IGTC18

The Challenge of Burning Diesel Fuel in Aero-derivative Gas Turbines Off-shore

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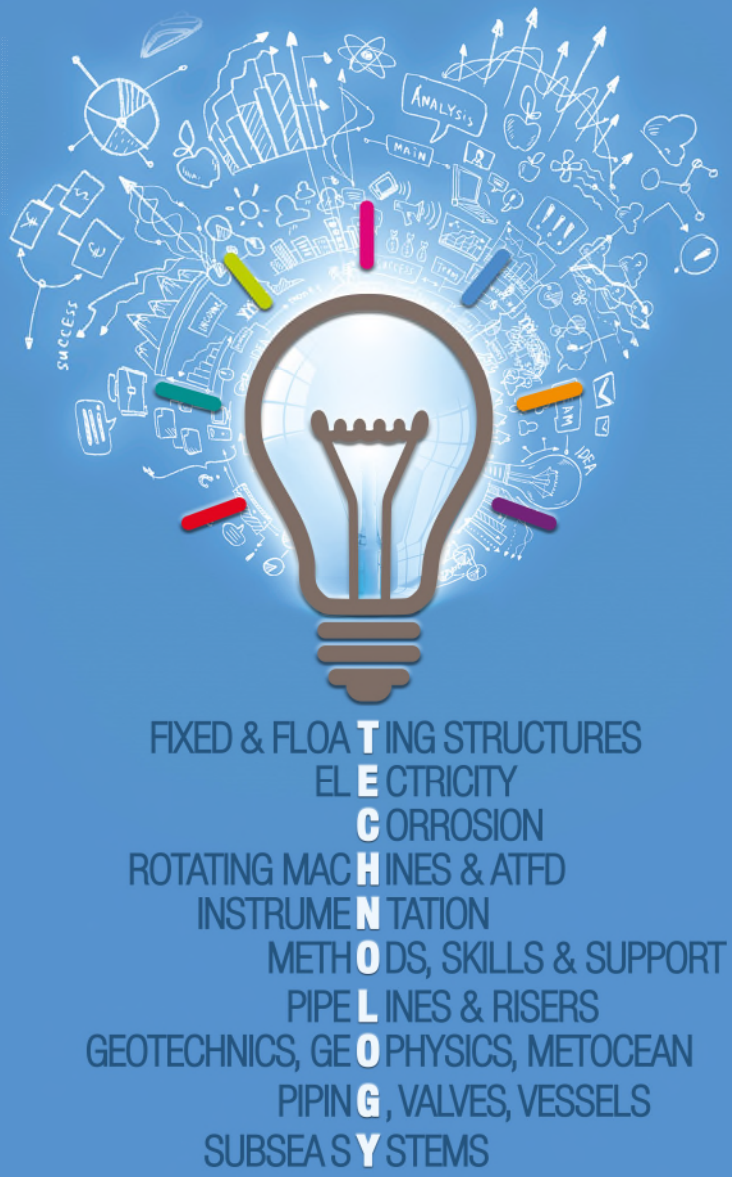


International Gas Turbine Conference IGTC18, Brussels, the 10th of October 2018

Standardized Kerosene and Diesel Oil for Gas Turbine Applicable Standards

Kerosene

- ASTM D1655-18a
  - Jet A
  - Jet A1

Automotive Diesels

- ASTM D975 for the US.
- EN590 for Europe.

Distillate Marine Fuels by ISO 8217

- DMX, DMA, DMZ, DMB.

Residual Marine Fuels by ISO 8217

- (RMA, RMB, RMD, RME, RMG, RMK) => not used in aero derivative gas turbines.

