New emulsion fuel production technology: will it save the Earth?

Prologue

The prospects of oil resources and emission gas from fossil fuel consumption have raised keen attention as urgent problems around the world. As one of the different solutions to these problems, emulsion fuel technology has received close attention because it may provide better combustion efficiency and would contribute to a reduction in emissions, such as NOx or particulate matter (PM). There are also great expectations that it would lead to a reduction in fossil fuel consumption and carbon dioxide emissions on a global level and eventually provide a final solution to environmental problems, such as effluent gas. This article will describe the great potential of emulsion fuel technology and introduce recent achievements in the technological development of emulsion fuel production equipment.

1. Introduction

Will emulsion fuels save the Earth? Emulsion fuel technology remains immature and falls short of providing a definitive solution to the question. Despite the great advances in the scientific and technological research of the technology, many different questions remain unsolved. Emulsion fuels refer to the emulsified mixture of petroleum-based fossil fuels, including gasoline, light oil, heavy oil, kerosene and waste oil, and water. A mechanism is assumed to work in emulsion fuels, which improves the combustion efficiency of the emulsified fossil fuel by virtue of the emulsified water. To provide this mechanism, various production devices have been proposed, although there has been no single technology developed to a satisfactory level. More recently, an innovative emulsion fuel production technology has been available that solves several problems inherent to this kind of fuel. This article will describe the recent developments in this technological area, putting a focus on its advantages.

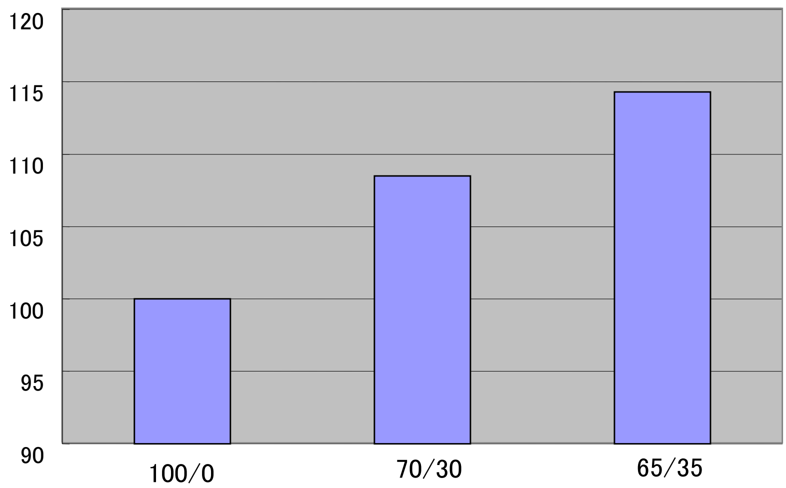
2. What is emulsion?

Emulsion is defined as a process where the initially mutually immiscible materials, such as water and oil, are mixed to form and maintain a temporary suspension by reducing their particulate sizes. The suspension goes back over time to the initial two-phase system where the materials separately exist as immiscible. The rate at which the emulsion returns to a two-phase mixture depends on the types, viscosities, particulate size, and composition of mixed materials and the temperature. Specifically, smaller particulate sizes, desirably reduced to a submicron level, tend to help keep the liquid emulsified for a longer period. A higher ratio of water to oil content results in an oil-in-water type suspension, while a reverse ratio results in a water-in-oil types. The water-in-oil type emulsion fuel may improve combustion efficiency when burned. The assumed mechanism is that water particles, which vaporize and are explosively dispersed due to heating (1 g [1 ml] of water is vaporized to expand 1,244 times to 1,244 ml) in turn disperses the surrounding oil particles and further reduces the oil particle size. The smaller size would give oil particles more contact area with the surrounding oxygen and would eventually improve combustion efficiency.

