

Study on the Operational Results of a Marine Diesel Engine Using Water Emulsified Fuel from the Marine Engineer’s Aspect

by Satoshi Yamamoto** Itirou Kanda**

The marine diesel engine using water emulsified fuel was operated in a diesel engine plant for the electric generator on Training Ship "Nippon Maru".

This practical operation was carried out 2,063 hours of total running.

However, several problems such as the lack of response performance to rapid increase of electric load and difficulty in disposal of leaked emulsified fuel from fuel injection system, occurred in this operation.

Further more, the influence of emulsified fuel to the constituent parts of diesel engine was investigated when it was overhauled and the followings were found:

1) On the case of using emulsified fuel, the opening pressure of injection valve lowered always in comparison with using marine diesel fuel.
2) Slight abnormal wear was observed at the fuel injection nozzle and pump plunger.
3) Glassy white deposit and wrinkled traces which were caused by the water contained contained in emulsified fuel were found on the piston head.

1. Introduction

Countermeasures on the environmental disruption issues on the global basis have been discussed earnestly, and new regulations are specified on the air pollution caused by the exhaust gas from ships by the IMO (International Maritime Organization) similar to the regulations on the marine pollution. Regarding the emission of nitrogen oxides (hereinafter, referred to as NOx) to be restricted by the regulations, the technology for reducing the emission has been developed actively toward 2000 in which the regulations will substantially come into force.

A variety of the NOx reducing methods are available including a method of the laminated water injection system which was jointly studied with the Institute for Sea Training (hereinafter, referred to as "Institute") of the Ministry of Transport on board the Training Ship "Ginga Maru" in the past. At the same time, the system in which the water emulsified fuel (hereinafter, referred to as emulsified fuel) with water diffused in fuel oil is burned, has also been developed, and many reports were made on the results of the tests on the shore. Since no verification studies have been made on board ships, and the verification was made on board the Training Ship "Nippon Maru" of the Institute, in which the emulsified fuel manufacturing device is mounted on the diesel engine for the electric generator No. 3 (the medium speed marine diesel engine, hereinafter, referred to as "diesel engine").

2. Test apparatus

2.1 Particulars of diesel engine and electric generator

Table 1 shows the particulars of the diesel engine and the electric generator.

2.2 Emulsified fuel manufacturing device

The SEKIEMAR SP300A (manufactured by Sekiguchi) was used to manufacture the emulsified fuel. This device comprises a mixing unit, a proportional water pouring unit, an additive pouring unit, a supplementary water tank, a control panel unit, etc. Fig. 1 shows the piping diagram after attachment to the fuel oil system.

The excessive fuel generated during the normal operation is returned to the A-oil service tank. When the A-oil is changed to the emulsified fuel during the test, the piping is changed to be returned to the suction side of the FO booster pump so that the emulsified fuel is not mixed in the A-oil service tank. Only this part is additionally changed in the piping for the test.

2.3 Test method

The test was carried out during the training navi-
gation of about one year including the ocean navigation to Hawaii islands over two months with the actual facilities while the modification of the diesel engine side was limited to only a part of the fuel piping. The total running time using the emulsified fuel was 2,063 hours.

During the test, the measurement was made on the NOx concentration, etc. in the exhaust gas, the inspection of combustion products, etc. by overhauling the engine before starting and after completing the test, and various parts.

These results were considered, and the contents including the problems on the operational control for the practical application of the operation with the emulsified fuel are reported below.

3. Measurement of NOx in using emulsified fuel

After the emulsified fuel manufacturing device was installed in October, 1996, the operation using the emulsified fuel (hereinafter, referred to as the “measurement operation”) was achieved to determine the running condition not to trouble the long-term operation of the diesel engine in the beginning, and to examine the influence on the concentration of NOx and CO in the exhaust gas and the ignition lag in the subsequent running condition.

The loads on the electric generator (the percentage with respect to the electric generator capacity of 400 kW) were set to 25%, 50%, and 75%, and the water addition ratios to the respective loads (the volumetric ratio of water to be mixed to water of 100) were set to 0%, 20%, 30% and 40%.

