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Actual Capability of Shipboard Fuel Oil Pre-treatment Systems

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Abstract: In recent years, the number of abnormalities with marine diesel engines, which are caused by the poor quality of fuel oil, has been steadily increasing. In particular, abnormal wear of the piston rings and the cylinder liners of the diesel engine causes serious problems for the safety and reliability of the vessel. In such a situation, the role of the on-board fuel oil pre-treatment system is becoming significantly important.

The actual capability of the fuel oil pre-treatment system was investigated and a suitable pre-treatment method of fuel was studied. The test plant of a fuel oil pre-treatment system (5m x 2m x 3m height) that simulated the on-board system was assembled on our shore facility. The test plant was plumbed so that various examinations could be performed. Heavy fuel oils that were actually used on-board were provided for this investigation, and in some cases test dust, sludge from an on-board fuel oil pre-treatment system, water etc. were added to fuel oil if needed. Oil samples from a test plant were analyzed in the on-site laboratory immediately, in order to minimize the change in sample properties with time.

Our investigation result shows as follows.

1) The capability of the pre-treatment system was influenced by fuel oil properties, system arrangements, individual abilities of equipments and machines, operating conditions and operating procedures among others.

2) The maximum separation efficiency of FCC catalyst fines in centrifuge at a single operation was about 85%. If heavy fuel oil contains an upper limit of FCC catalyst fines defined by ISO8217 standard (Al+Si 80mg/kg max), FCC catalyst fines may not be removed sufficiently to the level of the engine manufactures' recommendations (7 to 15 mg/kg) by centrifuge at a single operation. However, the maximum separation efficiency of FCC catalyst fines was increased to about 95% by a series operation of the centrifuges.

3) Homogenizer decreased a small amount of the total sediment in the heavy fuel oil. The homogenizer decreased the water separation efficiency of centrifuges and slightly improved the FCC separation efficiency of the centrifuge, when it was equipped at the inlet of the centrifuge.

The useful results concerning the performance and operation methods of the pre-treatment system were obtained by examination.

In order to prevent the engine troubles resulting from the degrading quality of fuel oils, we wish to utilize the result for improvement in the design of the on-board pre-treatment system and an improvement in the operation method.

INTRODUCTION

In recent years the number of problems with marine diesel engines caused by poor quality fuel oil has been steadily increasing. In particular, abnormal wear to the piston rings and the cylinder liners of diesel engines cause serious safety and reliability problems for the vessel. In such a situation, the role of the on-board fuel oil pretreatment system is becoming increasingly important.

From the viewpoint of performance of shipboard fuel oil pretreatment systems, the actual capability of the fuel oil pretreatment systems was researched and a suitable pretreatment method was studied. The test plant of a fuel oil pretreatment system (5m in length x 2m in width x 3m in height) that simulated the on-board fuel oil pretreatment system was assembled on land. The fuel oil supply/circulation lines of the test plant were skillfully plumbed so that various examinations could be performed. Heavy fuel oils that were collected from ocean going vessels were provided for this research, and in some cases, impurities such as test dust, sludge taken from an on-board fuel oil pretreatment system and water were added to fuel oil when needed. Oil samples from the test plant were analyzed in the laboratory as quickly as possible in order to minimize changes of properties in samples over time. The test results of the examinations are provided below.

1. EXPERIMENTAL PROCEDURES

1.1 Experimental Apparatus

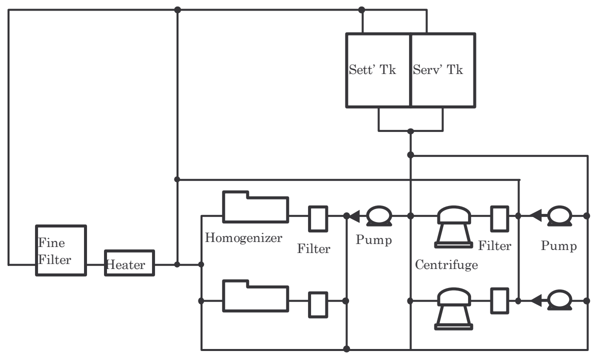


Figure 1 - Outline of experimental apparatus

The apparatus used for this experiment was assembled based on the common type of pretreatment systems generally installed on large size ocean going vessels. The apparatus has been designed and arranged to simulate the shipboard pretreatment system and the same pretreatment procedures can be carried out for fuel oil treatment. An outline of the apparatus is shown in Figure 1.

