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# The fuel oil spin test: a method to help fuel users predict sludge issues at the fuel oil separator

Fuels - Conventional Fuels

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## ABSTRACT

In 2019, ahead of the IMO 2020 transition, CIMAC released a guideline to compliment and expand on the information given in ISO/PAS 23263:2019 “Considerations for the fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0.50% sulfur in 2020”. The intent of this guideline was to encourage a ‘common industry approach’ to the accepted available test methodologies for evaluating the stability and compatibility of marine Fuel Oils. As such, the guideline explains stability and compatibility, provides advice on how to manage these properties and also provides details on the test methodologies, covering their applicability and correct interpretation.

However, as comprehensive as the guideline may be in its efforts to aid Fuel Oil producers and users in their decision-making with respect to Fuel Oil stability and/or compatibility, we believe there is scope for the industry to consider an additional performance based methodology which, considers the operability of the Fuel Oil (i.e. how ‘fit-for-purpose’, or difficult to process the Fuel Oil may be in the separator). This is where the Fuel Oil Spin Test methodology could compliment the methods already addressed by offering a prediction of how a Fuel Oil might perform at the separator onboard the ship.

The overview of the test is simple – the Fuel Oil is centrifuged in a lab-scale separator and the volume % of sludge separated is identified. Alfa Laval are confident that, under the conditions of the test, this result will be correlated to what is observed onboard at the Fuel Oil separator. Rather than focusing directly on how stable the Fuel Oil is, or how compatible a blend is (neither of which we are proposing to neglect), this methodology simply offers an additional and valuable indication of how the onboard purifier will handle the Fuel Oil in question and thus is a test focused purely on Fuel Oil operability. As such, we believe this test could be invaluable in supporting the evaluation of how ‘fit-for-purpose’ a Fuel Oil is.

This paper outlines the test methodology and shares results across a range of Fuel Oils, with and without the presence of sludge management technology.

## 1. INTRODUCTION

### 1.1 VLSFO and Total Sediments

Since IMO 2020, which brought the sulphur content of fuels used outside emission control areas (ECAs) from 3.5% to 0.50% for onboard consumption, the stability of 0.50% Very Low Sulphur Fuel Oil (VLSFO) at the point of sale has largely been on specification. Based on the off-specification marine fuel data from Lloyd's Register FOBAS indicates that 19.2% were due to a total sediments result exceeding the respective grade limit set out in the marine fuels standard, ISO 8217[1] in 2022. However, uncertainty around the operability of these Fuel Oils remains a key areas of concern, for which there have been no new methods to provide a prediction of onboard experience.

Ship operators mainly rely on the total sediment content (test method ISO 10307-2)[2] as an indication of asphaltene stability to protect against sludge formation. The base test method is known as the total sediments *existent* (TSE), which may be coupled with either chemical or thermal ageing methods. The total sediments *aged* (TSA), involves treatment of the Fuel Oil sample with hexadecane (cetane) as part of the chemical ageing procedure, prior to the sample experiencing a 1-hour period at 100 °C. The total sediment *potential* (TSP) involves holding Fuel Oil samples at 100 °C for 24 hours for thermal ageing. Perhaps unsurprisingly, the different approaches to obtaining the total sediments value have resulted in general opinions that the latter is more appropriate for considering the thermal stability of the Fuel Oil over time, whereas the former is more appropriate for considering compatibility with other Fuel Oils. It is worth noting that, at the time of writing, the TSP is designated as the referee method. As such, an on-specification TSP result would be desirable for a seller.

This has been the case for several decades and the parameter has resided within the ISO 8217 specification since the first edition released in 1987. The specification has an upper limit of 0.10% mass, and it is accepted that if a Fuel Oil returns a result at or below this, then the Fuel Oil should not be problematic onboard. This approach has served the industry well for decades, however since the transition to VLSFO, there have been increased incidences of experiencing operational issues despite the Fuel Oils meeting the specification requirements. Conversely, there are also examples where Fuel Oils may exceed this 0.10% mass limit whilst remaining problem-free onboard. Onboard issues appear both in the form of sludge deposition in tanks and excessive sludge formation at separators. This indicates the need for a test method which focuses more on the operability of the Fuel Oil. Where total sediments is a static test, giving information on aggregation in the fuel, the Fuel Oil Spin Test is dynamic, and considers the aggregate size, fuel viscosity and the combination of these effects to determine how likely it is for sludge to form under centrifugal forces at the temperatures used onboard.

A method which focuses purely on the operability aspect of the Fuel Oil may help provide additional information to both the seller and consumer over the quality of the Fuel Oil, as to avoid bunkering problematic Fuel Oils. Should such a scenario develop, ships can be placed in the precarious position of trying to use a Fuel Oil that is producing excessive sludge. If this occurs, the vessel has to manage the sludge waste that is produced. Even worse, the vessel may find themselves in a position where there is no choice but to debunker the problematic Fuel Oil. In either scenario, both inconvenience and cost are associated with the problem. The expenditure associated with debunkering is further compounded by the additional 'hidden' cost of having the ship stationary in a port (rather than conducting its commercial duties).

