

Development for Lubricating Oil Life Extension/ Regeneration Technology Contributing to Low Carbon and Recycling-oriented Society



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Mitsubishi Heavy Industries, Ltd. (MHI) is developing technologies to extend the service life of and regenerate lubricating oil to achieve a reduction of CO₂ emissions through material recycling of lubricating oil. Conventional lubricating oil regeneration methods have an issue of using energy in collecting waste oil and in the regeneration process. Therefore, we researched an on-site method that does not require waste oil collection and does not use heat in regeneration, and found a new process to extend the service life of and regenerate lubricating oil by combining additive supplementation and acid component removal. This report describes the degradation characteristics of lubricating oil and presents the effects of extending the service life of and regenerating lubricating oil that additive supplementation and acid component removal proposed by us bring.

1. Introduction

To realize a low-carbon and recycling-oriented society, there is a need to reduce CO₂ emissions in the life cycle and supply chain of products. General-purpose mineral oil in lubricating oil used for machinery is made from fossil fuels and contains carbon, which generates CO₂ when incinerated during the industrial waste disposal process. In Japan, it is recognized under the Act on Promotion of Global Warming Countermeasures that thermal recycling of waste oil reduces the use of new petroleum fuel and CO₂ emissions, but in fact the thermal recycling of waste oil emits CO₂. In contrast, extending the service life of and regenerating lubricating oil is thought to contribute to a low-carbon, recycling-oriented society by reducing the amount of industrial waste disposal.

A conventional approach to regenerate lubricating oil was that the base oil was extracted by redistilling used lubricating oil (waste oil) collected from many users, and then adding additives to the base oil. The technology based on this approach has already been commercialized in the US and Europe. In the EU, about 2 million kiloliters of waste oil is collected and recycled into about 1 million kiloliters of base oil annually⁽¹⁾. The regenerated oil is recycled from waste oil to base oil, thereby reducing CO₂ emissions from incineration during the industrial waste disposal process.

The regeneration of lubricating oil through large-scale collection follows the process of collection of waste oil from an unspecified number of sources, regeneration into base oil, production of lubricating oil using the regenerated base oil, and sales of the product. While this method can eliminate incineration during the industrial waste disposal process, it can hardly be called low-carbon if fossil fuels are used as the source of energy required for the collection of waste oil, the distillation process, etc. In addition, since various types and brands of oil are collected, there are issues regarding the maintenance and reproducibility of the performance of the regenerated base oil.

Customers using turbine equipment manufactured by MHI have demanded a reduction in the cost of purchasing lubricating oil. Turbines use a large amount of oil, and each purchase of lubricating oil costs tens of millions of yen. Even when using lubricating oil regenerated through large-scale

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collection, the regeneration process requires energy, and the cost is expected to be on par with new oil.

In response, we propose an on-site lubricating oil regeneration method that does not require the collection of waste oil and does not use heat for the regeneration of lubricating oil. Unlike partial oil change, this method is a new and unconventional approach taken by supplementing lubricating oil with additive components that inhibit degradation and removing waste that accelerate degradation. We have clarified the degradation characteristics of lubricating oil and found the feasibility of this concept by applying it to turbine equipment, which uses a large amount of oil, as an example. This report presents an on-site method to extend the service life of and regenerate lubricating oil proposed by MHI based on test results obtained from elemental tests.

2. Change and management of lubricating oil in power plant

Lubricating oil gradually deteriorates with use. As it deteriorates, the viscosity increases, the acid number increases (increase in acid components), and sludge (solids derived from oil and additives) is generated, which can cause seizure, wear or corrosion of mechanical parts, bearing temperature rise, filter clogging, and other adverse effects. Therefore, in power plants, all or part of the used lubricating oil is changed with new oil before the management indicator of lubricating oil does not reach the warning limit. In addition, the lubricating oil is periodically analyzed once every few months and checked for its condition.

