VPS ARTICLE

How Stable is Your Marine Fuel?

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Today's ships can carry a number of different marine fuel types, from High Sulphur Fuel Oils (HSFOs), to Very Low Sulphur Fuel Oils (VLSFOs), Marine Gas Oils (MGOs), Ultra Low Sulphur Fuel Oils (ULSFOs), Biofuels, LNG and Methanol. Each of these fuels have varying degrees of stability, or instability, which can be triggered by numerous causes and effects.

However, to mitigate the risks of de-stabilzation, a range of fuel management approaches can be applied to marine fuels. This paper aims to cover the more common fuels, their associated stability issues and how to monitor and potentially overcome them.

High Sulphur Fuel Oil (HSFO) & Very Low Sulphur Fuel Oil (VLSFO)

Today, residual fuel is often referred to as HSFO, whereas VLSFO is a blended fuel of mainly distillates and residual fuels, which results in a usually less stable fuel than HSFO. Yet VLSFOs are still prone to certain similar stability concerns as its 100% residual counterpart and hence the associated test parameters.

Residual fuel, is comprised of process residues where the fractions did not boil during refining. These fuels contain asphaltenes, usually between 3-10%, which are the organic part of the crude oil, or residual oil, that is not soluble in straight chain solvents, eg pentane, heptane.

Asphaltenes exist as a colloidal suspension stabilized by resin molecules (aromatic ring systems) in the oil. The stability of asphaltic dispersions depends on the ratio of resin to asphaltene molecules.

The determination of the quantity of resin is important in estimating the potential damage created by asphaltenes. Asphaltene precipitates as a result of pressure drop, temperature, acids, mixing of incompatible oils, chemical contaminants, or other conditions and/or materials that break the stability of the asphaltic dispersion. This is the sludge witnessed when marine fuels de-stabilize.

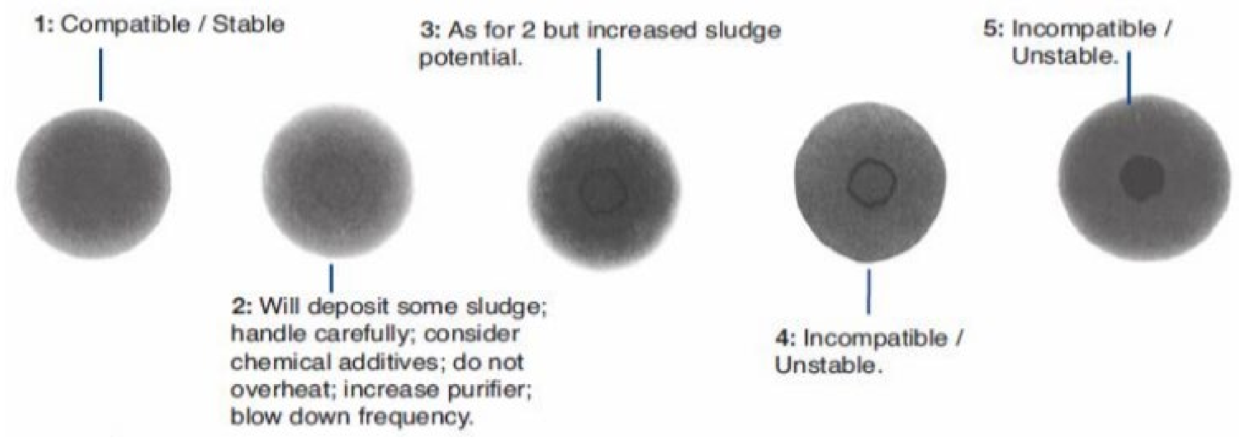
The ability to retain asphaltenes within the fuel solution is known as the **"Stability Reserve"** of the fuel.

Bulk residual fuel stored for long periods can become unstable, where the asphaltene content can precipitate out of solution causing the formation of sludge. This has the potential to block filters and pipes, leaving tanks with an unpumpable residue.

The 'fuel break up' is dependent on the nature of the liquid hydrocarbons in which the asphaltenes are suspended. If the medium is aromatic then they will remain in suspension. If it's paraffinic, the asphaltenes may have a propensity to coalesce into sludge. Once a fuel has chemically broken down there is no way to satisfactorily reverse the process. Precipitated asphaltene cannot be redissolved.

Industry best practice is to avoid mixing fuels. Arbitrary comingling can lead to incompatibility problems and a loss of stability in the resultant blend. For example, when a heavy fuel oil with a high asphaltene content is mixed with a low-gravity distillate with a predominance of paraffinic aliphatic hydrocarbons, the **stability reserve** can be depleted and asphaltenes can flocculate and precipitate as sludge.