### 1.2 Alternative Test Methods

Indeed, prior to IMO 2020, CIMAC released a guideline to compliment and expand on the information given in ISO/PAS 23263:2019 "Considerations for the fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0.50% sulfur in 2020".[3] The intent of this guideline was to encourage a common industry approach to the accepted available test methodologies for evaluating the stability and compatibility of marine Fuel Oils. As such, the guideline explains stability and compatibility and provides advice on how to manage these properties. The guideline also imparts details on the test methodologies (**Table 1**), covering their applicability and correct interpretation, which includes total sediments methods. Additionally, the guideline refers to other methods that may also be considered, which includes the Separability Number (also known as Reserve Stability Number - ASTM D7061).[4] However, these other methods are not viewed with the same relevance as those in **Table 1** and are not discussed further for the following reasons: they are lacking criteria for evaluating stability or compatibility and/or, lack in standardization, and/or the methods require scientific recognition and cross industry experience to uniformly apply and interpret.

Table 1. Test methods deemed suitable by CIMAC for determining the stability of marine residual Fuel Oils.[5]

| Test Method | Reference | Applicability | | |
|---|---|---|---|---|
| | | Stability | Compatibility | Prediction of compatibility without testing |
| TSE, TSP, TSA | ISO 10307 (ASTM D4870, IP 375/390) | ✓ | ✓ | No |
| Spot Test | ASTM D4740 | ✓ | ✓ | No |
| S-Value | ASTM D7157 | ✓ | ✓ | ✓ |
| P-Value | ASTM D7112 | ✓ | ✓ | ✓ |
| P-Ratio | ASTM D7060 | ✓ | ✓ | ✓ |

Despite the introduction of this guideline and spreading awareness of the additional methods within, whilst the bulk of Fuel Oils supplied were usable, problematic Fuel Oils causing sludging issues onboard were continued to be reported (e.g. Fuel Oils becoming unusable after a short period of storage within 1 to 2 months). Indeed, **Table 1** highlights the focus on stability and compatibility considerations only. These qualities of the Fuel Oil are important, and for the most part indicate the Fuel Oil to be usable onboard ships. However, the complex nature of VLSFO blends stocks and their more paraffinic nature has raised additional questions regarding predicting Fuel Oil operability. It has become clear that an additional performance based operability test method would be advantageous to address the capacity of a Fuel Oil to remain stable through the stresses of onboard Fuel Oil processing. The resistance of the Fuel Oil to mechanical force can only be assessed by a centrifugal test method, which simulates separator operations and fuel processing onboard.

As such, we have been exploring alternative test methods with the aim of providing this indication of operability. A preference was also made for methods which do not adulterate the fuel by using solvents, so that correlation back to onboard separator performance is clear. We have identified that such a procedure exists in the form of a small, lab-based centrifugation method known as the 'Fuel Oil Spin Test', which we believe correlates to onboard experience of processing Fuel Oils.

## 2. General Discussion: Fuel Oil Spin Test

### 2.1 Spin Test development

The Spin Test has been developed and used by Alfa Laval for over 50 years to determine the optimal separator design for fluid separation, which is why it is ideally suited to test the susceptibility of Fuel Oils to generate sludge under centrifugal forces. The test is primarily used as a diagnostic tool to select the best type and size of separator for a given process (e.g. wine, vegetable oil or yeast separation).

Alfa Laval is a leading provider of Fuel Oil purifier equipment for the marine industry and conducts the test routinely at their laboratories to indicate the level of sludge that will be separated from a Fuel Oil being centrifuged in their larger scale purifiers. This has been a requirement for them ever since separators have been used for purification of residual Fuel Oils, to ensure that separator design matches the user requirements. Extensive use of the test can help answer design and field operation/maintenance questions such as:

- How large should the sludge space in the separator be?
- How often does the separator need to discharge?
- What is the maximum flow rate of Fuel Oil for the separator to operate efficiently?

As this test was designed to simulate as closely as possible the expected behaviour of a large-scale marine separator, we propose that it offers an indication of operability, and would like to draw attention to the potential for the method to provide additional operational advice to ship operators for more effective handling. In the future, when greater correlations are built between the test method and onboard operability, the Fuel Oil Spin Test could be a viable candidate for adding to the existing list of recognized, relevant methods for evaluation of a marine Fuel Oil with respect to sludge management. The method could be similar to the ISO 9030 centrifuge method for determining sediment and water content in crude petroleum,[6] or the ASTM D1796–11 method for determining sediment and water content in Fuel Oil.[7]

### 2.2 Spin Test background

Just as it is in the larger scale separators, Stokes' law is the fundamental scientific principle which underpins the Fuel Oil Spin Test.[8] Ultimately, in a fluid at fixed viscosity (temperature dependent), smaller or less dense particles will move through the fluid under the effects of the centrifugal force more slowly than larger or more dense particles. With respect to sludge management, this is to say that larger, more compact agglomerates will be more easily separated out during the centrifugation process in comparison to smaller ones. Indeed, if the agglomerates are small enough, they may not be separated out of the Fuel Oil at all. At such a level, the particles would have to be small enough to not expect any negative consequence to the ship. As the Fuel Oil Spin Test uses an unadulterated Fuel Oil, it directly measures the amount of sludge expected to be produced at the larger scale.