One of the periodic analysis items for lubricating oil is a Rotating Pressure Vessel Oxidation Test (RPVOT) value⁽²⁾, which is obtained from accelerated degradation test of the oil for evaluating its remaining life and is an indicator of the oxidation stability of oil. The RPVOT value is generally correlated with the percentage of remaining antioxidant. On the other hand, an acid number represents the amount of acid components contained in the oil. For MHI's management criteria for the RPVOT value and acid number, the former is defined as the RPVOT residual ratio (i.e., the ratio of RPVOT value of degraded oil to that of new oil) of 25% or more, and the latter is set to the new oil value plus 0.4mgKOH/g or less. When lubricating oil is exposed to an environment where oxidative deterioration occurs, the antioxidant added to the oil inhibits degradation of the base oil by oxidizing itself, but when the antioxidant is exhausted, the base oil is oxidative deteriorated and organic acids are formed.

Figure 1 shows example results of an accelerated degradation test of turbine oil. As shown in Figure 1(a), the acid number begins to increase rapidly when the RPVOT residual ratio falls below about 25%; and as shown in Figure 1(b), the sludge is also rapidly formed when the RPVOT residual ratio falls below about 25%. Therefore, it is reasonable to perform management so as to keep the RPVOT residual ratio at 25% or higher⁽³⁾.

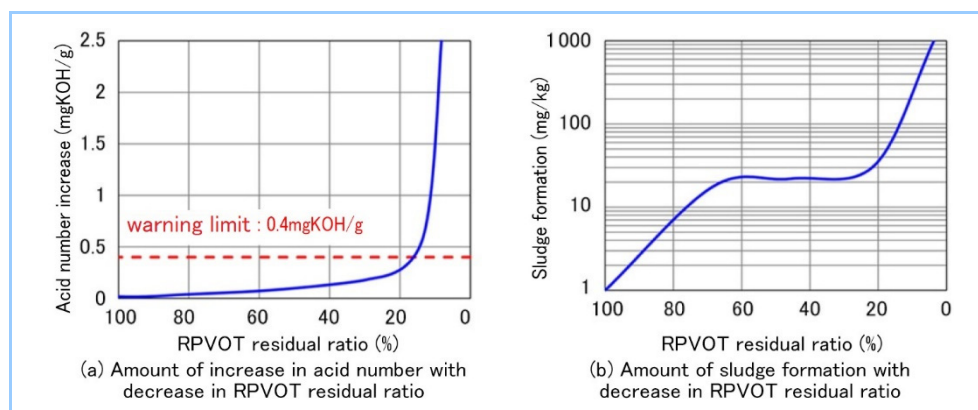


Figure 1 Acid number increase and sludge formation with decrease in RPVOT residual ratio resulted from accelerated degradation test

Since the RPVOT residual ratio decreases approximately linearly with the plant operation time, it is the most suitable for the management of the degree of oxidative degradation of lubricating oil, and can be a good indicator to prevent equipment failure caused by oxidative degradation of lubricating oil.

3. On-site lubricating oil regeneration method we invented

Based on the above, we considered that if the management value of lubricating oil is kept within the warning limit, lubricating oil change would not be necessary. Methods to suppress the decrease in the RPVOT residual ratio and the increase in the acid number include supplementing an antioxidant to keep the RPVOT residual ratio high (additive supplementation) and removing waste that accumulates in the oil to decrease the acid number (acid component removal).

As such, we have developed a process for extending the service life of and regenerating lubricating oil by combining additive supplementation and acid component removal to achieve a significant cost reduction effect. **Figure 2** shows the developed process for extending the service life of and regenerating lubricating oil using additive supplementation and acid component removal. The periodic supplementation of additives maintains the RPVOT residual ratio at a high level. Then, occasionally when additives are supplemented, at the point when waste accumulates, acid component removal is performed using silica to restore the acid number to a value equivalent to that of new oil. Although ion exchange resins can be used for acid component removal, it was confirmed from the test results that the silica method is highly efficient and inexpensive.

We found that this process has the potential to extend the service life of and regenerate lubricating oil on-site. As a result, lubricating oil change becomes almost unnecessary. So, that would reduce lubricating oil purchase and disposal costs, and help contribute to the realization of a low-carbon and recycling-oriented society. In addition, since the customer's oil in-use itself is life-extended and regenerated for continued use, the regenerated oil can be of more stable quality than the conventional method of regenerating lubricating oil through large-scale collection.

