IMO2020 FUELS

VLSFO Testing overview
New VLSFO products

SNAME Athens
4th December 2019

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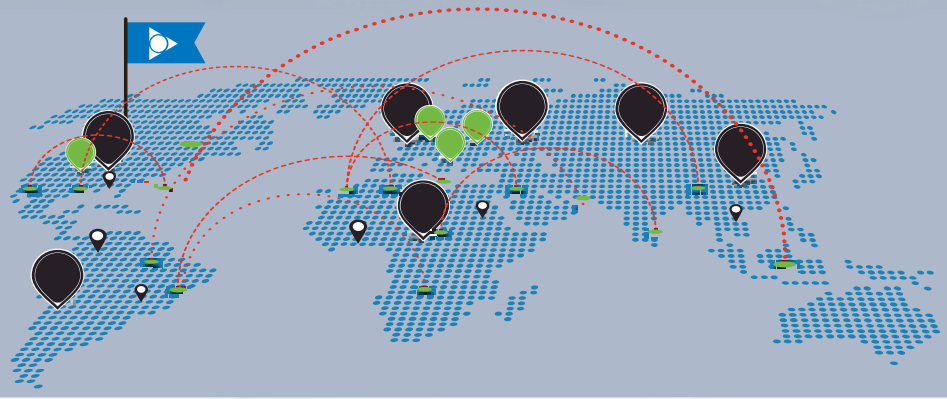
FUEL SPECIALTIES

COMPANY PROFILE: Innospec, Inc. NASDAQ (IOSP)



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Corporate HQ
Englewood, CO

Regional Locations
USA, UK, Continental Europe, Africa, Russia, Brazil and Asia

Global Network
Global Network of Manufacturing, Sales & Testing Facilities:

Business Profile

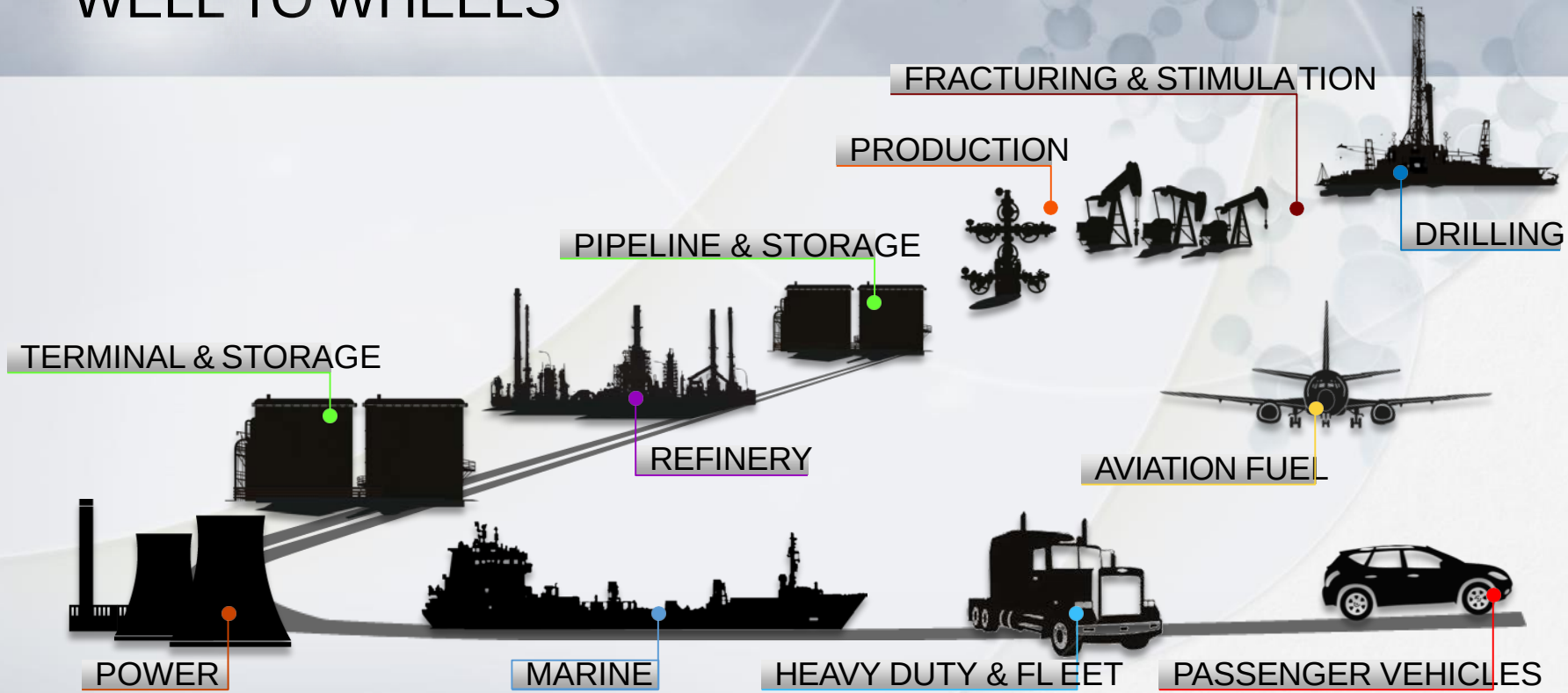
$1.5 billion sales

2000 Employees in 23 countries

Business Focus

Fuel Specialties
Performance Chemicals
Oilfield Services
Octane Additives

WELL TO WHEELS



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UK plant & R&D laboratories

Two plants in Germany

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CUSTOMERS INCLUDES

INNOSPEC IN MARINE INDUSTRY GROUPS / PRODUCT VERIFICATION

- Innospec are represented on the ISO working group responsible for the development of the Classification & Specification of Marine Fuels – ISO8216 and ISO8217
- International Council of Combustion Engines (CIMAC) working group 7 (Fuels).
- Lloyds Register & Shell Marine have independently verified the claims associated with certain Innospec products under rigorous conditions, providing assurance that the product performs.

CERTIFIED LR PRODUCT VERIFICATION SCHEME

Shell

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INNOSPEC SHIPPING CUSTOMERS

2020 FUEL CHANGE – IMO DECISION

In 2016 IMO´s Marine Environment Protection Committee (MEPC) decided to reduce S content in Bunker Fuel Oils.

With effect January 1st, 2020 following options only allowed:

- Operate with max. 0.5% S Fuel Oil
- Operate on dual fuel engine with LNG, LPG and LEG as fuel
- Continue operating on 3.5% S Fuel Oil and using scrubber system

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2020 IMO FUEL PROJECTION

HFO S content 0.5% - introduction of Very Low Sulphur Fuel Oil
HFO S content 3.5% - only allowed when using scrubbers

Bunker Fuel Demand – Million MT		
Fuel Type	2012	2020 Projection*
3.5% S HFO	**228**	**36****
MGO / 0.1% S Hybrid (ULSFO)	64	39
0.5% S Hybrid (VLSFO)	**0**	**245**
TOTAL	**300**	**320**

*Source: Delft Study
**Projected demand considering aforementioned market uptake of scrubbers.