Onboard, the Fuel Oil experiences a relatively short through-put time in the separator, at relatively high centrifugal force (~11,000 rpm, resulting in ~10,000 g), which is sufficient to separate out the target particles.[9] The Fuel Oil Spin Test is correlated to the onboard proceedings by employing a lower rpm, but a longer 'throughput' time (i.e. test duration) to ensure equivalence.

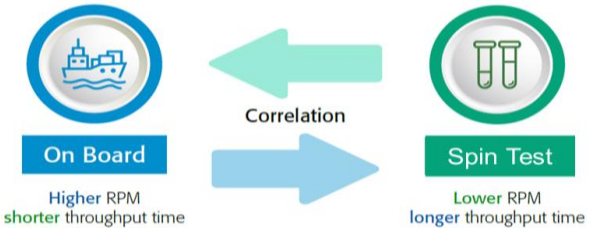



Figure 1. Diagram describing the theory (based on Stokes Law) behind the correlation between an onboard separator and the Fuel Oil Spin Test.

The temperature at which the test is conducted can also be varied from one Fuel Oil to another. The temperature should mirror what would be used in the field for the sample in question, with more viscous Fuel Oils typically run at higher temperatures since temperature is inversely related to viscosity; a determining parameter in Stokes' law.

Something important to note about the Fuel Oil Spin Test is that, unlike other centrifugation-based methods (e.g., ASTM D1796), the Fuel Oil sample in the Fuel Oil Spin Test is not diluted or altered in any kind of way prior to, or during, testing.[7] In the Fuel Oil Spin Test, the Fuel Oil is subjected to the test without any such alterations and is centrifuged as it would be in the field. Typically, two repeats would be simultaneously run, with 10 mL sample in each test tube.

### 2.3 Fuel Oil Spin Test - method detail

This section sets the guidelines for the test and explains how the results can correlate towards separator behavior, considering each large-scale separator may have different configurations. General test conditions are suggested, but for more accurate correlations, some parameters could be adjusted after consultation with the separator manufacturer (OEM) and chief engineer.

#### 2.3.1 Temperature

The temperature of the test is the temperature at which the Fuel Oil is processed in the separator. The test is often limited at 98°C for practical and safety reasons in the laboratory, but is sufficient to developing an understanding of the degree of sludge formation onboard.

The temperature used in the test is a crucial parameter, since the temperature of the Fuel Oil determines its viscosity, and therefore the separation efficiency according to Stokes Law. Under gravity driven settling:

$$V_g = \frac{d^2(\rho_p - \rho_l)}{18\eta} \times g \qquad (1)$$

Where $V_g$ is the settling velocity, $d$ is the particle diameter, $\rho_p$ is the particle density, $\rho_l$ is the liquid density, $\eta$ is the viscosity of the liquid and $g$ is the gravitational constant (9.81 m/s$^2$). During the test, the force of gravity is replaced by the centrifugal force of the separator, thus achieving a separation force of 5000 to 15000 times the force of gravity.

For HSFO, the viscosity should usually be lowered as much as possible by heating the Fuel Oil to the maximum temperature of 98°C in the separator. However, VLSFO and blends containing biofuels can have a much lower viscosity, and it is therefore reasonable to consider the question: Can separation be done more efficiently at a lower temperature? Typical general temperature recommendation are given by Alfa Laval in Table 2.

The test is recommended to be run at the expected onboard fuel separation temperature to give the most suitable result, therefore Table 2 should also be used to determine the temperature of the Fuel Oil Spin Test. However, note that the maximum temperature of the Fuel Oil Spin Test is 98oC for safety purposes, and therefore the more viscous Fuel Oils (>80 cSt) should be run at 98oC. This will result in the Fuel Oil behaving as similarly as

possible to when it is passed through the vessel's larger-scale purifiers.

Table 2. Relation between recommended storage and separation temperatures for the Fuel Oil Spin Test based on the Fuel Oils viscosity.

| Viscosity @ 50ºC | Storage temperature | Separation temperature |
|---|---|---|
| Up to 20 cSt | 30ºC | 40ºC |
| 20 – 30 cSt | 30ºC | 50ºC |
| 30 – 40 cSt | 15ºC above PP | 60ºC |
| 40 – 50 cSt | 15ºC above PP | 70ºC |
| 50 – 70 cSt | 15ºC above PP | 80ºC |
| 70 to 180 cSt | 15ºC above PP | 98ºC |

*Separation temperature can be set up to 98°C. Higher temperatures will result in more separation. However, despite ISO specification 8217 stipulating a maximum viscosity of 700 cSt, there is no minimum viscosity limit. Care must be taken with low-viscosity Fuel Oils to not over-heat which can cause problems in other equipment (e.g. consult OEM guidance on minimum fuel injection viscosity at engine inlet).