The apparatus is composed of the following components:

a) Tank

Settling tank Capacity of 1m³ (heater and agitator are fitted) 1 unit

Service tank Capacity of 1m³ (heater and agitator are fitted) 1 unit

b) Centrifuge

Manufacturer A 1 unit

Manufacturer B 1 unit

c) Homogenizer

Manufacturer C 1 unit

Manufacturer D 1 unit

d) Fine Filter

Manufacturer E 1 unit

1.2 Test Fuels

In the test program six different fuel oils collected from various regions of the world were used. The main properties of the test fuel oils are shown in Table 1.

Other than the above fuel oils, impurities such as water, test dust, sludge collected from an actual on-board fuel oil pretreatment system were intentionally added to the test fuel oils to make additional test fuel oils. Furthermore, some test fuel oils were intentionally heated to best replicate the characteristics of deteriorated oil.

1.3 Experiment Procedures

A number of fuel oil treatments were carried out with different combinations of the test fuel oils and the pretreatment equipment.

Sample oils were taken at sampling points on the pretreatment system and the properties of the fuel oils and the operational data of the pretreatment system were analyzed and recorded.

Table 1 - Properties of Test Fuel Oils

		Sample 1	Sample 2	Sample 3
Density	g/cm3@15	0.9690	0.9785	0.9907
Kinematic viscosity	cSt@50°C	140.4	315.5	99.3
Water	wt%	0.02	0.07	0.12
Residue	wt%	11.3	10.6	9.8
Asphaltene	wt%	2.1	5.1	4.7
Sodium	ppm	19	18	28
Vanadium	ppm	24	92	45
Iron	ppm	23	13	14
Aluminium+Silicon	ppm	2	0	66

		Sample 4	Sample 5	Sample 6
Density	g/cm3@15	0.9867	1.0116	0.9897
Kinematic viscosity	cSt@50°C	546.6	500.3	395.0
Water	wt%	0.02	<0.1	0.04
Residue	wt%	17.5	19.9	11.5
Asphaltene	wt%	7.4	9.0	5.5
Sodium	ppm	16	9	18
Vanadium	ppm	107	106	267
Iron	ppm	14	28	22
Aluminium+Silicon	ppm	0	16	15

		Minimum	Maximum
Density	g/cm3@15	0.9690	1.0116
Kinematic viscosity	cSt@50°C	99.3	546.6
Water	wt%	0.02	0.12
Residue	wt%	9.8	19.9
Asphaltene	wt%	2.1	9.0
Sodium	ppm	9	28
Vanadium	ppm	24	267
Iron	ppm	13	28
Aluminium+Silicon	ppm	0	66

1.4 Contents of Experiment

Sole operation of each piece of equipment and combined operation of the equipment were both conducted, and the following monitored:

(1) Changes in operational performance of the centrifuge under different operational conditions. (adjustment of the amount of treated fuel oil, selection of the size of the gravity disc, the number of units in use, etc.)

(2) Changes in the operational performance of the homogenizer under different operational conditions.

(3) Effect on the fuel oil pretreatment system by combination operation of the centrifuge and the homogenizer.

2. Experiment Results and Considerations

2.1 Centrifuge

The following factors are assumed to be contributors for removal capabilities of impurities for the centrifuge.

1) Flow rate

2) Kinematic viscosity when fuel oil is treated

3) Kinds of impurities to be removed

4) Impurity content in fuel oil (the amount of impurities contained)

5) The number of treatments with the centrifuge (single operation and series operation)

6) Treatment before fuel oil goes into a centrifuge

7) Characteristics of fuel oil (impurities contained in fuel oil, hydrophilic characteristics of fuel oil)

8) Other

The removal efficiency of impurities was determined by use of the following simple equation and an experiment was conducted.

Removal efficiency of impurities (%) = (inlet impurity content - outlet impurity content) / inlet impurity content

(1) Fuel Oil Throughput and Removal Efficiency

Other than actual fuel oil containing catalytic fines (FCC), test dust (JIS Z8901 Type-11) was used as an alternative to catalytic fine particles and was added to fuel oils. Since a high correlation between catalytic fines (FCC) and test dust was verified in the relationship between the flow rate and the removal efficiency, test dust was used for the experiments and the tests in order to verify the capacity of the pretreatment system. Properties of test dust are given in Table 2.

