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WHITEPAPER

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Analysis Methods for Measuring Stability, Stability Reserve & Compatibility of Residual Marine Fuels

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1. Introduction

Since 1 January 2020, the International Maritime Organization (IMO) has enforced a 0.50% global sulphur cap for the shipping industry to reduce sulphur oxide emissions. A comparison of pre-IMO 2020 fuels and post-IMO 2020 fuels reveals that the latter exhibit greater instability, waxiness, lower density & viscosity, lower micro carbon residue (MCR), lower calculated carbon aromaticity index (CCAI), lower vanadium content, higher net specific energy, higher pour point, and higher acid number. The decreased stability reserve (higher paraffinic and lower aromatic content) of post-IMO 2020 fuels also raises concerns about compatibility issues when different fuels are mixed.

To address these challenges, Maritec lab is equipped with the necessary equipment and testing methods to assess the cleanliness, stability, stability reserve, compatibility, and cold flow properties of post-IMO fuels. Given that fuel stability is the primary concern with Very Low Sulphur Fuel Oils (VLSFOs), this article focuses on reviewing fuel stability, fuel stability reserve, and the corresponding analysis techniques.

2. Blending Residual Marine Fuel: Ensuring Quality, Stability, and Combustion Properties

Conventionally, residual marine fuel is produced through a blending process that combines residues with cutter stocks, or diluents. These residues can come from various sources like atmospheric residue, vacuum residue, and visbreaking residue. Cutter stocks, on the other hand, are derived from atmospheric gas oil, vacuum gas oil, light cycle oil, heavy cycle oil, slurry oil (or the bottom stream of FCC), visbreaking gas oil, coker gas oil, or other low-value by-products of petroleum refineries.

The main purpose of blending was to meet the quality requirements outlined in the ISO 8217 specification for marine fuel. Residues, which have high viscosity and density, need to be mixed with cutter stocks to ensure the fuel meets these quality standards. This blending process is crucial for safe and efficient handling, storage, treatment/purification, and consumption of marine fuel on board ships. Additionally, blending is necessary to achieve optimal stability, preventing the precipitation of asphaltenes and waxes, as well as to enhance ignition and combustion properties.

3. Blending of Very Low Sulphur Fuel Oil (VLSFO, IMO 2020 Compliant Fuel)

IMO global sulphur cap of 0.5%S has changed the primary blending target from viscosity and density to sulphur. Marine fuels post-IMO 2020 has seen a wide variability of fuel formulations and characteristics.

Typically, very low sulphur fuel oils can be blended using three categories of blend stocks (1):

Three Categories of Blend Stocks	**Example of Blend stocks**
From existing low sulphur blend stocks to produce 0.5%S bunker (or very low sulphur fuel oil)	Straight-run diesel, fluid catalytic cracking (FCC) light cycle oil, hydrotreated fluid catalytic cracking (FCC) light cycle oil, hydrotreated light atmospheric gas oil, fluid catalytic cracking (FCC) slurry oil, vacuum gas oil, low sulphur vacuum gas oil, marine gas oil, low sulphur pyrolysis oil and others.
Using blend stocks produced from low sulphur crudes to blend 0.5%S bunker (or very low sulphur fuel oil)	Atmospheric residues, vacuum residues, straight-run diesel, fluid catalytic cracking (FCC) light cycle oils, hydrotreated fluid catalytic cracking (FCC) light cycle oil, hydrotreated light atmospheric gas oil, fluid catalytic cracking (FCC) slurry oil, vacuum gas oil, low sulphur vacuum gas oil and others which are processed from low sulphur crudes.
Using blend stocks produced from various desulphurization units to blend 0.5%S bunker (or very low sulphur fuel oil)	Hydrotreated gas oil, hydrotreated fluid catalytic cracking (FCC) light cycle oil, hydrotreated vacuum gas oil, hydrotreated residue and others.