In general, the operation using the emulsified fuel with high water addition ratio has been regarded as an extremely effective NOx concentration reducing method except the low load area1). Also, in this test, the temperature of the exhaust gas was dropped by about 10-15℃ during the operation using the emulsified fuel, and reduction of the NOx concentration was also confirmed as shown in Fig. 2. This figure also shows that, regarding the rise of the water addition ratio in the low load area of 30% or under, the NOx concentration is higher than the water addition ratio of 0% except the water addition ratio of 40%, or rather in the rising trend. It is estimated that, in such a low load area, the ignition lag during the combustion by the emulsified fuel is more influential than the NOx reduction effect by the

![Fig. 1 Fuel piping plan of test apparatus](image)

![Fig. 2 Relationship between load factor and NOx concentration according to water addition](image)

<table>
<thead>
<tr>
<th>Table 1 Particulars of Diesel engine and electric generator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of diesel engine</strong> : DAIHATSU 6DS-18AN 4-cycle with turbocharger, single acting, 6-cylinder combustion system : direct injection type</td>
</tr>
<tr>
<td><strong>Fuel oil</strong> : A-oil mono-fuel combustion</td>
</tr>
<tr>
<td><strong>Inside diameter X stroke</strong> : 180 mm X 230 mm</td>
</tr>
<tr>
<td><strong>Output X number of revolution</strong> : 441 kW (600PS) X 900 rpm</td>
</tr>
<tr>
<td><strong>Maximum pressure</strong> : 11.28 MPa (115 kgf/cm²)</td>
</tr>
<tr>
<td><strong>Indicated mean effective pressure</strong> : 1.68 MPa (17.09 kgf/cm²)</td>
</tr>
<tr>
<td><strong>Compression ratio</strong> : 16.3</td>
</tr>
<tr>
<td><strong>Top clearance</strong> : 15 mm</td>
</tr>
<tr>
<td><strong>Piston seed</strong> : 6.9 m/s</td>
</tr>
<tr>
<td><strong>Suction valve opening (closing)</strong> : 80 (35) degrees before TDC (after BDC)</td>
</tr>
<tr>
<td><strong>Exhaust valve opening (closing)</strong> : 50 (60) degrees before BDC (after TDC)</td>
</tr>
<tr>
<td><strong>FO injection timing</strong> : 16 degrees before TDC</td>
</tr>
<tr>
<td><strong>FO valve opening pressure</strong> : 29.4 MPa (300 kgf/cm²)</td>
</tr>
<tr>
<td><strong>Diameter (number) of FO injection nozzle</strong> : about 0.2-0.3 mm (concentric 8)</td>
</tr>
<tr>
<td><strong>Model of electric generator</strong> : Brushless, drip proof type, manufactured by Shiniko Electric Co., Ltd. TVU-4-686 AC60C/S 450 x 500 kVA (400KW)</td>
</tr>
</tbody>
</table>

---

February 2001
temperature drop of the combustion flame. It is also proved from the combustion pressure diagram in the cylinder in Fig. 3 that the ignition lag is increased by the increase of the water addition ratio under the constant load, and the CO concentration in the exhaust gas is rapidly increased when the load reaches 50% or under as illustrated in Fig. 4, and its trend becomes remarkable as the water addition ratio is increased. The increase in the CO concentration is an index to indicate the defective combustion, and in summing up, it is proved that the operation using the emulsified fuel in the low load area is not suitable at any water addition ratio.

The load on the electric generator means the power load to be consumed onboard the ship, which is fluctuated according to the time zone, and is not always constant due to the presence of the equipment in the engine room to repeat the stop/start, and due to the change in the navigational condition and the life pattern of the crew. Taking into consideration these factors, the water addition ratio in the full operation was decided to 30% which is relatively small in influence on the diesel engine against the fluctuating load in an extensive range, and effective in reducing the NOx concentration.

In addition, the additive was poured in the emulsified fuel. This was poured for the purpose of promoting and maintaining the unification of the properties, and keeping the lubrication effect in each parts of the fuel system2), and the pouring ratio was set as the volumetric ratio to the emulsified fuel.