Table 2 - Characteristic properties of Test dust JIS Z8901 Type-11 (Kanto loam)

Particle density		2.9 to 3.1 g/cm^3
Particle size distribution	> 1 micron	65±5 %(m/m)
	> 2 micron	50±5 %(m/m)
	> 4 micron	22±3 %(m/m)
	> 6 micron	8±3 %(m/m)
	> 8 micron	3±3 %(m/m)
Material		Kanto loam (Volcanic ash)

The relationship between the flow rate and the removal efficiency by centrifuge is shown in Figure 2. The removal efficiency can be improved with reduction of the flow rate, however, the upper limit of the removal efficiency was 86% with approximately 30% of the flow rate. The experiment results indicated that no significant reduction in the removal efficiency was observed with 30% or less of the flow rate.

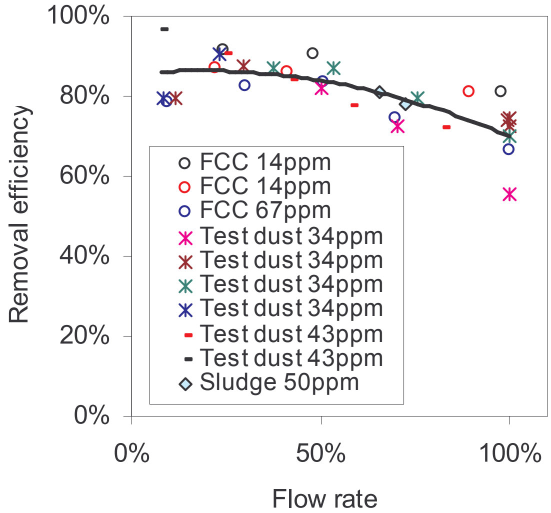


Figure 2 - Relationship between Flow Rate and Removal Efficiency

(2) Effect of Kinematic Viscosity

The effect of kinematic viscosity on the removal efficiency of Al+Si content was examined by using the same test fuel oils and the results of the experiment are shown in Figure 3. The removal efficiency was examined by using fuel oils with 44 cSt and 52 cSt of kinematic viscosity at the same flow rate. It was verified that the removal efficiency decreased approximately one percent on average for every 1 cSt increase in kinematic viscosity.

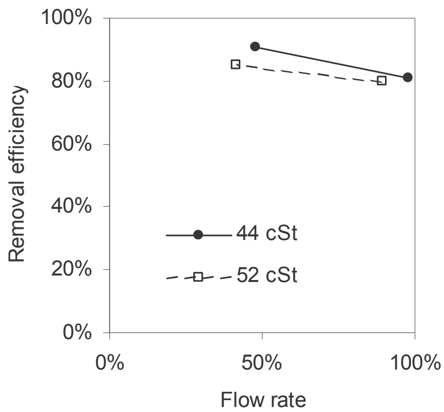


Figure 3 - Changes in Removal Efficiency with Kinematic Viscosity

(3) Effect of Gravity Disc

Figure 4 shows the reduction of the removal efficiency when using an improper disc. (smaller than the correct size recommended by the manufacturer)

The removal efficiency decreased by approximately 20% when a using a disc two sizes smaller than the correct size recommended by the manufacturer.

The removal efficiency of water content was greatly affected by gravity disc size as compared with the test dust.

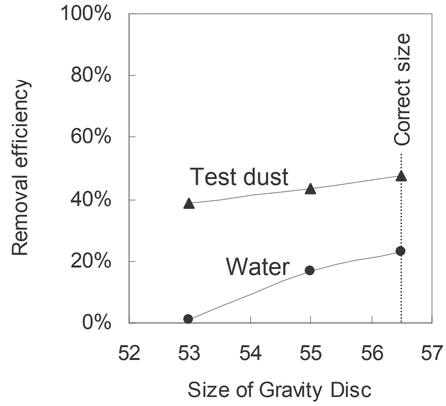


Figure 4 - Changes in Removal Efficiency with Gravity Disc

(4) Effect on Impurity Content (FCC, Test dust)

Figure 5 shows the results of the experiment when the impurity content in the fuel oil was changed with the same kinematic viscosity of the test fuel oil.

