixed condition to the above space or it is permissible to supply kerosene, water, and a surfactant in a mixed condition to the above space.

Further, although the rotating body having the expanding portion is rotated and the fixed body is fixed, the present invention is not restricted to this concept, and it is permissible to rotate the fixed body and fix the rotating body in this case.

Although a case in which the emulsion fuel is injected to a flame produced by burning gas has been described above, the present invention is not restricted to this concept, and it is permissible to inject the emulsion fuel to a target such as a heater heated at a temperature higher than the ignition temperature of the emulsion fuel or inject the emulsion fuel to a cylindrical member in which coil-shaped heaters are arranged on its inner circumference so as to burn the emulsion fuel. Although a case in which a flame is produced by using LPG has been described above, it is permissible to use gas such as urban gas. Although a case in which eight gas-injection holes are arranged on a circumference has been described above, it is permissible to dispose 2 to 7 or more than 9 each symmetrically. The gas-injection hole may be structured with a nozzle. Although a horizontal emulsion fuel combustion apparatus has been described above, it is possible to apply a vertical emulsion fuel combustion apparatus.

Although sorbitan monooleate is used as the lipophilic surfactant and polyoxyethylene sorbitan trioleate is used as the hydrophilic surfactant in the above case, it is permissible to use other lipophilic and hydrophilic surfactants, and to further add a surfactant to one of petroleum fuel and water and further use polyethylene glycol instead of ethylene glycol.

Although a case in which kerosene is used as the material for the emulsion has been described above, it is permissible to use petroleum fuel such as heavy oil (A heavy oil, B heavy oil, C heavy oil) and gasoline.

Claims

1. An emulsion fuel production method comprising the steps of:

   producing an initial-phase emulsion by mixing petroleum fuel, water, and a surfactant and then agitating said mixed liquid at a predetermined agitation speed; and
   producing an emulsion fuel by mixing said produced initial-phase emulsion and water and then agitating said mixed liquid at an agitation speed lower than said previous agitation speed.

2. An emulsion fuel production method according to claim 1, wherein said initial-phase emulsion is produced by mixing and agitating petroleum fuel mixed beforehand with a lipophilic surfactant and water, petroleum fuel and water mixed beforehand with a hydrophilic surfactant, or petroleum fuel mixed beforehand with a lipophilic surfactant and water mixed beforehand with a hydrophilic surfactant.

3. An emulsion fuel production apparatus comprising:

   a first agitation bath for producing an initial-phase emulsion by mixing petroleum fuel, water, and a surfactant and then agitating said mixed liquid at a predetermined agitation speed; and
   a second agitation bath for producing an emulsion fuel by mixing said initial-phase emulsion produced in said first agitation bath and water and then agitating said mixed liquid at an agitation speed lower than said previous agitation speed.

4. An emulsion fuel production apparatus according to claim 3, wherein said initial-phase emulsion is pro-

duced by mixing and agitating petroleum fuel mixed beforehand with a lipophilic surfactant and water, petroleum fuel and water mixed beforehand with a hydrophilic surfactant, or petroleum fuel mixed beforehand with a lipophilic surfactant and water mixed beforehand with a hydrophilic surfactant.

5. An emulsion fuel combustion apparatus comprising:

   an emulsion fuel production apparatus for producing an initial-phase emulsion by mixing petroleum fuel, water, and a surfactant and agitating said mixed liquid at a predetermined agitation speed and mixing said produced initial-phase emulsion and water and then agitating said mixed liquid at an agitation speed lower than said previous agitation speed;
   a temperature maintaining means for maintaining a temperature of a position in which the emulsion fuel is injected at a temperature higher than the ignition temperature of said emulsion fuel; and
   a fuel injection means for injecting the emulsion fuel produced in said emulsion fuel production apparatus to the position maintained at a temperature higher than the ignition temperature of said emulsion fuel.

6. An emulsion fuel combustion apparatus according to claim 5, wherein said initial-phase emulsion is produced by mixing and agitating petroleum fuel mixed beforehand with a lipophilic surfactant and water, petroleum fuel and water mixed beforehand with a hydrophilic surfactant, or petroleum fuel mixed beforehand with a lipophilic surfactant, and water mixed beforehand with a hydrophilic surfactant.

7. An emulsion fuel combustion apparatus according to claim 5, wherein said temperature maintaining means contains a gas injection means for injecting a combustion gas to a position in which said emulsion fuel is injected so as to burn said combustion gas to maintain a temperature of a position in which said emulsion fuel is injected at a temperature higher than the ignition temperature of said emulsion fuel.

8. An emulsion fuel combustion apparatus according to claim 7, wherein said gas injection means is so constructed that a plurality of combustion gas injection holes is arranged on a circumference so as to converge said combustion gas injected from the plurality of combustion gas injection holes to a position in which said emulsion fuel is injected.

9. An emulsion fuel combustion apparatus comprising:

   a temperature maintaining means for maintaining the temperature of a position in which emulsion fuel is injected at temperatures higher than the ignition temperature of said emulsion fuel; and
   a fuel injection means for injecting said emulsion fuel to the position maintained at a temperature higher than the ignition temperature of said emulsion fuel.

10. An emulsion fuel combustion apparatus according to claim 9, wherein said temperature maintaining means contains a gas injection means for injecting combustion gas to a position in which the emulsion fuel is injected so as to burn said combustion gas to maintain the temperature of the position in which said emulsion fuel is injected at a temperature higher than the ignition temperature of said emulsion fuel.

11. An emulsion fuel combustion apparatus according to claim 10, wherein said gas injection means is so constructed that a plurality of combustion gas injection holes is arranged on a circumference so as to converge said combustion gas injected from said plurality of combustion gas injection holes to the position in which the emulsion fuel is injected.

12. An emulsion fuel combustion apparatus according to claim 9, wherein said emulsion fuel is produced by mixing petroleum fuel, water, and surfactant at weight ratios of 1:1 to 0.5:0.004 to, 0.008.

13. An emulsion fuel combustion apparatus according to claim g, wherein the average particle diameter of liquid particles of said emulsion fuel is 0.05-3 μm.

