CIMAC CONGRESS 25
ZURICH, MAY 19 – 23, 2025

2025 | 238

Stability assessment of bio-residual marine fuels (RF grades) through extended TSP and spin testing

Fuels - Alternative & New Fuels

Muhammad Usman, Lloyds Register

Chrysa Tsesmeli, Lloyds Register
Sophia Themelarou, Lloyds Register

ABSTRACT

The use of biofuels on ships for combustion purposes is not new. However, biofuels piqued the interest of ship operators since IMO 2020 and then as a compliance pathway for environmental regulations such as IMO's CII, EU ETS and FuelEU Maritime. There has been an extensive discussion within the ISO TC28/SC4/WG6 developing ISO 8217 marine fuel standard, about the sediment potential and asphaltene stability of the residual blends containing FAME (fatty acid methyl ester) i.e., RF grades. As outlined in Table 3 of ISO 8217:2024, the stability of RF grades is assessed similar to the conventional residual grades of Table 2 through standard total sediment methods i.e., total sediment potential (TSP) and total sediment accelerated (TSA). As RF grades are still relatively new to the marine market, there remains an apparent knowledge gap regarding asphaltene stability and long-term storage behavior of residual fuels containing FAME. The study aims to provide an insight into the behavior of RF grades and how their stability performance stack up against their fossil counterparts. This is pursued through the selection of two sets of real-world samples received in LR FOBAS fuel testing lab. Set 1 is RF (Table 3) grade samples and set 2 is RM (Table 2 or 4) grade samples. Both sets of samples have been subjected to standard total sediment, extended TSP (48 hours instead of 24 hours) and centrifugal load (spin) test to simulate onboard storage and separator conditions respectively. Finally, an analysis has been performed on the results with relevant commentary. Moreover, this set of tests will help to understand if the modified TSP and fuel oil spin test (FOST) can be used as supporting methods to assess stability of new and conventional types of residual fuel blends.

1 INTRODUCTION

The stability of marine residual fuels is a critical factor in ensuring uninterrupted ship operation and consistent performance of the vessel’s main and auxiliary engines. An unstable fuel will cause asphaltene precipitation, commonly referred to as sediment formation or sludging, and deposition at various points of the vessel’s fuel system resulting in operational implications such as sludge accumulation within tanks, piping or filter clogging, purification plant clogging and malfunction, injector fouling, and combustion inefficiencies [1].

Residual Marine (RM) fuel is a mixture of hydrocarbons derived from petroleum refining processes [2], typically characterized by high concentration in aromatic compounds of high molecular weight, the asphaltenes, maintained in colloidal dispersion. The asphaltenic molecules consist of a large number of fused aromatic rings, heteroatoms, such as sulphur and nitrogen, and short peripheral paraffinic alkane chains of various functional groups primarily including carboxylic acids, carbonyls, phenols, and potentially pyrroles and pyridines [3],[4],[5]. These functional groups render a relatively high polarity to the asphaltene molecule. They are capable of forming dipole-dipole and hydrogen bonds with the surrounding molecules comprising of saturates, aromatics and resins (SARA). As soon as the surrounding liquid has a comparable polarity to the asphaltenes, then their relative solubility is similar and the asphaltenes can be maintained in stable suspension. This is defined as a stable fuel mix.

A fuel will remain stable until any disturbance is imposed to the equilibrium between the asphaltenes and the SARA [5]. In case the polarity of the SARA is reduced, e.g. by addition of less polar components, then the asphaltenes will agglomerate and precipitate causing what is commonly referred as sludging [4],[6]. Asphaltenes formed during thermal refining processes have less complex structures and demonstrate poorer aggregative stability compared to native asphaltenes. Additionally, in straight-run residues, naturally occurring resins in crude oil stabilize electrostatically charged asphaltenes. However, refining processes can alter these resins, leading to deteriorated dispersion of asphaltenes and reduced fuel stability [7].

During fuel storage and/or use, however, aging (oxidation) and environmental conditions such as temperature and imposed mechanical load (pressure) can also disturb this equilibrium and undermine the fuel’s initial stability [5],[6]. Asphaltenic aggregation has been shown to rise with age as the asphaltenes oxidize and tend to conceal their polar heads [6].

The commitment of the maritime industry to actively pursue maritime emissions reduction has led to the adoption of sulphur cap of 0.50% mass for vessels operating outside the emission control areas (ECAs) as well as a turn to low carbon intensity fuel options such as biofuels or other carbon free fuels such as ammonia or hydrogen. The shift towards low-sulfur fuels and alternative fuel blends has imposed the use of new or different low sulphur content cutter stocks. These residuals based 0.50% maximum sulphur fuels also named VLSFO (Very Low Sulphur fuel Oil) are now commonly in use and have an increased paraffinic content, which has lower polarity and hence highlighting the fuel stability as a major area of concern during their use. Lloyds Register FOBAS (Fuel Oil Bunker Advisory Service) data suggest that 19.2% of specification failures reported in 2023 were attributed to Total Sediment exceeding the maximum allowable limit; with Total Sediment being the fuel property used to determine the fuel stability [8]. Moreover, FOBAS data suggests that 54% of the reported onboard operational problems have been attributed to sludge generation [8].

The introduction of Fatty Acid Methyl Esters (FAME) into residual fuel blends poses new challenge in fuel handling as the effect of FAME's oxygenated nature and hygroscopicity on the VLSFO blend properties and operational requirements needs to be fully comprehended and studied. It is known that the presence of FAME will favour phenomena such as microbial growth, water retention, oxidation, and possibly stratification that influence the long-term stability of blended fuels. However, there are studies using Molecular Dynamic Modelling that suggest that the particularly increased polarity of FAME will actually increase the FAME solubility and hence enhance the biofuel blend stability [9].

While the stability of conventional RM fuels has been studied, the behaviour of FAME-blended fuels in marine applications is not well-documented. This study aims to address these knowledge gaps by exploring the stability characteristics of RM fuels and their blends with varying FAME levels and comparing the results with conventional RM fuels. More specifically, the research aims to evaluate the sedimentation tendencies through two different approaches. The first will be the referring directly to the actual aggregation in the fuel using the Total Sediment Potential (TSP) method and the second will be co-evaluating the contribution of aggregation, aggregate size and viscosity [10] using the Fuel Oil Spin Test (FOST).

2 TEST METHODS

2.1 Standard test methods to determine fuel stability

The stability of a residual fuel is defined by its resistance to breakdown and precipitation of asphaltenic sludge, even when subjected to forces such as thermal and ageing stresses under normal handling and storage conditions [11].

Fuel stability is typically evaluated through the measurement of total sediment, with a maximum allowable limit of 0.10% mass. This represents the sum of insoluble organic and inorganic material filtered from a fuel sample under specified conditions.