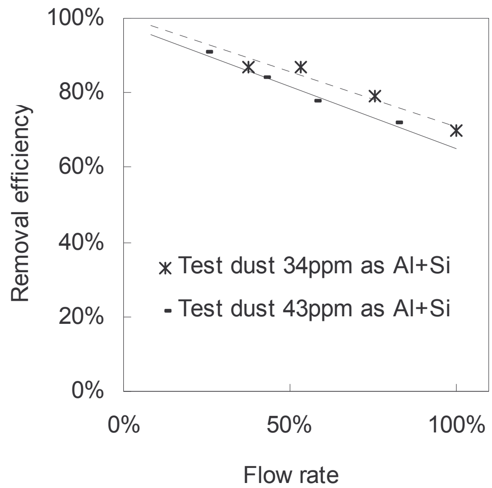


Figure 5 - Relationship between Impurity Content and Removal Efficiency

Test dust was used as an impurity in this experiment.

The removal efficiency decreased as the impurity content in the fuel oil increased.

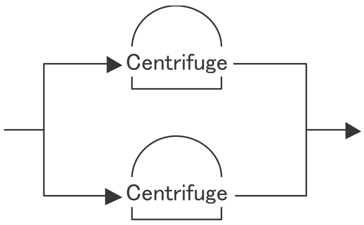
There was an approximately 5% difference on average in the removal efficiency between the test fuel oil containing 34ppm of test dust and the other one with 43ppm.

(5) Combination of Centrifuge

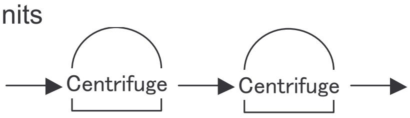
The typical combination of the centrifuge is shown as follows:

Single operation   Sole operation by one unit

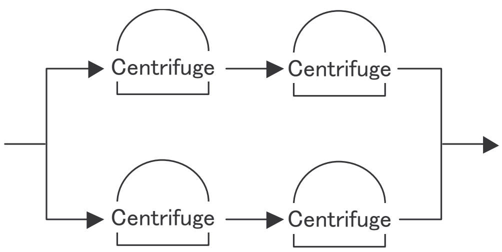
Parallel operation   Parallel operation by two or more units



Series operation   Series operation by two or more units



Combination of series operation and parallel operation   Combination of series operation and parallel operation by three or more units



a) Parallel operation

Although removal efficiency is the same as with single operation, the amount of treated fuel oil is double when the flow rate is set at the same rate as for single operation. When the same amount of fuel oil is to be treated, the flow rate can be reduced to half. For removal of impurities, the removal efficiency varies with the amount of impurities contained in fuel oil. Better removal efficiency can be obtained at lower flow rates with parallel operation. The removal efficiency is the same as the one of single operation.

Figure 6 shows the comparison of the removal efficiency between the single operation and the parallel operation.

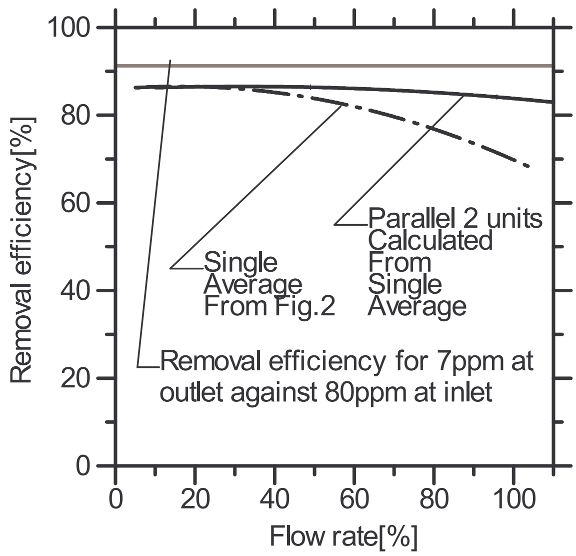


Figure 6 - Relationship between Flow Rate and Removal Efficiency in Single Operation and Parallel Operation

b) Series operation

Figure 7 shows the results of the experiment when the fuel oil containing FCC was treated with the centrifuge in series operation.