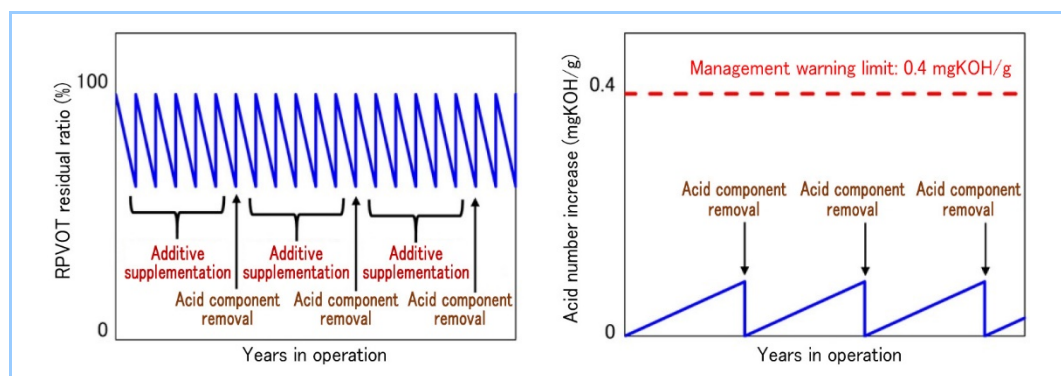


Figure 2 Proposed process for extending service life of and regenerating lubricating oil by combining additive supplementation and acid component removal

4. Verification of effect of extending service life of and regenerating lubricating oil

4.1 Preparation of degraded oil

We verified the effect of extending the service life of and regenerating lubricating oil by additive supplementation and acid component removal through elemental testing. The degraded oil used in the tests was prepared by accelerated oil degradation according to ASTM D943⁽⁴⁾ and ASTM D7873⁽⁵⁾ using Turbine oil Oxidation Stability Test (TOST) equipment.

4.2 Test results for extending service life of lubricating oil by additive supplementation

We verified whether the RPVOT value could be restored to that of new oil by supplementing the prepared degraded oil with antioxidants. **Figure 3** shows the results of supplementing degraded oil having different RPVOT residual ratios with the antioxidant in an amount equivalent to that contained in new oil. The RPVOT values were restored equally when the same amount of antioxidant was added, even when the RPVOT residual ratio of the degraded oil was different. It was also confirmed that the amount of RPVOT value restored differed depending on the type of antioxidant (antioxidant A or B). However, in the case of lubricating oil the RPVOT residual ratio of which had fallen lower than the management warning limit, the RPVOT value could not be restored at all by supplementing the lubricating oil with an antioxidant. Therefore, it is considered that the RPVOT

value can be restored to a value equivalent to that of new oil by, in addition to selecting an appropriate antioxidant, supplementing the lubricating oil with the antioxidant before the RPVOT residual ratio falls to the management warning limit. However, as shown in **Figure 4**, increasing the amount of antioxidant supplementation to the degraded oil tends to saturate the restoration of the RPVOT value, and so, the method of increasing the amount of antioxidant supplementation is not considered appropriate. To realize the additive supplementation shown in Figure 2, it is necessary to supplement the lubricating oil with the antioxidant while the RPVOT residual ratio of the lubricating oil is still relatively high and to restore the RPVOT value to that of new oil with a small amount of supplementation.