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IMO2020 COMPLIANT FUEL – VLSFO

Major change: Introduction of Very Low Sulphur Fuel Oil (VLSFO)

50-70% of 2020 Marine fuels will be VLSFO

VLSFO can be processed directly, but:

- 20% direct refined fuels (desulphurization units)
- **80%** of volume will be blended fuel - many (!) different types
- VLSFO quality will vary from port to port, batch to batch

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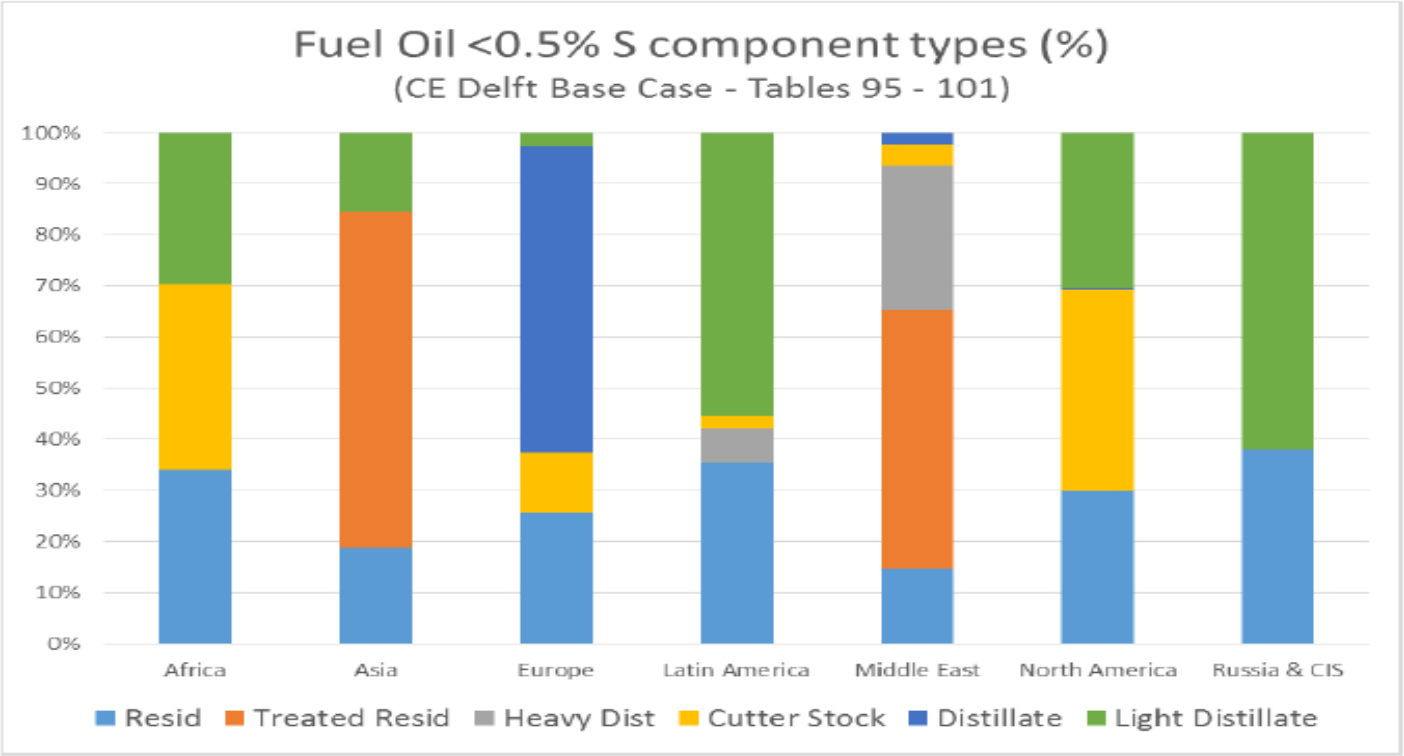
2020 FEASIBILITY STUDIES MARINE FUEL SUPPLY FORECASTS



Source: IMO MEPC 70 – CE Delft study

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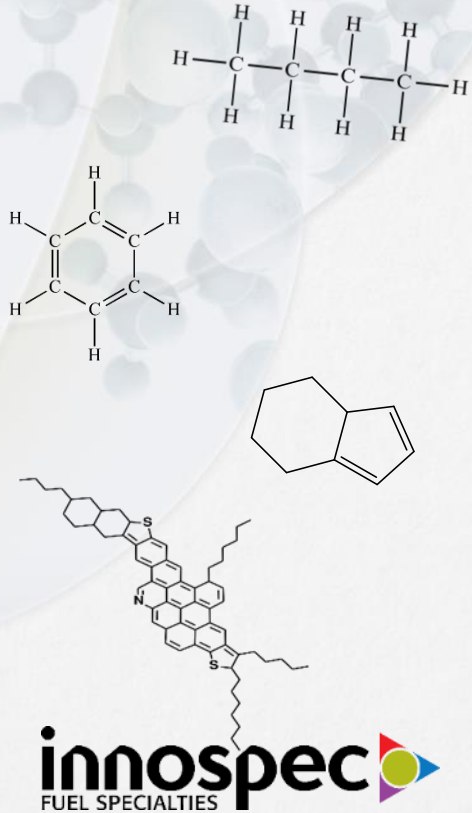
S.A.R.A TEST METHOD

- **Saturates** - Saturates are the lightest fractions present in Oil, single bond hydrocarbons which burn readily in Diesel engines but cause Asphaltenes to crash out of solution.
- **Aromatics** – Heavier fraction ‘benzene ring’ hydrocarbons, commonly carry sulphur and other impurities. Hold Asphaltenes in solution
- **Resins** – Grouped benzene rings which are lighter than Asphaltenes, when Resins attach themselves to Asphaltenes in sufficient number they can prevent them from Agglomerating and forming sludge
- **Asphaltenes:** are molecular substances that are found in crude oil, along with resins, aromatic hydrocarbons, and saturates. Asphaltenes impart high viscosity to crude oils and form sludge’s in refined products.



VLSFO COMPOSITION – SARA ANALYSIS

- **Globally** representative (fuel will vary depending on location)
- **Large variation** in components
- **High Risk** fuels for operability: mixing of Distillate and Asphaltenes components is **highly unstable**.