Based on the available blend stocks, very low sulphur fuel oils can generally be blended into four major types/groups (1):

Blending Options	**Blend stocks**	**Remark**
Paraffinic Grades	Low sulphur straight-run HFO, low sulphur vacuum residue, low sulphur light atmospheric gas oil, low sulphur heavy atmospheric gas oil, low sulphur vacuum gas oil, ECA marine gas oil, low sulphur automotive gas oil, and others	Considered stable. Low aromaticity & low asphaltene solubility. No cracked components. Contain paraffinic wax.
Aromatic Grades	Visbreaking low sulphur residue, low sulphur light cycle oil, low sulphur heavy cycle oil, low sulphur FCC slurry oil/clarified oil, low sulphur residue hydrocracker bottoms, light pyrolysis oil, heavy pyrolysis oil and others.	Stable. Contain cracked components
Mixed Aromatic-paraffinic Grades	Low sulphur straight-run HFO, low sulphur light cycle oil, low sulphur FCC slurry oil/clarified oil, visbreaking low sulphur tar, low sulphur light atmospheric gas oil, low sulphur heavy atmospheric gas oil, low sulphur vacuum gas oil and others	Potentially not stable
Paraffinic and Naphthenic Grades	Derived from naphthenic crude. The key difference between paraffins and naphthenes is that paraffins are n-alkanes (straight-chain saturated hydrocarbons) & isoalkanes (branched-chain saturated hydrocarbons) while naphthenes are cycloalkanes (monocyclic saturated hydrocarbons).	Generally have high acid number due to presence of naphthenic acids

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4. Fuel characteristics evolution and potential quality issues due to 0.5%S Limit

Post-IMO 2020 fuels (VLSFOs) exhibit lower density, lower viscosity, lower MCR (Micro Carbon Residue), lower CCAI (Calculated Carbon Aromaticity Index), lower vanadium content, higher net specific energy, higher pour point, and higher acid number compared to pre-IMO 2020 fuels.

It is also noted that VLSFOs generally have better ignition and combustion properties, which contribute to efficient fuel utilization and combustion processes.

However, there is a rise in cold flow property issues within paraffinic-grade very low sulphur fuel oils (VLSFOs), characterized by higher pour points, can potentially introduce concerns regarding cold flow problems, particularly wax formation.

An increase in fuel stability issues is also observed which arises from two factors. Firstly, the use of hydrotreated blend stocks reduces the stability reserve of the fuel due to lower aromaticity and asphaltene solubility. Secondly, when low sulphur aromatic and paraffinic blend stocks are mixed, fuel instability may occur if the blend lacks adequate aromatic content to dissolve the asphaltenes present. Additionally, an increase in fuel compatibility issues can occur when aromatic and paraffinic-grade VLSFOs are co-mingled, leading to incompatibility and potential flocculation of asphaltenes if the blend lacks sufficient aromatics.

5. Composition of residual marine fuels leading to sludging issues

The composition of residual fuels is complex to define (depending on crude source and refining processes as shown earlier) but generally residual fuels consist primarily of saturates, aromatics, resins and asphaltenes. In order to keep the asphaltenes in colloidal suspension, the asphaltenes are dispersed by resins and the dispersions dissolved in aromatics.

An asphaltene is a high molecular weight compound containing polar functional groups. Polar functional groups are regions within the molecule that have an uneven distribution of electron density, resulting in a separation of positive and negative charges. This polarity makes the compound interact differently with other substances, especially in terms of solubility and chemical reactions.

Asphaltene sludge can precipitate when the asphaltenes, which are high molecular weight polar molecules having a predominantly aromatic structure, are not kept in colloidal suspension. This can occur when the fuel is subjected to external forces, such as thermal, mechanical, and ageing (storage time) stresses (2).

In layman terms, asphaltenes is soluble in aromatics and resins but not soluble in saturates (such as cetane). Although a fuel contains high level of asphaltene as long as the fuel has sufficient resins and aromatics to dissolve the asphaltene, the fuel is stable. In contrast, even if a fuel contains a low amount of asphaltenes, if the fuel does not have sufficient resins and aromatics to dissolve the asphaltenes, flocculation/precipitation of the asphaltenes can happen.

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6. Common Terminology for describing the risk of asphaltene precipitation

6.1. Stability

Stability of a residual fuel is defined by its resistance to the breakdown and precipitation of asphaltene sludge despite being subjected to external forces, such as thermal, mechanical, and ageing (storage duration) stresses, while handled and stored under normal operating conditions.