The removal efficiency at the secondary stage was considerably low compared with the one at the primary stage.

A solid line in Figure 7 indicates the total removal efficiency in series operation.

Although the removal efficiency reduces at the secondary stage in series operation, the total removal efficiency can be improved, namely a higher removal efficiency of impurities can be obtained compared with single operation or parallel operation.

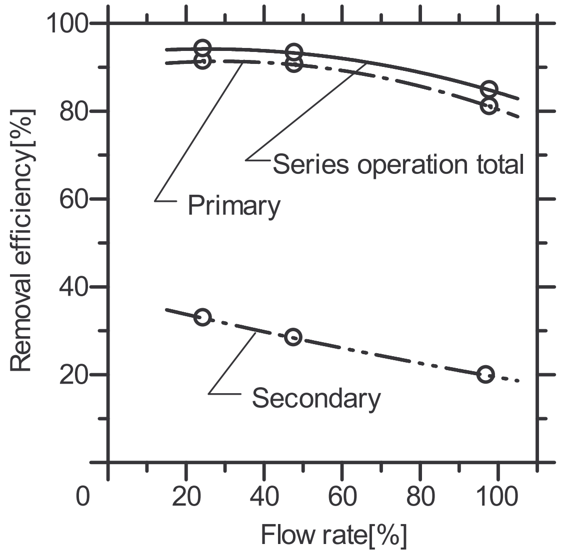


Figure 7 - Removal Efficiency at Primary and Secondary Stage

Figure 8 shows the comparison of the removal efficiency between the single operation and the series operation.

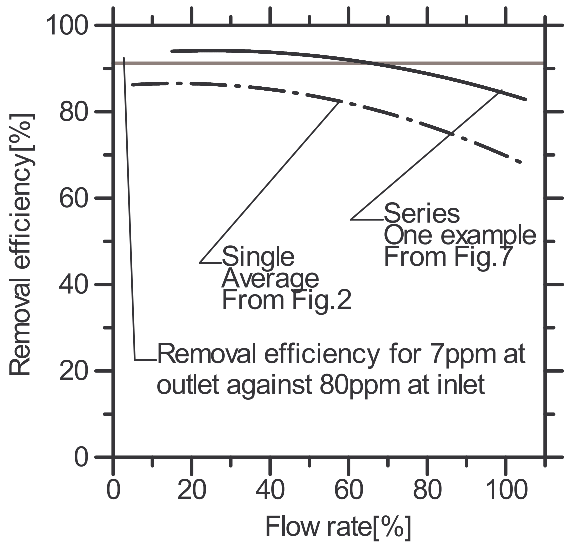


Figure 8 - Relationship between Flow Rate and Removal Efficiency in Single Operation and Series Operation

(6) Responses to Fuel with Al+Si 80ppm (Upper limit Value Specified in ISO)

a) Present situation

When a value of Al+Si content is 80ppm at the centrifuge inlet and the maximum removal efficiency of the centrifuge is 86%, a value of Al+Si content after treatment with the centrifuge can be obtained by the following equation.

80ppm x (1 - 0.86) = 11.2ppm

80ppm :ISO RMG35 Standard of Al+Si content at the centrifuge inlet

As shown in Table 3 the recommended values of Al+Si content at the engine inlet specified by the engine manufacturers are 7, 10, and 15 ppm respectively.

Table 3

Case of Removal efficiency 86%			
Recommendation for Main engine inlet	Wartsila・DU 15 ppm	MHI UEC 10 ppm	B&W MES 7 ppm
Upper limit before Pre-treatment	107 ppm	71 ppm	50 ppm
Ageinst 80ppm	Possible	Impossible	Impossible

If the lowest value of 7ppm is considered as the standard value to be cleared, sufficient removal results cannot be obtained with a single-stage treatment when fuel oil with 80ppm of Al+Si content is supplied which is the upper limit value specified by the ISO Standard.