### 2.3.2 Separation efficiency

Alongside some knowledge of geometrical factors, there are two main factors which are needed to identify the *cleaning capability* of the separator:

- The rotation speed of the separator.
- The size of the discstack: The number of discs and the surface area of the discs, with greater area resulting in greater separation.

*Separation efficiency* is a combination of *cleaning capability* and *flow rate*. The higher the flow rate, the lower the efficiency of the separator. Certified flow rate, for example, is defined as the flow rate at which 85% of 5 micron test particles is removed from the Fuel Oil.

The general recommendation for the Fuel Oil Spin Test with dimensions as shown in the '*Setting up the test*' section is to use 2100 rpm and 4 minutes. To better correlate the test with onboard experience, the general conditions could be amended to consider the *cleaning capability* of the separator and *flow rate* used onboard. With this information, which may be provided by the separator OEM or chief engineer, one can better calculate the appropriate speed and duration of the test.

Separator manufacturers correlate their cleaning capability for a given liquid with the maximum flow through the separator, the load factor. The load factor is different for different fluids, for example, the load factor for a residual Fuel Oil will be different to a distillate Fuel Oil, lubricant, or aqueous liquids. Differences in load factors are mainly a result of viscosity changes, but also different aggregation propensities. This means that HSFO and VLSFO have different load factors, and even within HSFO or VLSFO categories, the Fuel Oils may have different load factors. Figure 2 compares the viscosity of HSFO and VLSFO, and highlights the greater variability in viscosity for VLSFO fuels compared to HSFO. The load factor is set at the design of the vessel; for example a separator flow and size will be selected for its capability of handling Fuel Oils which have a viscosity of 380 cSt at 50ºC.

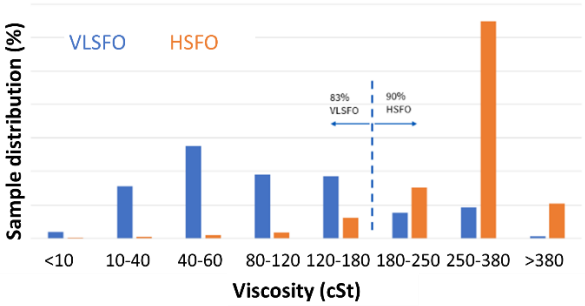



Figure 2. Variability in viscosity of residual fuels, highlighting a) VLSFO as a lower viscosity fuel than HFO on average, and b) the greater variability in viscosities for VLSFO fuels than for HFO. This is based on 2020/2021 FOBAS data, courtesy of Lloyd's Register.

### 2.3.3 Sludge amount

The goal of the Fuel Oil treatment system, and in particular the separator, is to remove undesirable fractions from the Fuel Oil. The removed sludge is likely to contain asphaltenes, catalytic fines and water. The separator is usually designed to hold a certain amount of sludge inside the bowl before it is discharged. The space holding the sludge on the outside of the discstack is called the sludge space. Separator discharge time is recommended based on the nature of the separated amount, with high total sediments results typically triggering a warning to the Chief Engineer that sludge discharge times may need to be adjusted for the Fuel Oil in question.

Although not essential, for full comprehension of what the test result shows and correlate this to onboard experience, one can also consider the size of the sludge space. This knowledge should also be obtained from the separator OEM or Chief Engineer, as it is dependent on the separator model.

### 2.3.4 Setting up the test

This section discusses some of the parameters which can be modified in the test, but is not meant as a comprehensive test plan.

The following equipment is needed to run a Spin Test:

- A laboratory test tube centrifuge which develops a g-force of 500 – 1000 *g*. A suitable centrifuge typically has a speed of rotation of 1000 – 3000 rpm. The centrifuge also needs to be able to control its operating temperature up to 98°C.
- A heated cabinet for samples to preheat the sample to the test temperature.
- Appropriate test tubes with a reading accuracy of 0.1 volume %, with highly tapered 10 mL graduated tubes typical (see Fig. 4).
- A means to measure time – a stopwatch for example, or built-in timer on the centrifuge.
- Auxiliary equipment to safely handle the Fuel Oils and execute the test.

Preparing the sample and execute the test:

1. Prepare a heated sample of the Fuel Oil to be spun. Heating to be done at the ***recommended separation temperature***.
2. Fill a test tube to 10 mL line with the Fuel Oil to be sampled. Please note that it is often necessary to run two samples in a Spin Test machine at the same time to balance the machine, therefore it is advised to run samples in duplicate.
3. Preheat the machine if possible.
4. Insert the sample in the machine and centrifuge for the ***recommended separation time***.

As previously mentioned, the recommended separation temperature is the temperature used onboard, which usually correlates to viscosity as shown in Table 2.

The test times are dependent on both the separators cleaning capability, and the flow rate through the separator. Typical times are between 4 and 15 minutes, but can depend on the model of Spin Test machine since diameters, positions and speeds may alter the G forces involved.

