Kinematic Viscosity of Mechanically Emulsified A-Heavy Oil

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Abstract

Kinematic viscosity of the emulsified A-heavy oil, produced mechanically by a gear pump type mechanical emulsifier, was examined. The effects of some conditions for emulsification; the temperature, the content of water and the revolution of driving gear of the emulsifier, on the kinematic viscosity were studied experimentally. The present study revealed some important dependence of the kinematic viscosity on the running conditions of the gear pump type mechanical emulsifier. The kinematic viscosity increases with increases in the water content and in the gear revolution, but decreases with increase in the temperature of emulsion.

Key Words: *W/O type emulsion, Gear pump mechanism, Kinematic Viscosity, A-heavy oil*

1. INTRODUCTION

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 and of the prevention of atmospheric 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 protection of environment.

The kind of emulsion fuels, consisting of usual petroleum 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 petroleum fuel. On the other hand, O/W type emulsion fuel has, inversely, dispersed many fine petroleum fuel particles in the water phase.

Many excellent studies on the combustion of emulsified petroleum fuels in furnaces have been reported experimentally[1-4,8-17,21-23,25-32,34,37,38,41] and theoretically [5-7,11,35]. From the point of view of fire hazard prevention also, some studies have reported the pool burning characteristics of emulsified petroleum fuels[10,15, 18-20, 24, 36]. An excellent review by Kadota and Yamasaki has reported the recent advances of the study on the emulsion combustion[40]. In the recent decade, some studies have reported the new technology for the emulsification of miscellaneous fuels[33,39,41,42].

Since over twenty years ago, Nakayama has devised and improved successfully an excellent mechanical emulsification device using a gear pumping mechanism consisting of some specified gears, which is described in his patent[43]. This mechanical emulsification device gives a strong shear stress to the mixture of water and petroleum 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 petroleum fuel, and some of them become extremely fine (less than about 10 μm in diameter), which cannot be attained by the usual mechanical methods of mixing, atomizing or both. This mechanical emulsification device has enabled also the new recycling fuel technology for some waste oils (from machine and food) in boilers and many combustion furnaces.

Our previous paper has reported some important performance of the gear pump type emulsification device including the stability of emulsions of A-heavy oil and gas oil[44]. Now the kinematic viscosity of emulsified fuel also is an important property for the characteristics of sprayed fuel jet into many combustion furnaces. In general, the decrease in the kinematic viscosity of fuel leads to the wide-angle spray area and the short length of fuel jet from the exit of nozzle. On the other hand, the increase in the kinematic viscosity of fuel leads to the long length of fuel jet from the exit of nozzle although the spray area angle will decrease. The present study reports the kinematic viscosity of the emulsified A-heavy oil, produced by the gear pump type mechanical emulsifier[44].

2. GEAR PUMP TYPE EMULSIFIER

The concept and the outline of the three gears pump type mechanical emulsifier used in this study are described in our previous paper[44]. Figures 1 and 2 show the top and the side views of the present gear pump type emulsifier, where the first gear is driven directly by motor at 300~1300 rpm. This emulsifier has a series of 3 gears: the diameters of gear tip circle and pitch circle; 27.5~22.5 mm and 25~20 mm respectively, the numbers of teeth; 20~16, the modules of gears; 1.25~1.23, the teeth length in the axis direction of gears; 40 mm.

The clearance between the gear tip and the housing wall; 0.05 mm for the first gear, 0.5 mm at one side of the second gear, about 0.15 mm at one side of the third gear and about 0.4 mm at the opposed side of the third gear. Owing to the very strong shear stress in the wider clearances around the second and the third gears, the fuel and water are mixed and emulsified.

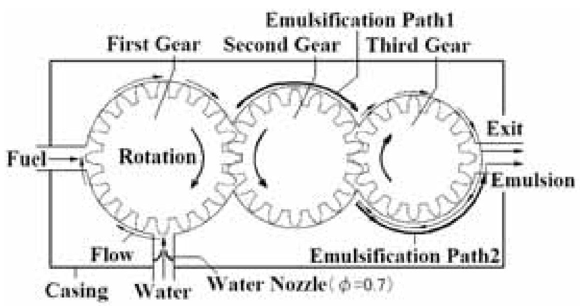

Fig.1 The scheme of top view of mechanical emulsifier (3-gears type) in this study.

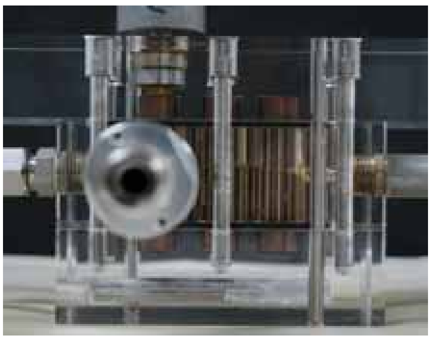

Fig.2 The side view of mechanical emulsifier (3-gears type) in this study.