3. Benefits of emulsion fuels and the role of water in combustion

Many studies on emulsion fuels reveal that they have various benefits, including improvement in combustion efficiency and a reduction in particulate matter (PM) and nitrogen oxide (NOx) emissions. Indeed, water particles vaporize and are explosively spread when emulsion fuels are ignited in an internal combustion engine and a boiler. The oil particles surrounding the water particles are also scattered and become finer with smaller particle sizes. Oil particles have more contact area with oxygen, and as a result, incomplete combustion is suppressed and combustion efficiency is improved. As a consequence, PM emissions are also reduced. In addition, nitrogen oxide (NOx) emissions are suppressed because the combustion temperature is relatively lower due to the heat from the evaporation of the vaporized water. An experiment on light oil emulsion fuel in a burner for boilers revealed that an increase in water composition (0 to 35%) improved the combustion efficiency (0% to 15%) (Fig. 1). Another combustion experiment found that light oil emulsion fuel with water content of 25% reduced NOx emissions and PM by 60% and 90%, respectively, when burned in a diesel engine. Thus, water in the emulsion fuels is shown to improve combustion efficiency and contribute to emission reduction. It should be noted that carbon dioxide and PM emissions are complementary to each other; the carbon content of the fuel is equivalent to the combined carbon content of COx and PM emitted after it is burned. Therefore, if less CO_2 (or CO) is emitted, more PM is discharged and vice versa. Therefore, when water reduces incomplete combustion and improves combustion efficiency, less PM and more COx are discharged. In other words, improved combustion efficiency boosts COx emissions, which is apparently a contradictory outcome. It is difficult to collectively estimate combustion efficiency and emissions of PM and NOx for the same type of emulsion fuels, since these parameters depend on the specific specifications of the engines or boilers used, combustion situations involved, and emulsifiers added.

Fig.1 Combustion efficiency of emulsion fuel for a boiler experiment



4. mulsion fuels from the viewpoint of consumers

Various questions have been posed on the practicality of emulsion fuels to date. Indeed, consumers have complaints about the fuels: 1) they do not sometimes provide performance or benefits (better combustion efficiency) as claimed; 2) they do not always achieve cost reductions as claimed and are not cost-efficient because of the expensiveness of emulsion fuel production equipment; 3) they cannot be stored for a long time because of inevitable phase separation; 4) there has been a prolonged delay in developing effective emulsifying agents, which are required to stabilize the emulsion and avoid phase separation; 5) the existing emulsifying agents are expensive and their possible adverse effects on emulsion combustion have not been considered; 6) the fuels are not usable for vehicles because of their unavoidable tendency to phase separation; 7) they are corrosive due to containing water; 8) water may freeze at lower temperatures; and 9) they may fail to ignite due to inherent low combustion temperatures when the machine is started or stopped.

5. Combustion mechanism of emulsion fuels

“Does water burn?” The doubt tenaciously remains around emulsion fuels. Common and old experience is that fire is extinguished with water. Nonetheless, the phenomenon of fire being boosted by water is also commonly observed. Indeed, in the Edo period, the foreman of the *hikeshi*, a traditional fire brigade, instructed his men to stop watering when fire was overwhelmingly raging. Some locomotive boiler men would wet coals before they threw them into the boilers with the intention of boosting the flame. Today, an imperative instruction is that water should not be cast over an oil fire because water will help the fire spread. Thus, practical knowledge suggests that water is involved in combustion.

In general, when hydrocarbons are completely burned in the presence of sufficient oxygen, the process is described by the following thermo-chemical formula:

$CnHm + (n+m/4)O_2 \rightarrow nCO_2 + m/2 \cdot H_2O$, Q kcal/mol ...**1**

In the presence of water at a high temperature, the following steam reforming reaction and water gas reaction may proceed before the above reaction is initiated.

$CnHm + nH_2O \rightarrow nCO + (m/2+n) H_2$, Q' kcal/mol ...**2**

CO and H_2 may react with O_2 and

$CO + 1/2 \cdot O_2 \leftrightarrow CO_2$

and

$H_2 + 1/2\ O_2 \leftrightarrow H_2O$

An equilibrium reaction is achieved. Since the equilibrium tends to shift rightward in the presence of sufficient oxygen, the combustion reaction of hydrocarbons eventually proceeds as described in formula **1**.