Compatibility problems must be treated as a critical concern, as they can lead to fuel starvation in diesel generators, potentially resulting in power loss. Incompatibility may cause fuel system paralysis and the subsequent clean-up is often both complex and time-consuming. There is a very simple, indicative test which can be carried out to highlight a fuels compatibility, the ASTM D4740 “spot test”. Here a blend composed of representative volumes of the sample fuel and the blend stock is heated and homogenized. A drop of the blend is put on a test paper and heated to 100°C. After 1 hour, the test paper is removed from the oven and the resultant spot is examined for evidence of precipitation and rated for compatibility against D4740 reference spots.



To provide valued information regarding a residual fuel’s stability there are a series of laboratory tests to further assess stability:

Total Sediment Potential (TSP)

The measurement of sediment involves filtering the oil through a filtration medium under vacuum. The mass of sediment is reported as a percentage by mass. The test provides an indication of the stability of the fuel as asphaltenes precipitate out forming sludge, blocking filters and choking purifiers. For residual fuels, TSP involves ageing the oil at 100ºC for 24 hours. So far in 2025, 1% of all HSFO off-specifications are related to TSP, whilst 3% of all VSLFO off-specifications are related to the same parameter.

Total Sediment Accelerated (TSA): (Chemical Aging) A sample of the fuel is heated to achieve a viscosity of approximately 50Cst. After 10 minutes, a measured amount of hexadecane is added and the sample is placed in an ageing bath at 100ºC for one hour. The sample is shaken vigorously prior to passing through a filter paper. The result of the test is reported to the nearest 0.01% m/m and is expressed as Total Sediment Accelerated (TSA)

The agreed limit for both TSP and TSA is 0.10% m/m. A fuel that falls below this limit should be viewed as thermally stable and able to homogenously maintain asphaltenic phase suspension.

Total Sediment Existent (TSE): A fuel sample is heated to 100ºC and passed through a filter paper. The amount of dry sludge retained on the filter paper correlates with the amount of sludge that is likely to be separated by an on-board centrifuge.

Separability Number, or Reserve Stability Number (RSN) is a complimentary test to the hot filtration stability methods of TSP, TSA, TSE. Using this method, the fuel is mixed with toluene which is aromatic and keeps the asphaltenes in solution. If the sample has poor stability reserve, then asphaltenes will precipitate when Heptane is added- which is naphthenic. As asphaltenes fall out of solution the transmittance through the sample increases resulting in a measure of the separability number.

Separability Number is an excellent accompaniment to the routine hot filtration methods. It can identify potentially troublesome fuels (unstable) even when the HFT method is indicating a low sediment content. Conversely, it may indicate that a high sediment fuel is in fact quite stable and unlikely to form sludge. This information in combination, is extremely useful from an operational perspective, as it will indicate in advance if and what mitigation steps are appropriate.

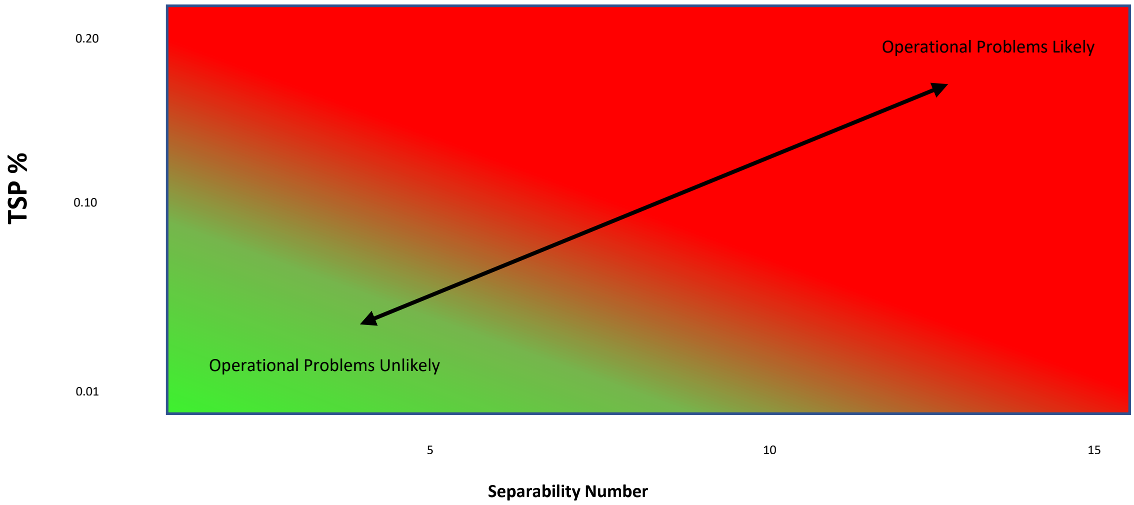


Figure 1: RSN v TSP indication of potential operational issues

It is estimated that the average storage life of a HSFO is around 6 months, whilst the more paraffinic to residual-blended VLSFOs have a storage life of approximately 3 months and tend to be far less stable.