Gas Turbine Fuel Oils, as Defined by ASTM D2880

- N°0-GT
- N°1-GT
- N°2-GT
- N°3-GT
- N°4-GT

Diesel Parameter Review: Specific Gravity

Specifications	Title	Fuel Grade	Specific Gravity[(a)]
ASTM D1655	Aviation Turbine Fuels	Jet A or Jet A1	775 kg/m3 Minimum 780 kg/m3 Maximum
ASTM D975	Diesel Fuel Oils (Automotive)	All Grades	No References to SG
EN590	Diesel Fuel Oils (Automotive)	All Grades and Classes	820 kg/m3 Minimum 845 kg/m3 Maximum
ISO 8217	Marine Fuel Oils	DMX DMA, DMZ DMB	No References to SG 890 kg/m3 Maximum 900 kg/m3 Maximum
ASTM D2880	Gas Turbine Fuel Oils	N°0-GT N°1-GT N°2-GT N°3-GT N°4-GT	No Reference to SG 850 kg/m3 Maximum 876 kg/m3 Maximum No References to SG No References to SG

Specific Gravity

- Low SG => High Distillate Quality
- Refers to 15°C
- ASTM D1250 calculates SG with temperature in order to refer to 15°C.
- Accurate correlation between LHV and SG.

Diesel Parameter Review: Specific Gravity

Aeroderivative on site experience

- 860 kg/m3 => Diesel Fuel, Rich in Heavy Ends.
- Some refinery in Africa specifies a low limit at 820 kg/m3 without upper limit.
- SG=845 kg/m3 Fairly Workable.
- SG=855 kg/m3 more Hardly Workable.
- 845/855: Values Close to N°1-GT Grade of ASTM D2880 and to Higher Limit of EN590.
- 845/855: Far below DMA SG of 890 kg/m3.
- 845/855: Values Typical to DMX or Good Quality DMA.

Diesel Parameter Review: Color

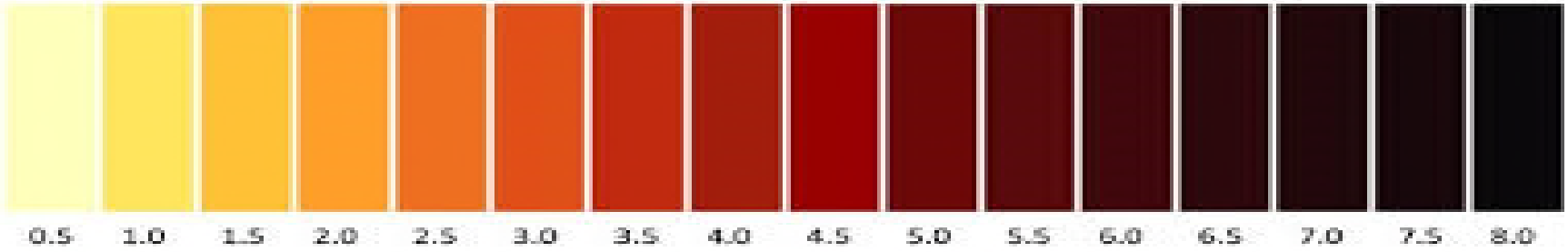
ASTM D1500
Scale 0,5 to 8 from

ASTM D1500

"the determination of the color of petroleum products is used for manufacturing control purposes and is an important quality characteristic, since color is readily observed by the user of the product"

ASTM D1655

"color can be a useful indicator of fuel quality and a change in fuel color may be the result of product contamination and may be an indicator that the fuel is off-specification."



Aeroderivative on site experience

- Fuel Oil Color, Precious Information for Operation Team.
- No diesel standards refer to color as operating guidelines.
- Color reports directly the addition of residues, pollution or oil degradation.
- Fuel color over 3,5 becomes an issue offshore for aero-derivative gas turbines.

Diesel Parameter Review: Clear & Bright, Cetane Number

Clear & Bright

- Certificates, delivered with fuel, systematically report the clarity and brightness evaluation.
- No international specifications refer to clarity and brightness, except standard relative to jet fuel (ASTM D1655).
- "Clarity and brightness" is a good parameter on site to check contamination. Nevertheless, clear & bright does not mean suitable fuel for aeroderivative gas turbines.
- Easy to evaluate at site.