	Saturates (%)	Aromatics (%)	Resins (%)	Asphaltenes (%)
FUEL 1	50.26	39.26	7.19	3.30
FUEL 2	55.46	31.40	7.36	5.78
FUEL 3	51.57	26.65	12.74	9.04
FUEL 4	47.52	41.32	6.75	4.41
FUEL 5	81.53	7.10	6.96	4.41
FUEL 6	38.63	39.99	16.48	4.91
FUEL 7	53.98	25.39	15.17	5.47
FUEL 8	33.10	36.06	24.30	6.55
FUEL 9	33.95	39.07	13.80	13.16
FUEL 10	61.94	27.21	7.64	3.22
FUEL 11	45.67	39.05	14.20	1.08
FUEL 12	74.04	16.59	6.96	2.42
FUEL 13	75.18	15.33	7.91	1.58
FUEL 14	81.84	14.59	3.32	<0.01
FUEL 15	82.70	8.78	6.09	2.43
FUEL 16	98.72	0.42	0.86	<0.01
FUEL 17	54.18	33.31	10.39	2.13

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S.A.R.A - TYPICAL FUELS

- This table shows the average values for a given fuel
- **Saturates** in VLSFO are from secondary, **low cost** streams which age rapidly
- Saturates and Asphaltenes at these ratios are at a **high risk** of being **unstable**

	Saturates (%)	Aromatics (%)	Resins (%)	Asphaltenes (%)
Diesel	75	25	0	0
VLSFO	60.00	25.00	10.00	5.00
HFO	30	45	15	10

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VLSFO - POUR POINT

Fuel and LIMS ID	Pour Point °C
Fuel 1	30.00
Fuel 2	-24.00
Fuel 3	-3.00
Fuel 4	19.00
Fuel 5	0.00
Fuel 6	-6.00
Fuel 7	-3.00
Fuel 8	34.00

- **VPS: - VLSFO will require heating to 10ºC above Pour Point**

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VLSFO - WEAKNESSES & ADVANTAGES

The blending of light paraffinic streams with residual fuel has the following side effects:

1) The residual part of the fuel and in particular the asphaltenes will be destabilized by the lighter paraffinic streams
   = problematic long term stability and poor compatibility
2) The distillate part of the fuel is subject to thermal and oxidation aging (especially since VLSFO requires heating!)
3) The paraffinic nature of the light streams will increase the pour point and the CFPP

The benefits of the new VLSFO are:

1) The more paraffinic / distillate nature of this fuel benefits the ignition and combustion quality (compared to HFO)
2) Lower density & viscosity allows for easier cat-fine removal
3) Sulphur reduction process by blending (instead of Hydro-processing as in 0,1% S MGO) does not affect the fuel's lubricity

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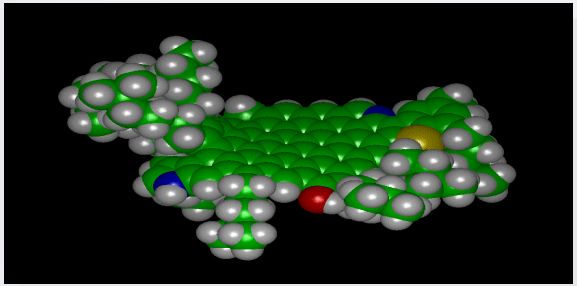
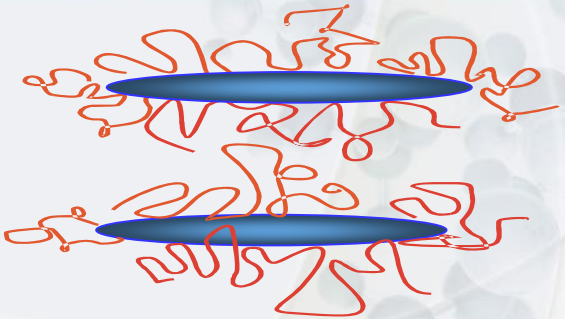
VLSFO RESIDUAL PART STABILITY



Asphaltenes



Facts:

- Asphaltenes are organic high energy heavy HC formations contained within all HFOs.
- They can consist of up to 5% or even more of the total VLSFO content
- By nature they tend to agglomerate = connect with each other
- Fuel sludge mainly consists of asphaltenes that have dropped out of fuel's suspension

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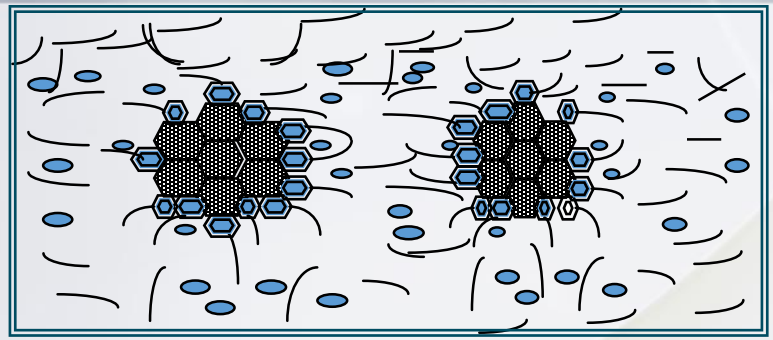
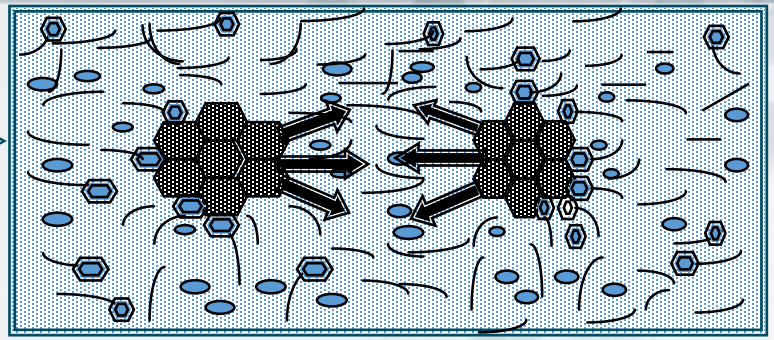
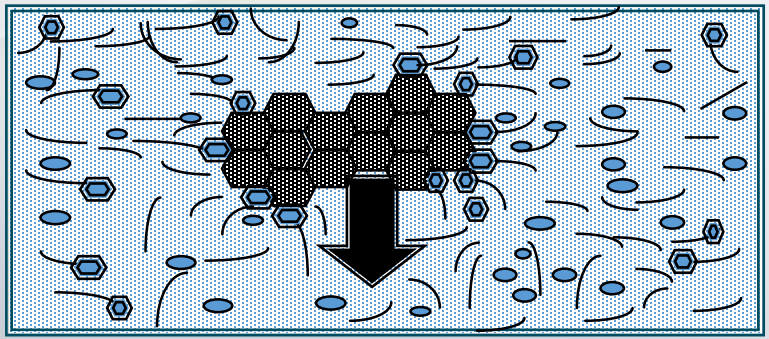
HOW ASPHALTENES DESTABILIZE OUT OF FUEL AS SLUDGE



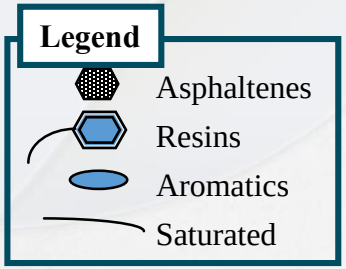
Stable condition



Loses it's resins for example after going through refining processes or blending incompatible fuels