14. An emulsion fuel production supply apparatus comprising:

   a first member having an expanding portion which expands in diameter around a spindle as the height is increased;
   a second member which is arranged so as to surround said first member and in which an inner face thereof corresponding to said expanding portion has a gap with respect to said expanding portion and the shape of said inner face corresponds to the shape of said expanding portion and which seals said gap;
   a rotating means for rotating one of said first member and said second member around said spindle;
   a supply means for supplying petroleum fuel, water, and surfactant to a first position located at the front end of said expanding portion of said gap;
   a pipe path which is located at a second position above said first position of said gap and in

which one end thereof is connected to the second position and the other end is connected to an emulsion fuel combustion apparatus; and

a plurality of protrusions provided on at least one of said first member and said second member which form said gap and in a range above said first position and below said second position.

15. An emulsion fuel production supply apparatus according to claim 14, wherein said first member contains a cylindrical portion which is located continuous with and above said expanding portion and formed around a spindle.

16. An emulsion fuel production supply apparatus according to claim 15 wherein said second position is located at a position corresponding to said cylindrical portion of said gap.

17. An emulsion fuel production apparatus according to claim 14, wherein said pipe path contains a path to be connected below said second position of said gap.

18. An emulsion fuel production supply apparatus according to claim 14, further comprising a raising means which is located at the front end of said expanding portion of said gap for raising petroleum fuel, water, and surfactant supplied by said supply means.

19. An emulsion fuel production supply apparatus according to claim 18, wherein said raising means is at least one blade disposed at an angle greater than 0° and less than 90° with respect to a direction opposite to the direction of said rotation.

20. An emulsion fuel production supply apparatus according to claim 14, wherein at least one baffle plate is provided at a position above said first position and lower than said second position on at least one face of said first member and said second member which said gap is formed.

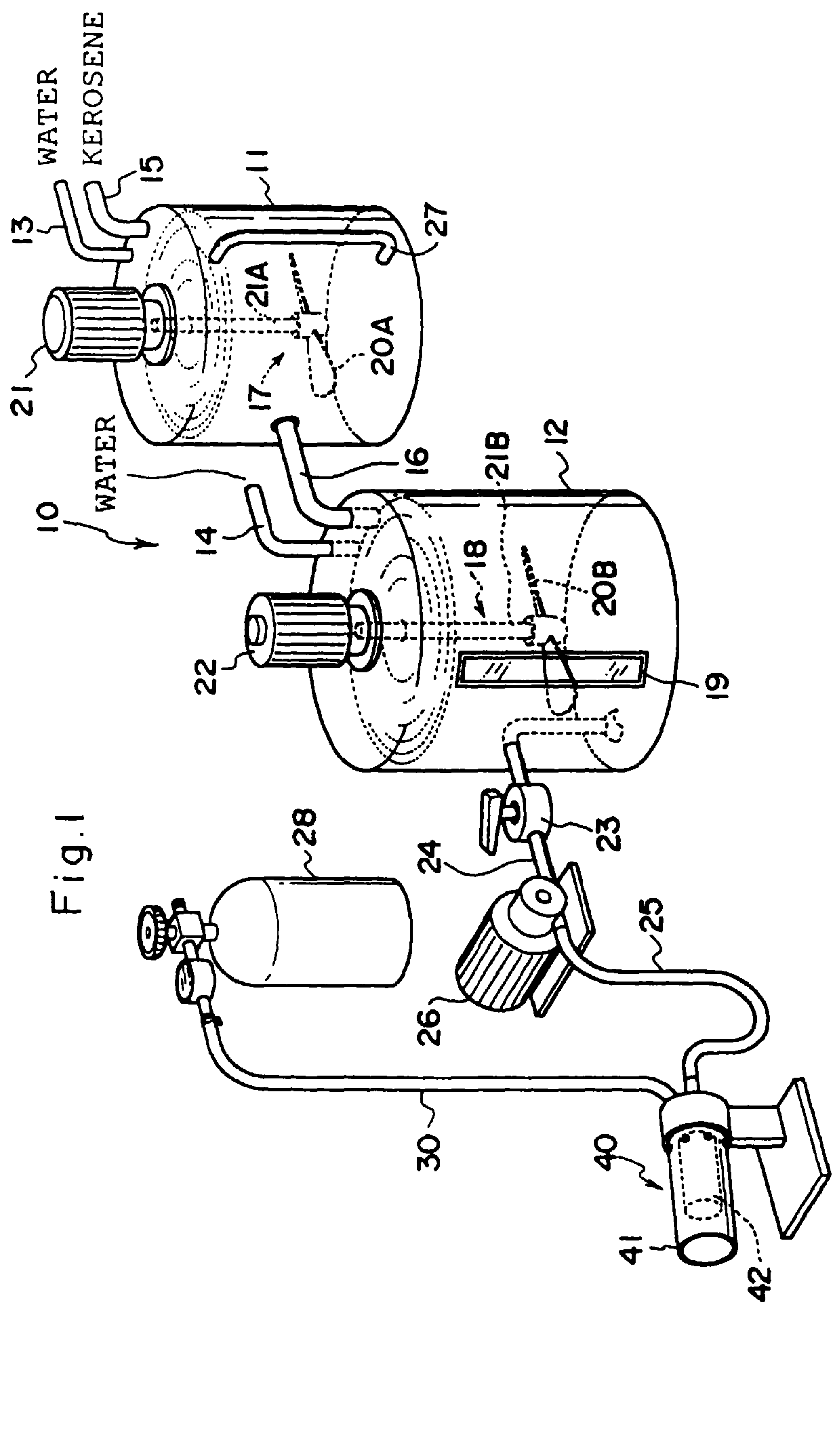
21. An emulsion fuel production supply apparatus according to claim 14, wherein said rotating means is structured to be able to change the width of said gap.

22. An emulsion fuel production supply apparatus according to claim 14, wherein a section of said protrusion is rectangular.

23. An emulsion fuel production method according to claim 1, wherein said emulsion fuel is produced by mixing petroleum fuel, water, and surfactant at weight ratios of 1:1 to 0.5:0.004 to 0.008.