Key test methods include:

- **Potential Total Sediment (TSP) – ISO 10307-2A:** Determines sediment formation after ageing a sample at 100°C for 24 hours, simulating thermal stress.
- **Accelerated Total Sediment (TSA) – ISO 10307-2B:** Simulates chemical and reduced thermal stress by diluting the fuel with a paraffinic solvent and ageing it at 100°C for one hour.
- **Existent Total Sediment (TSE) – ISO 10307-1:** Measures sediment present at the time of testing via filtration and weighing.

TSP measures resistance to thermal stress, while TSA assesses the ability of a fuel to retain asphaltenes in suspension when commingled with paraffinic fuel under limited thermal stress.

Before 2020, residual fuels, primarily aromatic in composition, exhibited TSA values typically higher than TSP. However, since the IMO 2020 regulation limiting marine fuel sulfur content to 0.50% mass, the characteristics of Very Low Sulfur Fuel Oils (VLSFOs) have changed significantly with TSAs commonly reported at lower levels than TSPs [1]. Achieving low sulfur content often involves blending low-sulfur components with high-sulfur ones, altering fuel stability. Mixing stable high-viscosity fuels with low-viscosity paraffinic fractions destabilizes asphaltenes, making the fuel mixture prone to instability.

To address these challenges, the ISO published PAS 23263:2019, outlining expected characteristics of new marine fuels and offering guidelines and recommending additional methods along with the standard TSP method for predicting the reserve stability testing. Three standard test methods, Intrinsic Stability expressed as *S-value* (ASTM D7157), Stability and Compatibility by Optical Detection (ASTM D7112) and Determination of the Maximum Flocculation Ratio and Peptizing Power (ASTM D7060), are introduced as prediction models that can evaluate both the compatibility between two fuels and the sole fuel's inherent stability. These advanced methods involve:

- Adding an aromatic solvent (e.g., toluene, xylene, or methylnaphthalene).
- Titrating with a non-aromatic solvent (e.g., heptane or hexadecane).
- Using optical detection to measure asphaltene precipitation and determine stability parameters.

A practical method, ASTM D4740 is also offered as a practical approach for assessing the cleanliness of residual fuel oils and their compatibility with blend stocks. Limitations include potential false negatives for waxy (paraffinic) fuels and difficulty in interpreting unclear spot results. In cases of doubt, segregating fuels and awaiting laboratory analysis is recommended.

Although the three test methods, ASTM D7157, D7112 and D7060, may be used for determining stability of a fuel and to predict the degree of compatibility, they are less practical as a routine test method where the TSP (ISO 10307-2) remains applicable and can be more easily run along with ASTM D4740.

Other methodologies (summarized in the Table 1 below) can also be utilized to evaluate fuel stability. However, their applicability and accuracy vary. Many have not been standardized, lack sufficient scientific validation, or have limited industry experience for use in marine fuel oils at present.

Table 1: Additional stability test methods

Test Method	Reference
Separability Number	ASTM D7061
Toluene Equivalent (TE)	N/A
Xylene Equivalent (XE)	N/A
Bureau of Mines Correlation Index (BMCI)	N/A

2.2 Alternative test methods used for this study

Effective onboard residual marine fuel storage and separation are the key aspects for smooth engine operations. Sludging issues in ships fuel tanks and separators are not uncommon. The standard methods outlined in ISO 8217 are mostly effective in predicting sediment potential of the fuels however on few occasions, satisfactory results from standard methods do not correlate with the onboard experiences where ship face sludging in storage and separator [8]. This study proposes following two performance methods which could be considered with the existing tests as complimentary methods to evaluate sludging in storage and separation.

2.2.1 Fuel Oil Spin Test (FOST)

The Fuel Oil Spin Test (FOST) has been developed and used by marine fuel separator manufacturers for many years in order to simulate the conditions on a small scale under controlled laboratory conditions. The test helps separator manufacturer to design the separators for a certain product based on laboratory test conditions [10]. The test works on simple principle which is to subject the residual fuel sample to high centrifugal force which will separate the heavier components in the fuel. The method is deemed similar to ISO 9030 and ASTM D1796 used to determined water and sediments in crude oils and fuels respectively [10].

There is a need to standardise the FOST method which has been discussed at various ISO and CIMAC working groups looking into the stability, cleanliness and compatibility of RM fuels. However, it appears that more information and extensive precision data is required to be made available for these working groups to take further steps towards standardisation and creating suitable guidelines respectively. This also translates into a current limitation of this method that there is no defined repeatability or reproducibility values for the chosen method. Nevertheless, it is expected that exercise such as these will help the industry with the data and improving the understanding of the test method.

2.2.2 Extended TSP method

The results from FOBAS indicate that on few occasions, off-specification TSP result from a fuel sample was consumed without ship experiencing operational problems and on some other instances, ship reported sludging issues when TSP is within the specification limit. This unpredictability in the field experience has generally been attributed to the complexity of the marine residual fuels of various blends and chemistries.

This study proposed extended TSP method is an attempt to assess the impact on fuel stability if keeping the fuels under thermal stress for 48 hours instead of standard 24 hours and following the rest of the method is exactly the same as outlined in ISO 10307-2 (Procedure A).

3 SAMPLE SELECTION AND PROTOCOL

3.1 Fuel samples

3.1.1 RF (Residual FAME) fuels

For this study, residual bunker fuel samples containing up to 35% FAME, classified as RF grades, were initially tested against the key requirements of table 3 of ISO 8217:2024 (parameter results presented in Appendix B). These samples were sourced from various geographical regions and suppliers to provide a representative overview of the quality of biofuel blends available globally. Majority of the selected RF grade samples are VLSFO (≤0.50% mass) fuels however three high sulphur content (>0.50% mass) RF samples were also included in the analysis program.

RF grade samples has been categorised based on their kinematic viscosity at 50°C into two groups:

1. RF**LV**: Lower viscosity: ≤40cSt (Thirteen samples from RFLV01 to RFLV13)
2. RF**HV**: Higher viscosity: >40cSt (Seven samples from RFHV01 to RFHV07)

This categorization was employed to ensure that the study captures the performance and characteristics of biofuel blends across a wide range of viscosities, reflecting the diversity of marine biofuels currently in use.

3.1.2 RM grade fuels

Residual bunker fuels that do not contain FAME or any other biofuels (RM grades) were also included in this study. Similar to the RF grades, RM fuels were tested in accordance with ISO 8217:2024 Tables 2 (for fuels with a sulphur content ≤0.50% mass) and 4 (for fuels with a sulphur content >0.50% mass). These fuels were sourced from various geographical regions and suppliers to ensure a comprehensive representation.