The factors that influence stability of residual fuels are fuel formulation *(an internal factor, fuel blend itself – on whether the fuel has sufficient aromaticity or contains any appreciable amount on non-hydrocarbons)* and the external factors such as thermal & mechanical stress and storage duration. The stability of a residual fuel is important for the safe handling and use on board ships (3).

6.2. Compatibility

As defined in CIMAC Guideline 01-2019, compatibility is the term used for the ability of two or more fuels to be comingled without evidence of material separation; or in other words, no asphaltenes precipitating when the fuels are mixed. It should be noted that two perfectly stable fuels can be incompatible resulting in asphaltene sludge precipitation when mixed. In addition, two fuels may be compatible at some mixing ratios and incompatible at other mixing ratios – or they can be compatible or incompatible over the entire mixing ratio (3).

6.3. Stability Reserve

Stability reserve is a measure of the ability of an oil to maintain asphaltenes in a dispersed state or to maintain asphaltenes in a peptized (colloidally dispersed) state and prevent flocculation of the asphaltenes. In another words, stability reserve is a measure of the available solvency power of a fuel with respect to precipitation of asphaltenes. In a layman terms, stability reserve is an indication of the capacity for one fuel to absorb another fuel without asphaltenes dropping out of suspension (3).

With fuel oils, the stability reserve test gives an indication of the available solvency power of a fuel with respect to precipitation of asphaltene, the higher the stability reserve the more stable is the particular fuel with respect to flocculation of asphaltenes.

7. Evaluating the stability reserve by chemical ageing

Chemical ageing looks at the balance between the required aromaticity of the asphaltenes and the available aromaticity of the oil phase, and tests whether a specified amount of a normal alkane *(a saturated hydrocarbon)* disturbs this balance to the extent that asphaltene precipitation occurs. Experience has shown that such precipitation indicates that sediment can form in the residual fuel oil during storage and handling (4).

7.1. Total Sediment Accelerated (TSA)

The test parameter Total Sediment Accelerated (TSA), by ISO 10307-2 with a limit of 0.10 mass % listed in ISO 8217 – 2010, 2012 & 2017 specification may be used as an indicator to evaluate fuel stability reserve of bunker fuels.

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For TSA test, a portion of 25g ± 0.2g of test sample is diluted with 10% of cetane and, after a prescribed heating and storage period, 10g of the mixture is filtered through the prescribed apparatus at 100 °C. After solvent washing and drying the total sediment on the filter medium is weighed and expressed as a % of the original sample mass filtered.

7.2. P-value by SMS 1600 for Measuring Stability Reserve

For P-value by SMS 1600 test, portions of the test sample are diluted with varying amounts of cetane (10% increment, 10% to 60% or more) and, after a prescribed heating and storage period, the mixtures are examined for the presence of flocculated asphaltenes by means of a microscope.

In this way, the *Critical Cetane Dilution* is determined from which the P-value of the sample is calculated. *Critical Cetane Dilution (Xmin) is the number of millilitres of cetane with which one gram of the sample can be diluted until it just does not flocculate the asphaltenes. P-value is equal to 1 plus Xmin (or 1 + Xmin).*

The P-value of an oil gives information on stability and stability reserve. A higher P-value indicates that an oil is more stable with respect to flocculation of asphaltenes. If flocculated asphaltenes are present in the original sample, the P-value is determined as <1.00. Interpretation of P-value by SMS 1600 test results is tabulated in Table 1.

Table 1

P-Value	**Stability**
P-value <1.00	Fuel is not stable, original sample has flocculated asphaltenes present
1.00 >= P-value < 1.30	Fuel is marginally stable
1.30 >= P-value =< 1.50	Fuel with acceptable stability
P-value > 1.50	Fuel is stable: For strategic long-term storage, fuels with a higher P value (E.g., > 1.5) are preferred as this provides a wide margin for ageing.

Although both the process are similar chemical ageing methods, P-value by SMS 1600 is a more comprehensive technique to ascertain fuel stability reserve as the method adds cetane at various incremental amounts ranging from incremental amount of 10% to 60% or more when compared to TSA which is only at 10% of cetane dilution. P-value can also be applied as a quick screening method to detect & identify unstable residual marine fuels.