Cetane Number

- International fuel specifications relative to gas turbine do not refer to Cetane Number.
- Certificates, delivered with fuel, systematically report the Cetane Number.
- Cetane Number according to international specifications may vary from 30 minimum to 51 minimum.
- Higher is the Cetane Number = > higher is the fuel quality.

Fuels as per Aeroderivative Gas Turbine Manufacturers

Aero-derivative Gas Turbine Manufacturer	ASTM D1655 Aviation Turbine Fuels	ASTM D2880 Gas Turbine Fuel Oils	ISO 8217 Marine Fuels
OEM 1	Jet A Jet A-1 Jet B	None	None
OEM 2	Jet A Jet A-1 Jet B	No 0-GT No 1-GT No 2-GT	DMA

Refer to analyses for examples

Parameter	OEM requirements	ASTM D1655 Jet A1	ASTM D2880 N°1-GT ASTM D2880 N°2-GT	ISO 8217 DMA	Reported in fuel Certificates(3)
Density at 15°C (kg/m3)	600 min(1) 880 max(1)	775 min 840 max	850 max N°1-GT 876 max N°2-GT	890 max	Always
Sulphur (% weight)	1 max(1)(2)	0,3 max		1,5 max	Always
Total Acid Number (mg KOH/g)	0,5 max(1)	0,1 max		0,5 max	Always
Aromatic Content (% volume)	5 min (1) 40 max(1)	25 max			Not Reported
Carbon Residue (100% sample)	1 max(2)				Not Reported
Carbon Residue on 10% bottoms	0,35 max(1) 0,25 max(2)		0,15 max N°1-GT 0,35 max N°2-GT	0,30 max	Always
Cloud Point	5°C below fuel temp.(1)				Always
Distillation 10% vol Recovery	250°C max(1)	205°C max			Not Reported
Distillation 90% vol Recovery	357°C max(1)	Report	282°C min 338°C max		Sometimes
Distillation Final Boiling Point	385°C max(1)	300°C max			Sometimes
Flash Point (°C)	10 above fuel temperature(1)	38 min	38 min	60 min	Always
Smoke Point (mm)	17 min(1)	25 min			Not Reported
Kinematic Viscosity (mm2/s or Centistoke)	1 min(1) 11 max(1)	8 max @-20°C	1,3 min @40°C N°1-GT 2,4 max @40°C N°1-GT 2,4 min @40°C N°2-GT 4,1 max @40°C N°2-GT	2 min@ 40°C 6 max @ 40°C	Always
Demulsification (min)	20 max(2)				Not Reported
Copper Corrosion	1 max(1)(2)	1 max			Sometimes
Hydrogen Content (% weight)	12 min(1) 12,7 min(2)				Not Reported
Olefin Content (% Vol)	5 max(1)				Not Reported
Free Water & Sediment (% Vol)	0,05 max(1) 0,10 max(2)		0,05 max		Sometimes
Ash (% Weight)	0,01 max(1)(2)				Always
Particulates	3 mg/l max(1) 2,6 mg/l max (2)				Not Reported
Particle Size	40 µm max(1)				Not Reported
Calcium (ppmw)	0,5 max(1) 2 max(2)				Not Reported
Sodium plus Potassium (ppmw)	0,6 max(1)				Not Reported
Sodium, Potassium & Lithium (ppmw)	0,2 max(2)				Not Reported
Lead (ppmw)	0,5 max(1) 1 max(2)				Not Reported
Vanadium (ppmw)	0,5 max(1) 0,2 max(2)				Not Reported

(1) = OEM 1 / (2) = OEM 2 / (3) Fuel quality certificates issued by the fuel provider at delivery

Conditions From Offshore Sites

- None of international standards satisfy the OEM specification.
- By the same, it is not possible to order fuels as per OEM specification.
- Fuel certificates cannot confirm the compliance with OEM specification.
- Fuel offshore logistic dedicated to drilling rigs and supply boats with reciprocating engines and not gas turbines.
- Finally, large gap between the required and the available fuel.