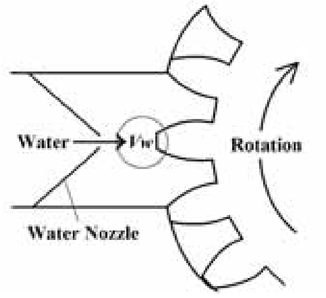

Fig.3 Scheme of the water injection (Velocity: V_w) from the fine exit of nozzle to the first gear for the emulsification.

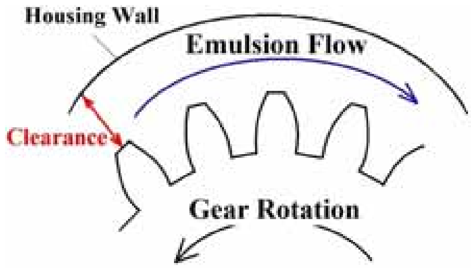

Fig.4 Schematic model of the emulsification region in the clearance between the gear teeth and the housing wall.

Fig.5 Representative photograph of emulsified A-Heavy oil (Water: 6 vol.% for Fuel, 800 rpm).

In the present mechanical emulsifier, water is transported by water pump and injected at high speed (9~13 m/s) from the fine exit hole (0.7 mm in dia.) nozzle toward the first gear aiming to enhance the emulsification effect, as shown in Fig.3. Fig.4 shows the schematic model of emulsification region in the wider clearance (Emulsification Path shown in Fig.1) between the gear tip and the housing wall.

In this wider clearance (Emulsification Path shown in Fig.1), the mixture of fuel and water is transferred (by the pressure due to the revolution of the first gear) in the opposite direction to the revolution of gear.

Although the theoretical explanation of this emulsification mechanism is not easy and cannot be given in the present stage, it should be noted that there is no other region for the emulsification except this wider clearance, where the very strong shear stress exists. We can expect thereby that the increase in the revolution of gear will enhance the stability of emulsion.

A typical W/O emulsified A-heavy oil is shown in Fig.5, where the water content is about 6 vol.% for A-heavy oil. As shown in this photograph, the color of W/O type emulsified A-heavy oil become whitish compared with that of the original fuel.

3. KINEMATIC VISCOSITY

The kinematic viscosity of the w/O type emulsified A-heavy oil in this study was measured by usual Cannon-Fenske Viscometer, shown in Fig.6. By the elapsed time of flow down of emulsion (T), from A to B shown in Fig.6, and the characteristic viscometer constant (C), the kinematic viscosity (ν) of emulsified A-heavy oil can be estimated as follows;

$$\nu = \mu/\rho_m = CT \qquad (1)$$

where μ is the viscosity of emulsion, and ρ_m is the density of emulsion.

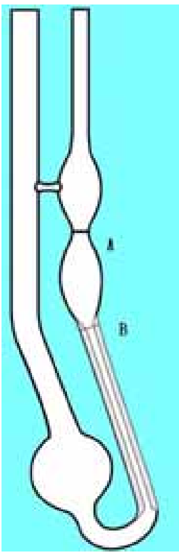

Fig.6 Cannon-Fenske Viscometer.

Figures 7, 8 and 9 show the effects of the temperature, the water content and the revolution of the first gear on the kinematic viscosity of the w/o type emulsified A-heavy oil respectively.

The density of emulsion (ρ_m) may be expressed as follows, using the ratio of water in emulsion (W);

$$\rho_m = \rho_A(1-W) + \rho_w W \qquad (2)$$

where ρ_A is the density of A-heavy oil (0.85 g/cm^3), and ρ_w is the density of water (1.0 g/cm^3).

At the standard state (20^{o}C), the kinematic viscosities (ν) of water and A-heavy oil are about 1.0 (mm^2/s) and 5.2 (mm^2/s) respectively. From the result shown in Fig.7, in addition to the temperature dependence, we can see an interesting and important result that the kinematic viscosity of W/O type emulsified A-heavy oil is slightly higher than that of original A-heavy oil.

According to the Eq. (1), the viscosity of emulsion also must increase simultaneously with increase in the density of emulsion, which increases with increase in the water content according to the Eq. (2). Thus, the kinematic viscosity of emulsion will increase slightly. This may be attributable to the existence and the motion of many fine water particles.