For your reference, the upper limit values of Al+Si content at the centrifuge inlet, with which the recommended values of Al+Si content at engine inlet specified by the engine manufacturers (7ppm, 10ppm, and 15ppm respectively) can be cleared with single-stage separation, are given in Table 3. (with 86% of removal efficiency)

91% of the removal efficiency (indicated in a light-colored solid line in Figure 6 and Figure 8) is necessary to clear the lowest recommended values of Al+Si content (7ppm) at the engine inlet specified by the engine manufacturer when fuel oil with 80ppm of Al+Si content, which is a upper limit value specified by the ISO Standard, is treated through the pretreatment system. To obtain this removal efficiency, two-stage separation is required with approximately 65% or less of the flow rate.

Based on the total removal efficiency shown in Figure 8, Table 4 shows whether or not the recommended values of Al+Si content at the engine inlet specified by the engine manufacturers can be obtained with the single operation or the series operation. The results are provided by each recommended value at engine inlet of engine manufacturer.

Table 4

		Case of Al+Si 80ppm Fuel oil				
		Removal efficiency	After Centrifuge	Wartsila・DU 15 ppm	MHI UEC 10 ppm	B&W MES 7 ppm
380cSt	Single 100%	70%	24 ppm	Impossible	Impossible	Impossible
	Single 50%	84%	13 ppm	Possible	Impossible	Impossible
	Single 25%	86%	11 ppm	Possible	Impossible	Impossible
	Series 100%	84%	13 ppm	Possible	Impossible	Impossible
	Series 50%	93%	6 ppm	Possible	Possible	Possible
	Series 25%	94%	5 ppm	Possible	Possible	Possible

a) Pretreatment plan for responding to fuel with 80ppm of Al+Si content

1) Carry out two-stage separation with 65% or less of the throughput recommended by manufacturer. This remedy can be implemented with the present shipboard pretreatment system. Figure 9 shows this plan.

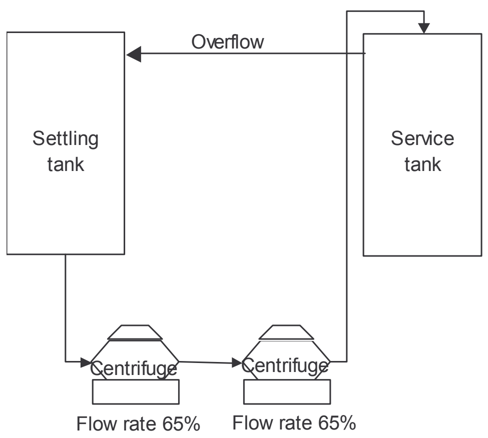


Figure 9 - Pretreatment Plan 1

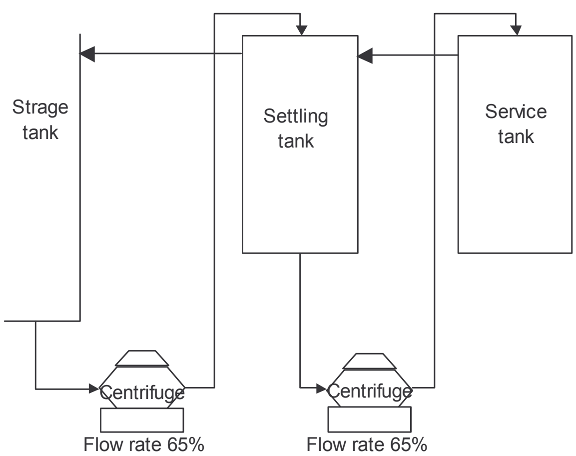


Figure 10 - Pretreatment Plan 2

2) Fuel oil is treated at storage tank outlet with 65% or less of the throughput recommended by manufacturer, and the treated fuel oil is transferred to the settling tank. The fuel oil is treated again between the settling tank and the service tank with 65% or less of the throughput recommended by manufacturer. The excessive treated fuel oil in the service tank will return to the storage tank through the overflow pipe. Figure 10 shows this plan.

3) In place of the storage tank in plan 2, an additional settling tank is installed. Figure 11 shows this plan.