Operational Issues – Case 1: Heavy Pollution

Certificates as per Original

Nothing Wrong on Paper. The limited number of parameters are met.

"Resample Bunker Gasoil BA7 ex JBS".

Property	Test Method	Limits	Results
Density @ 15°C, kg/l	D 1298	0,8195min	**0,8780**
Density @ 20°C, kg/l	D 1298	0,816min	0,8747
Specific Gravity @ 60°F/60°F			0,8785
API Gravity			30
Distillation: 90% Vol Rec, °C	D 86	367max	330
Flash Point PMCC Composite	D 93	62min	88
Flash Point PMCC Top	D 93	62min	88
Flash Point PMCC Middle	D 93	62min	87
Flash Point PMCC Bottom	D 93	62min	88
Kinetic Viscosity @ 40°C, cSt	D 445	2,2min - 6,0max	2,84
Redwood Viscosity @ 100°F, Sec's	Calc.		34
Water Content: Karl Fisher ppm	D 1744	500max	58
ASTM Color	D 1500	3,0max	**<1,0**
Appearance	D 1476	Pass	Pass
Odor		Marketable	m/a

"Bunker Gas Oil (DMA)".

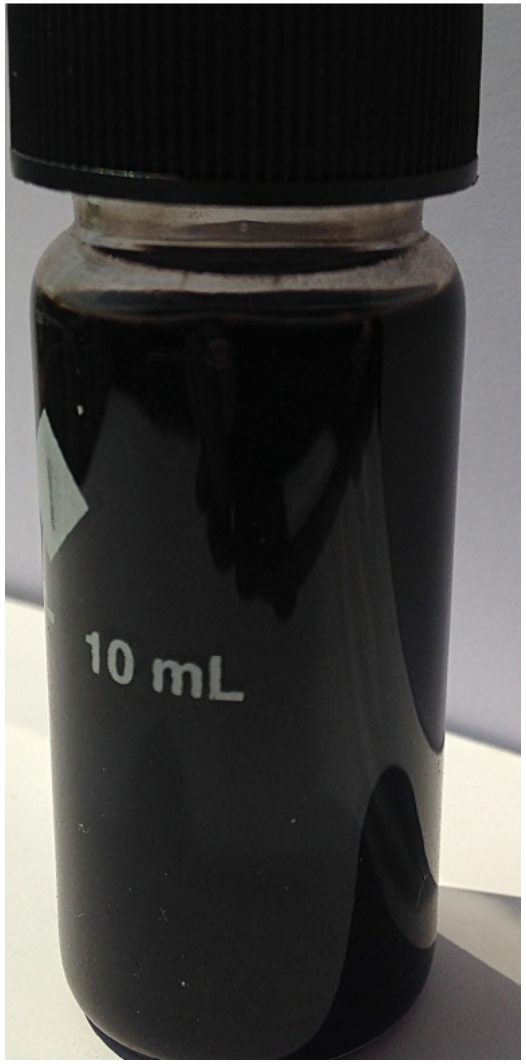
Property	Test Method	Specification	Results
Appearance - Haze Test	ASTM D.4176 – Procedure 2	2max	N°1
Ash Content – Petroleum Products, mass%	ASTM D.482	0,01max	<0,01
Ransbottom Carbon Residue, %m/m	ASTM D.524	0,30max	0,05
Calculated Cetane Index	ASTM D.4737	40min	43
Density @ 15°C, kg/l	ASTM D.4052	0,890max	**0,8693**
Density @ 20°C, kg/l	ASTM D.4052	Report	0,8657
Pour Point, °C	ASTM D.97	0max	-6
Sulphur – X-ray Method, % m/m	IP 336/ASTM D.4294	1,50max	1,3320
Viscosity @ 40°C, cSt (mm2/s)	ASTM D.445	1,50-6,00max	3,374
Water – Coulometer Karl Fisher, mg/kg	ASTM D.4928	250max	214,5
Flash Point Pensky-Martens, °C	ASTM D.93 – Proc.A	62min	87