The RM samples were categorized based on their Total Sediment Potential (TSP) results obtained from the initial ISO 8217 standard analysis. The two categories in this set are as follows:

1. RM**LS**: Low Sediment ≤0.04% mass (six samples from RMLS01 to RMLS06)
2. RM**HS**: High Sediment >0.04% mass (eleven samples from RMHS01 to RMHS11)

The reason for picking different sample selection criteria for RM and RF grades is mainly because, for the RF grade samples, the standard TSP results have generally been very low (<0.04% mass) hence viscosity is used instead to represent various fossil blend components which is the primary factor in varying viscosity RF grades. However, for RM grades, there were choices to select from high and low sediment fuel samples which fits one of the objectives of this study to evaluate the impact of different stability test methods on high and low sediment fuels.

3.2 Methodology and test protocol

Alongside the sample selection criteria described in the section above, it was important that each selected sample should have sufficient volumes (min. 150 ml) to perform required analyses. Figure 1 describes the distribution of primary sample into sub-samples and the analyses protocol for the study.

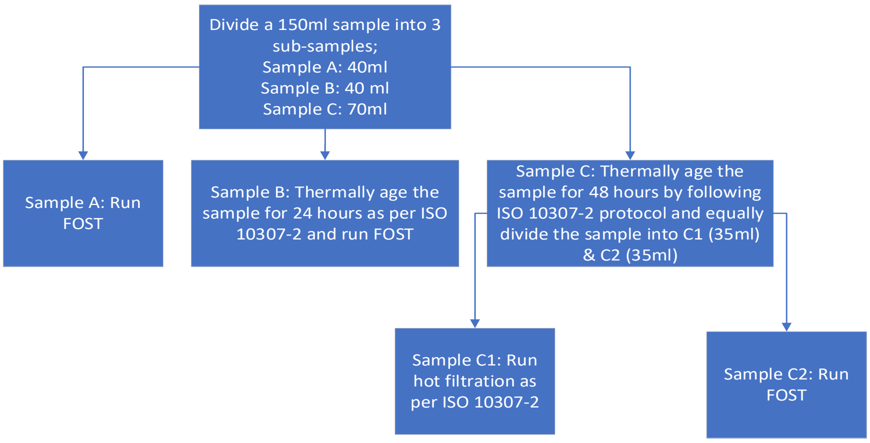


Figure 1: Lab testing protocol for each sample (section 3.2)

With the understanding that each sample has already been tested for standard ISO 8217 parameters, practically this study aims to perform four additional tests i.e., i) FOST without thermal aging (FOST$_{0H}$), ii) FOST after 24 hours of thermal aging (FOST$_{24H}$), iii) FOST after 48 hours of thermal aging (FOST$_{48H}$), and iv) extended TSP test after 48 hours of thermal aging (TSP$_{48H}$).

Note: In this paper, to differentiate between the TSP as a standard method and TSP$_{48H}$, TSP$_{24H}$ has been used for clarity.

3.2.1 FOST

In the absence of a standardised approach for FOST analyses, this study adopts a similar method which has been outlined by Dewi et al., [10]. Following key steps have been performed in the lab;

1. Firstly, the equipment is pre-heated to bring the equipment to the separation temperature which is known for the specific fuel to be tested (separation temperature is advised by the separator manufacturers based on the viscosity of the fuel sample – see Table 2)

Table 2: Guideline for fuel cleaning temperatures [12]

Viscosity@50°C	**Separation Temp.**
Up to 20 cSt	40 °C
20 to 30 cSt	50 °C
30 to 40 cSt	60 °C
40 to 50 cSt	70 °C
50 to 70 cSt	80 °C
70 to 700 cSt	98 °C

2. The samples are equally poured into two 10ml sample tubes and then placed into the test equipment (Figure 2) and run at 2100 rpm at a separation temperature for 4 minutes. Then the sample tubes are taken out and placed upside down for draining in an oven at the

Figure 2: FOST lab equipment

same separation temperature for at least 10 hours

3. After draining, the tubes are taken out of oven and then inspected/weighed to quantify the sludge
4. To report the result for each tube, a similar approach as outlined in the ISO 10370 (Petroleum products – Determination of carbon residue – Micro method) has been used. Firstly, the mass of the empty centrifuge tube is measured m_{empty}. Secondly, when the sample tubes are filled with sample then weight is measured i.e., m_{full}. This gives the mass of the sample as;

$$\mathbf{m}_{sample} = \mathbf{m}_{full} - \mathbf{m}_{empty}$$

5. Once the test is performed and tubes are drained, centrifugal tubes are then weighed again to record m_{final}. The original mass of the empty vial m_{empty} may be subtracted from m_{final} to obtain a mass for the deposit $m_{deposit}$ as;

$$\mathbf{m}_{deposit} = \mathbf{m}_{final} - \mathbf{m}_{empty}$$

6. The '% mass' is reported of the sample as;

$$\mathbf{m}_{deposit} / \mathbf{m}_{sample} \times 100$$

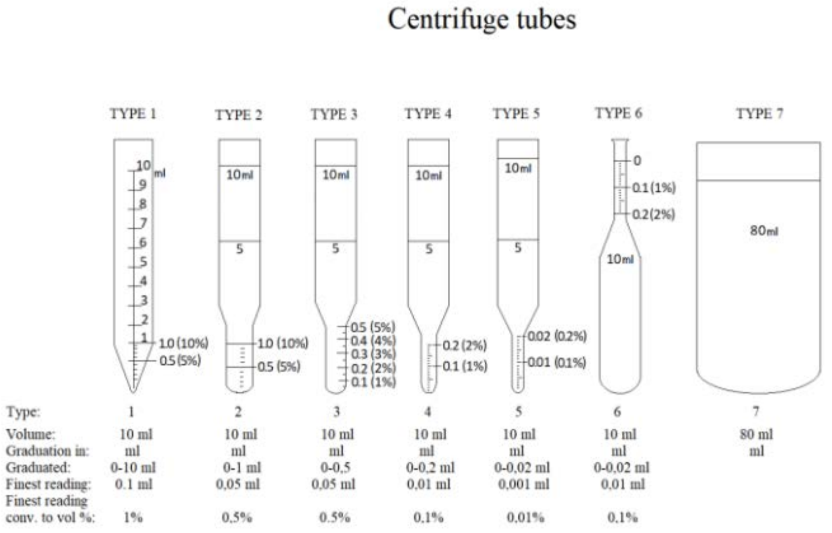
7. The result from the test is an average from the two sample tubes

3.2.2 Interpretation of FOST results

The FOST results below 0.2% mass is considered satisfactory whilst results of >0.2% ~ <0.5% mass are likely to cause some operational problems and results ≥0.5% mass are deemed unusable. The figures are not considered definitive but indicative and are in alignment with the Alfa Laval and some real-world case studies [10].

3.2.3 Sample tube selection

The equipment manufacturer supplies tubes of various shapes and sizes as per Figure 3. These have been categorised from type 1 to type 7.