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8. Findings

Based on CTI-Maritec empirical data, instability of fuels is generally grouped into the following, which are attributed to fuel formulations:

a) Chemical ageing stress causing flocculation of asphaltene. The presence of high concentration of polar chemical species such as alkylresorcinols, phenolic compounds, chlorinated organic compounds and high concentration of slightly reactive hydrocarbons with double bonds - has tendency to cause fuel instability in terms of sludge precipitation or formation.

b) Insufficient resins and aromatics levels to dissolve the asphaltenes causing asphaltenes to drop out from suspension.

In addition, borderline stability with fuels having TSP at higher side (>0.06%) and marginally stable by stability reserve test (P-value: 1.00 >= P-value < 1.30). This type of fuel may cause issues like floucculation of asphaltene after certain period of storage time.

Some of CTI-Maritec case history on fuel instability associated with factors mentioned above are documented in the following sections.

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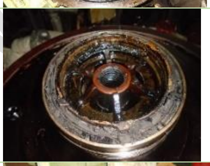
8.1. Low Stability Reserve Fuels and Unstable Fuels Which Contain Alkylresorcinols & Phenolic Compounds - Summary Data

Number of Cases	P-value Range	Alkylresorcinols and Phenolic Compounds	Range of Concentration (ppm)	GC/MS Techniques	Problem Reported onboard Vessel
52	<1.00	Alkylresorcinols	57 - 263,885	GC/MS by Solid Phase Extraction	Overloading and blockage of fuel purifiers, filters, and damage to fuel injection equipment. High level of 4-cumylphenol may impact sticking fuel plungers and fuel pump seizures.
		Phenol	90 - 2616	ASTM D7845 GC/MS	
		1-Phenylethanol	174 - 1014		
		2-Phenylethanol	202 - 923		
		2-Ethylphenol	53 - 725		
		2,4-Dimethylphenol	146 - 2294		
		4-Ethylphenol/3-ethylphenol	230 - 2986		
		4-Isopropylphenol	57 - 995		
		1-Naphthalenol	121 - 1666		
		2-Naphthalenol	81 - 1436		
		4-Cumylphenol	248 - 8169		
		Methyl phenol Isomers	333 - 6035		
1	1.00 to 1.25	Alkylresorcinols	847	GC/MS by Solid Phase Extraction	

Example of Case History

Example of Case History	Photos of the Damaged Machinery		Flocculated asphaltenes/ carbonaceous materials in the original sample:
1 **[redacted]4606** **VLSFO**			P-value is <1.00 Alkylresorcinols: 6463ppm Phenolic Compounds: 590ppm
2 **[redacted]2250** **VLSFO**			P-value is <1.00 TSP:0.15%m/m Alkylresorcinols: 3335ppm Phenolic Compounds: 423ppm
3 **[redacted]8283** **VLSFO**			P-value is <1.00 TSP: 0.09%m/m Alkylresorcinols: 9764ppm Phenolic Compounds: 1647ppm
4 **[redacted]0780** **VLSFO**			P-value is <1.00 Alkylresorcinols: 6205ppm Phenolic Compounds: 559ppm

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8.2. Low Stability Reserve Fuels and Unstable Fuels Which Contain Phenolic Compounds – Summary Data

Number of Cases	P-value Range	Phenolic Compounds	Range of Concentration (ppm)	GC/MS Techniques	Problem Reported onboard Vessel
12	<1.00	Phenol	83 to 3516	ASTM D7845 GC/MS	Purifiers sludging and filters clogging, and sometimes fuel pump issue.
		1-Phenylethanol	149 to 3165		
		2-Phenylethanol	167 to 4440		
		2-Ethylphenol	78 to 2104		
		2,4-Dimethylphenol	676 to 1922		
		4-Ethylphenol/3-ethylphenol	307 to 1889		
		4-Isopropylphenol	184 to 857		
		4-Cumylphenol	425 to 6675		
		Methylphenol Isomers	657 to 2009		
2	1.00	Phenol	64 to 775	ASTM D7845 GC/MS	
		1-Phenylethanol	702		
		2-Phenylethanol	438		
		2-Ethylphenol	184		
		2,4-Dimethylphenol	528		
		4-Ethylphenol/3-ethylphenol	434		
		4-Isopropylphenol	252		
		4-Cumylphenol	299 to 1740		