After losing the resins, asphaltenes agglomerates and forms sludge



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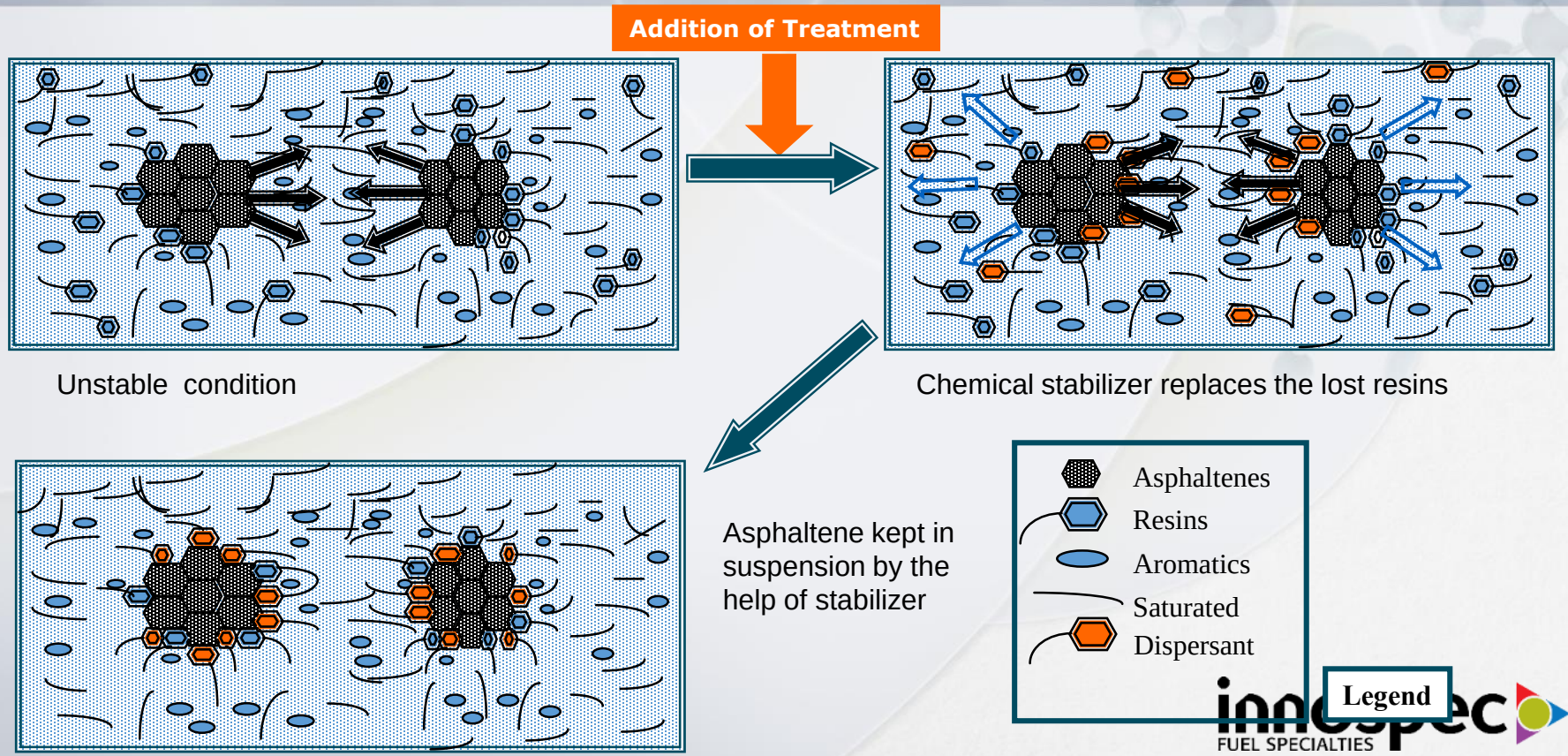
HOW TO STABILIZE THE ASPHALTENES = IMPROVED STABILITY/COMPATIBILITY



HOW IS STABILITY MEASURED?

- Stability is generally assessed by Hot Filtration, with the TSP or TSA method
- It is believed that this method may be unsuitable for modern marine fuels which have undergone secondary refining
- There are other test methodologies used within the industry which give additional information
- It is advisable to test stability not only with Hot Filtration and use additionally complementary test methods.

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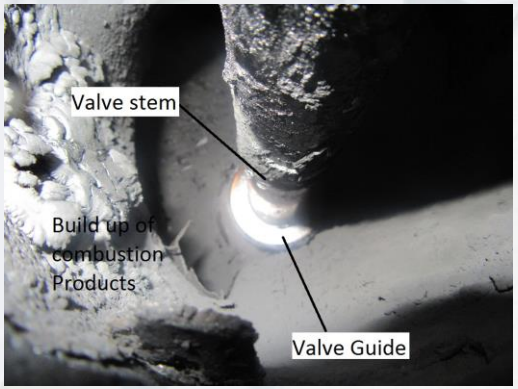
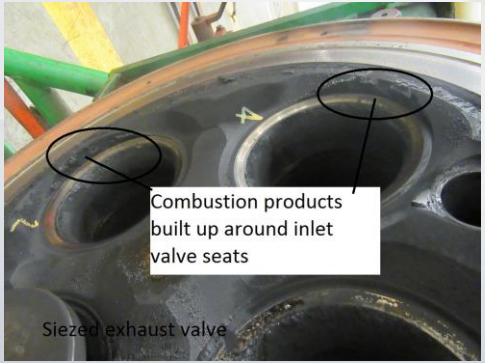
ONGOING CASE - VLSFO

- Loaded into a completely clean tank
- Failed **within 4 hours** of first use
- Fuel was well within ISO 8217 specification…

Total failure of fuel systems, 4 x injector failure, 2 x exhaust valve failure, loss of propulsion.





	Density (kg/m³@15°C)	Viscosity (cSt@50°C)	Sulphur (%mass)
Specification	991.0	380.0	0.50
Supplier BDR	974.8	77.9	0.46
Analysed sample	951.8	30.77	0.40

Parameter	Result	Units	Spec Limit	Test Variance (±)	Method
Viscosity (50°C)	30.77	cSt@50°C	380.0 max	16.60	ISO 3104
Density	951.8	kg/m³@15°C	991.0 max	0.9	ISO 12185
CCAI	846	Index #	870 max		ISO 8217:B
Sulphur	0.40	% mass	0.50 max	0.030	ISO 8754
Flash Point	>70.0	°C	60.0 min		ISO 2719
Total Sediment	0.01	% mass	0.10 max	0.05	ISO 10307-2
Micro Carbon Residue	6.46	% mass	18.00 max	0.99	ISO 10370
Pour Point	+6	°C	30 max	4	ISO 3016
Water	0.15	% vol	0.50 max	0.12	ISO 3733
Ash	0.021	% mass	0.100 max	0.014	ISO 6245
Vanadium	12	mg/kg	350 max	33	IP 501
Sodium	11	mg/kg	100 max	8	IP 501
Aluminium plus Silicon	10	mg/kg	60 max	12	IP 501
Net Specific Energy	41.54	MJ/kg			ISO 8217:A