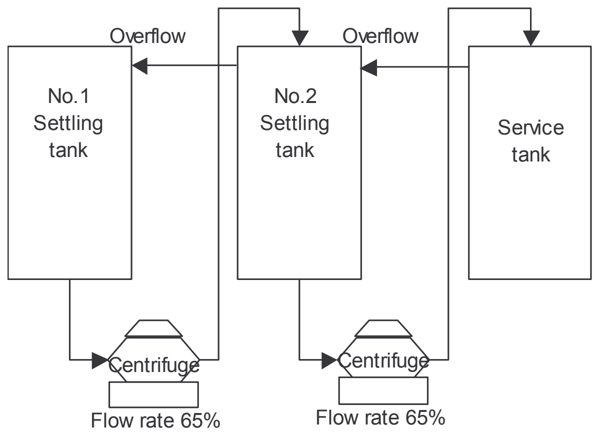


Figure 11 - Pretreatment Plan 3

2.2 Homogenizer

(1) Changes in Oil Properties

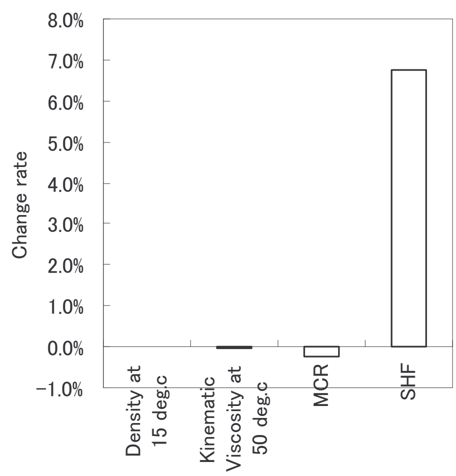


Figure 12

Figure 12 shows the average change rate of general properties in the fuel oils at the homogenizer inlet and outlet.

No significant changes were observed in values of density, viscosity, carbon residue, however, the total amount of sediment (SHF) decreased approximately 7%. No correlation was verified between the items to be analyzed and the flow rate or the viscosity.

2.3 Combination of Centrifuge and Homogenizer

(1) Effect of Homogenizer on Water Separation Efficiency of Centrifuge

When a homogenizer was installed upstream of the purifier as a pretreatment unit, oil-water emulsion occurs and had an adverse effect on water separation efficiency in the purifier.

Figure 13 shows changes in the water separation efficiency of the purifier when a homogenizer was installed upstream of the purifier.

The water separation efficiency of the purifier in sole use was approximately 40% with 11% of the flow rate and approximately 20% with 50% of the flow rate, while water separation efficiency reduced to 10% or less regardless of the flow rate when the homogenizer was installed upstream of the purifier.

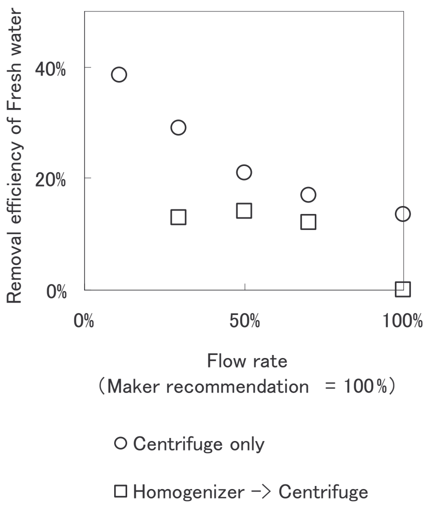


Figure 13

(2) Effect of Homogenizer on FCC Removal Efficiency of Centrifuge

Figure 14 illustrates changes in FCC removal efficiency of the purifier when the homogenizer was installed upstream of the purifier.

Although there was a large variation in the removal efficiency at the smaller flow rates, the results show almost no significant changes in the removal efficiency of FCC or test dust even when the homogenizer was installed upstream of the purifier.

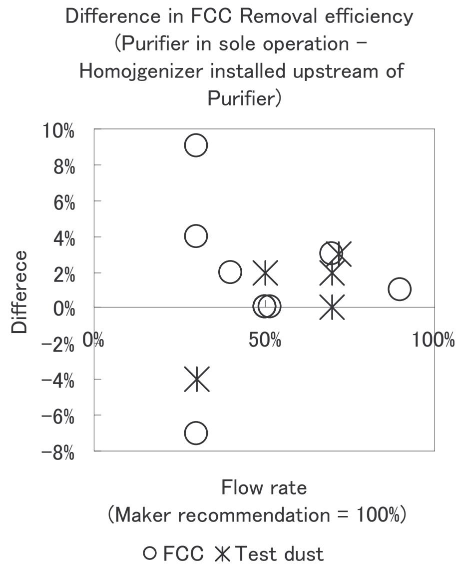


Figure 14

(3) Combination with Purifier and Reduction of Sediment (SHF)