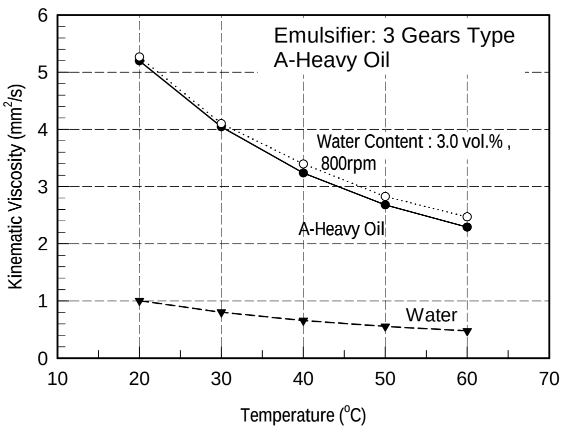

Fig.7 Effect of Temperature on the Kinematic Viscosity.

From the results shown in Figs.8 and 9, we can see clearly that both the increase in the water content and the increase in the gear revolution increase the kinematic viscosity of emulsion.

The increase in the water content means the increase in the number of fine water particles in emulsion, shown in Fig.10, and the increase in the gear revolution will lead to the strong smash of water particles in the emulsification path, shown in Fig.1, and to the extremely finer water particles in the emulsion (Fig.10).

Thus, both the increase in the water content and the increase in the gear revolution will increase the contact surface area between the water and the hydrocarbon fuel.

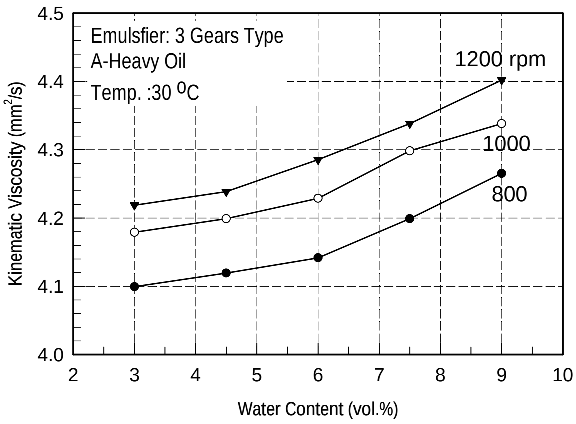

Fig.8 Effect of Water Content on the Kinematic Viscosity

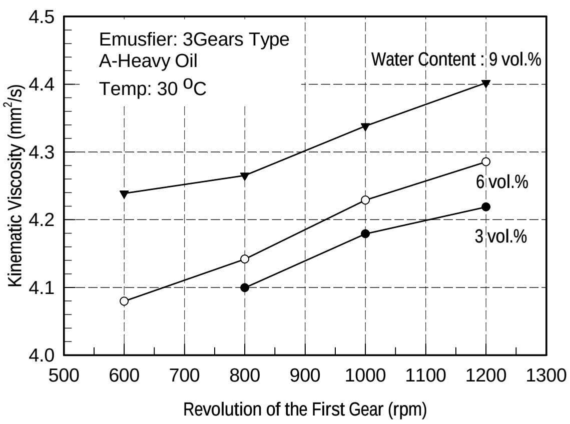

Fig.9 Effect of Revolution on the Kinematic Viscosity.

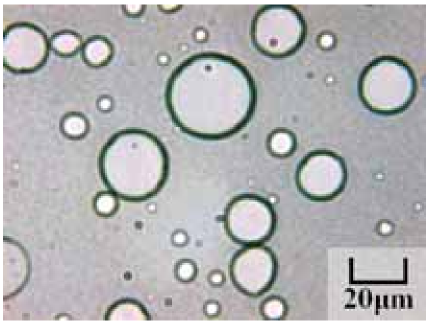

Fig. 10 Microscopic Photograph of Water Particles in the Emulsified Gas Oil (Water: 9 vol.%, 800 rpm).

The increase in the contact surface area will increase the kinematic viscosity of W/O type emulsion. We can find many reports through the Internet, referring the increase in the kinetic viscosity of emulsion due to the increase in the water content and to the decrease in the size of water particles.

4. CONCLUDING REMARKS

For the kinematic viscosity of the W/O type emulsions of A-heavy oil, produced by the gear pump type mechanical emulsifier without surface-active agent, the present study revealed some interesting and important characteristics as follows;

(1) The kinematic viscosity of W/O type emulsified A-heavy oil is higher than that of original A-heavy oil, which may be due to the existence of many fine water particles.

(2) Both the increase in the water content and the increase in the gear revolution increase the kinematic viscosity of W/O type emulsified A-heavy oil.

(3) The increase in the kinematic viscosity of W/O type emulsion may be attributable to the increase in the contact surface area between the water and the original hydrocarbon fuel.

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