3.1 Full running condition of emulsified fuel

Based on the results of the above-described analyses, the emulsified fuel running conditions in the full running operation to examine the influence on the components of the equipment (hereinafter, referred to as "full running") are as follows.

1. The electric loads are 200 kW (50%) to 300 kW (75%) in principle, and the loads shall be stable. (For example, the unstable loads in leaving/arriving conditions shall be avoided.)
2. The water addition ratio shall be constant at 30%.
3. The additive pouring ratio shall be constant at 0.5%.

3.2 Precautions in operation

In achieving the full running using the emulsified fuel, the precautions predicted from the results of the measurement operation were determined as follows.

1. When the emulsified fuel running is completed, the operation of the diesel engine is continued for about one hour even after the switching operation in order to sufficiently switch the A-oil in the fuel oil system.
2. In addition to the monitoring of the regular operation of the diesel engine, the drain is removed from the bottom part of the secondary filter of the fuel oil system one a day, the drain is separated to remove water settled therein, and the emulsifying condition of the emulsified fuel.
3. When the power load is out of the emulsified fuel running condition, the fuel is switched to the A-oil if the power reaches 200 kW or under, or the other diesel engine is started to achieve the parallel running if the power reaches 300 kW or over.

4. Full running operation of emulsified fuel

4.1 Operational schedule and maintenance

Three sets of diesel engines are equipped on board Nippon Maru for electric generators, and the annual operational schedule of each diesel engine is substantially uniformly divided into three parts (about 2,900 hours). The electric generator No. 3 served for the test was also operated following the regular schedule. The regular maintenance work was also achieved with the normal maintenance intervals.
4.2 Events in full running operation
Various events (troubles) occurred during the full running using the emulsified fuel, and major two ones are as follows:

4.2.1 Power loss (black out)
The ratio of the fuel oil in the emulsified fuel is 77% \( (=\frac{100}{100+30}) \) of the total discharge by the fuel injection pump in the case of the water addition ratio of 30% in the test, and is 23% reduction with respect to the original fuel discharge. Thus, the increase in capacity of the fuel injection pump was considered. Based on the estimation from the affordability of the capacity and the load in the peak power consumption, the capacity was judged to be sufficiently affordable on the operational control under the load limit of 300 kW.

However, during the navigation, the influence of the starting current on the electric generator is large when the large motor is started/stopped, and in addition to the air-conditioning timing with much power consumption on board the ship, the power load was unexpectedly and temporarily higher. As a result, the governor of the diesel engine was operated and the fuel injection pump was operated to the limit of the torque limiter to maintain the engine speed of the diesel engine; however, in the actual condition, the fuel became insufficient as described above, the engine speed could not be maintained, the protective system was operated, leading to the power loss (black out).

Fig. 5 show a graph to indicate the relationship between the load on the diesel engine measured during the continuous operation using the emulsified fuel in the ocean navigation and the rack scale of the fuel injection pump. The solid line indicates the relationship during the A-oil mono-fuel combustion, while the broken line indicates the plotted data during the operation using the emulsified fuel. The load on the diesel engine shown by the axis of abscissas corresponds to the onboard power load, while the rack scale of the axis of coordinates can be converted into the change in the fuel discharge of the fuel injection pump (the discharge is increased if the scale is increased), and thus, the difference in the rack scale between the solid line and the broken line on the graph at the same load is substantially equivalent to the quantity of water addition, and it is thus shown that the rack scale of 23 mm equivalent to the load of 100% can cope with only about 75% of the load (300 kW).

The power load at that time was temporarily above 350 kW. The spare diesel engine for the electric generator was immediately started without any further trouble. This is attributable to the result that the operation was started without any countermeasures such as the increase in capacity of the fuel injection pump. The manual for countermeasures such as the reinforcement of the monitoring of the operation and the stop of the power supply to the equipment low in importance when the power load is high was additionally prepared, and the operation was continued.

4.2.2 Swelling of oil in waste oil tank
Leakage of oil from the fuel injection valve during the full running using the emulsified fuel was supported to be treated together with the waste oil containing water in the engine room.