24. An emulsion fuel combustion method according to claim 1, wherein the average particle diameter of liquid particles of said emulsion fuel is 0.05-3 μm.

Fig.1


WATER
KEROSENE
13
15
11
27
21
21A
17
20A
10
WATER
14
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21B
12
18
20B
22
19
23
24
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26
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30
40
41
42

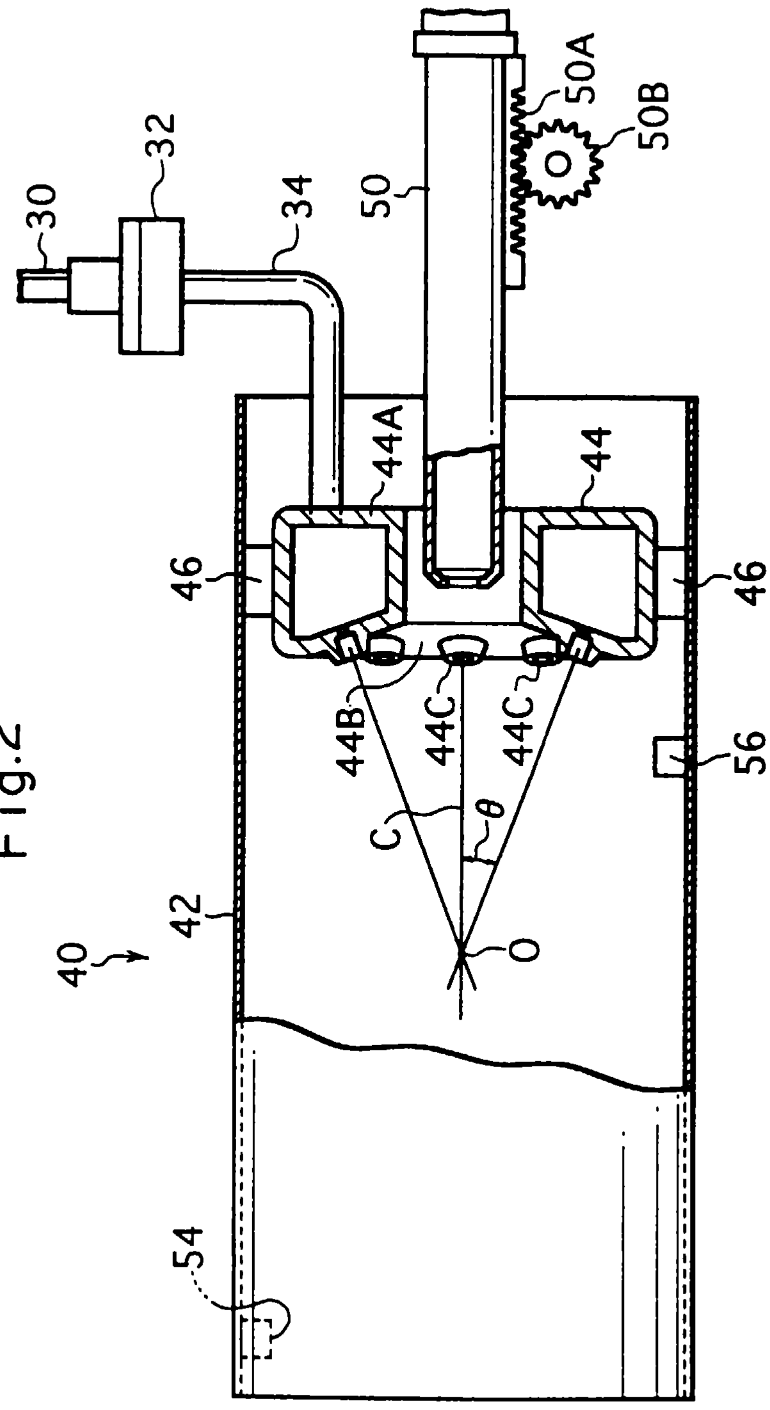


Fig.2

Fig.3

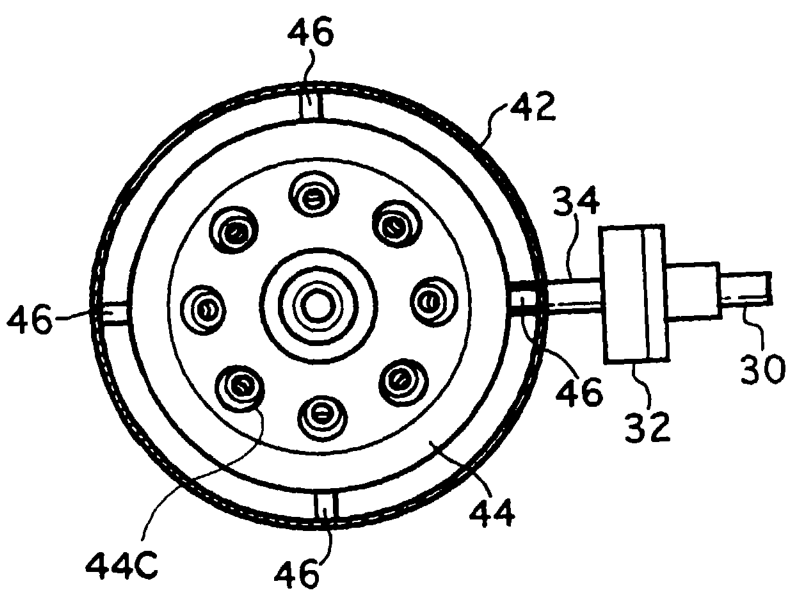


Fig.4

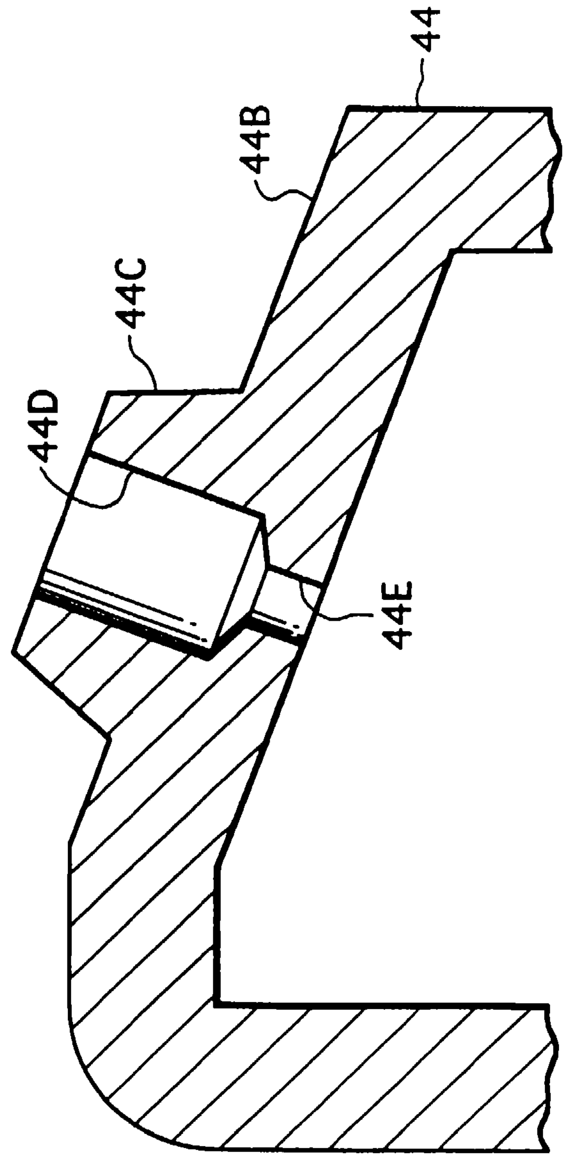


Fig.5

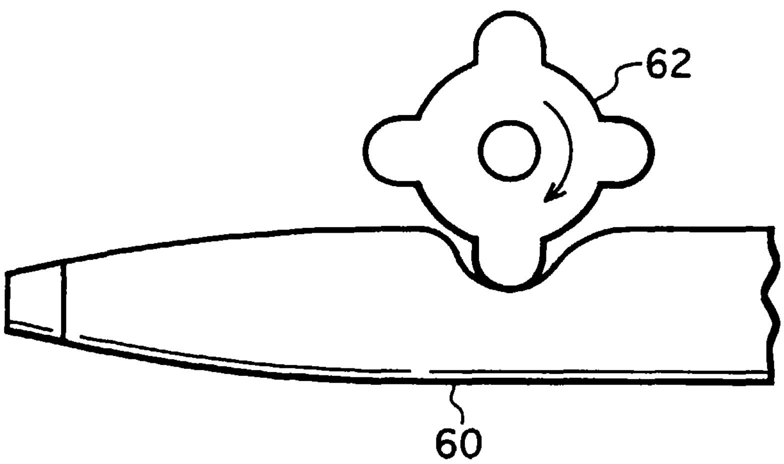
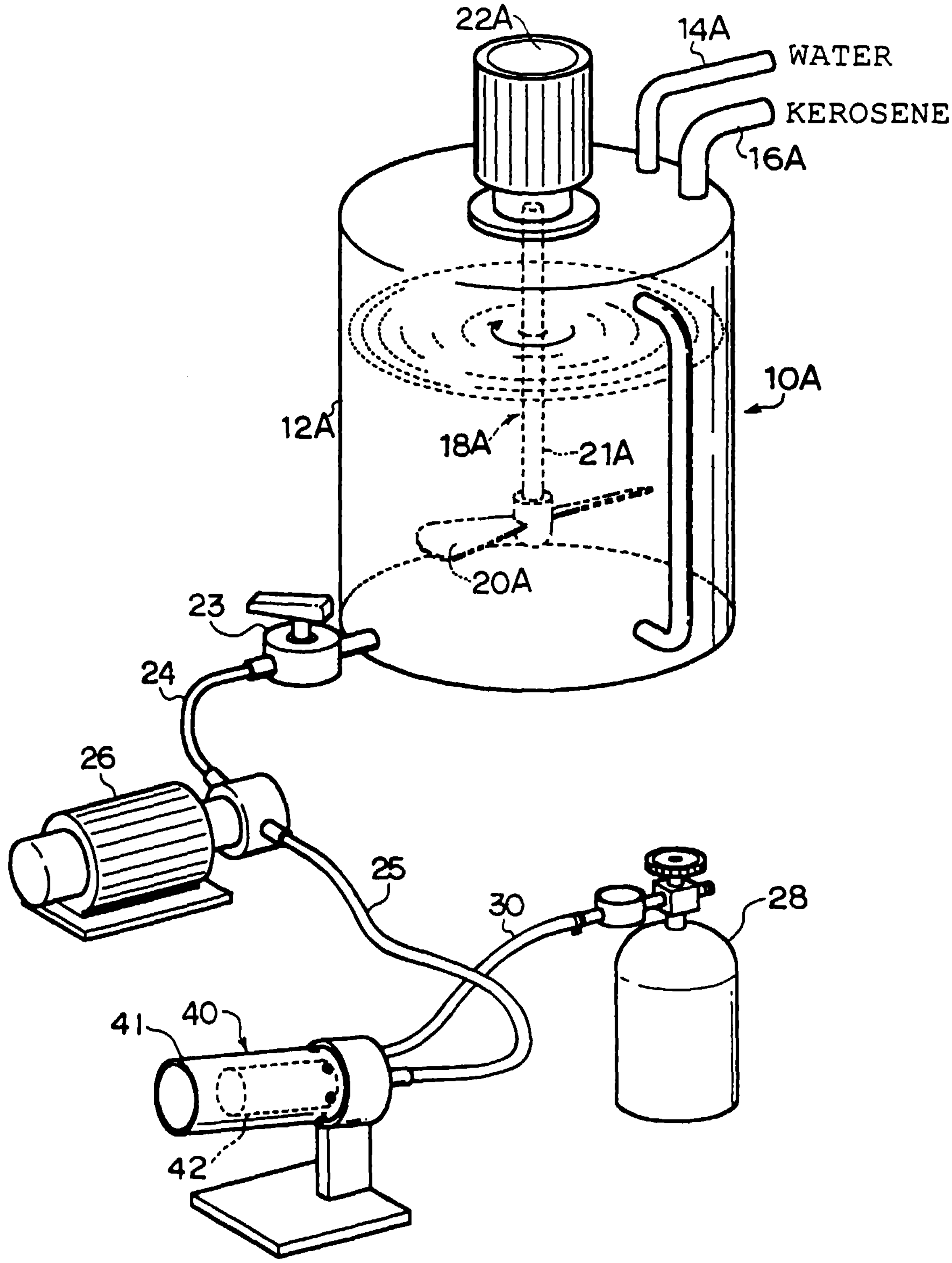