Type:	1	2	3	4	5	6	7
Volume:	10 ml	10 ml	10 ml	10 ml	10 ml	10 ml	80 ml
Graduation in:	ml	ml	ml	ml	ml	ml	ml
Graduated:	0-10 ml	0-1 ml	0-0,5	0-0,2 ml	0-0,02 ml	0-0,02 ml	
Finest reading:	0.1 ml	0,05 ml	0,05 ml	0,01 ml	0,001 ml	0,01 ml	
Finest reading conv. to vol %:	1%	0,5%	0.5%	0,1%	0,01%	0,1%	

Figure 3: Types of centrifuge tubes used in FOST (Courtesy: https://hotspin.se/)

Based on the experience from past study [10], it was primarily a decision between selecting either Type 3 or Type 4 tube for this study. Previously, type 4 tube was selected however due to its narrow bottom part, the lab reported that the draining of the fuel from tubes after the testing was sometimes obstructed and 'poking' was required to break the surface tension to allow fluid to drain out of narrow part of the tube. However, apparently this was not an issue with type 3 tube which has relatively bigger circumference of the bottom narrow part of the tube allowing the fuel to flow easily out of the narrow part of the tube.

3.2.4 Extended TSP test

Total sediment potential as per ISO 10307-2 (Procedure A) is a reference test method outlined in the ISO 8217 for residual fuel stability evaluation. The test is performed after fuel sample is kept for 48 hours at 100°C i.e., under thermal stress and then the sample is filtered as per the test method to measure the sediment levels in % mass. The fuel sample results above 0.10% mass are considered off-specification as per ISO 8217 limit.

4 TEST RESULTS AND DATA ANALYSIS

4.1 General overview

All samples have been analysed as per ISO 8217:2024, where key quality parameters have been reproduced for reference in Appendix B. The detailed test results of FOST and TSP performed for this study have been presented in Appendix A. The sample selection criteria for RF and RM grade fuels have been outlined under Section 2 above.

Most of the RF grades are around 30% (±5%) volume FAME blends which is currently the most common blending ratio in the bunker industry to produce a 0.50% mass sulphur VLSFO. The key quality characteristics of the examined fuels are presented in Figure 4 below. The average viscosity of the selected RF fuels is low; around 38cSt, due to the presence of low viscosity FAME, whilst average viscosity of RM counterparts is around 200cSt. However, there is insignificant difference in the average densities of the two sets of fuels which results in slightly higher aromaticity (Calculated Carbon Aromaticity Index, CCAI) of RF grades compared to RM grades.

It is not unexpected to find the average acid number of the RF grades higher compared to the RM grades as found in this study. This difference can be attributed to the presence of higher acidic components in the FAME part of the blend however this may also be driven largely by the acid number of the fossil part of the blend.

Average reported results suggest that the RF and RM fuels behaved differently to the stability tests performed in the study. For RM grade fuels, there is an increasing trend on FOST when the fuel is being thermally aged from 0 to 24 to 48 hours, however, there does not appear to be a clear trend for RF grades. This appears to indicate that RF grades exhibit better thermal stability compared to RM counterparts. Similarly, average TSP_{48H} is slightly higher compared to TSP_{24H} for RM fuels however again for RF grades, there is no clear impact on average TSP_{48H} compared to TSP_{24H} results.

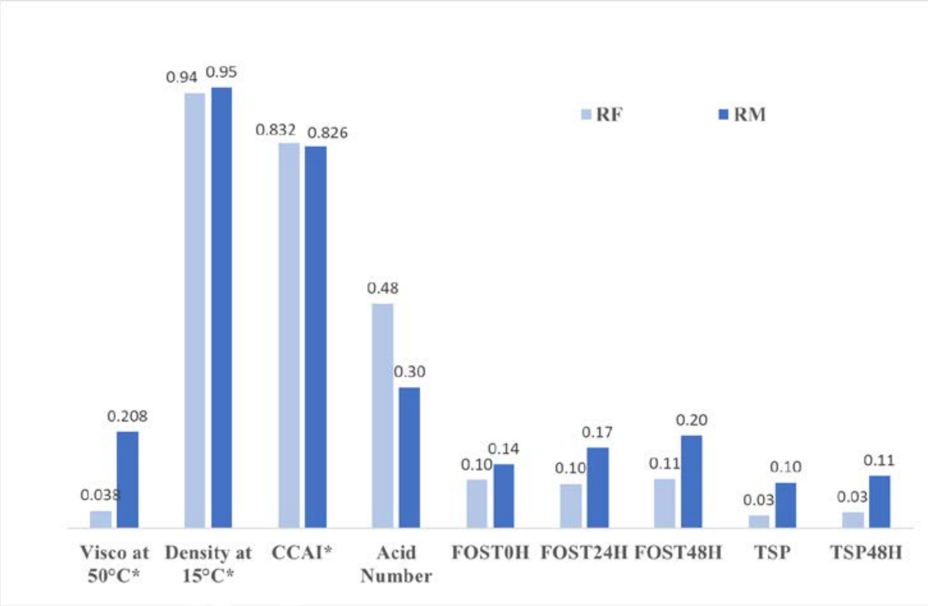


Figure 4: Variations between average results of selected RF and RM samples. (*Viscosity, density and CCAI values have been divided by 1000 to fit the scale)

4.2 Detailed analysis

The $FOST_{0H}$, $FOST_{24h}$, $FOST_{48H}$ along with TSP_{24H} and TSP_{48H} results for all samples have been included in this research are presented in Figures 5 and 6.

4.2.1 TSP_{24H} and TSP_{48H}

According to the results illustrated in Figure 5, overall, no significant changes were observed between 24 and 48 hours apart from few samples which reacted to extended thermal aging. An increase in the reported TSP_{48H} is observed for most of the samples in both RF and RM categories, however this happens in a small scale not exceeding a gap of 0.03% mass in 90% of the cases. There is no fuel sample in this study which has TSP_{24H} result within specification however when subjected to TSP_{48H} have exceeded 0.10% mass limit.