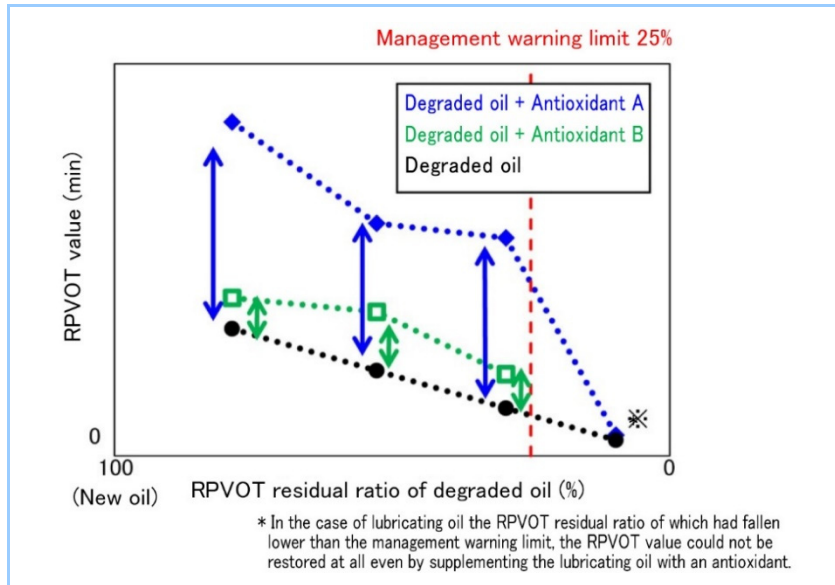


Figure 3 Change in RPVOT value of lubricating oil when supplemented with antioxidant in amount equivalent to that of new oil

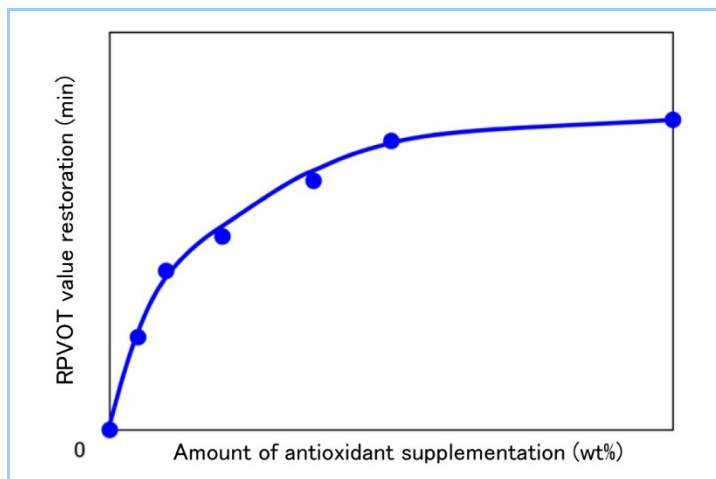


Figure 4 Relationship between antioxidant supplementation and RPVOT value restoration

Figure 5 shows why the RPVOT value does not change when an antioxidant is added to lubricating oil the RPVOT residual ratio of which has fallen below the management warning limit. It is considered that new oil to which an antioxidant is added to the base oil exhibits 100% of the ability of the antioxidant to inhibit oil degradation, but lubricating oil with the RPVOT residual ratio of which has fallen below the management warning limit cannot fully exhibit the ability of the antioxidant because of the accumulation of substances such as acid components that inhibit the antioxidant's ability. In the case of usable degraded oil, it is thought that the RPVOT value is difficult to restore to that of new oil even when supplemented with the antioxidant in an amount equivalent to that of new oil as shown in Figure 3 because the antioxidant's ability remains, but substances that inhibit its ability coexist. Therefore, to make it easier to exhibit the ability of the antioxidant, removing substances that inhibit the ability, i.e., acid component removal is necessary.

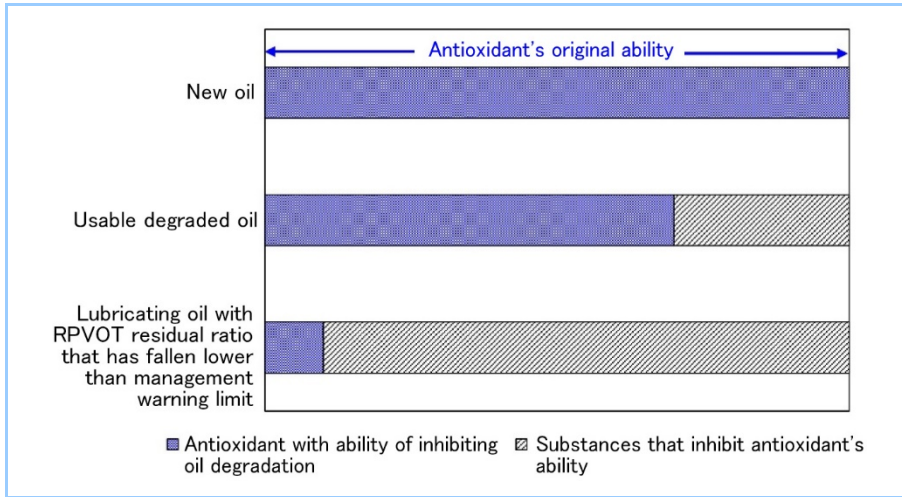


Figure 5 Antioxidant's ability of inhibiting oil degradation depending on oil condition