Fig.6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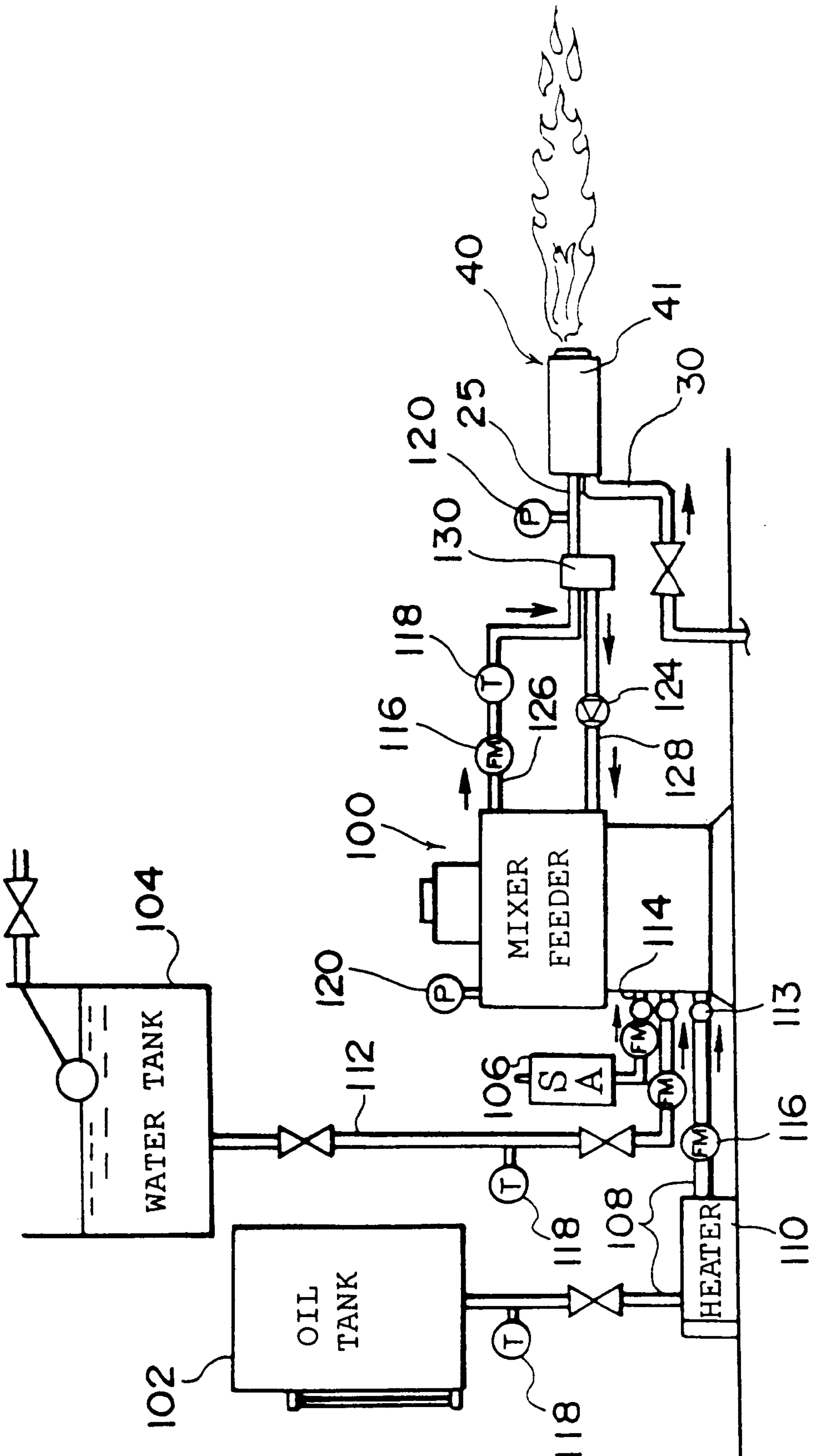
14A
WATER
KEROSENE
16A
10A
12A
18A
21A
20A
23
24
26
25
30
28
41
40
42