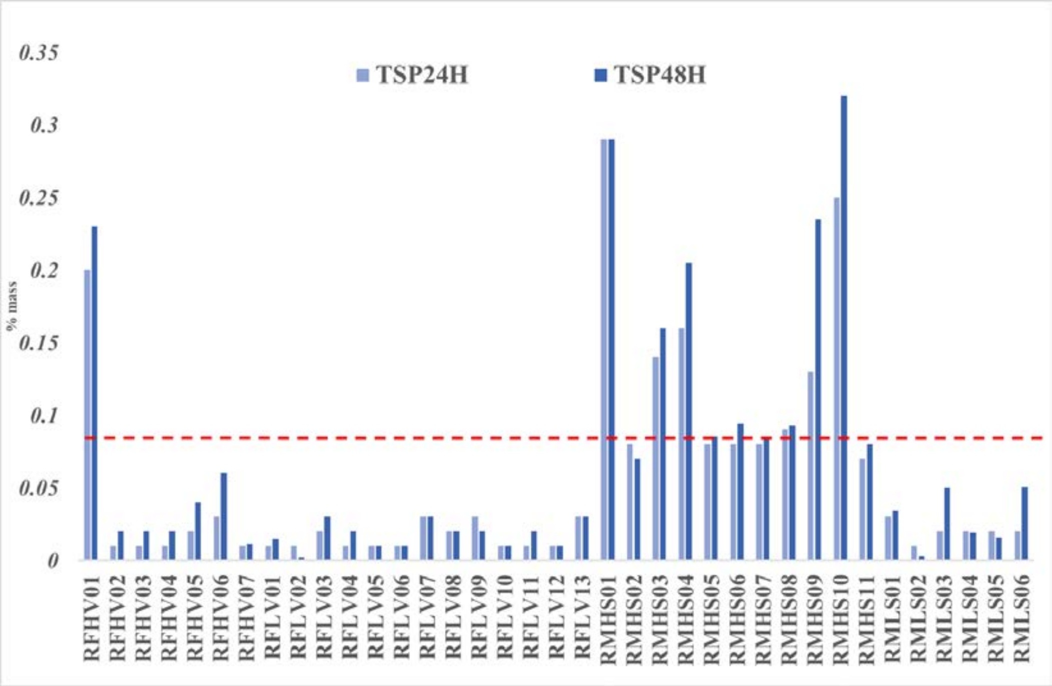


Figure 5: TSP results for all samples.

4.2.2 FOST$_{0H}$, FOST$_{24H}$ and FOST$_{48H}$

Substantial variations have been observed in various samples during FOST analyses as per Figure 6. In few of the cases, FOST$_{24H}$ and FOST$_{48H}$ values increased significantly compared to FOST$_{0H}$ exceeding 0.20% mass threshold which is considered a warning level with the potential to cause onboard sludging [10]. Corresponding TSP$_{24H}$ results for these samples were also above the 0.10% mass specification limit.

4.2.3 FOST$_{0H}$, FOST$_{24H}$ and FOST$_{48H}$

Substantial variations have been observed in various samples during FOST analyses as per Figure 6. In few of the cases, FOST$_{24H}$ and FOST$_{48H}$ values increased significantly compared to FOST$_{0H}$ exceeding 0.20% mass threshold which is considered a warning level with the potential to cause onboard sludging [10]. Corresponding TSP$_{24H}$ results for these samples were also above the 0.10% mass specification limit.

All three trends are evident in the FOST results i.e., ‘increasing’ trend which shows that thermal aging is having an impact on stability, few results show ‘decreasing’ FOST values and some are staying the same (no change). This variation remains less than 0.03% mass for 76% of the samples after 24 hours of thermal aging whereas this percentage is further lowered to 87% after 48 hours. Results of the RM samples appeared to be more sensitive to the thermal aging after the 24 and the 48 hours period. Figure 7 supports this statement, since significantly higher changes in the FOST$_{0H}$, FOST$_{24H}$ and FOST$_{48H}$ results for the RM than for the RF samples were reported.

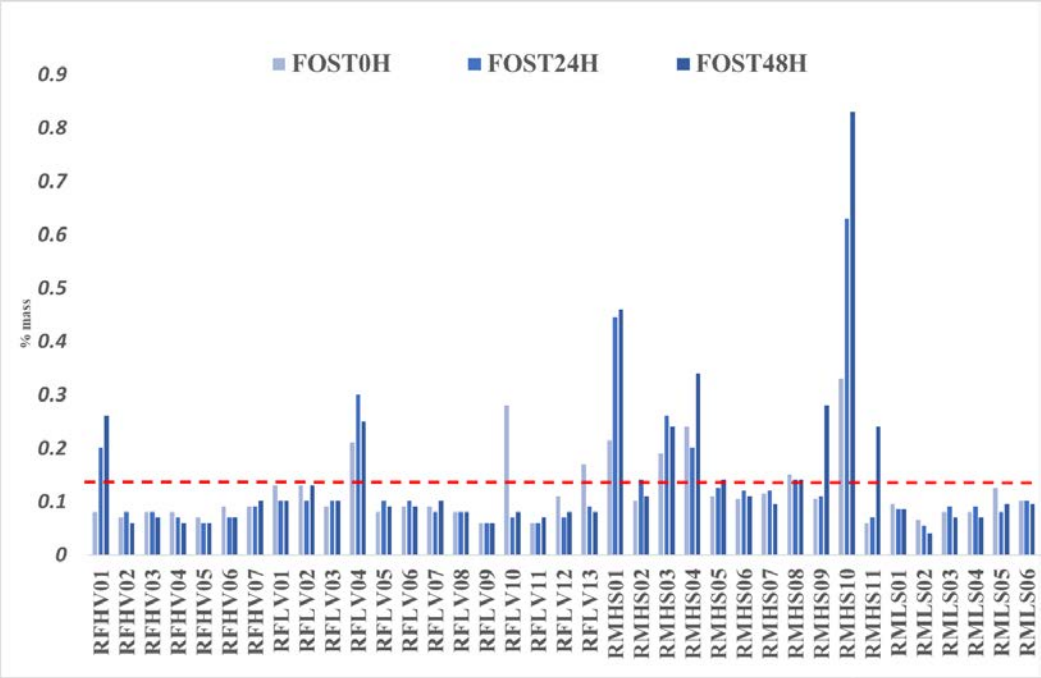


Figure 6: FOST results for all samples.