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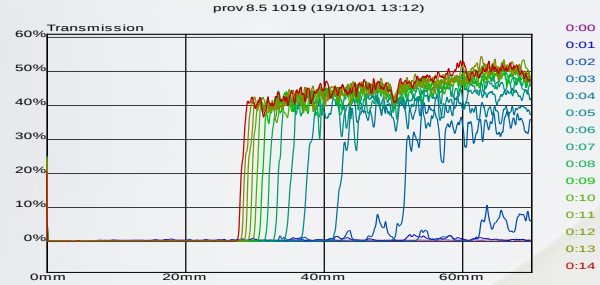
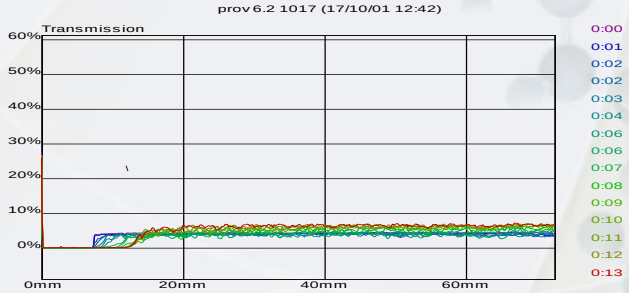
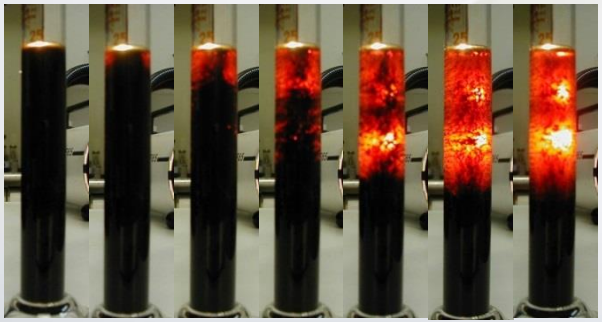
HOW TO RELIABLY PREDICT THE STABILITY OF ASPHALTENES?

Turbiscan RSN (ASTM D7061-12), RSN = Reserve Stability Number







0 min 1 min 2 min 3 min 4 min 5 min 6 min

Without additive

0 min 60min

With additive

Turbiscan or RSN (ASTM D7061-12)
RSN = Reserve Stability Number

RSN	**< 3:**	**Good stability reserve**
RSN	**3 - 10:**	**Limited stability reserve**
RSN	**> 10:**	**Unstable**

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VLSFO COMPATIBILITY
RSN (ASTM D7061-12) – VLSFO ASPHALTENE STABILITY STUDY

Very Low Sulphur Fuel Oil (VLSFO) Fuel Test Matrix

- 6 Fuel samples tested
- Each individual Fuel sample un-additised tested
- Each Fuel tested in a 50:50, 90:10 and 10:90 blend with each other, all un-addititised
- Each Fuel and fuel combination additised with 100 ppm Octamar™ HF-10 Plus

- Summary
- More than **35%** of fuels failed in stability testing
- More than **50%** of the fuel combinations failed in stability testing
- All additised fuels showed excellent stabilities

For best asphaltene stability results treat rate: 1:10,000 – 1:15,000

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TEST RESULTS (NO ADDITIVE & PRE-TREATED WITH OCTAMAR HF10 PLUS)

- 90.8% AVERAGE REDUCTION IN INSTABILITY ACROSS ALL BASE FUELS AND BLENDS

Unadditised		50%					
		Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5	Fuel 6
50%	Fuel 1	0.49	-	-	-	-	-
	Fuel 2	0.26	2.27	-	-	-	-
	Fuel 3	15.63	2.42	11.82	-	-	-
	Fuel 4	8.12	5.90	8.81	2.92	-	-
	Fuel 5	0.67	1.12	9.53	1.08	10.80	-
	Fuel 6	5.08	7.97	12.23	14.02	8.70	0.31

HF-10 Additised		50%					
		Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5	Fuel 6
50%	Fuel 1	/	-	-	-	-	-
	Fuel 2	/	/	-	-	-	-
	Fuel 3	0.47	/	0.86	-	-	-
	Fuel 4	1.68	0.22	0.50	/	-	-
	Fuel 5	/	/	0.40	/	2.41	-
	Fuel 6	0.29	0.27	0.20	0.23	0.72	/

Unadditised		90%					
		Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5	Fuel 6
10%	Fuel 1	0.49	-	-	-	-	-
	Fuel 2	0.20	2.27	-	-	-	-
	Fuel 3	4.34	0.42	11.82	-	-	-
	Fuel 4	0.12	0.34	9.48	2.92	-	-
	Fuel 5	0.24	0.27	11.37	0.22	10.80	-
	Fuel 6	0.38	0.43	12.88	0.51	15.71	0.31

HF-10 Additised		90%					
		Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5	Fuel 6
10%	Fuel 1	/	-	-	-	-	-
	Fuel 2	/	/	-	-	-	-
	Fuel 3	0.34	/	0.86	-	-	-
	Fuel 4	/	/	0.71	/	-	-
	Fuel 5	/	/	0.45	/	2.41	-
	Fuel 6	/	/	0.92	/	0.92	/

Unadditised		10%					
		Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5	Fuel 6
90%	Fuel 1	0.49	-	-	-	-	-
	Fuel 2	0.32	2.27	-	-	-	-
	Fuel 3	10.83	12.13	11.82	-	-	-
	Fuel 4	0.13	0.19	0.43	2.92	-	-
	Fuel 5	9.66	9.81	9.16	8.78	10.80	-
	Fuel 6	5.25	3.02	4.15	5.60	4.96	0.31

HF-10 Additised		10%					
		Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5	Fuel 6
90%	Fuel 1	/	-	-	-	-	-
	Fuel 2	/	/	-	-	-	-
	Fuel 3	0.14	0.12	0.86	-	-	-
	Fuel 4	/	/	/	/	-	-
	Fuel 5	1.53	1.04	1.45	1.18	2.41	-
	Fuel 6	0.45	0.56	0.4	0.32	0.63	/

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PRE-TREAT WITH **OCTAMAR HF-10 PLUS**

VLSFO 1

Untreated

Pre-Treated

VLSFO 2

Untreated

Pre-Treated

	Pre- treated	Treated	SARA			
Fuel	**RSN**	**RSN**	**Saturates(%)**	**Aromatics(%)**	**Resins(%)**	**Asphaltenes(%)**
VLSFO 1	10.8	2.4	81.53	7.10	6.96	4.41
VLSFO 2	3.95	0.4	28.56	44.36	17.97	9.10