Fig.7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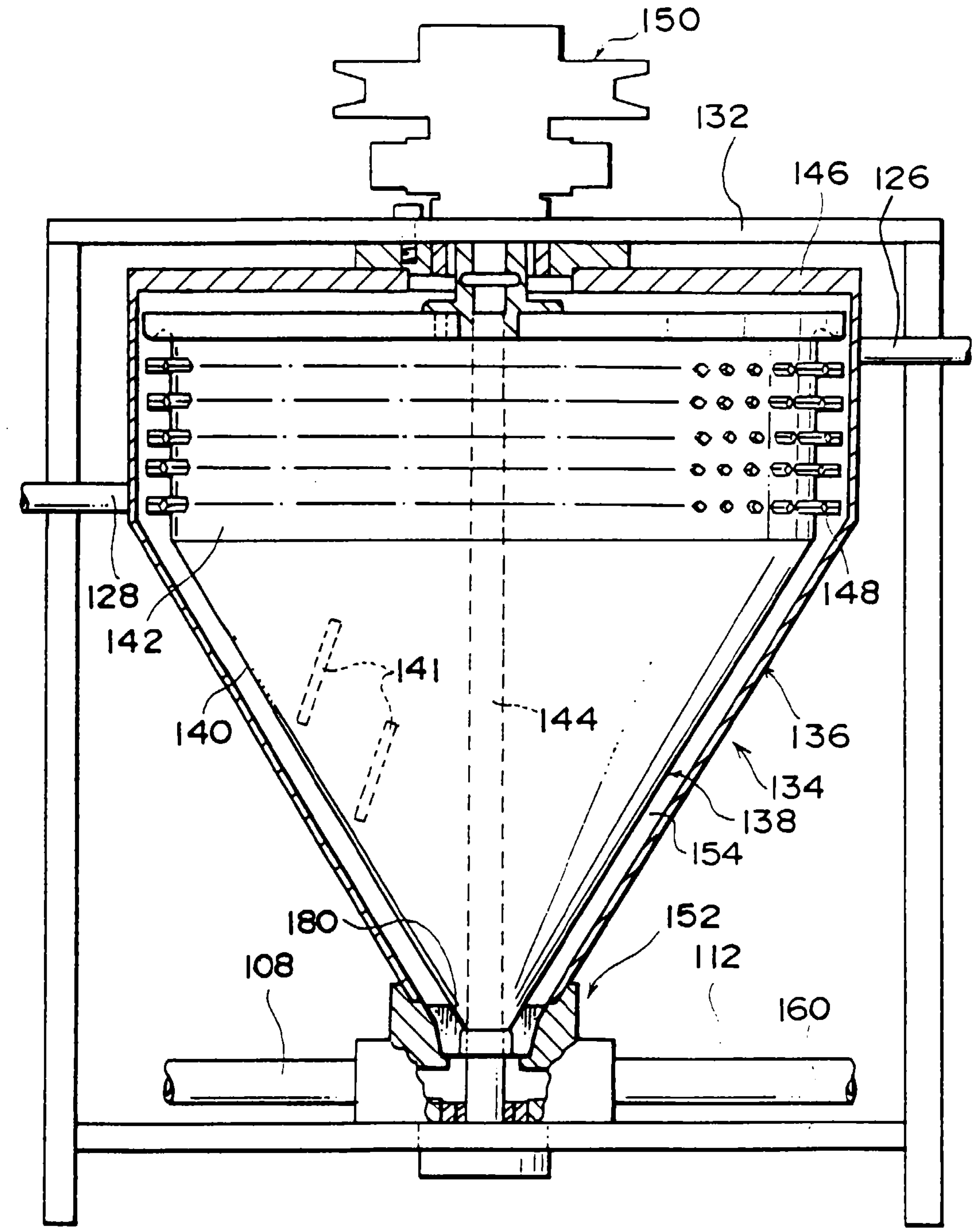
OIL TANK
HEATER
MIXER FEEDER
S A
P
T
FM
40
41
25
30
120
130
118
116
126
124
128
100
104
114
113
112
106
108
110
102

Fig. 8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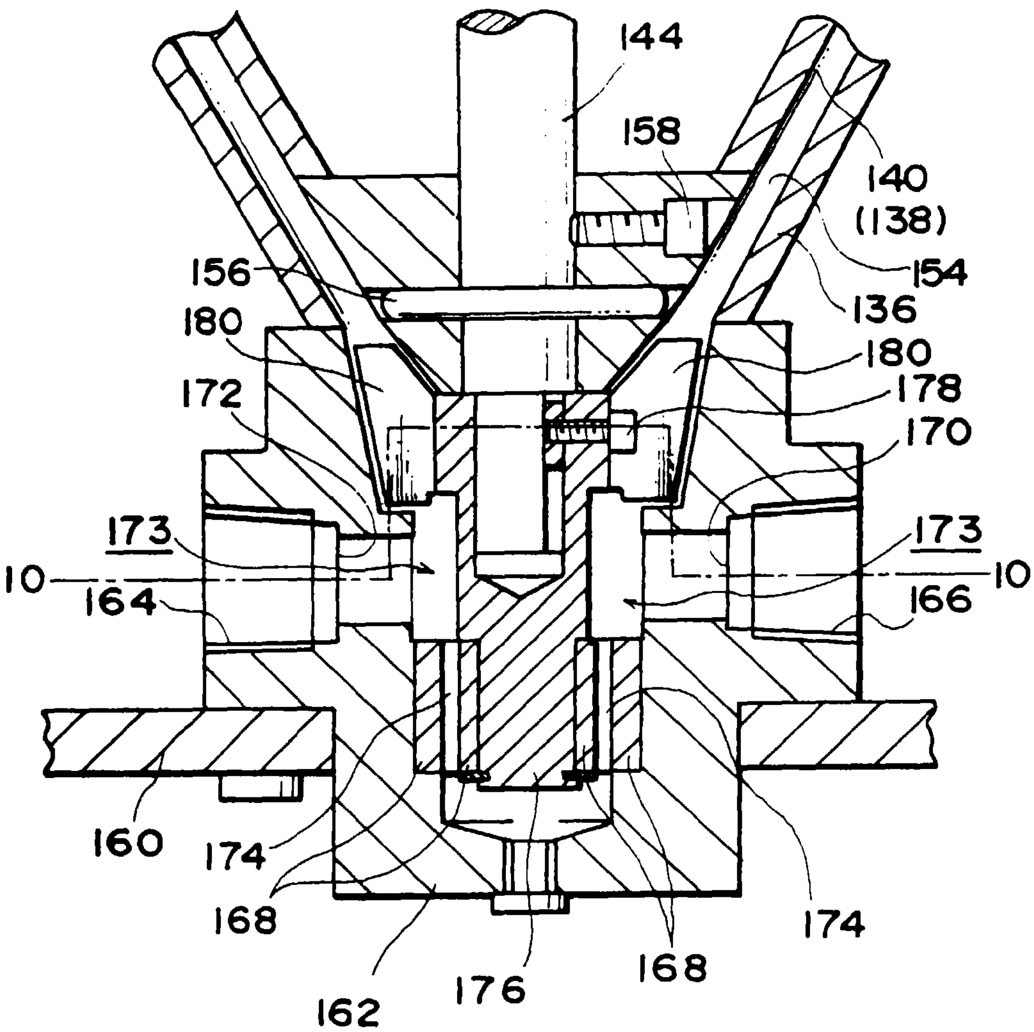
132
146
126
128
142
148
141
140
144
136
134
138
154
180
152
108
112
160

