Emulsion Fuel Technology in Combustion Furnaces

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Background

In the recent several years, as same as in over about thirty years ago, the technology of application of emulsion fuels to many boilers, furnaces and diesel engines has attracted much attention from the point of view of the energy saving policy and of the prevention of atomospheric pollution caused by the exhaust from many combustion facilities.

It is, mainly, due to the recent high cost of crude oil and to the prevalence of the national consensus of the prevention of environmental pollution.

The kind of emulsion fuels, consisting of usual hydrocarbon fuels and water, is divided into two types; W/O and O/W emulsions. W/O type emulsion fuel has dispersed many fine water particles in the base hydrocarbon fuel. On the other hand, O/W type emulsion fuel has, inversely, dispersed many fine hydrocarbon fuel particles in the water phase.

Development of Emulsion Fuel

For W/O emulsion fuel, there are some very difficult points to produce and maintain the stable emulsified fuel; uniform and stable dispersion of insoluble fine water particles in the hydrocarbon fuels, the transportation into combustion chambers and/or furnaces without any disruption of emulsion state. It is thereby not easy to attain the stable combustion of sprayed emulsion fuel without any trouble for a long running period of combustors.

Many combustion device manufacturers have, therefore, tried to develop and improve the emulsification devices and emulsion combustors for recent over twenty years.

Through the survey of many reports, it is shown that almost all manufacturers have tried to produce the stable emulsion fuels by using the surface-active agent in the mixture of hydrocarbon fuel and water. The ratio of water in the mixture is 20-40 vol.% or more.

Although it is the fact in itself that even the fuels including water can be burned, the application of the experimental results to the real stable many kinds of combustors without any trouble is, of course, never easy.

Surface-Active Agent and Water Content in Emulsion

Needless to say, the cost of the surface-active agent in emulsion fuel cannot be negligible during the long running period of large-scale combustors, although the needed amount of the surface-active agent is not so large. In addition, the exhaust gases from the combustors will contain the species of the molecules of surface-active agent.

It should be noted here that the use of the emulsion fuels that contains too much water can never be a good energy-saving technology owing to the increase in fuel consumption rate due to the large decrease in the combustion efficiency.

The content of water in the emulsion fuel, therefore, should be determined and controlled appropriately for the kind of base hydrocarbon fuels, and never be increased so much for the long and safe running of the combustors (furnaces) without any trouble. For the emulsified fuels of light oil and A-heavy oil, the appropriate water content will be less than about 10 vol.%, and less than about 20 vol.% even for the emulsion of C-heavy oil.

Mechanical Emulsification Device

Japanese environmental device manufacturer, N-Techno, has developed an excellent mechanical emulsification device since over twenty years ago, which can produce mechanically the stable W/O type emulsion fuel without using any surface-active agent. This device has a kind of gear pumping mechanism consisting of original tree or four gears.

This mechanical emulsification device gives a strong shear stress to the mixture of water and

hydrocarbon fuel in the squish among the rotating gears and in the clearance between the gears and surrounding housing wall.

Water particles are thereby strongly ground and mixed with base hydrocarbon fuel, and they become extremely fine (less than 10 μm), which cannot be attained mechanically by the usual mixing and/or atomizing mechanism.

By using this mechanically produced emulsion fuel (the water content is usually less than 10 vol.%) in boilers and many forging furnaces, both of the increase in the combustion efficiency (decrease in the fuel consumption rate) and the clean exhaust gas (reduction of soot and particulates) have been attained successfully.

In addition, the recycling technology of waste oils (machine and food) for the fuels in boilers and many furnaces has been, thereby, developed.

Needed Specification of Emulsion Fuel

For the stable and long running of many emulsion combustors (including boilers and forging furnaces) without any trouble, the following specifications will be needed in the use of emulsion fuel;

(1) Diameters of water particles in the sprayed each emulsion fuel droplet should be uniform and less than 10 μm.

(2) Emulsion should be stable, namely no separation between the base hydrocarbon fuel and the water occurs until the emulsion fuel is transported into the combustors.

(3) The stability of emulsion fuel should not be affected by the changes of the temperature and of the flow rate into the combustors.

(4) There is no corrosion in any parts of combustor owing to the use of emulsion fuel.

(5) The amount of the used surface-active agent for emulsification should be as small as possible.

(6) The system of emulsion production is not so expensive.

Advantages of Emulsion Combustion

In many research reports in the previous three or four decades, we can see the excellent ideas of the combustion technology by the mixture of petroleum fuel with a small mount of water.

It is due to some outstanding advantages in the characteristic combustion behavior of the sprayed emulsified fuel droplets, caused by the included many fine water particles in each droplet.

The diameters of the liquid fuel droplets sprayed into the combustors are, usually, in the range of 30-130 μm. Under the usual standard atmospheric pressure, the volume of one water droplet is expanded about 1700 times larger than the original volume due to the vaporization.

Namely, in the high temperature atmosphere in the combustion chamber, water droplets in the sprayed each emulsion fuel droplet will explode due to the instantaneous vaporization, and smash the fuel droplet. This is called as the *micro-explosion* of the fuel droplet, which brings about the increase in the mixing of the fuel with the surrounding air in combustion chamber.