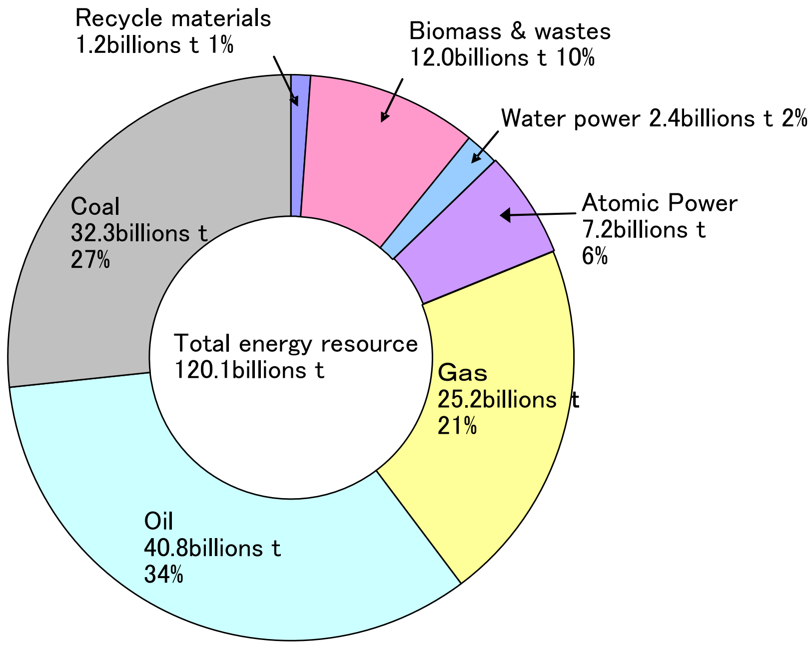
The overall process via this reaction route is governed by Hess's total heat conservation principle, according to which heat generation is determined by the state of the thermal reaction at its beginning and end, independent of the intermediate reaction routes involved. Therefore, if any elementary reaction of water occurs, water itself will not be directly involved in the production of combustion energy as long as an energy balance is maintained. The combustion theory indicates that water will not be directly involved in the reaction.

6. Benefits of emulsion fuels

Carbon dioxide emissions have been of vital concern globally because its reduction is critical to preventing global warming and saving humanity from the looming catastrophe. The "enemy" of this objective is our practices of fossil fuel consumption for sustaining our energy-intensive human lives. The data for 2007 show that fossil fuel consumption accounts for 82% of total energy consumption with the portions of coal and natural gas at 27% and 21%, respectively, while the rest includes nuclear energy (6%), biomass and waste (10%), and hydraulic power generation (2%). (Source: OECD/IEA; World Energy Outlook, 2009 Edition) The contribution of alternative energy technologies, such as photovoltaic and wind power generation, apparently remains slight, accounting for less than 1% of total consumption (Fig. 2). Therefore, the portion of petroleum, or fossil fuel minus coal and natural gas, is 34% of the total energy consumption globally. Fossil fuels, the overwhelming 82 percent portion of energy, are widely burned for energy conversion in manufacturing, processing and power plants, vehicles including automobiles, vessels including tankers and fishing boats, and garbage incinerators around the world.

To more familiar examples, greater consumption of oil products for greenhouses, fisheries, and residential heating have placed very serious financial problems on farmers, fishermen, and the public. Thus, the impact of energy consumption ranges from industrial base structures to leading industries. Clearly, more efficient use of fossil fuels is one of the most urgent challenges for humanity in order to conserve energy resources, prevent global warming, revivify industry, and increase productivity relative to cost. Emulsion fuel technology is considered one of the most promising solutions to the conservation of fossil fuels. To date, many different attempts have been made to put the technology into commercial use, although they have failed to yield reliable and reproducible performance.

Fig.2: Energy consumption diagram



7. A manufacturing process for emulsion fuels

The manufacturing process for emulsion fuels is not straightforward; you cannot produce the fuel simply by putting together water and fossil fuel. You need to generate a dispersion of oil and water droplets with very small particle sizes. High-grade emulsion fuels are produced when the particle sizes of the components are distributed down to the orders of microns or submicrons. These particle sizes are obtained when mixed with high-speed blades rotating at 3,000 to 4,000 rounds per minute or in a centrifugal mixer. The dispersion of fine water and oil droplets, which are inherently mutually immiscible, is very unstable and goes back to the initial condition of the two-phase mixture over time. This phase separation phenomenon makes it difficult to accurately evaluate combustion efficiency for individual emulsion fuels. Since the phase separation phenomenon gradually proceeds over time, the combustion efficiency of the particular fuels involved varies depending on the time when the combustion experiment is performed. Now, the most urgent problem is how phase separation can be avoided to produce optimal emulsions and how the emulsified condition can be stabilized during a longer period. Currently, ultrafine emulsion fuel products are available, although there has not been any technology to maintain the products in a stable emulsified state. Emulsifying agents may be added to protect oil and water droplets in order to maintain the emulsified suspension. The development of these agents, however, is still in the fledgling stage and presents several challenges, including the possible effects on combustion.