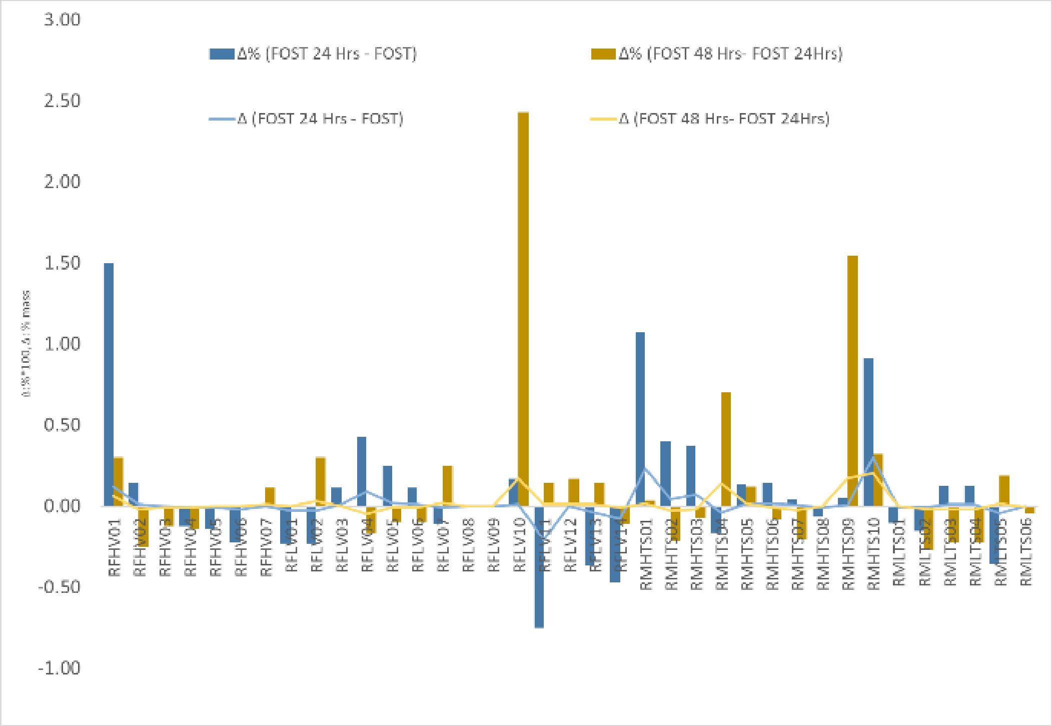


Figure 7: Change (%) in the reported FOST results after 24 hours and after 48 hours

4.2.4 Comparison between FOST and TSP testing

Generally, there has been a good correlation between samples where TSP_{24H} or TSP_{48H} are low, corresponding FOST results are also low. Similar is the trend in cases where TSP_{24H} or TSP_{48H} results are high also show elevated $FOST_{0H}$, $FOST_{24H}$ or $FOST_{48H}$ values. This observation has been illustrated through Figure 8, where samples only exhibiting high TSP_{24H} value (>0.10% mass) have been presented.

Figure 8 shows that TSP_{48h} for these samples was higher than TSP_{24H} for the RM samples. All these samples indicated a high $FOST_{48H}$ (>0.20), while in most of the cases, $FOST_{24H}$ was higher than $FOST_{0H}$. Only one RF sample (RFHV01) had TSP_{24H} above 0.10% which also responded with high $FOST_{24H}$ and $FOST_{48H}$ values whereas

$FOST_{0H}$ was relatively lower. All these cases show a tendency of increasing measured sediment after thermal aging. Both intensity (applied temperature) and duration affected the reported results, however the temperature appears to have a stronger effect. Overall, these fuels appear to be more susceptible to thermal fatigue.

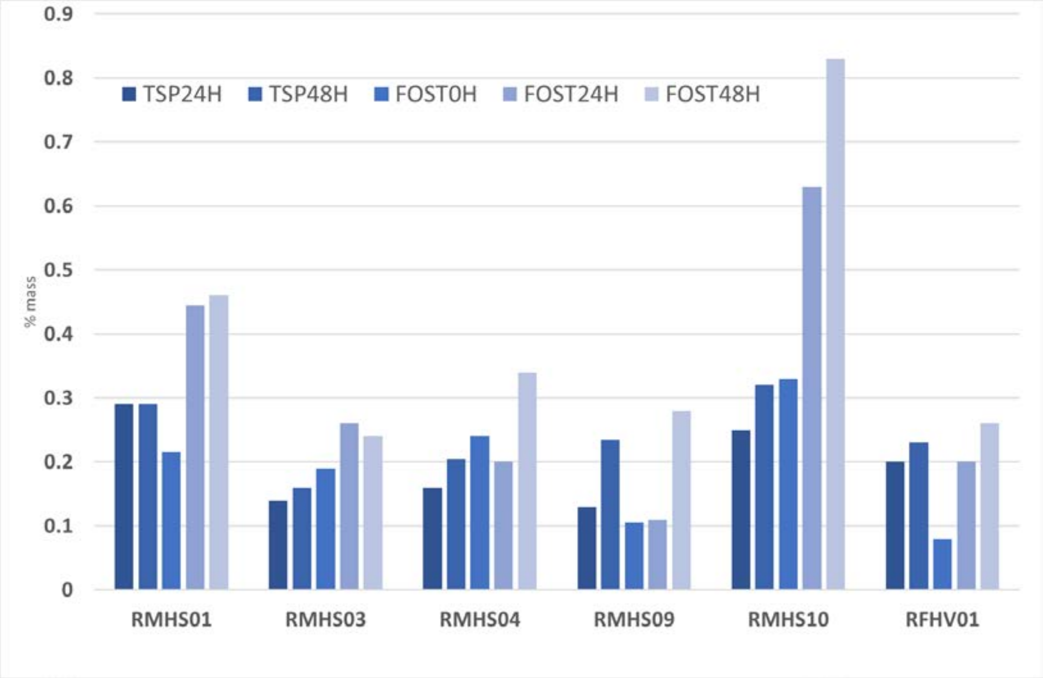


Figure 8: Stability results of samples where TSP_{24H}>0.10% mass

4.2.5 Deviations

A few deviations from the norm have also been observed. Figure 9 shows the data for three samples which are deemed unusual.

For RFLV04, FOST values are fairly elevated though the TSP results are low. This discrepancy may be attributed to the fact that the FOST was conducted at 50°C instead of 100°C used to thermally age samples for TSP testing, it is possible that paraffinic compounds present in the fuel required a higher temperature to melt. This finding suggests that the FOST can predict sludging potential but can also identify other compounds that may cause operational issues, providing a better simulation of real conditions.

For RFLV10, while $FOST_{0H}$ exceeded the 0.20% mass limit, $FOST_{24H}$ & $FOST_{48H}$ and showed low values, aligning with TSP_{24H} and TSP_{48H}. Further investigation, either through vessel feedback or by retesting sample may be required to explain this discrepancy and identify the cause.

The sample RMHS11, only $FOST_{48H}$ failure was noted, while $FOST_{0H}$ and $FOST_{24H}$ were within acceptable limits. This indicates that this fuel sample might be sensitive to the thermal load imposed for the extended time (48 hours) although TSP_{48H} was also low though slightly higher compared to TSP_{24H}.