In the general treatment method of waste oil onboard ships, the waste oil generated mainly in the engine room is collected in the waste oil tank, and heated with steam, etc., the water is evaporated to increase the oil concentration, and the waste oil is incinerated in the incinerator, etc.

Also, in this case, the waste oil was heated as usual; however, the trouble occurred, in which the oil level in the waste oil tank rose instantaneously and abnormally,
the waste oil overflowed the waste oil tank, and flowed into the waste oil incinerator room.

When the waste oil is heated in the conventional basic operating method onboard ships, there is a trend that the level rises due to the swelling of water as the boiling of water is started when heated if the liquid high in viscosity such as lubricating oil is mixed. Thus, a sufficient empty space should be ensured in the waste oil tank when the waste oil is transferred, and in this case, a much larger empty space was ensured. Nevertheless, the waste oil overflowed the waste oil tank again. When the full running operation was started, the subsequent incineration works were stopped considering the possibility of the mixing of unexpected foreign matters (other than the conventional waste oil generated onboard) in the waste oil tank.

The emulsified fuel of water-droplet-in-oil type used in this test is of the structure that fine water particles are enveloped by the oil film, and there is a report 3) that water lower in boiling point than the fuel oil is first evaporated and inflated at a stretch when heated. It is told that this phenomenon achieves the excellent fuel oil additive effect as the small explosion effect during the after-burning period in the case of the in-cylinder combustion.

In this test, the additive was poured in order to unify the properties of the emulsified fuel, and it is considered that the water in the waste oil was enveloped and this phenomenon was further amplified. Fig. 6 shows the image of the oil swelling in the waste oil tank. The test to heat the waste oil was carried out on board the ship to confirm the instantaneously bubbling phenomenon when the temperature reaches the boiling point of water. Thus, the leaked emulsified fuel in the Electric generator No. 3 was separated from other waste oils and independently collected, soaked in clothes, and incinerated in the waste oil incinerator.

4.3 Result of NOx concentration reduction

The NOx concentration, etc. in the exhaust gas was measured twice, i.e., before starting and after completing the full running operation as illustrated in Fig. 7, in addition to the measurement operation, confirming that the effect of reducing the NOx concentration is maintained.

5. Influence of the use of emulsified fuel on engines, and consideration thereof

An outline is given on the maintenance works during the full running period, and the results of the engine overhaul inspection before and after the operation. The parts expected to be largely influenced were observed by the cut inspection and by the Scanning Electronic Microscope (SEM) on the running surface. In order to compare the influence of each parts in the use of the emulsified fuel, the parts for the A-oil mono-fuel combustion which were used for a similar period and the new parts which are not used were similarly inspected.

The crystalline phase of the component of the combustion products deposited on each part, and the element were analyzed by the X-Ray Diffraction (XRD) and the Electronic Probe Micro Analyzer (EPMA).

5.1 Fuel injection valve

5.1.1 Drop of valve opening pressure

The fuel injection valve was exchanged and maintained at the interval of about 900 hours in service time as usual. Generally, there is a trend that the valve-opening pressure of 29.4 MPa (300 kgf/cm²) is dropped by about 0.98 MPa (10 kgf/cm²) with the A-oil mono-fuel combustion at the timing of exchange. However, the pressure drop was 1.96 to 2.94 MPa (20-30 kgf/cm²) for 5 maintenance results after the valve was used and exchanged in the emulsified fuel mode, and this pressure drop was larger than that of the A-oil mono-combustion mode. The cause thereof has not been elucidated clearly; however, it is considered that the valve opening period of the fuel injection valve is longer than that in the A-oil mono-combustion mode with the same load since more added water must be ejected during the full running condition. However, no noticeable abnormality was found in the temperature of the exhaust gas during the operation.