One fact to note regarding residuals, is the fuel can stratify over time, meaning the fuel components separate into distinct layers due to differences in density, temperature or composition. In storage tanks the heavier components settle at the bottom, with the lighter components at the top. Water and sludge may accumulate leading to microbial growth and corrosion. Stratified fuel can cause inconsistent combustion and damage to fuel systems.

Within a combustion chamber thermal stratification can lead to uneven air-fuel mixtures affecting ignition timing and combustion stability.

To prevent stratification within tanks, maintain homogeneous mixing, control temperatures and pressure and if necessary fuel stabilizers can be used. Whilst in a combustion system, optimized injection timing must be adhered to and the use of split-injection techniques can be employed.

In terms of HSFO stability, 2025 year to date, shows global TSP data is relatively stable, with only 7.1% of all HSFO samples tested exhibiting a TSP of 0.06-0.10% and only 0.1% of samples tested exceeding the specification of 0.10%.

Whilst, 3.5% of all VLSFO samples tested showed a TSP of 0.06-0.1% and only 0.3% exceeding the specification 0.10%.

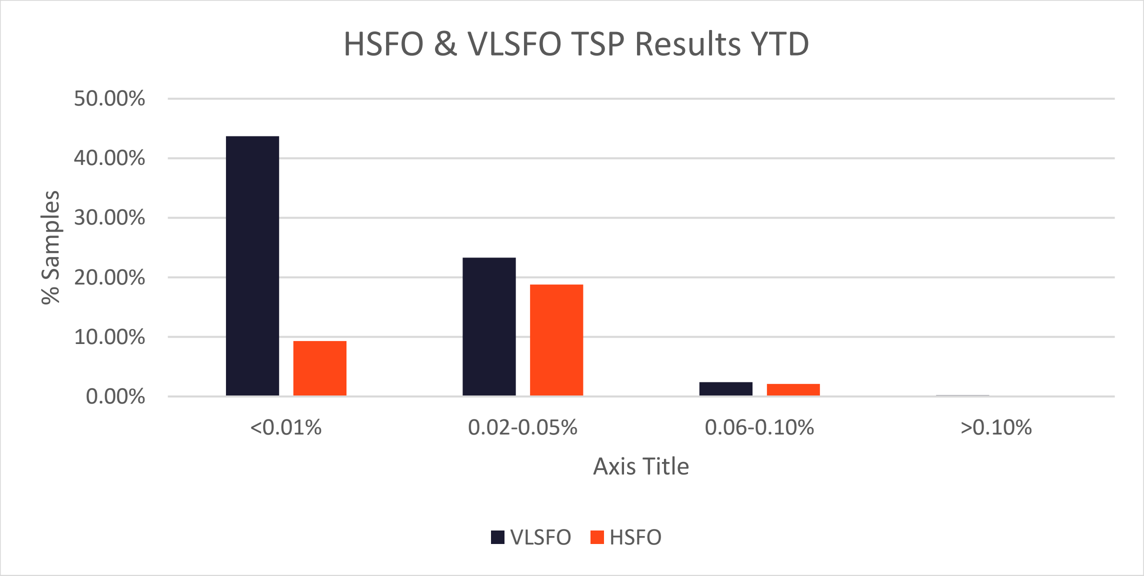


Figure 2: Combined HSFO + VLSFO TSP Results - 2025 YTD

However, the same HSFO samples when tested for RSN, show 44% exhibit poor stability reserve, 36% show intermediate stability reserve and only 20% showing a stable level of reserve. This data indicates that whilst the HSFO may have a low volume of potential sediment, the likelihood is that 44% of the fuel will precipitate asphaltenic sludge.

However, VLSFOs tested for RSN this year have shown only 3% of samples with a RSN>10 and only 5% with an RSN of between 5-10.