4.3 Test results for regenerating lubricating oil by acid component removal using silica

We verified whether antioxidant supplementation after acid component removal from the prepared degraded oil can restore the RPVOT value and acid number to values equivalent to those of new oil. **Figure 6** shows the results for acid component removal from degraded oil with an RPVOT residual ratio of 25%. Figure 6(a) shows the case in which acid component removal was not performed, the antioxidant in an amount equivalent to that of new oil was supplemented, and the oil was degraded continuously. When acid component removal was not performed, the restoration of the RPVOT value by antioxidant supplementation was small. The degradation rate after antioxidant supplementation was equivalent to that of new oil.

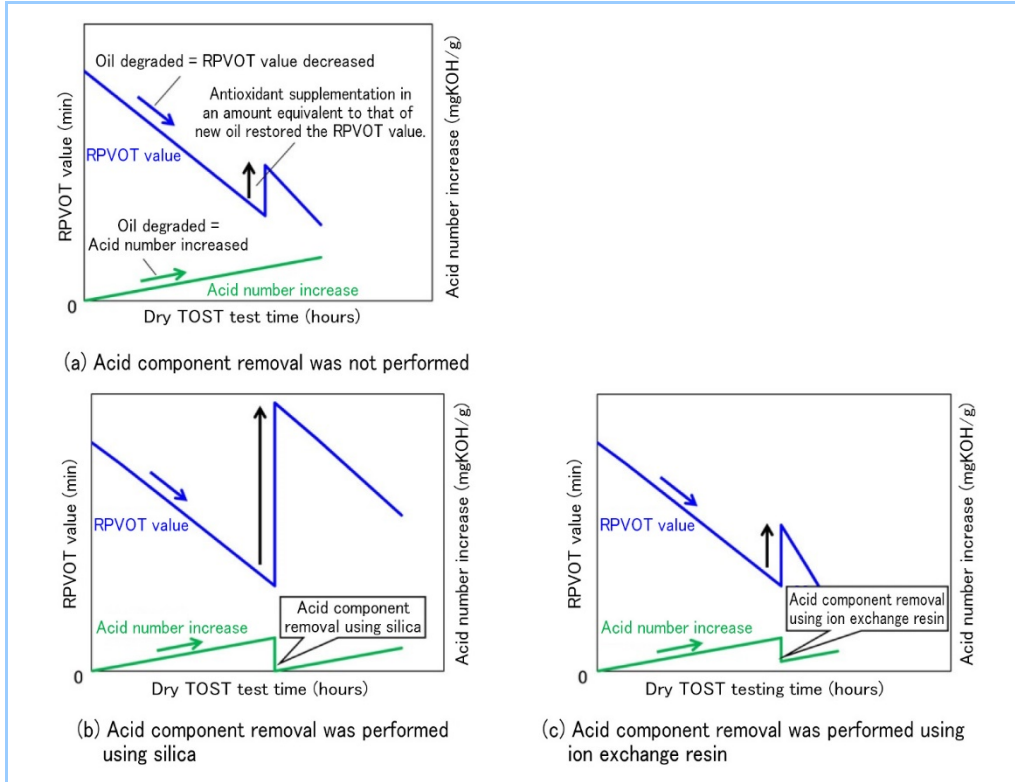




Figure 6 Effect of acid component removal on degraded oil

On the other hand, Figure 6(b) and Figure 6(c) show the cases in which acid component removal was performed using silica in the case of (b) and ion exchange resin in the case of (c) as acid component removal agents. The analysis results of the restoration of the RPVOT value after antioxidant supplementation showed that the RPVOT value was restored to a value equivalent to that

of new oil after acid component removal with silica, but not to a value equivalent to that of new oil after acid component removal with ion exchange resin. This difference in the RPVOT value restoration rate between silica and ion exchange resin is thought to be due to the difference in the concentration of residual acid components and the like. **Table 1** shows the test conditions and results for the two acid component removers. When processed with silica, a one-time filtration brought the color of the oil to colorless and transparent, and lowered the acid number to about the same as that of new oil. When processed with ion exchange resin, five-time filtration brought the color of the oil to lighter and lowered the acid number to about the same as that of new oil.