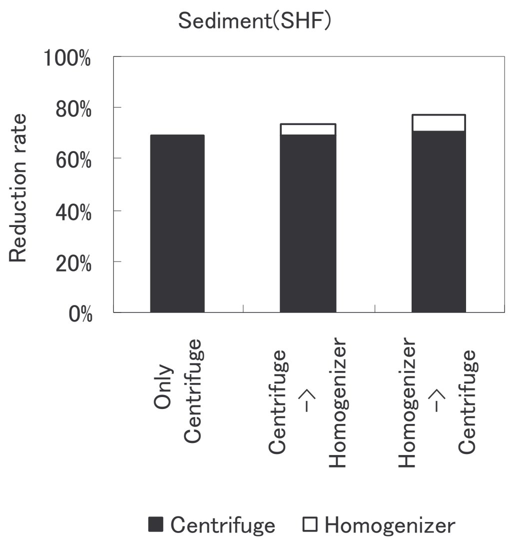


Figure 15

Figure 15 shows the reduction rate of sediment content when the homogenizer was used in combination with the purifier.

As illustrated in a bar chart the highest effectiveness of reduction was demonstrated in "homogenizer + purifier," followed by "purifier + homogenizer," and lastly "purifier in sole operation."

Compared to "purifier in sole operation," the reduction was larger by 6% in "homogenizer + purifier," and 4% in "purifier + homogenizer" respectively.

CONCLUSIONS

(1) Purifier in Sole Operation

a) The removal efficiency of impurities was improved by throttling the flow rate. The relationship between the flow rate and the removal efficiency varies with the manufacturers and the type of equipment.

In this experiment, for removing impurities 70% of the removal efficiency was obtained with 100% of the flow rate (recommended flow rate by the manufacturer), and 86% of removal efficiency was obtained with 30% of the flow rate. However, almost no improvement was observed in reducing impurities even when the flow rate was throttled to 30% or less of the recommended flow rate.

b) The total removal efficiency improved when two purifiers were installed in series operation. The total removal efficiency of impurities with two-stage purification was 85% with 100% of the flow rate, and 94% with 30% of the flow rate.

c) The gravity disc has a significant effect on the removal efficiency of impurities. The smaller the gravity disc installed, the smaller the effect in removing impurities was observed.

When a disc two sizes smaller than the correct size was used, the removal efficiency of impurities decreased by 20%.

d) The higher the kinematic viscosity used, the smaller the effect in removing impurities was observed. The removal efficiency decreased one percent on average when the kinematic viscosity degraded one point in cSt.

e) When the recommended values of Al+Si content at the engine inlet specified by the engine manufacturers are 7 to 15ppm, fuel oils with 50 to 107ppm or more cannot be dealt with a single-stage treatment. In such case double or two-stage operation is required.

f) Test dust "JIS Z8901 Type-11 (Kanto loam)" can be used as alternative impurities when the capability of a purifier is verified.

g) The removal efficiency decreased with an increase in impurity content.

(2) Homogenizer

The total amount of sediment (SHF) in fuel oil decreased approximately 7% with treatment by a homogenizer, however, no significant changes were observed in values of the other items (such as density, viscosity, and carbon residue).

No correlation was verified between changes of values in other properties at the homogenizer inlet/outlet and the flow rate or the viscosity.

(3) Combination of pretreatment equipment

a) The water separation efficiency decreased when the Homogenizer was installed upstream of the purifier. When water needs to be separated, the homogenizer installed upstream of the purifier should be stopped.

b) An improvement (4% to 6%) was verified in reducing sediment content (SHF) when the homogenizer was used in combination with the purifier compared to the "purifier in sole operation."

(4) Concluding Remarks

Through this experiment, useful results were obtained on the performance and operating method of the pretreatment system.

We can employ the results in this experiment in the improvement associated with the design of a pretreatment system and operating procedures to help prevent engine trouble attributed to degraded heavy fuel oil.

We would like to pay attention to the quality of marine fuel oil, responses to degraded fuel oil with present pretreatment systems, and improvement and development of shipboard pretreatment systems.

We also would like to conduct further surveys on actual performance of shipboard pretreatment systems as the need arises.