5.1.2 Observation of each part after the test is completed

The photos of the inside of the nozzle and the surface and cut of the needle show the trace of promotion of the corrosion on the surface of the nozzle injection holes and oil storage parts of the fuel injection valve used in the test, while no remarkable changes are found in the diameter of the injection holes.
5.1.3 Enlarged photos of internal surface of nozzle

Fig. 8-a is the photo of the surface at the tip part of the fuel injection valve which has never been used, Fig. 8-b is the photo of that of the fuel injection valve used in the A-oil mono-fuel mode, and Fig. 8-c is the photo of that of the fuel injection valve used in the emulsified fuel mode. The machining traces are found on the surface inside the new nozzle substantially orthogonal to the running direction. Damages generated by the running operation of the needle valve were found inside the nozzle in addition to the machining traces in the fuel injection valve in the A-oil mono-fuel mode. Damages in the running direction similar to those in the A-oil mono-fuel mode were found in the fuel injection valve in the emulsified fuel mode. In comparison with the A-oil mono-fuel mode, the machining traces are still left behind though its degree is worse, and the degree of the running damages is small. In the A-oil mono-fuel mode, the A-oil itself achieves the lubrication effect to the running part. On the other hand, the emulsified fuel is more viscous than the A-oil, and the sufficient lubrication effect to the running part cannot be demonstrated. It is thus estimated that the wear of the running part was suppressed since the additive was poured in the emulsified fuel to maintain the lubrication effect.

5.2 Fuel injection pump

As illustrated by the photo of the surface of the plunger in Fig. 9, the gloss of the running part around the notch in the plunger was dull compared with that in the A-oil mono-combustion mode.

5.3 Fuel oil system

Generation of rusts caused by water in the fuel oil piping was feared, but no changes were found through the internal observation by cutting the additionally fitted pipe.

5.4 Turbine blade of turbocharger

 Fouling of the exhaust gas system was feared; however, fouling was less different from that in the normal overhaul inspection, and the degree of deposition of the soot was felt to be rather small. Further, no abnormality was felt in the wetness of the soot.

5.5 Products of combustion

Table 2 shows the result of the analytical inspection of the sampled combustion product of each part when the engine was overhauled. Since the sampling amount was different by the sampling part, the names of the detected elements are listed, and the quantity of the elements is omitted. What is characteristic of each part in comparison with the components identified in

<table>
<thead>
<tr>
<th></th>
<th>A-oil mono-fuel combustion</th>
<th>Water-emulsified fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piston head</td>
<td>C  O  S  Ca  Zn</td>
<td>C  O  S  Ca  Zn  Si  Na  K  V</td>
</tr>
<tr>
<td>Exhaust pipe</td>
<td>C  O  S  Ca  Fe</td>
<td>C  O  S  Ca  Fe  Si  Cu</td>
</tr>
<tr>
<td>Turbocharger</td>
<td>C  O  S  Ca  Fe</td>
<td>C  O  S  Ca  Fe  Si</td>
</tr>
</tbody>
</table>

Table 2 Result of analysis of products of combustion

Fig. 9 Comparative photos of notched parts of plunger
the A-oil mono-combustion mode is that sodium (Na) and silicon (Si) were contained only in the emulsified fuel mode. Further, vanadium leading to the high-temperature corrosion was contained in the piston head part.

5.6 Result of piston overhaul

5.6.1 Piston head

In the visual inspection when the cylinder cover was overhauled, it seemed that the fouling condition by the deposition of the soot on the cylinder cover and the piston head part was less different from that in the A-oil mono-combustion mode (Fig. 10); however, the white substance was deposited on the piston head part of every cylinder along the fuel injection traces (see Fig. 11). The emulsified fuel sprayed from the fuel valve is longer in the combustion time (poor in burning) than that in the A-oil mono-combustion mode, the flame becomes longer and the unburnt part is blown against the piston head part, and thus, the piston head part is exposed to the high temperature. This deposition looks like a glossy and hard glass, and Si and Na are detected from the piston head part according to the component analysis of the combustion product. It is thus estimated that this combustion product was generated through the alternate high temperature and cooling for a long time on the piston head part according to the component analysis of the combustion product. It is thus estimated that this combustion product was generated through the alternate high temperature and cooling for a long time on the piston head part such that the element (Si, etc.) in the emulsified fuel was exposed to the high temperature in the expansion (explosion) process of the combustion stroke, and then, subjected to the rapid cooling in the suction process through the exhaust. Such a phenomenon has never been experienced in the A-oil mono-combustion mode, and since the deposition was very hard and melted, it was very difficult to remove it.