A recently developed innovative emulsifier, the Emulsionizer, (Fig. 3), has successfully overcome the problems of conventional emulsifiers by featuring unique and new capabilities: a pressurizing centrifugal pump that entrains gas (Fig. 4), valves to generate microbubbles (Fig. 5) and a liquid circulation system. The centrifugal pressure pump efficiently promotes emulsification using cavitation resonance,* which provides shear and impact forces using agitation, compression, and centrifugation. A novel technology, the microbubble generating valve reduces the particle sizes of oil and water droplets and emulsifies them to a higher level by blowing the droplets through a ultrafine nozzle. The liquid circulation system delivers a higher level of emulsification, which is not achievable through a single passage of this emulsification process. The continued circulation helps maintain the optimum emulsified condition and satisfactorily compensates for the emulsion fuel's shortcoming, i.e., the tendency for phase separation.

Fig. 3 Emulsionizer

Fig. 4 Pressurizing centrifugal pump

Fig. 5　Microbabble generator

8. Conventional emulsification/dispersion device

The emulsifiers/dispersers have been essential equipment for processing foods, cosmetics, and chemicals for a long time. Emulsification/dispersion techniques include mechanical and chemical processes, including phase-transfer and liquid crystal emulsification and some methods using component solubility.

In general, mechanical forces are mobilized to emulsify or disperse particles via shear, impact, cavitation, and friction forces. Emulsifiers/dispersers include agitators, vacuum emulsifiers (e.g., Homo-Mixer®), homogenizers, colloid mills, and ultrasonic homogenizers.

1) Dispersers are mainly used to disperse subjects with its low-speed rotating blades. The applications including emulsification, for which particle size reduction is required, are precluded for their use.
2) Vacuum homogenizers (e.g., Homo-Mixer) are the most common emulsifiers. They are equipped with high speed rotating blades, which cause shear, impact, cavitation, and/or friction forces between the blades and the stator to reduce particle sizes.
3) Homogenizers emulsify the liquid by blowing the pressurized liquid through an ultrafine nozzle and sometimes combining the collusion of the liquid with a wall or between itself. As well vacuum homogenizers, they have been long used for the applications where particle size reduction is required, including manufacturing dairy products.
4) Colloid mills are composed of a fixed portion and high-speed rotating disk. They emulsify materials by crushing with a mechanism similar to a millstone, which serves as a kind of prototype for this kind of emulsifier.
5) Emulsifiers such as the Nanomizer® and Microfluidizer® are classified into the homogenizer category. Materials are ejected through the ultramicroscopic pores of a diamond nozzle for

emulsification under a high pressure of up to 300 MPa. The resultant liquid has a mean particle size reduced to submicron levels. The equipment is used for manufacturing cosmetic creams and emulsion fuels.

6) Microbubbles occur when ultrasonic waves are applied to a liquid. The negative pressure of the ultrasonic waves generates bubbles in the liquid, while the positive pressure crushes the bubbles. The alternating cycles provide significant agitation. Novel emulsifiers/dispersers that build on this ultrasonic property have been developed and are now being tested for industrial use in emulsion fuel production.

Conventional emulsifiers based on mechanical force have several challenging problems yet to be solved, among them the phase separation phenomenon of emulsified components. More recently, an emulsifier product called the Emulsionizer has been marketed commercially, which may solve the challenges associated with emulsified suspensions. The device features a pump that causes cavitation resonance and microbubble effects and a pump-driven circulation system.