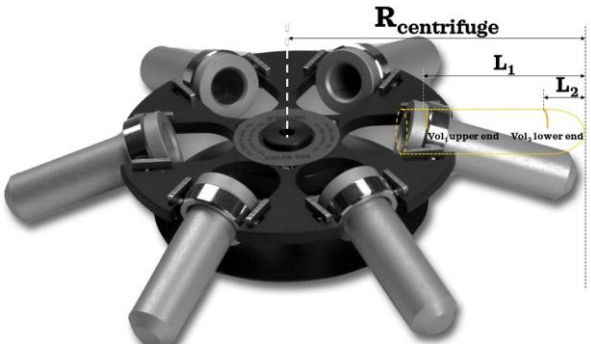



Figure 3. Diagram showing key parameters involved with the Fuel Oil Spin Test, e.g. radius of machine, test tube size/position. These impact the G forces involved in the separation.

The radius from the centre of the centrifuge, $R_{centrifuge}$, and the liquid level $L_1$ from that centre need to be known. Alfa Laval uses a centrifuge with 10 mL sample bottles where:

$$R_{centrifuge} = 150 \text{ mm}$$

$$L_1 = 76.2 \text{ mm}$$

$$\text{Speed} = 2100 \text{ rpm}$$

Once the test is run, the tubes should be turned upside down in a heated cabinet for a minimum of 12 hours to let all Fuel Oil run out – the sludge particles stay behind. This will result in tubes similar to those shown in Fig. 5, where the sludge volume amount can be read.

### 2.4 Interpretation of results and examples

Results are reported by observing and reading the volume of densely packed sludge left in the tubes at the end of the test procedure, with results expressed in volume % sludge. Interpretation of the results is summarized in **Table 3**. Note that the results are not absolute, but generally hold up to the real-world experience as per Alfa Laval's experience (as well as our own – see section **2.5**) across a range of large-scale separators. Volumes above 0.5% not only potentially cause separator malfunctions, but can cause problems with handling of the sludge tank itself (e.g. blockages or overfill).

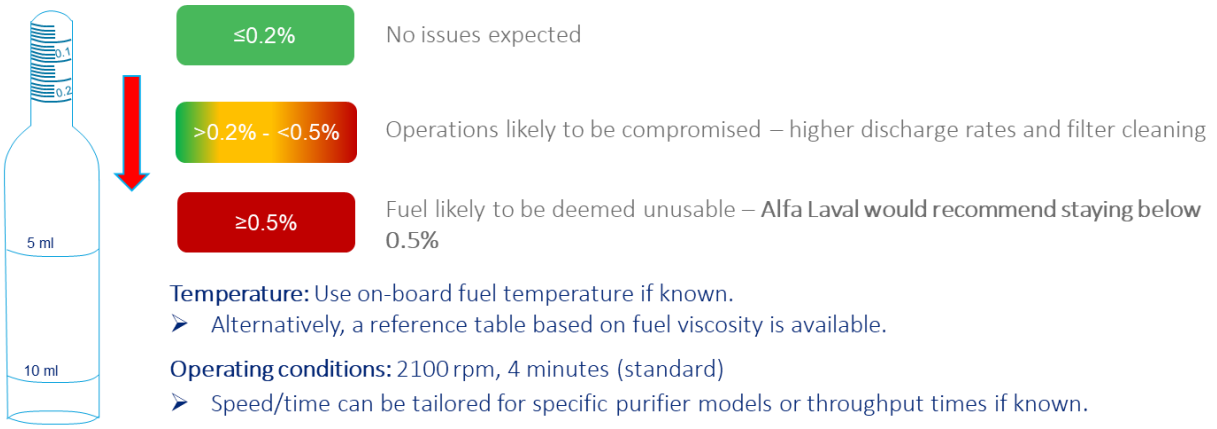



Figure 4. Diagram depicting the interpretation of the spin test and the general conditions under which it is run. Note: 0.1 mL of sludge translates to 1% of the Fuel Oil coming out as sludge, as 10 mL of sample is used.

Table 3. Interpretation table for the Fuel Oil Spin Test.

| Volume of Sludge (%) | Rating | Interpretation |
|---|---|---|
| <0.2 | Fit for use onboard* | Other than due diligence, no further adjustment of the separation process needs to be considered. Run this Fuel Oil through the Fuel Oil installation as normal. |
| 0.2 – 0.5 | Extra care required in handling the Fuel Oil. | The Fuel Oil may cause the sludge space of the separator to fill up faster then the regular discharge time allows. Even though the separator control automation can detect such an event, this can lead to blockages and larger amounts of sludge in the frame and the sludge tank, to a degree that the sludge can build up in the frame depending on the sludge properties. A precautionary action is to decrease the discharge time so that more flushing takes place. |
| >0.5 | Very likely to generate large amounts of sludge. | The Fuel Oil is very likely to generate large amounts of sludge. If processed in a separator, the discharge times need to be minimized – once every 5 to 10 minutes – or risk blocking the separator bowl and/or frame. It is strongly recommended to contact the separator OEM for additional advice and assistance in such a case and, if possible, offload the Fuel Oil. |