- Each sample was heated for 24 hours at 100°C to age the fuel

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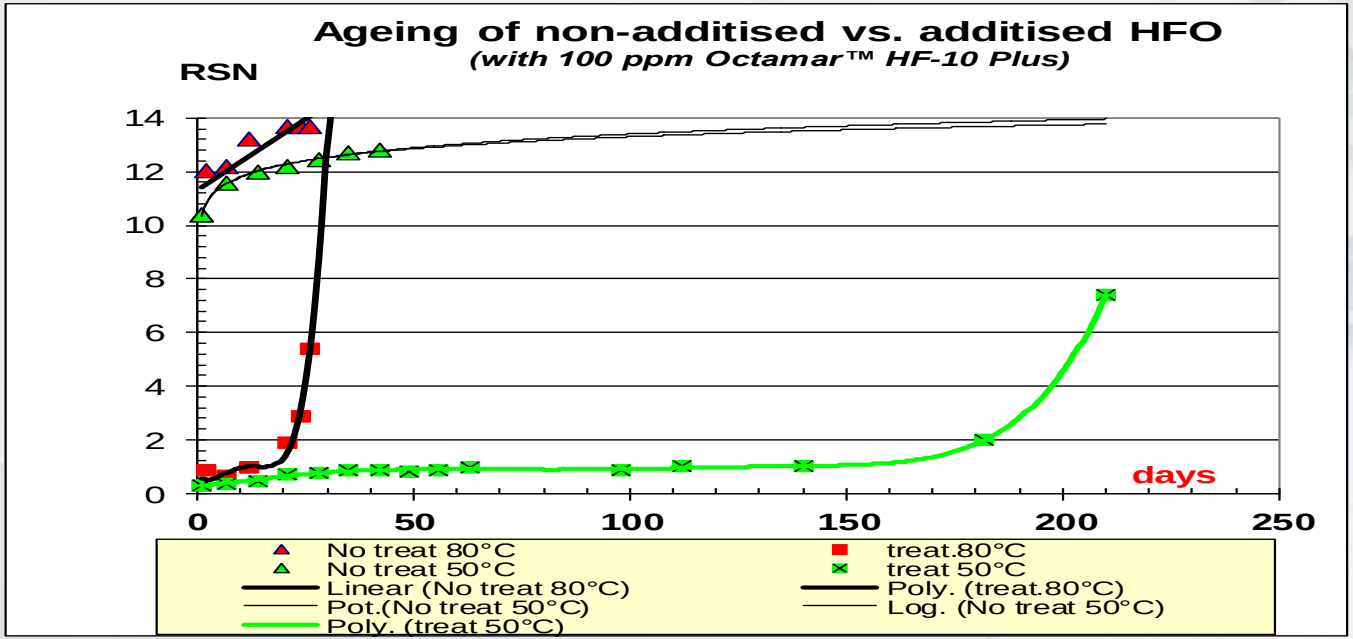
LONG TERM STABILITY

RSN (ASTM D7061-12) – ASPHALTENE STABILITY AND FUEL AGEING



Octamar™ HF-10 Plus: Fuel stable in settling tanks for more than 3 weeks !!!
& Stable in Storage tanks for 200 days

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VLSFO MIDDLE DISTILLATE PART STABILITY

Middle distillates / gas oils are mixtures of hydrocarbons susceptible to degradation through three external factors:

These are

- Light (UV Stability)
- Air (Oxidation Stability)
- Temperature (Thermal Stability)
- Storage time

Instability of the distillate part of fuel will lead to sludge/gum (peroxides) formations, filter plugging, and increased risk of poor compatibility

Stability additives are designed to counteract these different reactions

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Distillate Stability Protection

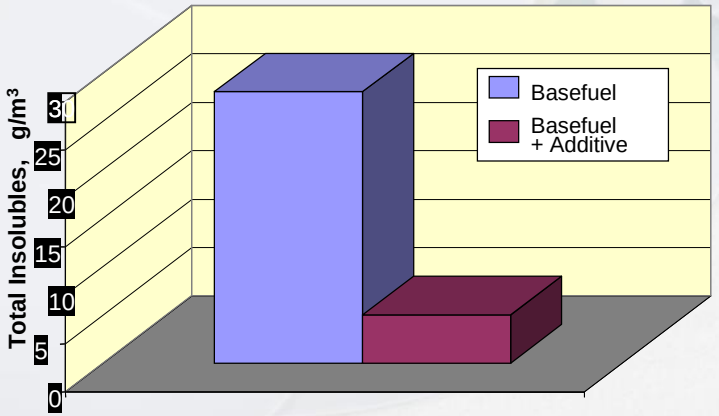
Stabilisation through additive treatment is an extremely effective way of protecting against thermal and oxidative initiated stability.

Octamar™ HF-10 Plus contains stabiliser which can help protect against thermal and oxidation stability

ISO 8217:2010 includes a limit for stability and oxidation
Test method ISO12205 with a limit of 25g/m^3

Left: Unaged base fuel Middle: Aged base fuel Right: Aged fuel containing additive

EN ISO 12205 and DMA



Total Insolubles reduced by 82 %

- **Only Pre-Treatment will work, cannot “rescue” Oxidised VLSFO**

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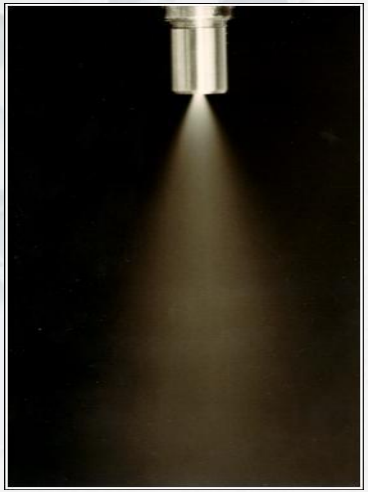
FUEL INJECTOR CLEANLINESS

- Octamar™ HF-10 Plus contains a powerful detergent which
  - prevents formation of, and removes existing, deposits caused by fuel decomposition
  - results in optimal fuel spray pattern being maintained
- Octamar™ HF-10 Plus provides a number of benefits
  - better fuel economy
  - reduced emissions
  - Improved engine durability



- Detergent effect = Good atomisation will enhance combustion

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FUEL INJECTOR CLEANLINESS

- Injectors from basefuel
- Injectors from additised fuel

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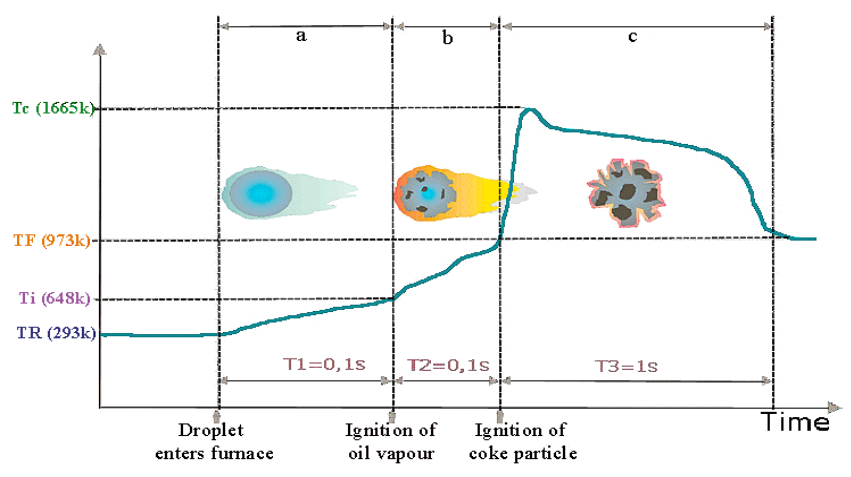
IMPROVED SPRAY PATTERN = IMPROVED IGNITION + COMBUSTION