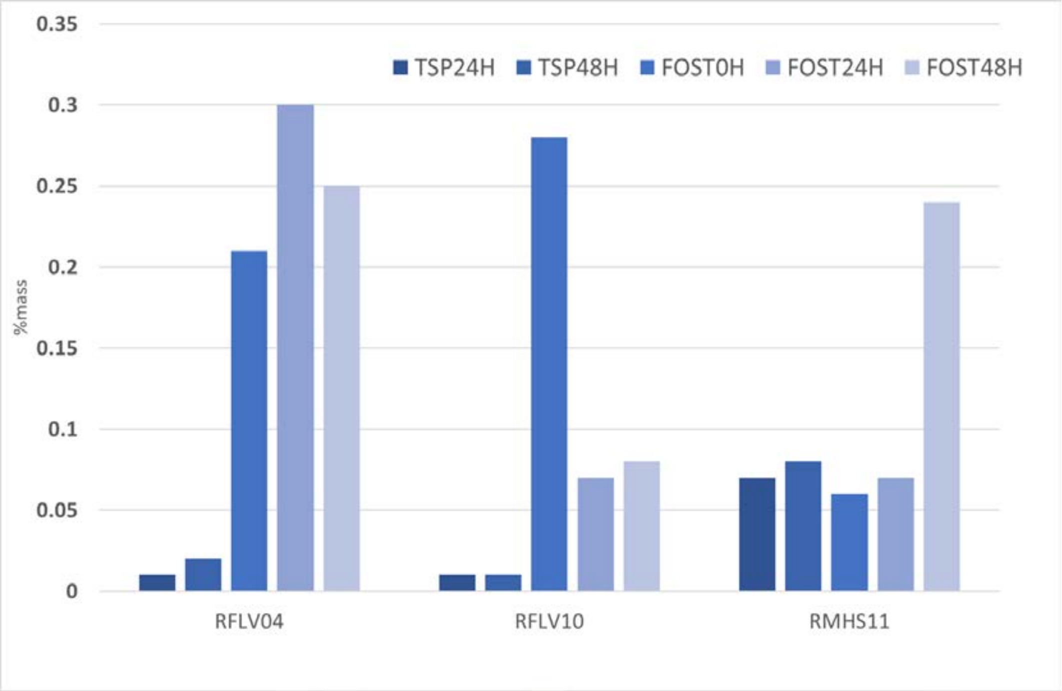


Figure 9: Three unusual results.

5 CONCLUSION

TSP and FOST tests generally provide a consistent assessment of the fuel stability for low sediment fuels. However, TSP and FOST do not align in 6 out of the 10 high sediment incidents with the TSP giving a more conservative assessment of the fuel stability. This can support the industry in cases where lower TSP fuels causing sludge generation and analysis methods like FOST can better identify the sludging potential of the fuel. In other cases, FOST not only detected asphaltene related sediments but can also pick up other compounds that may cause operational issues at varying temperatures, providing a better simulation of real conditions. A correlation of these tests with practical experience on board is deemed necessary for future study as does a more extensive comparison to include more fuel samples.

Note: Establishing any correlation of the findings from this study with the onboard operational feedback and experiences is vitally important. Currently, authors are in process of collecting the feedback from ships who burnt these fuels used in these analyses however due to time constraints, this aspect remains as ‘work in progress’. Authors hope that during the CIMAC congress, they will be able to elaborate on this particular aspect.

6 DEFINITIONS AND ABBREVIATIONS

CCAI	Calculated Carbon Aromaticity Index
ETS	Emission Trading Scheme
FAME	Fatty Acid Methyl Esters
FOBAS	Fuel Oil Bunker Advisory Service
FOST	Fuel Oil Spin Test
FOST_{xH}	FOST after time-based thermal aging, e.g., FOST_{24H} is FOST performed after fuel is thermally aged for 24 hours
ISO	International Organisation for Standardisation
RF	Residual FAME
RM	Residual Marine
RFHV	Residual FAME Higher Viscosity
RFLV	Residual FAME Lower Viscosity
RMHS	Residual Marine Higher Sediment
RMLS	Residual Marine Lower Sediment
SARA	Saturates, Aromatics and Resin
TSA	Total Sediment Accelerated
TSP	Total Sediment Potential
TSP_{xH}	TSP_{24H} is a standard TSP test as per ISO 10307-2A whilst TSP_{48H} is extended 48 hours thermal age testing
VLSFO	Very Low Sulphur Fuel Oil (max. 0.50% mass sulphur fuel)

7 ACKNOWLEDGEMENT

Authors would like to compliment FOBAS UK lab staff who despite their busy day-to-day routine made extra effort to perform the lab testing for this study. Special thanks for Babatunde Abayomi, Jon Sturgeon, Doug Brownbridge and Paul Livingston, without their support, this paper would not have been possible.

8 REFERENCES

[1] CIMAC Guideline "Overview and interpretation of total sediment test results in the context of ISO 8217:2024" [available at: https://www.cimac.com/cms/upload/workinggroups/WG7/CIMAC_Guideline_Interpretation_of_marine_fuels_total_sediment_test_results_2024-03.pdf], published April 2024.

[2] ISO 8217:2010 Petroleum products – Fuels (class f) Specification of marine fuels [online]. Available at https://www.iso.org [Accessed: 1st January 2025]

[3] K.L. Gawrys, P.K. Kilpatrick, Asphaltene aggregation: techniques for analysis, Instrum Sci Technol, 32 (3) (2004), pp. 247-253

[4] Michael Kass, Brian Kaul, Beth Armstrong, Jim Szybist, Vladislav Lobodin, Stability, rheological and combustion properties of biodiesel blends with a very-low sulfur fuel oil (VLSFO), Fuel, Volume 316, 15 May 2022, 123365

[5] Sherif Fakher, Mohamed Ahdaya, Mukhtar Elturki & Abdulmohsin Imqam, Critical review of asphaltene properties and factors impacting its stability in crude oil, Review Paper - Production Engineering, Volume 10, pages 1183–1200, (2020), 05 December 2019

[6] Aref Abbasi Moud, Asphaltene induced changes in rheological properties: A review, Fuel, Volume 316, 15 May 2022, 123372

[7] Zvereva, Alisa E., et al. "Use of Asphaltene Stabilizers for the Production of Very Low Sulphur Fuel Oil." Energies 16.22 (2023): 7649.

[8] Lloyd's Register FOBAS database, 2025 [available at: lrgmt.com]

[9] Daping Zhou, Haijun Wei, Zhiwen Tan, Shuye Xue, Ye Qiu, Shen Wu, Biodiesel as Dispersant to Improve the Stability of Asphaltene in Marine Very-Low-Sulfur Fuel Oil, *J. Mar. Sci. Eng.* 2023, *11*(2), 315; https://doi.org/10.3390/jmse11020315

[10] Dewi Ballard, Remco de Witte, Usman Muhammad, The fuel oil spin test: a method to help fuel users predict sludge issues at the fuel oil separator, Fuels, Conventions Fuels, CIMAC Congress, 2023-014

[11] ISO/PAS 23263:2019(E) "Petroleum products — Fuels (class F) — Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0,50% mass sulphur in 2020", 2019-09

[12] CIMAC Guideline "Design and operation of fuel cleaning systems for diesel engines" [available at: https://www.cimac.com/cms/upload/workinggroups/WG7/2024-09_v2_CIMAC_Design_and_operation_of_fuel_cleaning_systems_for_diesel_engines.pdf], [Accessed: 4th January 2025]

9 CONTACT

Corresponding author (Dr Muhammad Usman) can be contacted via email at usman.muhammad@lr.org or visit www.lr.org/fobas