*Fit for purpose refers specifically to the outcome of the Fuel Oil Spin Test

As such, this relatively quick test can indicate the expected behaviour of the Fuel Oil before it is bunkered. This could help to avoid unexpected operability issues which other Fuel Oil testing may not readily indicate, enabling pre-emptive handling measures. Some examples of results are shown below (**Fig. 5**). As is visible, the untreated VLSFO is separating out a relatively high level of sludge. Exceeding 0.5% volume sludge, the indication aligns with the Fuel Oil not being fit for purpose. Practically, this means that the chief engineer may need to modify operations onboard to handle the severe amounts of sludge. They may even decide, or be forced to, stop using the Fuel Oil.

It has been shown that certain additive technologies have the capability of vastly improving the performance within the Spin Test (as well as the total sediments result), as also displayed in **Fig. 5**. The same Fuel Oil blend when treated with Formulation A produces an entirely different result. The clear conclusion for the treated case is that there would be no issues whatsoever. The additive technology, through thoroughly dispersing asphaltene agglomerates, has reduced the sizes of

the particles so effectively that they would not be separated out in the centrifuge onboard.




| Untreated | Treated |
|---|---|
| TSP: 0.14% | TSP: 0.01% |
| FOST: 1.5% | FOST: <0.1% |
| Not fit for purpose | Fit for purpose |

Figure 5. Examples of a VLSFO blend, with and without additive treatment.

The benefits for additive use in such a scenario has enormous potential. To begin with, there is an obvious benefit in the reduction of sludge waste being generated and captured. This will directly save the shipper costs associated with disposing of the material. Furthermore, this effect could be so profound that it is the difference between a Fuel Oil being usable and not, as the examples above would indicate. Beyond this, however, by simply retaining the asphaltenes in the Fuel Oil that would otherwise be separated out, it is logical to conclude that more hydrocarbon material is making its way towards the combustion chamber. As such, one would anticipate energy and efficiency benefits for the treated Fuel Oil.

### 2.4.1 Correlating to performance in the field (relating to field trial experience)

To try and evaluate this method in more detail, Infineum have conducted a study in order to relate Fuel Oil Spin Test performance back to a successful ship trial that had been carried out on a Suezmax tanker with a two-stroke engine. To recap, the Fuel Oil supplier had produced on-spec VLSFO (<0.1 mass % total sediment), which deteriorated rapidly onboard ship to the point where the Fuel Oil was unusable (>0.23 mass % TSP) and had to be de-bunkered. An identical VLSFO blend was made, treated with Formulation A to give a TSP <0.04 mass %. The trial with the treated Fuel Oil lasted 15 weeks and throughout that time TSP was maintained at 0.04 mass % with no operational issues being reported by the ship's engineer.

As such, we theorized that the test would align itself with the observed outcome of the trial, which Infineum examined and found to be the case (**Fig. 6**). Note that even though the components used to create the blend were now approximately 18 months old, we still believed that discrimination would be visible between the treated and untreated case, and that the latter would certainly return a higher volume % sludge result.

Our findings do indeed indicate that the untreated Fuel Oil blend would have been expected to create issues onboard whilst the Formulation A treated sample showed a clear improvement. We also held the created Fuel Oil blends for 10 weeks before evaluating again – conscious that the Fuel Oil may worsen over time as it did so during the trial without additive. In this case, we did experience the untreated Fuel Oil deteriorating over the duration (increasing to 1.4% volume sludge), whereas the treated counterpart remained at 0.3%. As such, these results align themselves well with the experience onboard, which not only provides confidence in the test method itself, but confidence in the effectiveness of Formulation A as a sludge management additive.




| Untreated | | Formulation A | |
|---|---|---|---|
| 0 weeks | 10 weeks | 0 weeks | 10 weeks |
| TSP: 0.11% | TSP: 0.19% | TSP: 0.04% | TSP: 0.12% |
| Spin Test: 0.8% | Spin Test: 1.4% | Spin Test: 0.3% | Spin Test: 0.3% |

Figure 6. The VLSFO blend used in the ship trial, with and without Formulation A, at 0 and 10 weeks old.

### 2.4.2 Correlating to performance in the field (blind study)

To further scrutinize the methods ability to predict issues experienced in the field, Infineum examined

20 different Fuel Oil samples provided by a marine service provider. Information regarding which samples had experienced issues (or not) was kept from Infineum until after results were generated. It was agreed to subject the samples to the general spin test conditions (2100 rpm, 4 minutes) and to use temperatures based on the KV50 values of the Fuel Oils being examined. All samples examined were within the ISO 8217 specification and, as such, no clues were available to Infineum regarding which samples may be those experiencing issues onboard. It is worth noting that two of the samples had either measured above the specification limit for either TSP or TSA, and these fuels did indeed go on to experience operability issues onboard.