Table 1 Test conditions and results for two acid component removers

Acid component remover	Number of filtration times	Acid component removal effect	Change in oil color
Silica	1	High	
Ion exchange resin	5	Medium	

Then, to confirm whether the acid components were really removed, we performed infrared spectroscopic analysis (FT-IR analysis) of the oil and observed the absorption peaks of carbonyl groups (two peaks around $1,700\text{cm}^{-1}$) associated with the acid components. **Figure 7** shows the analysis results. The absorption peaks of the carbonyl group disappeared in the case of the oil processed with silica, whereas they remained in the case of the oil processed with ion exchange resin. This indicates that the process using silica completely removes acid components, while the process using ion exchange resin lowers the acid number but may leave degraded substances that have no effect on the acid number unremoved. However, there is still a possibility that the efficiency of acid component removal using ion exchange resins can be improved by reviewing the processing conditions such as temperature and contact time.

Table 2 shows the estimation results of the amount of each acid component remover required to remove acid components from lubricating oil and reduce the acid number to a value equivalent to that of new oil, as well as the cost of materials. The amount of silica required for acid component removal is three times greater than that of ion exchange resin, but silica costs one-thirtieth per unit weight compared to ion exchange resin, so the cost for the required amount is one-tenth compared to ion exchange resin. Based on the results of the test and cost estimation, we decided to use silica for acid component removal from lubricating oil.

Figure 8 shows the result of repeated degradation of lubricating oil and its regeneration by acid component removal using silica. The regeneration process was judged by the following indicators: the hue became transparent and the acid number became less than 0.1mgKOH/g . In regeneration undertaken three times, the acid number decreased to less than 0.1mgKOH/g when the hue was made transparent, and the RPVOT value was restored by antioxidant supplementation. Therefore, we confirmed that the regeneration of lubricating oil can be performed repeatedly and can extend the service life about four times compared to the conventional method.

The reasons why silica removes acid components and color components from degraded oil are considered to be physical adsorption due to weak intermolecular attraction (van der Waals force) and chemical adsorption due to the affinity between acid/color components and silica. In the future, it may be possible to reduce the amount of silica required to remove acid components from lubricating oil by increasing the specific surface area of silica to improve the physical adsorption capacity and optimizing the functional groups on the silica surface to improve the chemical adsorption capacity. However, silica also removes necessary additives such as rust inhibitors, so these additives also need to be supplemented.

Based on the results of sections 4.2 and 4.3, we have found a new method to extend the service life of oil by additive supplementation and to regenerate the oil by acid components removal and additive supplementation at the point when waste accumulates therein. **Figure 9** shows the result of cost estimation in the case of using the process for extending the service life of and regenerating

lubricating oil (Figure 2). Compared to the conventional of purchasing new oil and changing all the lubricating oil three times, a cost reduction of about 40% is expected.

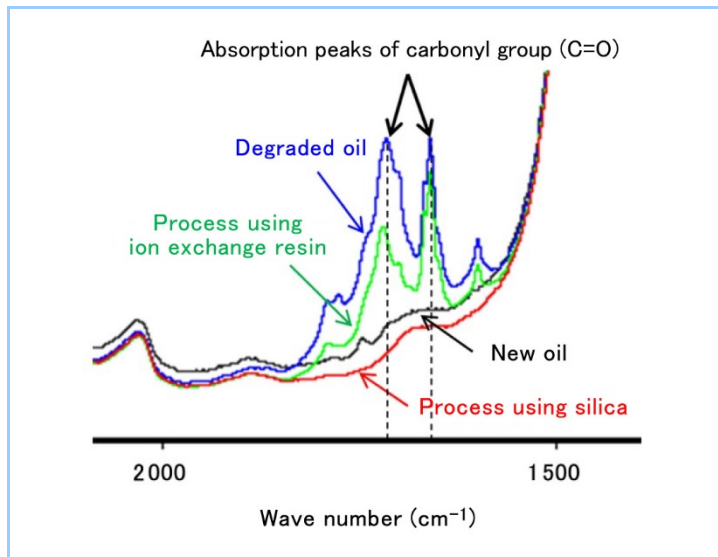


Figure 7 Results of infrared spectroscopic analysis of lubricating oil before and after acid component removal