Example of Case History

Example of Case History	Photos of the Damaged Machinery		Flocculated asphaltenes/ carbonaceous materials in the original sample:
1 **[redacted]8431** **VLSFO**			P-value is <1.00 TSP: 0.06%m/m Phenolic Compounds: 5937ppm

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8.3. Low Stability Reserve Fuels and Unstable Fuels Which Contain Chlorinated Organic Compounds – Summary Data

Number of Cases	P-value Range	Phenolic Compounds	Range of Concentration (ppm)	GC/MS Techniques	Problem Reported onboard Vessel
2	<1.00	1,2-Dichloroethane	3668 to 4397	ASTM D7845 GC/MS	Sludging of fuel system and damage to fuel injection equipment and components.
		Tetrachloroethylene	210 to 219		
		1,1-Dichloroethane	25 to 28		
		Trichloromethane/Chloroform	71 to 91		
		Chlorobenzene	50 to 53		
23	1.00 to 1.20	1,2-Dichloroethane	230 to 7429	ASTM D7845 GC/MS	Plunger barrel, fuel pump and other machinery issues.
		Tetrachloroethylene	26 to 425		
		1,1-Dichloroethane	13 to 84		
		Trichloromethane/ Chloroform	12 to 271		
		Chlorobenzene	33 to 264		

Example of Case History

Example of Case History	Photos of the Damaged Machinery		Flocculated asphaltenes/ carbonaceous materials in the sample after addition of 20% of cetane/hexadecane:
1 [redacted]5473 HSFO			P-value is 1.10 TSP: 0.08%m/m Chlorinated organic compounds: 7661ppm
2 [redacted]5881 HSFO			P-value is 1.10 TSP: 0.09%m/m Chlorinated organic compounds: 4006ppm

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8.4. Low Stability Reserve Fuels and Unstable Fuels Detected to Contain Slightly Reactive Hydrocarbons with Double Bond – Summary Data

Number of Cases	P-value Range	Phenolic Compounds	Range of Concentration (ppm)	GC/MS Techniques	Problem Reported onboard Vessel
9	<1.00	Styrene	37 to 4080	ASTM D7845 GC/MS	Purifiers sludging and filters clogging
		3-Methylstyrene	36 to 372		
		4-Methylstyrene	394 to 717		
		2-Methylstyrene	238 to 1541		
		Limonene	90 to 650		
		Dicyclopentadiene	71 to 549		
		Indene	46 to 13,394		
		2,5 dimethyl styrene	65 to 178		
		2,4 dimethyl styrene	78 to 166		
		Dihydro-dicyclopentadiene	710 to 1288		
7	1.00 to 1.20	Styrene	57 to 290	ASTM D7845 GC/MS	
		3-Methylstyrene	149 to 188		
		4-Methylstyrene	97 to 289		
		2-Methylstyrene	43 to 1961		
		Limonene	-		
		Dicyclopentadiene	37 to 1254		
		Indene	424 to 3699		
		2,5 dimethyl styrene	34 to 186		
		2,4 dimethyl styrene	43 to 193		
		Dihydro-dicyclopentadiene	230 to 10,397		

Example of Case History

Example of Case History	Photos of the Damaged Machinery		Flocculated asphaltenes/ carbonaceous materials in the sample after addition of 30% of cetane/hexadecane:
1 **[redacted]1969** **VLSFO**			P-value is 1.20 TSP: 0.02%m/m Slightly reactive hydrocarbon with double bond (C=C): 6359ppm
			

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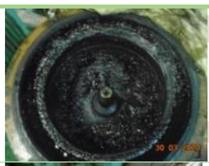
8.5. Low Stability Reserve Fuels and Unstable Fuel Due to Insufficient of Aromaticity - No Deleterious Materials are Detected by GC/MS Analysis