Following our testing it was revealed that in most cases alignment between the spin test and experience in the field is found (**Table 4, Fig. 7 Fig. 8**). Of the three results not aligned, two of these were 'false positives' in the sense that the spin test predicted no operational issues, yet they experienced issues onboard, and one of them was in the 0.2-0.5% region (where extra care would be advised), but no issues were reported. For the remaining Fuel Oils (85% of those examined), the spin test result correlated with experience onboard. Of note is that all samples exceeding 0.5% volume of sludge (and thus being deemed not fit for purpose) also exhibited sludging issues onboard (i.e., none of these samples were used without issue).

Table 4. Key ISO 8217 parameters of the Fuel Oils examined. Green shading in the final 2 cells denotes alignment between test result and field experience. Red shading denotes misalignment between spin test result and onboard experience.

| Sample No. | KV50 (°C) | Density (kg m$^{-3}$) | TSP (% m/m) | TSA (% m/m) | TSE (% m/m) | CCAI | Asphaltene Content (% m/m) | Storage Temp (°C) | Purifier Inlet Temp (°C) | Test Running Temp (°C) | Volume Sludge (%) | Issue Experienced Onboard? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 32.44 | 942.3 | 0.09 | <0.01 | <0.01 | 835 | 1.5 | 45 | 98 | 60 | >1 | Y |
| 2 | 85.90 | 975.1 | 0.02 | 0.04 | <0.01 | 853 | 4.0 | 40 | 98 | 95 | <0.1 | Y |
| 3 | 71.84 | 948.1 | 0.04 | 0.05 | 0.05 | 829 | 1.6 | 22 | 80 | 95 | 0.25 | Y |
| 4 | 85.53 | 937.6 | 0.04 | 0.07 | 0.07 | 816 | 2.4 | - | 80 | 95 | >1 | Y |
| 5 | 129.0 | 955.0 | 0.06 | 0.13 | 0.08 | 828 | 3.1 | 20 | 98 | 95 | 0.4 | Y |
| 6 | 32.52 | 931.6 | 0.04 | <0.01 | <0.01 | 825 | 1.1 | 28 | 68 | 60 | 0.4 | Y |
| 7 | 157.9 | 925.6 | 0.02 | 0.02 | <0.01 | 796 | 1.5 | 40 | 98 | 95 | 0.5 | Y |
| 8 | 124.2 | 926.0 | <0.01 | <0.01 | <0.01 | 800 | 1.1 | 40 | 98 | 95 | <0.1 | N |
| 9 | 91.55 | 946.9 | 0.01 | 0.01 | <0.01 | 825 | 1.4 | 20 | 98 | 95 | <0.1 | N |
| 10 | 324.8 | 959.0 | <0.01 | <0.01 | <0.01 | 822 | 1.3 | 37 | 98 | 95 | 0.1 | N |
| 11 | 43.1 | 924.9 | <0.01 | - | <0.01 | 814 | - | 20 | 70 | 60 | <0.1 | N |
| 12 | 63 | 941.2 | 0.06 | - | - | 824 | 3.5 | 20 | 80 | 80 | 0.3 | Y |
| 13 | 59.87 | 948.7 | 0.33 | 0.09 | 0.15 | 832 | - | 30 | 80 | 80 | <0.1 | Y |
| 14 | 122.1 | 948.9 | 0.1 | - | - | 823 | - | 20 | 98 | 95 | ~0.5 | Y |
| 15 | 71.3 | 946.7 | 0.09 | - | - | 828 | - | 29 | 98 | 90 | >2 | Y |
| 16 | 121.9 | 953.5 | 0.09 | - | - | 827 | - | 40 | 98 | 95 | 0.3 | Y |
| 17 | 117.2 | 930.8 | 0.09 | - | - | 805 | - | 37 | 98 | 95 | 0.3 | Y |
| 18 | 13.7 | 915.8 | <0.01 | - | <0.01 | 826 | - | 20 | 50 | 40 | 0.4 | N |
| 19 | 45.92 | 960.2 | 0.02 | - | - | 848 | - | 30 | 98 | 60 | >1 | Y |
| 20 | 25.1 | 923.5 | 0.01 | - | <0.01 | 821 | - | 20 | 60 | 50 | 0.1 | N |