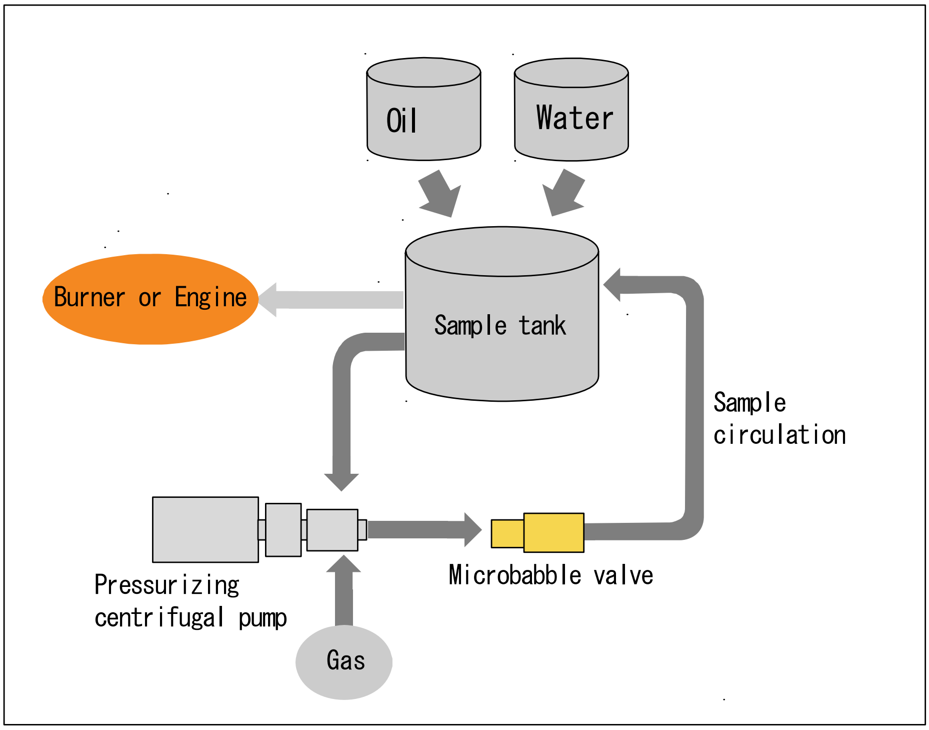
These unique features have proved their usefulness in the applications for beverage, food, and cosmetic product manufacturing, although its most promising application would be emulsion fuel production. The innovative emulsifier is characterized by (1) elimination of the need for stabilizing or emulsifying agents, (2) a circulation system that maintains a continuously optimal emulsified condition and avoids any phase separation phenomena inherent in emulsion during operation, (3) gas-induced cavitation resonance that enables the device to yield a large amount of uniform and high quality emulsion during a limited time period (150 l of emulsion is prepared within ten minutes using a 3.7 kW pump), (4) a microbubble generating valve capable of adjusting particle sizes within a range from 1 to 30 μm, and (5) compact and relatively inexpensive equipment that may contribute to a reduction in emulsion product manufacturing costs in combination with versatility, operability, and cleanliness. If an emulsifier with these technological advantages is sufficiently downsized for installation in a vehicle, there will be greater expectations for bringing emulsion fuels to engines for industrial use.

9. Characteristics of the new emulsifier, Emulsionizer

A schematic is provided in Fig. 6 to show the features and structure of the Emulsionizer.

The emulsifier comprises a pressurizing centrifugal pump, a microbubble generating valve, and s liquid circulation system that circulates the liquid between the storage tank and pump. Different emulsification mechanisms work along the following process sequence in the different sections of the device.

Fig. 6 Emulsion process of Emulsionizer



Process 1

The new emulsifier is equipped with a special high-pressure centrifugal pump that is able to entrain gas with the liquid up to 30% by virtue of its lifting pressure and to then transfer them together to a pump case. The performance of the pump is described together with the comparison to conventional pumps in Tables 1 and 2. The pump independently mixes gas into the liquid using a kind of aspirator mechanism when it pumps the liquid to the pump case, where steady state cavitation is achieved when the gas-liquid mixture is dispersed by the high-speed rotating blades (impellers). The steady state is interpreted as achievement of cavitation resonance.* When the gas volume changes, the steady state collapses and the resonance condition disappears. As long as the resonance persists, however, compression, centrifuging, dispersion, and shear forces effectively promote emulsification.

Table 1 : Performance of the pump

Lifting height	Power	Pump out	Efficiency
m	kw	L/min.	%
23	1.06	193	68.4
33	1.35	183	73.1
43	1.62	162	70.3
53	1.92	143	64.5
63	2.25	129	59.0
73	2.53	109	51.4
83	2.95	91	41.8
93	3.41	77	34.3
103	3.82	60	26.4

Table 2 : Comparison to conventional pumps

Pump	Power	Rotation	Bore of pump	Stage	Pump performance		
					Pump in	Lifting height	Pump out
	kw	rpm	mm	S	m3/min.	m	m3/min.
New pump	5.5	3600	40	1	0.246	92	0.249
Usual pump	5.5	3600	40	3	0.11	92	0.16

Process 2

When cavitation resonance is achieved, the difference in compression ratio* between the gas and liquid increases static pressure from 0.15 MPa up to 0.6 MPa (3.7 kW in three phases, 200 V, pipe size of 1 inch, impeller diameter of 12 cm). Once discharged from the pump outlet, the gas-liquid mixture reaches the venturi pipe of the microbubble generating valve at a flow rate of 150 l/min. Microbubbles occur in the valve according to Bernoulli's theorem.* In addition, once the liquid approaches the nozzle orifice of the needle-shaped gate valve, the subject liquid is violently blown out through the tapered valve nozzle orifice. The blowing off further reduces particle size and emulsifies the liquid. The characteristic of this process lies in that the liquid is directly introduced into the pump casing for direct emulsification. In addition, the microbubble generating valve will provide a higher quality of emulsification. The overall emulsification system of the Emulsionizer is, therefore, distinctly superior to conventional systems. Note that similar emulsification mechanisms also work when the system does not involve any gas.