Number of Cases	P-value Range	Chemical Species	GC/MS Techniques	Problem Reported onboard Vessel
2	<1.00	No chemical species are detected	ASTM D7845 GC/MS and GC/MS by Solid Phase Extraction	Main engine damage, purifier sludging and piston rings breakage
4	1.00 to 1.20	No chemical species are detected	ASTM D7845 GC/MS and GC/MS by Solid Phase Extraction	

Example of Case History

Example of Case History	Photos of the Damaged Machinery		Data from P-value by SMS 1600 and TSP
1 [redacted]1585 VLSFO	 	 	Flocculated asphaltenes/ carbonaceous materials in the original sample: P-value is <1.00 TSP: 0.09%m/m
2 [redacted]3954 VLSFO			Flocculated asphaltenes/ carbonaceous materials in the sample after addition of 20% of cetane/hexadecane: P-value is 1.10 TSP: 0.01%m/m
3 [redacted]9095 VLSFO	 	 	Flocculated asphaltenes/ carbonaceous materials in the original sample: P-value is <1.00 TSP: 0.08%m/m

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9. Recommended counteractions by operators when onboard fuel is unstable.

a) Watch and monitor the fuel systems filters for signs of blockage and increased cleaning cycle frequency. Ensure spare filter elements are available for safe and quick exchange with minimum downtime.

b) Watch and monitor centrifuges for signs of overloading, and disc stack cleanliness.

c) Reduce the throughput through the centrifuges to the minimum required.

d) Split the flow further by running another centrifuge in parallel *(this is provided the initial centrifuge can cope with the fuel without excessive sludging)*

e) Decrease interval between desludging if required to prevent the bowl from overloading.

f) Decrease the time between manual bowl cleaning for better purification efficiency, a dirty disk stack will have the same effect as increasing the throughput.

g) Adjust the purifier inlet temperature to the minimum required for effective purification as per the centrifuge maker or testing lab recommendation.

h) Consider contacting your additive supplier for a suitable fuel stabilizer that can effectively disperse the sludge and reduce the sludge formation.

i) Circulate the fuel from tank to tank. This technique helps to homogenize the dispersed particles

The objective is to effectively remove the sludge from the fuel without overloading the treatment plant causing unwanted breakdown.

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10. Maritec Fuel Cleanliness, Stability, Stability Reserve, Asphaltene Content and Fuels Compatibility Analysis Techniques

In spite of the fact that VLSFOs are generally low in asphaltene content, however, many cases of off-specification of total sediment-aged have been reported and even for some cases, the total sediment-aged are within the specification limit of 0.10%m/m but vessels reported sludging and filter clogging problems onboard ships due to low stability reserve of the VLSFOs.

To allow long term stability, fuels are manufactured to withstand the expected forces through normal onboard use and storage. It does however not necessarily follow that two stable fuels when mixed together form a stable mixture. When storing fuel, ship operators must attempt to segregate different fuels. In case, when comingling is unavoidable, it is advised that fuels compatibility check must be performed prior to mixing of the fuels.

In order to have better understanding of potential phase separation/material separation of a fuel, in particular asphaltenes flocculation, asphaltene content by IP 143, fuel cleanliness by TSE, fuel thermal stability by TSP and fuel stability reserve by P-value (SMS 1600) & TSA can be determined (refer to Table 2).

For fuel compatibility, compatibility check on blend of ROB and new bunkers can be determined by TSP (refer to Table 2).

Table 2

No.	Accredited Test Parameters	Method	Significance of Test
1	Asphaltenes (Heptane Insolubles)	IP 143 / ASTM D6560	To determine asphaltene content of a fuel
2	Total Sediment, Existent	ISO 10307-1/ ASTM D4870	To determine cleanliness of a fuel, to check for presence of sediments, extraneous dirt, flocculated aphaltenes, inorganic particles and others in a fuel.
3	Total Sediment, Potential	ISO 10307-2 / ASTM D4870	To determine the sediment formed after a fuel is subjected to thermal stress, to check for thermal stability of a fuel. TSP test result will indicate long term storage capability.
4	Total Sediment, Accelerated	ISO 10307-2 / ASTM D4870	As a quick test to determine fuel stability reserve of a fuel.
5	Manual P-value	SMS 1600	To determine fuel stability reserve of a fuel.
6	Compatibility check of ROB and New Bunker based on three blending ratios; Evaluated by Total Sediment Potential (TSP)	ASTM D4870 / ISO 10307-2	To determine compatibility of two or more fuels.