No glassy combustion product was visually identified on the exhaust pipe or the blades of the turbocharger forming the passage of the gas emitted from the cylinder, and little combustion product was found in the analysis of the combustion product, and it seems that the combustion product passed but was not deposited.

In the emulsified fuel used in this test, tap water was added, and it seems that more mixed components such as Si were contained than in the A-oil mono-combustion mode; however, the environment repeatedly subjected to the high temperature and the low temperature is considered to be very influential.

5.6.2 Piston head

After the above-described hard deposited substance was removed, the regular wrinkle-like pattern was found on the metal surface of the piston head part (formed of aluminum alloy). Fig. 12 shows the sketch thereof. These wrinkles were possibly caused by the high-temperature corrosion such as vanadium attack in which the flame of the sprayed emulsified fuel was extended, and touched the piston head part directly, and the surface temperature was locally high. In addition, a part of the piston head of the cylinder No. 5 was found eroded.

Fig. 10 Photos of piston head (A-oil mono-fuel combustion : 2850 hours)

Fig. 11 Photos of piston head (emulsified fuel : 2063 hours)

Fig. 12 Piston head and sketch of wrinkles
5.6.3 Others

The pistons of No. 2 and 5 cylinders were drawn, and various parts were measured; however, no dimensional changes such as abnormal abrasion of each equipment could be confirmed.

5.7 Properties of lubricating oil

During the test period, the properties were analyzed three times. As shown in Table 3, no remarkable changes attributable to the use of the emulsified fuel were found, and the lubricating oil was not affected thereby.

6. Conclusion

The following points were clarified through the above-described examination.

(1) In this test, the operation in the emulsified fuel mode was achieved without any special modification of the diesel engine, and the reducing effect of the NOx concentration measured in the beginning and in the end of the full running operation for 2,000 hours plus was continued, and it is confirmed that each parts of the diesel engine is fully withstandable. However, some signs were partly foreseen, which seem leading to a possible serious accident such as erosion of the piston if the continuous operation for longer time is achieved, and thus, it is necessary in future to change the material for the parts, and the shape of the fuel injection valve and the piston and the design of the structure of the combustion chamber.

(2) Judging from the deposition of the glassy white substance on the piston head of all cylinders and the discovery of the erosion-like traces on a part of the pistons, it seems that the leaked oil from the fuel injection valve reaches the piston head directly, and overheated. It is necessary to take into consideration this point in developing the engine using the emulsified fuel.

(2) Little combustion product was deposited in the combustion chamber and the exhaust gas system (including the turbine). This is considered to be partly attributable to the operational condition that the load is at least 50%.

(3) Corrosion of the fuel oil system was slightly shown in the running part of the fuel pump as generation of damages, and in the fuel injection valve. The degree of corrosion was small, and it is considered that the effect of the additive having the lubricating effect was ensured.

(4) When the emulsified fuel is used in the diesel engine for the electric generator, it is desired that the capacity of the fuel pump be determined taking into consideration the quantity of water to be added, and the capacity be sufficiently affordable.

(5) It is desired to change the system to shorten the time required in replacement of the A-oil in the fuel oil piping when the operation of the emulsified fuel is completed.

(6) It is desired to use distilled water in order to prevent deposition of the elements contained in the water fed to the exhaust system.

(2) Regarding the treatment of the leaked emulsified fuel onboard ships, the simplest and safest method of waste incineration system was adopted this time; however, there is a possibility leading to the marine pollution, etc. if the heating treatment system is adopted, and it is necessary to provide the facility to burn the leaked emulsified fuel directly in the boiler in a separate manner from the other leaked oils. If possible, it is desired to develop a safe, inexpensive and labor-saving system.

(3) It was confirmed that the emulsified fuel manufacturing device used in this test is sufficiently withstandable for the continuous use during the test.