10 APPENDIX A: FOST AND TOTAL SEDIMENT RESULTS

Sample ID	FOST Temp (°C)	$FOST_{0H}$ (%mass)	$FOST_{24H}$ (%mass)	$FOST_{48H}$ (%mass)	TSP_{24H} (%mass)	TSP_{48H} (%mass)
RFHV01	70	0.08	0.2	0.26	0.2	0.23
RFHV02	70	0.07	0.08	0.06	0.01	0.02
RFHV03	70	0.08	0.08	0.07	0.01	0.02
RFHV04	80	0.08	0.07	0.06	0.01	0.02
RFHV05	98	0.07	0.06	0.06	0.02	0.04
RFHV06	70	0.09	0.07	0.07	0.03	0.06
RFHV07	80	0.09	0.09	0.10	0.01	0.01
RFLV01	40	0.13	0.10	0.10	0.01	0.02
RFLV02	40	0.13	0.10	0.13	0.01	0.002
RFLV03	50	0.09	0.10	0.10	0.02	0.03
RFLV04	50	0.21	0.30	0.25	0.01	0.02
RFLV05	50	0.08	0.10	0.09	0.01	0.01
RFLV06	50	0.09	0.1	0.09	0.01	0.01
RFLV07	50	0.09	0.08	0.10	0.03	0.03
RFLV08	60	0.08	0.08	0.08	0.02	0.02
RFLV09	60	0.06	0.06	0.06	0.03	0.02
RFLV10	60	0.28	0.07	0.08	0.01	0.01
RFLV11	60	0.06	0.06	0.07	0.01	0.02
RFLV12	60	0.11	0.07	0.08	0.01	0.01
RFLV13	60	0.17	0.09	0.08	0.03	0.03
RMHS01	98	0.22	0.45	0.46	0.29	0.29
RMHS02	80	0.1	0.14	0.11	0.08	0.07
RMHS03	80	0.19	0.26	0.24	0.14	0.16
RMHS04	80	0.24	0.2	0.34	0.16	0.21
RMHS05	98	0.11	0.13	0.14	0.08	0.09
RMHS06	98	0.11	0.12	0.11	0.08	0.09
RMHS07	98	0.12	0.12	0.10	0.08	0.08
RMHS08	98	0.15	0.14	0.14	0.09	0.09
RMHS09	98	0.11	0.11	0.28	0.13	0.24
RMHS10	60	0.33	0.63	0.83	0.25	0.32
RMHS11	60	0.06	0.07	0.24	0.07	0.08
RMLS01	98	0.10	0.09	0.09	0.03	0.03
RMLS02	98	0.07	0.06	0.04	0.01	0.00
RMLS03	98	0.08	0.09	0.07	0.02	0.05
RMLS04	98	0.08	0.09	0.07	0.02	0.02
RMLS05	98	0.13	0.08	0.10	0.02	0.02
RMLS06	98	0.10	0.10	0.10	0.02	0.05

11 APPENDIX B – KEY QUALITY PARAMETETS FOR TESTED SAMPLES

Sample ID	Density @ 15°C (kg/m3)	Viscosity at 50°C (cSt)	Pour Point (°C)	Sulphur (%mass)	TSP (%mass)	Al + Si (mg/kg)	Acid Number (mgKOH/g)	CCAI	CVG	Paraffinic/ Aromatic	FAME (% vol)
RFHV01	972.6	49.7	< 6	2.06	0.03	33	< 0.05	859	0.92	Aromatic	30%
RFHV02	962.2	43.8	< 6	0.46	0.01	3	0.20	851	0.91	Aromatic	30%
RFHV03	921.1	44.7	15	0.36	0.01	8	-	809	0.86	Paraffinic	24%
RFHV04	929.2	51.2	21	0.46	0.01	40	0.33	815	0.87	Paraffinic	24%
RFHV05	931.1	76.8	27	0.46	0.02	31	-	811	0.86	Paraffinic	24%
RFHV06	970.1	43.4	< 6	2.04	0.03	25	0.33	859	0.92	Aromatic	30%
RFHV07	929.4	63.6	< 6	0.43	0.01	13	0.22	812	0.86	Paraffinic	28%
RFLV01	945.4	15.4	< 6	0.38	0.01	18	0.49	853	0.91	Aromatic	24%
RFLV02	945.6	16.1	< 6	0.39	0.01	20	0.48	852	0.91	Aromatic	24%
RFLV03	927.1	29.4	24	0.35	0.02	12	-	822	0.87	Paraffinic	24%
RFLV04	888.9	28.9	27	0.21	0.01	5	0.11	784	0.83	Paraffinic	35%
RFLV05	912.4	21.0	18	0.35	0.01	6	0.93	813	0.86	Paraffinic	30%
RFLV06	950.2	25.8	< 6	0.45	0.01	24	1.10	847	0.90	Aromatic	30%
RFLV07	935.3	29.2	27	0.36	0.03	22	0.40	830	0.88	Paraffinic	24%
RFLV08	942.4	41.8	< 6	0.45	0.02	2	0.25	831	0.89	Paraffinic	30%
RFLV09	957.0	33.4	< 6	2.16	0.03	23	-	850	0.91	Aromatic	30%
RFLV10	932.8	37.3	< 6	0.47	0.01	21	0.22	824	0.88	Paraffinic	27%
RFLV11	966.8	37.7	< 6	0.49	0.01	10	0.16	858	0.92	Aromatic	30%
RFLV12	926.7	37.8	15	0.45	0.01	9	1.45	817	0.87	Paraffinic	24%
RFLV13	936.7	31.1	27	0.38	0.03	21	0.60	831	0.89	Paraffinic	24%
RMHS01	968.6	79.7	9	0.50	0.29	32	0.43	848			
RMHS02	978.7	67.2	< 6	0.48	0.08	48	0.06	861			
RMHS03	912.6	56.9	21	0.47	0.14	15	< 0.05	797			
RMHS04	903.4	62.9	27	0.35	0.16	4		786			
RMHS05	949.1	253.8	< 6	0.47	0.08	32	< 0.05	814			
RMHS06	955.5	322.7	21	0.49	0.08	6	0.14	818			
RMHS07	951.6	269.2	18	0.43	0.08	13	1.00	816			
RMHS08	988.4	363.6	< 6	0.47	0.09	40		850			
RMHS09	947.7	234.6	12	0.51	0.13	41	0.19	814			
RMHS10	889.1	33.4	33	0.40	0.25	5		782			
RMHS11	945.2	36.0	< 6	0.42	0.01	2	< 0.05	837			
RMLS01	983.3	194.0	6	0.45	0.03	23	0.26	852			
RMLS02	942.9	79.6	< 6	0.45	0.01	4	0.49	822			
RMLS03	988.6	377.3	< 6	3.27	0.02	39	0.12	850			
RMLS04	988.6	308.4	< 6	1.21	0.02	22	0.25	852			
RMLS05	973.5	342.5	9	0.47	0.02	42	0.27	836			
RMLS06	948.5	302.9	< 6	0.49	0.02	18	0.14	812			