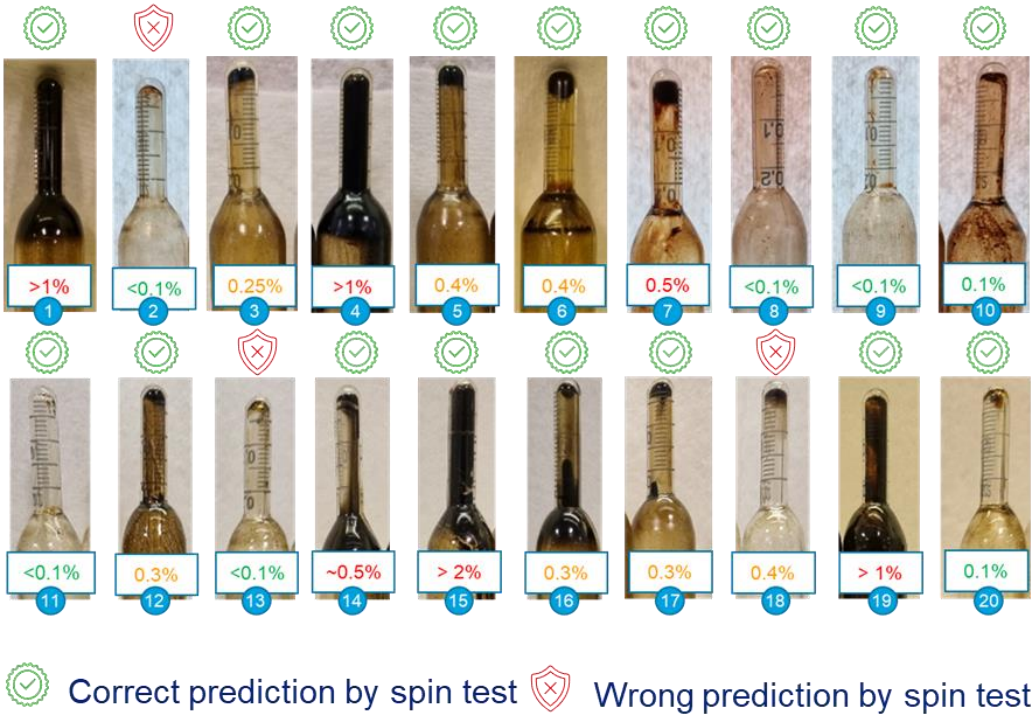



Figure 7. The Fuel Oil Spin Test results for all 20 Fuel Oils, with green, orange and red colouring indicating the likelihood of experiencing stability problems onboard.

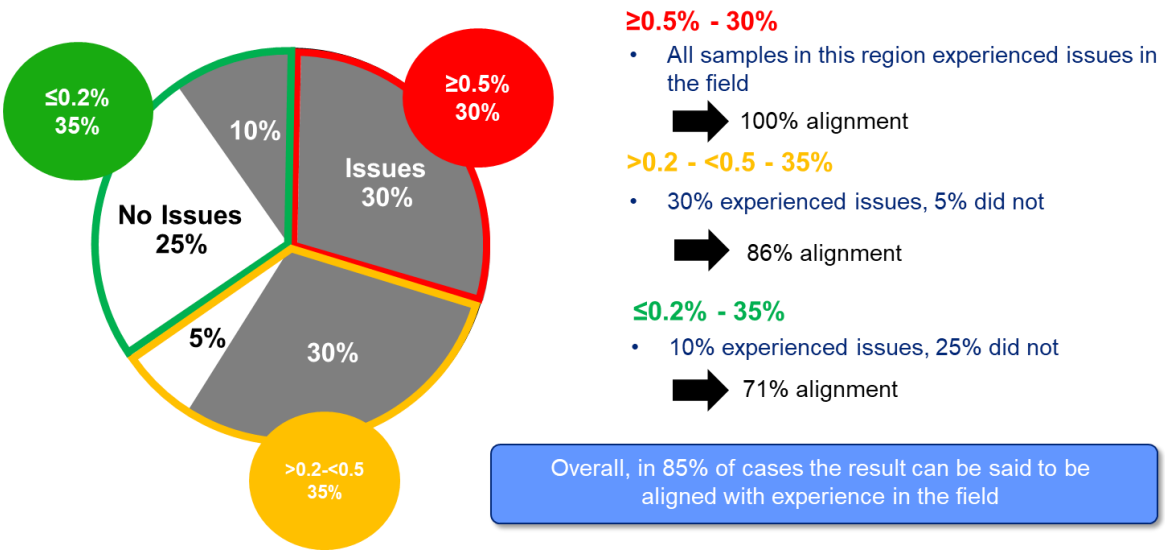



Figure 8. Pie chart expressing the correlation between the Fuel Oil Spin Test results and field experience. White areas are Fuel Oils which did not experience problems onboard, whereas gray areas are Fuel Oils which did. The green/orange/red regions are the Fuel Oil Spin Test results as shown in Figure 6.

## 3. Conclusion

We believe that the marine industry could benefit from employing a new test to provide guidance on the operatbility of Fuel Oils. The Fuel Oil Spin Test described in this paper has a scientific basis for being an appropriate test. The fuel is not modified in any way by addition of solvents, nor does it focus on measuring aspects of the fuel related to sludge (e.g. particle size). It's sole purpose is to determine the operability of the Fuel Oil, which it does by applying a centrifugal force similar to that experienced in a Fuel Oil separator. The result is a direct volumetric measurement of the level of sludge that a fuel will generate in the separator.

From the perspective of avoiding sludge-related issues onboard, we believe it could be used

in conjunction with onboard operations planning and effective sludge management additives in order to offer the most complete protection for ship operators.

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