<table>
<thead>
<tr>
<th>Running time (hour)</th>
<th>New oil</th>
<th>442</th>
<th>1409</th>
<th>2063</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic viscosity (40°C, mm/sec)</td>
<td>107.7</td>
<td>99.47</td>
<td>109.69</td>
<td>109.8</td>
</tr>
<tr>
<td>Index of viscosity</td>
<td>100.0</td>
<td>88.0</td>
<td>100.0</td>
<td>106.0</td>
</tr>
<tr>
<td>Total basicity (mg KOH/mg)</td>
<td>10.5</td>
<td>11.0</td>
<td>11.3</td>
<td>9.59</td>
</tr>
<tr>
<td>Water content (ppm)</td>
<td>2146</td>
<td>1112</td>
<td>708</td>
<td></td>
</tr>
<tr>
<td>Carbon (wt.%)</td>
<td>0.9</td>
<td>1.0</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

**Metal (ppm)**

<table>
<thead>
<tr>
<th>Element</th>
<th>New oil</th>
<th>442</th>
<th>1409</th>
<th>2063</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>&gt;3.59</td>
<td>422</td>
<td>449</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>&gt;3.51</td>
<td>332</td>
<td>359</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>&gt;13.0</td>
<td>19.5</td>
<td>37.2</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>&gt;1.8</td>
<td>22.2</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>&gt;13.0</td>
<td>17.2</td>
<td>18.1</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>9.1</td>
<td>15.8</td>
<td>18.9</td>
<td></td>
</tr>
<tr>
<td>Ba</td>
<td>&gt;4.0</td>
<td>3.3</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>&gt;1.0</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>&gt;1.1</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Mo</td>
<td>&gt;1.0</td>
<td>0.2</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Ni</td>
<td>&gt;0.0</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>&gt;0.0</td>
<td>1.1</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>
period as a result of the adjustment of each part though the device is placed in the onboard environment which is severer than the land-based device in oscillation, vibration, salt damage, high temperature, etc.

7. Consideration

One of the conditions for this test was not to cause any troubles in the navigational plan or the maintenance plan since the practical training must be fulfilled. The technology to reduce the NOx concentration by using the emulsified fuel in the diesel engine for the electric generator has been substantially established on the laboratory level, and the targets of this test were as follows:

1. Operation for a long time onboard the ship;
2. Examination of the influence of the long-term continuous operation on the diesel engine; and
3. Verification that the emulsified fuel manufacturing device is adaptable for the severe environment onboard the ship.

Fortunately enough, the satisfactory results could be obtained with the results of at least 2,000 hours, and it is considered significant that the test was carried out using the diesel engine for the electric generator whose load was roughly fluctuated. The author feels happy if the results of this test will be of help to the research and development toward the year 2,000.

The authors express their gratitude to those in the Internal Combustion Engine laboratory, Engine Power Department and the Function Evaluation Laboratory of Material Machining Department of the Ship Research Institute for their advice to the measurement of the NOx concentration in the exhaust gas and the determination of the appropriate research condition, and the cooperation in the analysis of the materials and the observation of the parts, and to the crew onboard Nippon Maru for their cooperation on the implementation of the research.

Literature: (Being omitted)

Questions and Answers:
1) Question: The drain was periodically removed from the bottom part of the secondary filter of the piping system, and what are the frequency and the drain stored a day?

Answer: The drain of about 100 to 150 ml (completely separated into water) was discharged once a day.

2) Question: The switching time from the emulsified fuel to the A-oil was reported to be about 1 hour, and how was the switching judged? What will be the switching time of the fuel oil if the water addition ratio is increased?

Answer: The switching time is defined as the time at which the leaked oil from the fuel injection valve is changed from the emulsified fuel to the A-oil. If the water addition ratio is increased, the quantity of the A-oil to the emulsified fuel at the same discharge rate is decreased; and the discharge rate is increased by increasing the rack quantity (the discharge capacity of the fuel injection pump), and it seems that there is little difference in the switching time of the fuel oil.

Reference
2) Yamashita, et al., MEST Regular Session Autumn (1996) P.18~20