Process 3

A single passage through the pressurizing centrifugal pump and the microbubble generating valve will not always achieve the sufficient level of emulsification. To compensate for the insufficiency, a system is incorporated that repeatedly circulates the liquid through the high-pressure centrifugal pump. Unlike the batch system, the circulation system raises the emulsification to the highest level. In addition, the system allows operators to flexibly select emulsification levels. As long as the circulation continues, the emulsification will be raised and maintained at the highest level. The system, therefore, offers a distinct advantage in avoiding the phase separation phenomenon inherent in emulsification to conserve the best emulsification.

Thus, the new emulsifier, the Emulsionizer, provides a unique and innovative emulsification capability by integrating the pressurizing centrifugal pump for a gas/liquid mixture, a bubble generating valve, and a circulation system. The pump technology has been patented in nine countries. The valve technology is also under review for a patent in Japan. The circulation system for emulsification is being brought within the Patent Cooperation Treaty (PCT) procedures. Note that the emulsifying system enabling gas/liquid mixture has been developed under the non-exclusive license granted by the inventor, Yonehara Giken Co., Ltd.

10. Promising applications of the Emulsionizer

The unique emulsification mechanisms provide the circulation-type emulsification pump system, the Emulsionizer, with the potential to develop versatile applications. First, it might be successfully used in the production of beverages. For example, the system more easily produces carbonated drinks by mixing carbon dioxide with water than conventional manufacturing processes. Similarly, it may be very useful in producing oxygenated water, hydrogen peroxide water, and ozonated water. The system emulsifies liquid-liquid mixtures as well as liquid-solid mixtures and, therefore, would be able to find successful applications in producing and/or processing cosmetics and food products. For example, it may prove to be useful in producing milky lotions and other cosmetic products, as well as salad dressings and homogenized milk. The most promising application for which its technological potential, however, would be that of emulsion fuels. Although emulsion fuel production involving fossil fuel, water, and air is relatively easy, the social implications exceed our expectations. The Emulsionizer would further improve the combustion efficiency of emulsion fuels, eventually resulting in significant conservation in fossil fuels, energy efficiency, reduction in carbon dioxide emissions, and a contribution to the abatement of global warming.

11. Impact of the Emulsionizer on the future of the emulsion fuels

The advent of the innovative emulsifier, the Emulsionizer, is opening up a new perspective for emulsion fuels. The technology may be applied to expand the emulsion fuel concept from the conventional fossil fuel-water mixture fuel to a gas-fossil fuel-water mixture. Not only air, but oxygen and hydrogen, can possibly be emulsified to form a new type of fuel. The future developments of this innovation will become the attentive focus of the industrial community. In addition, there is an emerging possibility that not only conventional fossil fuels, including gasoline, light oil, heavy oil, kerosene, and waste oil, but biofuels including ethanol and butanol will be used for emulsion fuels. Another possibility is a new type of mixed fuel made of emulsified fossil and biofuels. The new story appears to be never ending.

As new emulsion fuels are developed, the Emulsionizer will have to be tested for combustion performance. Now, analytical studies on the Emulsionizer are underway to estimate the emissions of COx, PM, and NOx discharged when the fuel supplied by the emulsifier shifts from the ideal complete combustion to incomplete combustion. An experimental study is also planned that will directly evaluate actual fuel efficiency for individual emulsion fuels by installing the Emulsionizer on the fuel tank of a combustion furnace. Currently, burners and nozzles, which are directly involved in the combustion of emulsion fuels, tend to focus on the research and development efforts since the fuels experience phase separation over time. The Emulsionizer emulsifier may serve as a pivotal point, which will encourage the efforts to come back to the combustion of emulsion fuels.

Epilogue

In the context where the topics of resource conservation, energy efficiency, emission control, and alternative energy resources such as ethanol or the butanol have attracted greater attention, the Emulsionizer seems to be very promising in terms of emulsion fuel production. Now, the newly available unique emulsifier is being tested for potential capabilities of creating unique emulsion fuels.

Table 1 Performance of the pump

Table 2 Comparison to conventional pumps