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As published in CTI-Maritec website,

https://www.maritec.com.sg/service/Enhanced_Fuel_Analysis_Package

Maritec offers the following Operational Assurance Package to address VLSFOs stability and compatibility issues:

1) Stability Package – Consist of Total Sediment Potential, Total Sediment Accelerated, Total Sediment Existent, P-value by SMS 1600 and Asphaltene Content.

2) Compatibility package - Compatibility check of ROB and New Bunker based on three blending ratios (10:90, 50:50, 90:10) evaluated using Total Sediment Potential (TSP) Test as recommended by International Council on Combustion Engines (CIMAC) in WG 07 on Fuels.

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11. Conclusion

The factors that influence stability of residual fuels are fuel formulation (an internal factor, fuel blend itself – on whether the fuel has sufficient aromaticity or contains any appreciable amount on non-hydrocarbons especially non-hydrocarbons containing hydroxyl group such as alkylresorcianols/alkyl-1,3-benzenediols and others) and the external factors such as thermal & mechanical stress and storage time/duration.

The data collated in this article indicates that most of the unstable fuels or marginally stable fuels that cause sludging and filter clogging issues were mostly due to fuel formulation (an internal factor) - either high or borderline high total sediment due to the presence of chemical contaminants, fuels containing appreciable amount of non-hydrocarbons that contain hydroxyl group such as alkylresorcianols/alkyl-1,3-benzenediols, phenolic compounds and others.

Our past historical data indicated that there are also instances that fuels are detected with certain concentration of alkylresorcinols, phenolic compounds and slightly reactive hydrocarbons however the vessels are able to consume the fuels without any operational issues. It is recommended that when a fuel is detected with the presence of alkylresorcinols, phenolic compounds and slightly reactive hydrocarbons, it is important that fuel stability reserve for the fuel shall also be evaluated, if the fuel is identified to contain alkylresorcinols, phenolic compounds & slightly reactive hydrocarbons and the fuel is also unstable or marginally stable, the vessel is recommended practice the aforementioned preventive measures to prevent, reduce and solve the potential sludging and filter clogging issues.

Table 3 below summarizes a guideline for evaluation/testing of fuel stability, fuel stability reserve and fuel compatibility based on the intended requirements:

Table 3

Requirements	**Guideline for evaluation/testing**
For comprehensive evaluation of fuel stability and fuel stability reserve.	Stability Package – Consist of Total Sediment Potential, Total Sediment Accelerated, Total Sediment Existent, P-value by SMS 1600 and Asphaltene Content.
For comprehensive evaluation of fuels compatibility.	Compatibility package - Compatibility check of ROB and New Bunker based on three blending ratios (10:90, 50:50, 90:10) evaluated using Total Sediment Potential (TSP). Test as recommended by International Council on Combustion Engines (CIMAC) in WG 07 on Fuels.
For evaluation of fuel stability reserve.	P-value by SMS 1600.
For fast screening to detect unstable fuels especially unstable fuels which also contain considerable amount of alkylresorcinols.	Microscopic examination of neat sample to check for fuel homogeneity and to detect unstable fuel which shows phase separation/materials separation.

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12. Moving Forward

In the near future when biofuels is widely adopted as drop-in marine fuel to achieve the regulatory requirements on reduction of carbon/GHG emission, due to the diversity of the liquid cutter stocks derived from biomass, marine fuel stability and marine fuel stability reserve will become critical test parameters.

13. Reference

1) Bunker Fuel Blending Course 2020 Edition, Ara Barsamian, Eliseo Curcio, Refinery Automation Institute, LLC.

2) ISO/PAS - Petroleum products — Fuels (class F) — Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0,50 % sulfur in 2020.

3) 01-2019, CIMAC Guideline Marine Fuel Handling in connection to stability and compatibility. By CIMAC WG7 Fuels.

4) ASTM D4870 – 18: Standard Test Method for Determination of Total Sediment in Residual Fuels.

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