Fig.9


144
158
140
(138)
154
136
156
180
180
178
172
170
173
173
10
10
164
166
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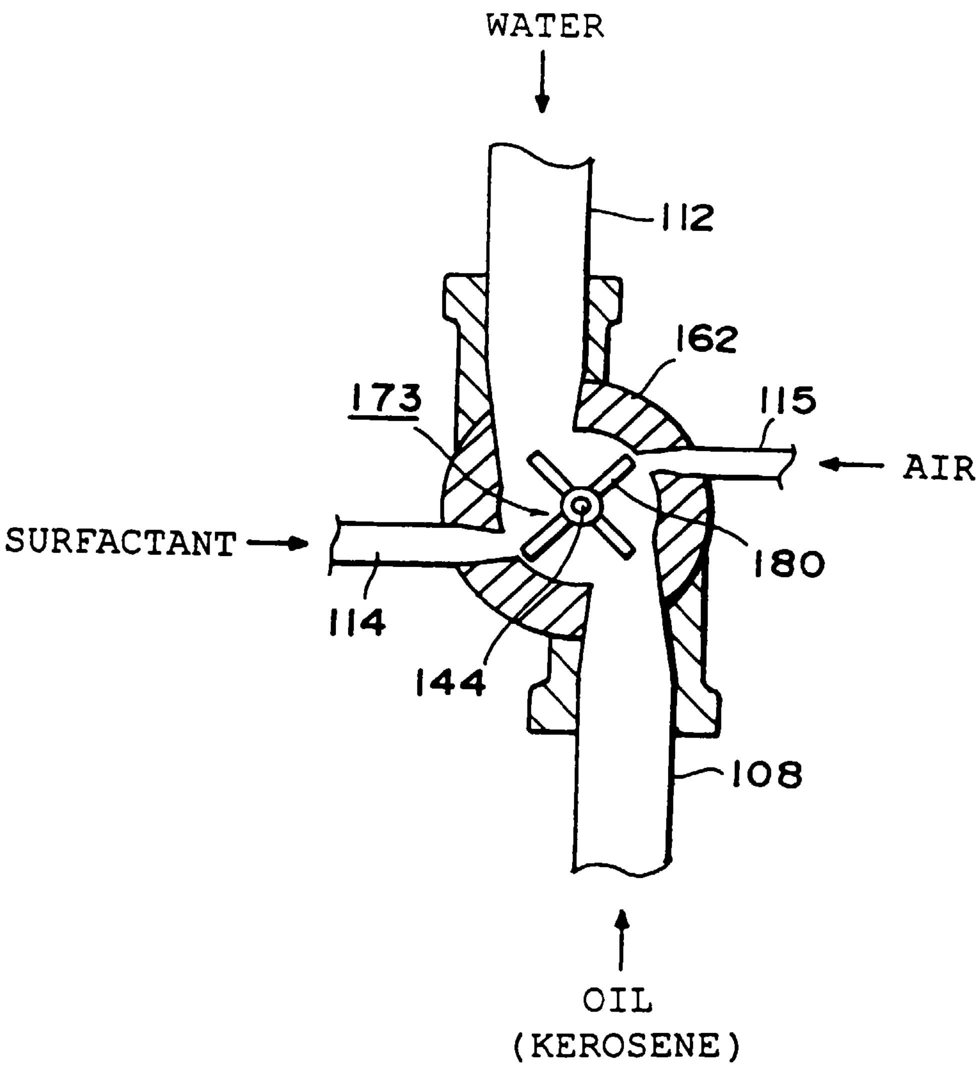
174
162
176
168

Fig 10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162
173
115
AIR
SURFACTANT
180
114
144
108
OIL
(KEROSENE)