The main advantages of the emulsion combustion are due to the *micro-explosion* and to the presence of water vapor as shown below;

(1) The *micro-explosion* of the fuel droplets due to the included water particles promotes the atomization of the fuel particles, namely promotes the mixing of the fuel with the surrounding air. The combustion efficiency can be increased thereby in high temperature combustion chambers; boilers, forging furnaces and diesel engines.

(2) Owing to the increase in the combustion efficiency in the furnaces and boilers using emulsion fuels, the needed amount of *cold excess air*, which is additionally blown into the furnaces for the complete combustion of fuels, can be reduced dynamically. Then the residence time of the hot combustion gases in the furnace becomes long. Heat loss from the furnaces and boilers can be thereby decreased dynamically, which leads to the obvious reduction of fuel consumption rate.

(3) The amount of soot and particulates in the exhausted gases can be reduced owing to the *Water-Gas Reaction* in the high temperature combustion chambers.

(4) Concentration of NO_x in the exhaust gas can be decreased owing to the decrease in the combustion gas temperature.

(5) Owing to the emulsification, some kinds of the waste oils (mechanical and food) can be recycled as the useful fuels in many forging furnaces and boilers.

Water-Gas Reaction in Emulsion Combustion

In many combustion reactions of usual hydrocarbon fuels in the high temperature combustion chambers; 1000-1800℃, the most fundamental reaction schemes can be shown as follows;

(1) $H_2 + \frac{1}{2}O_2 = H_2O + 57.8\ Kcal$

(2) $C + O_2 = CO_2 + 94.1\ Kcal$

(3) $C + \frac{1}{2}O_2 = CO + 26.4\ Kcal$

By the reactions of (1) and (3), the reaction (4) will occur, and the reaction (5) will occur by the reactions of (2) and (3). Moreover, the reaction (6) will occur by the reactions of (1) and (5).

(4) $C + H_2O = H_2 + CO - 31.4\ Kcal$

(5) $CO + \frac{1}{2}O_2 = CO_2 + 67.7\ Kcal$

(6) $CO + H_2O = CO_2 + H_2 + 9.9\ Kcal$

As is well known, if the amount of air (Oxygen) is insufficient for the combustion of hydrocarbon fuels, some amount of soot and particulates will be produced and emitted in the exhaust gas from the combustion chambers due to the incomplete combustion.

However, if the combustion gas in the chambers contains some amount of water molecules, an endothermic reaction will occur as shown in (4), which is called *water-gas reaction*.

The amount of soot and particulate in the exhaust gas can be reduced dynamically owing to this endothermic *water-gas reaction*, which is promoted with increase in the temperature of combustion chamber.

The product CO in this reaction (4) becomes CO_2 due to the reaction (5). Moreover, by the reaction (6); the product CO in the reaction (4) and H_2O in the combustion chamber, CO_2 and H_2 will be produced (sometimes also the reaction (6) is called as *water-gas reaction*). Because the reactions (5) and (6) are exothermic reactions, they are reduced with increase in the temperature of the combustion chamber.

Reduction of NO_X *in the Exhaust Gas*

In the combustion of emulsion fuel, the concentration of NO_x in the exhaust gas can be decreased dynamically owing to the decrease in the combustion gas temperature. The decrease in combustion gas temperature is due to the endothermic reaction (4) and to the latent heat of vaporization of water.

There are mainly two patterns for the production of NO_x in combustion chamber; Thermal NO_x (T-NO_X) and Fuel NO_x (F-NO_X).

Thermal NO_X is produced by the reaction of Nitrogen and Oxygen; both are in air, in the high temperature combustion gas. The production rate of T-NO_X will thereby change dynamically by the temperature of the combustion gas.

Some emulsion combustion technologies for boilers, forging furnaces and diesel engines have tried to reduce the generation of thermal NO_X by the reduction of combustion temperature due to much water content, 20-40 vol.% or more, in emulsion. However, the use of the emulsion fuel that contains too much water can never be a good energy-saving technology owing to the increase in fuel consumption rate due to the large decrease in the combustion efficiency (combustion temperature).

Fuel NO_X is produced in the combustion reaction owing to the Nitrogen included as the element of the original fuel. For the decrease in Fuel NO_X, thereby the combustion with low air-ratio, namely the reduction of Oxygen concentration is needed. It, however, brings about the incomplete combustion, which leads to the increase in soot and particulate in the exhaust gas.

Respectable Emulsion Combustion Technology

Today, the search of "*Emulsion Fuel*" through the Internet shows us about 300-600 reports, articles and research papers even in Japan.

From the point of view of the combustion science, however, many doubtful reports and articles also can be found.

Who can believe the article where the emulsion fuels with 60 vol.% of water content can be used in combustors for long period without any trouble? Who can believe the article that aims finally *water-combustion* by the emulsion fuel with ultra high content of water?

Needless to say, we have known already that the use of emulsion fuel in boilers, forging furnaces and diesel engines is the excellent combustion technology for energy-saving and for prevention of environmental pollution.

In many today's reports, articles and papers, we should, therefore, try to find strictly the real emulsion technologies that satisfy the aforementioned *Needed Specification of Emulsion Fuel*. （October, 2005）