- Improve spray pattern exposing more fuel to charge air (improve atomization)
- Reduce droplet size (less mass) allowing faster heat up and earlier ignition
- Smaller coke particles require less time for complete burn through



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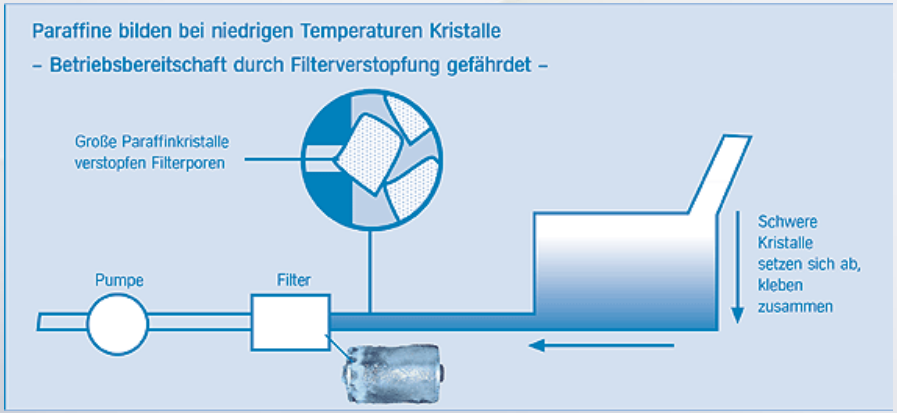
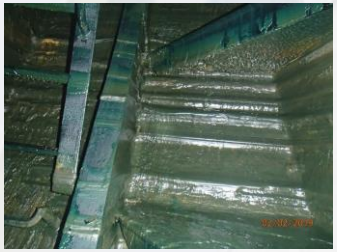
POUR POINT AND THE CFPP

VLSFO samples have indicated a high Pour Point. This has to do with the fact that:

- 60-70% of VLSFO is distillate containing paraffins which tend to crystalize at lower temperature
- Paraffin crystals will settle down and precipitate and finally form a waxy layer
- Fuel operability temperature is limited
- Paraffin waxes may cause blockings of fuel line and filters





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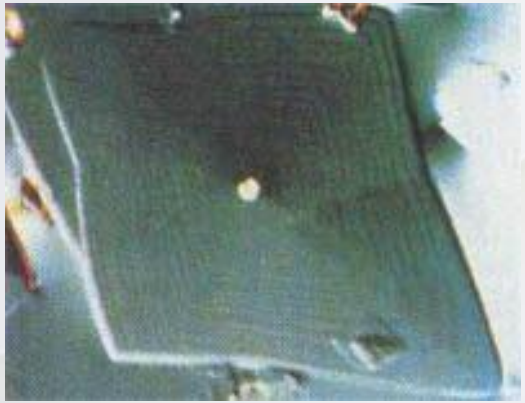
COLD FLOW IMPROVER ADDITIVES : MECHANISM OF ACTION

Form and size of n-paraffin crystals are influenced by adding Cold Flow Improvers



Cold Flow Improver

Crystallisation depends on type and amount of n-paraffins as well as on VLSFO matrix, e.g. aromatics, naphthenics

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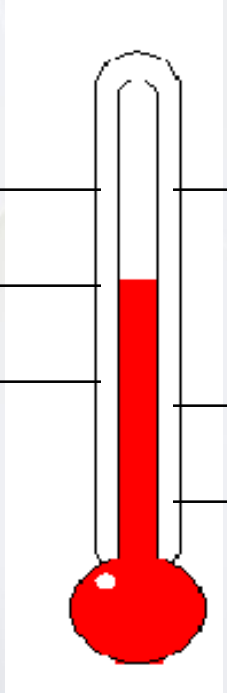
COLD TEMPERATURE BEHAVIOUR OF MARINE FUELS

Without CFI

Cloud Point (CP)

Cold Filter Plugging Point (CFPP)

Pour Point (PP)



With CFI

Cloud Point (CP)

Cold Filter Plugging Point (CFPP)

Pour Point (PP)

CP = Point where crystallisation begins
CFPP = Operability point
PP = point at which fuel becomes solid

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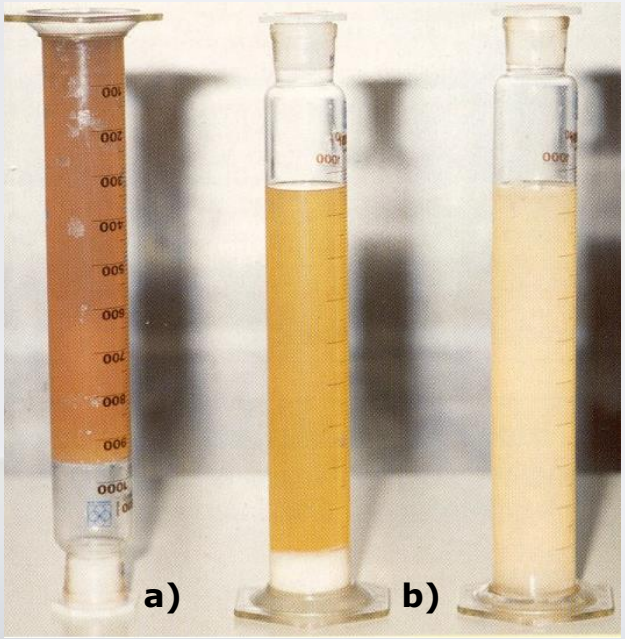
WAX ANTI SETTLING ADDITIVE - WASA



a) Fuel without CFI and WASA

⇒ Solid, not pumpable

b) Fuel containing CFI only

⇒ Paraffin sedimentation

c) Fuel containing CFI and WASA

⇒ No paraffin sedimentation observed

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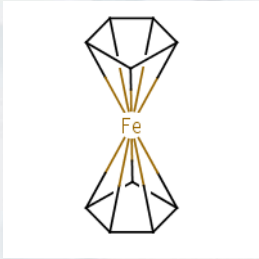
FUEL SPECIALTIES