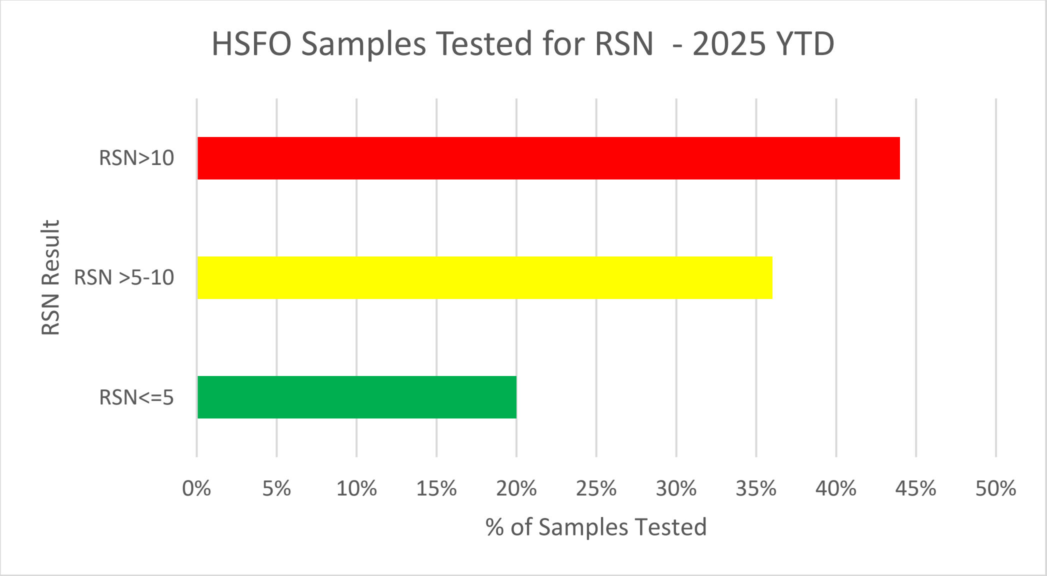


Figure 3: HSFO Samples Tested for RSN – 2025 YTD

A further cause of destabilization of fuel is the presence of chemical contaminants. Chemical contamination can arise from various sources. With increased levels of fuel blending, various blending agents and cutter stocks can contain potential contamination. The complex fuel supply chain is also a potential entry point for cross-product contamination, along with possible adulteration of fuel with waste materials.

Contaminants such as volatile chemicals, styrene, dicyclopentadiene, indene, chlorinated hydrocarbons, phenols, have a proven history of destabilizing fuel, initiate sludging, as well as causing operational issues such as, injector failures, fuel pump damage, exhaust problems, to name but a few.

To mitigate the risks associated with the presence of chemical contaminants, pre-burn screening of the fuel using Gas Chromatography Mass Spectrometry (GCMS), is a highly effective means of identifying potentially dangerous chemicals within the fuel. Last year, 8.2% of samples which undertook GCMS-Headspace Screening, gave rise to a "Caution" result, indicating the presence of at least one volatile chemical contaminant, highlighting the benefit and value if undertaking fuel screening before even burning the fuel.

Marine Distillates

As marine distillates are relatively highly refined fuels compared with residual fuels, they contain no asphaltenes and consequently are more stable than residual fuels. A typical distillate may be stable for 12 months.

They main concerns with distillates relate to their cold-flow properties, lubricity, microbial contamination, oxidation stability and concerns relating to the presence of Fatty Acid Methyl Esters. For further marine distillate information, please refer to the VPS article:

Distillate Fuels: The "Trouble-Free" Marine Fuel? | VPS

Biofuels

Fatty Acid Methyl Ester (FAME) based biofuels, are the most common biofuel used for marine applications. However, this fuel-type is far less stable than marine fossil fuels due to a high degree of unsaturation and propensity to oxidise. Exposure to light, increased temperatures and length of storage time, will all contribute to the destabilization of the fuel. As FAME-based biofuels oxidize, their colour becomes darker, plus their viscosity and acidity increases. All this can lead to sludging, blocked filters and pipes and possibly lead to fuel-starvation to the engine.

There are specific tests which can be carried out to monitor and determine the stability of FAME-based biofuels:

Oxidation Stability (EN 15751) – The Rancimat method is an accelerated-aging test, where the results are given a traffic-light coding: **Green >8hr; Amber 5-8hr; Red <5hr**

Iodine Value (EN 14111) is used to determine the total unsaturation of fatty acids. Iodine Value is reported as the number of iodine grams necessary to react completely with 100g of samples and its limit is set by the EN 14214 regulation.

VPS results show a good inverse correlation between Oxidation Stability & Iodine Value as expected

Linoleic Acid & Linolenic Acid – FAME stability is strongly affected by the presence of polyunsaturated fatty acids (PUFAs) in the feedstock, and the 2 most common PUFAs are linoleic acid and linolenic acid and can be measured in 100% FAME only by using this GC method.

Summary

In terms of precautionary actions relating to fuel stability, irrespective of fuel type, the following should be undertaken:

- Avoid mixing bunker fuels from different sources wherever possible
- Store fuels separately until compatibility testing has been carried out
- Do not mix straight-run fuel oil (the product of atmospheric or vacuum distillation) with a cracked (additionally processed) one. If this is not possible, keep the ratio to a minimum.
- Steer clear of mixing fuels with greatly dissimilar densities
- Where possible choose fuels with similar viscosities and densities
- Where operationally possible, do not mix a fuel oil with a marine gas oil, or biofuel.

All marine fuels exhibit numerous and different stability issues depending upon their type and grade. Each fuel requires specific fuel management considerations and testing requirements to determine and monitor their stability.

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