Table 2 Ratio of cost required for acid component removal from lubricating oil

Acid component remover	Cost per unit weight	Amount required for acid component removal	Cost for amount required
Silica	1	3	1
Ion exchange resin	30	1	10

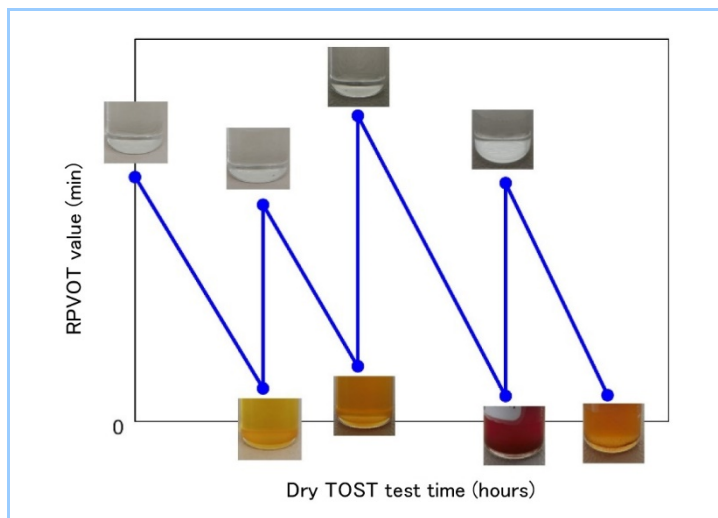


Figure 8 Repeated degradation of lubricating oil and its regeneration by acid component removal using silica

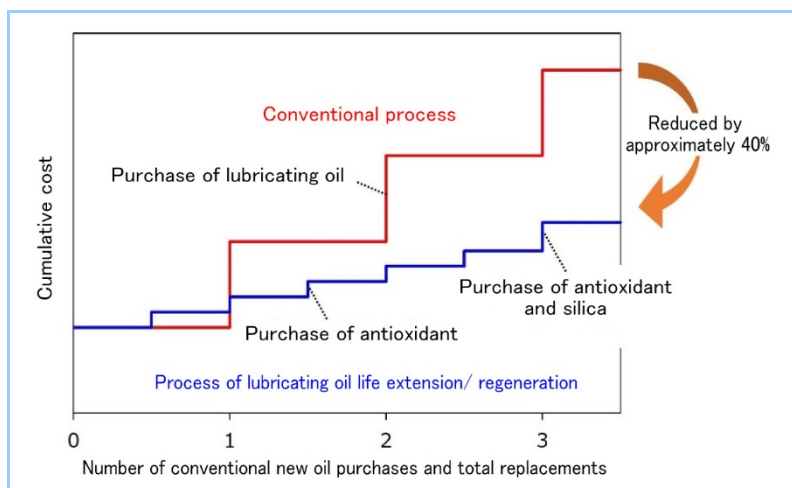


Figure 9 Cost reduction effect of process for extending service life of and regenerating lubricating oil

5. Conclusion

This report presented an on-site method to extend the service life of and regenerate lubricating oil by combining additive supplementation and acid component removal proposed by MHI.

We developed a process based on the results of elemental tests to maintain the RPVOT residual ratio of the lubricating oil at a high level by periodically performing additive supplementation to prevent the RPVOT residual ratio from lowering, and to increase the effect of additive supplementation by restoring the acid number to a value equivalent to that of new oil by removing acid components using silica occasionally when additives are supplemented at the point when waste accumulates.

Going forward, we will use small test equipment to confirm the effects of repeated additive supplementation and acid component removal, as well as to examine the operational method of the oil circulation system. In addition, we are considering establishing MHI standards for the properties that the additives to be supplemented need to meet.

References

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