OCTAMAR™ ULTRA HF

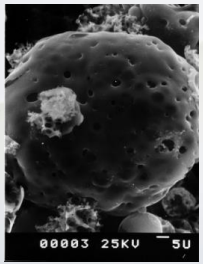
OPTIMUM COMBUSTION OF VLSFO WITH IRON COMBUSTION CATALYST & COMBUSTION IMPROVER

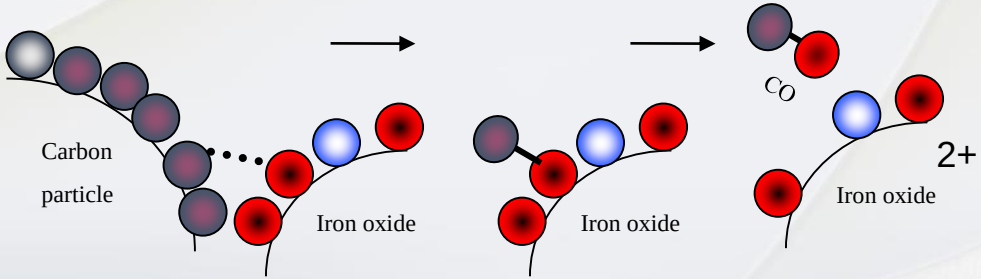
For companies who pay for the fuel they use and require to reduce the Specific Fuel Consumption + reduce GHG emissions

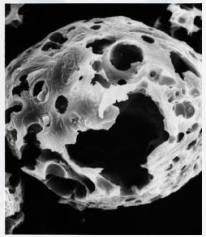


(C5H5)2 Fe

- Oxidation of Carbon Particulates during combustion is 16 times faster with Ferrocene catalysts
- Ferrocene catalysts reduce the ignition temperature of Carbon by approximately 125ºC.
- Release free radicals for more vapor production (influence earlier ignition) with organic combustion improver







$2\ Fe_2O_3 + 3C \rightarrow 4\ Fe + 3\ CO_2$

$FeO + C \rightarrow Fe + CO$

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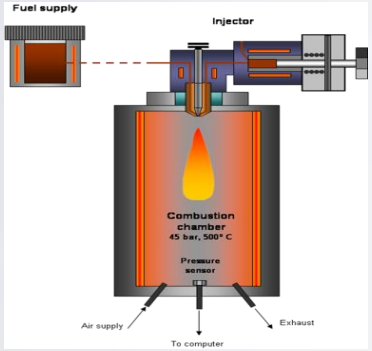
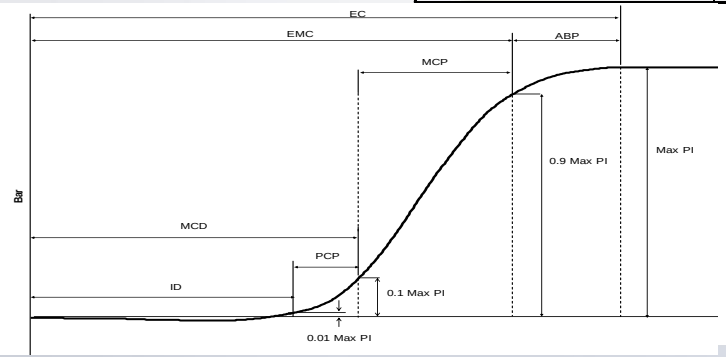
FIA/FCA IGNITION - COMBUSTION PROPERTIES

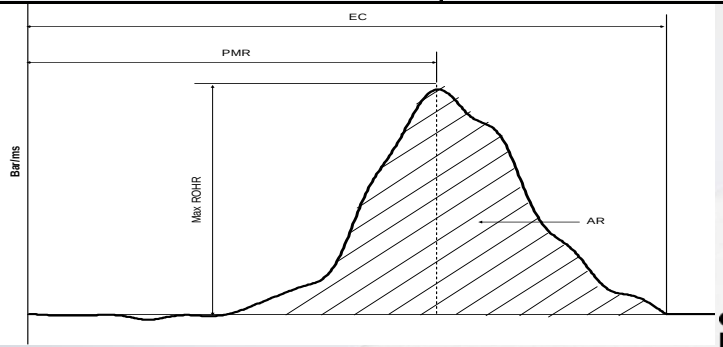
Octamar™ Ultra HF FIA result is an average of 20 combustion cycles



FIA	Description	Repeatability	r +/-	Base	Additive
ID (ms)	Ignition Delay	0.01979 x ID	0.10489	5.3	5.12
MCD (ms)	Main Combustion Delay	0.02292 x MCD	0.15265	6.66	6.4
EMC (ms)	End of Main Combustion	0.03328 x EMC	0.39969	12.01	11.54
EC (ms)	End of Combustion	1.16480	1.16480	18.97	18.46
PCP (ms)	Pre Combustion Period	0.07373 x PCP	0.10027	1.36	1.29
MCP (ms)	Main Combustion Period	0.06226 x MCP	0.33309	5.35	5.13
ABP (ms)	After Burning Period	0.95310	0.95310	6.96	6.92
Max ROHR (bar/ms)	Maximum Rate of Heat Release	0.08502 x max ROHR	0.21595	2.54	2.83
PMR (ms)	Position of max ROHR	0.0004406(PMR)^3	0.1851356	7.49	7.15
AR (bar)	Accumulated ROHR	0.92280	0.92280	7.12	7.35
Max PI (ms)				7.26	7.5
ECN	Estimated Cetane Number	Linked to MCD		22.8	**24.5**

Positive impact
Positive but within r
No Impact
Negative but within r





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FUEL SPECIALTIES

INNOSPEC'S SOLUTIONS

- **Octamar HF-10 Plus**:
  - **Stabilise the asphaltenes** and provide: Long term storage stability & improved Compatibility
  - Provide **thermal / oxidation stability** to the distillate part of the VLSFO for long term heating and storage stability of the paraffinic part of the fuel – avoid aging (gumming deposits)
  - **Clean up of fuel injectors** for improved fuel efficiency
- **Octamar Winterflow:** to directly reduce the pour point and CFPP of distillate part if required but also keep paraffins homogeneously distributed with WASA
- **Octamar Ultra HF:** same stabilizing abilities as Octamar HF-10 Plus but further optimizes the combustion procedure with a combination of an iron combustion catalyst & organic combustion improver

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FUEL SPECIALTIES

OCTAMAR PRODUCTS - SPECIFICATIONS

Octamar™ HF-10 Plus

Typical Properties
Appearance ……..…Brown, reddish liquid
Density .....870 kg/m³ at 15°C
Flash point…….……> 61°C

Dosage Rate
1 :15,000

Application
A unique product for sludge reduction, stability and combustion improvements for Very Low Sulphur Fuel Oil (VLSFO) driven diesel engines

Octamar™ Winterflow

Typical Properties

Appearance ……..…opaque to lightly yellow liquid
Density ..... 895 kg/m³ at 15°C
Viscosity…….....….max. 5 cSt at 40°C
Pour point…….....…<-9°C
Flash point…….…….....…>60°C

Dosage Rate
1 : 1,000 (1000 ppm)
Application
A proven product for improvement of the cold flow properties of MGO/MDO and VLSFO

Octamar™ Ultra HF

Typical Properties

Appearance ……..…Reddish, brown liquid
Density .....930 kg/m³ at 15°C
Flash point…….……> 61°C

Dosage Rate
1 : 6,000

Application
A unique product for stability, ignition, combustion improvements and fuel savings for very low sulphur fuel oil (VLSFO) driven diesel engines

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FUEL SPECIALTIES

QUESTIONS

Thank you very much!

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FUEL SPECIALTIES