Fig.11

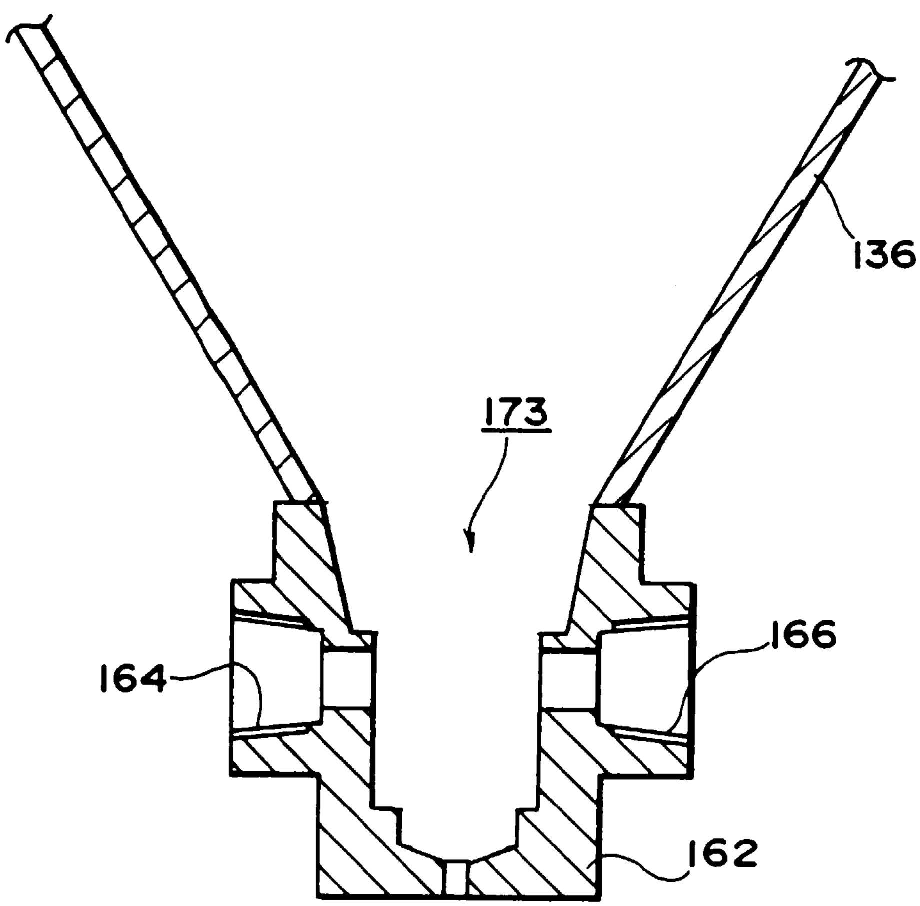

Fig.12

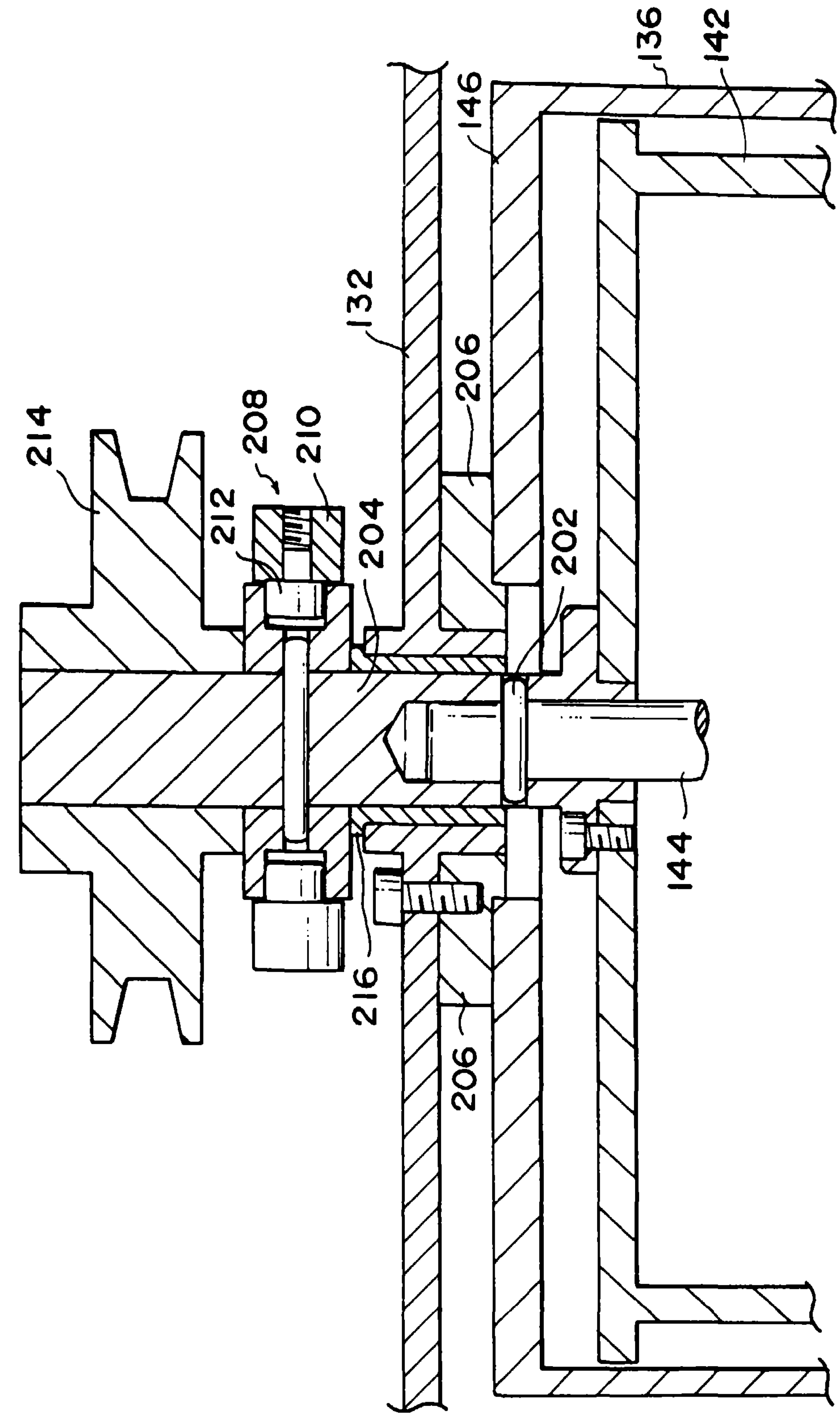

Fig.13A

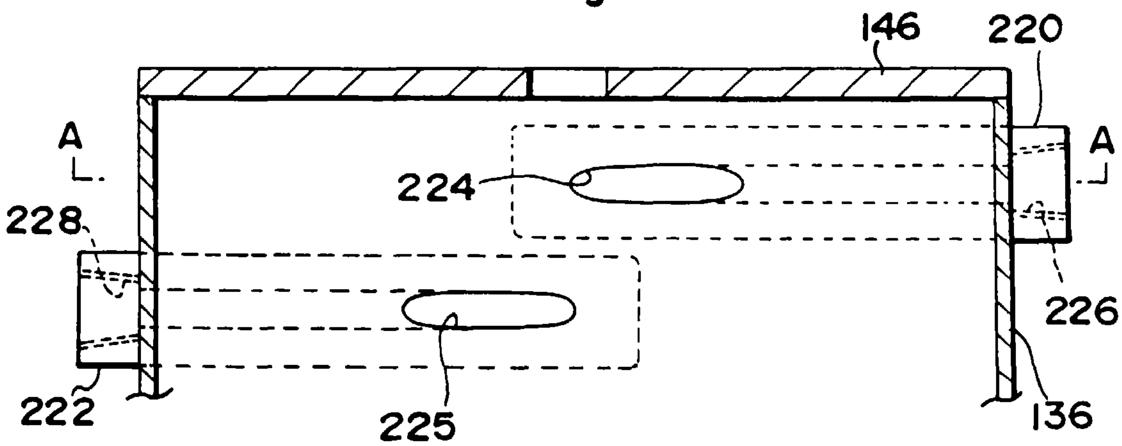

Fig.13B