Operational Issues – Case 1: Heavy Pollution

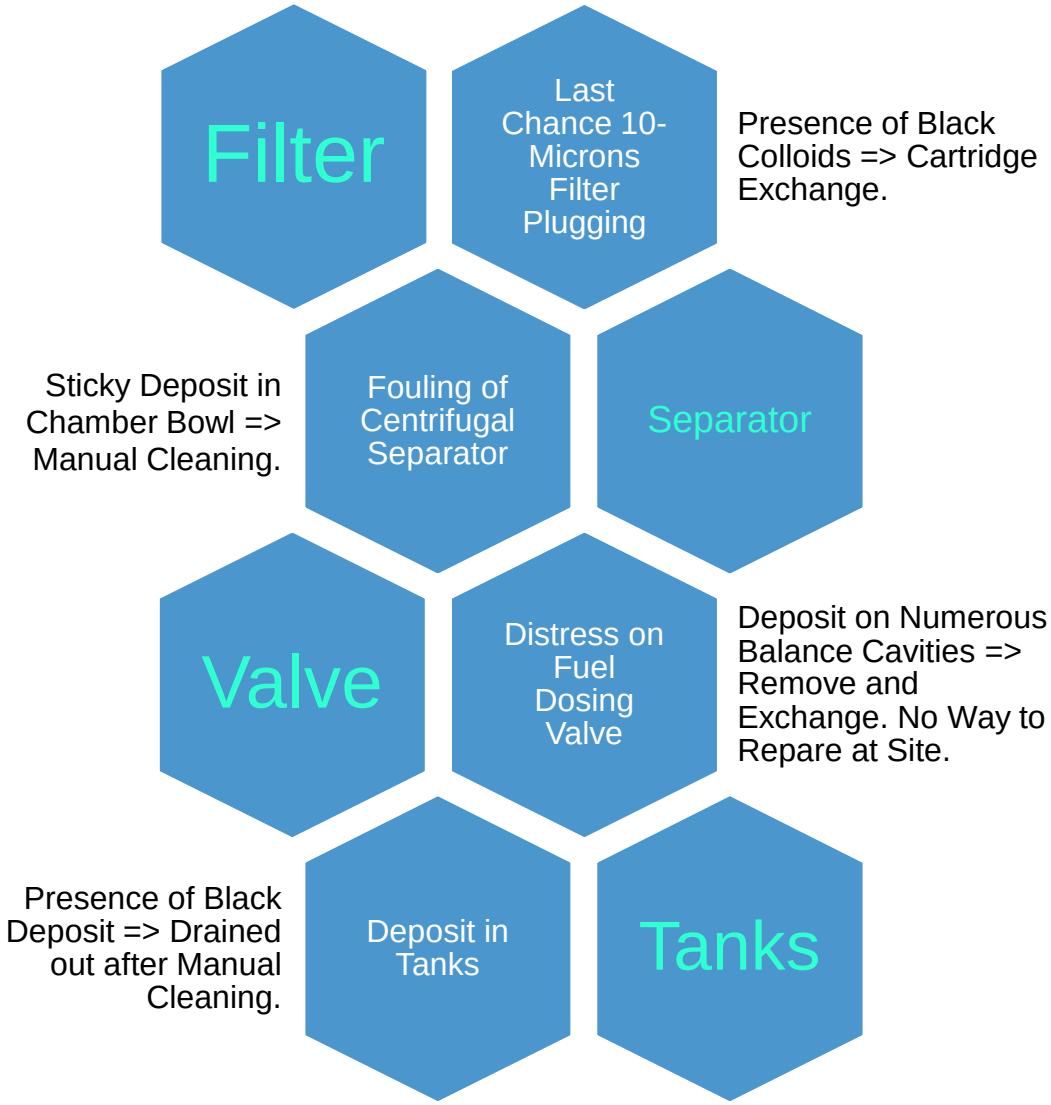
Long Hydrocarbon Chains
=
Residue
or
Recombination of Unsaturated Hydrocarbons (Photosynthesis, Heat, Recirculation)

Diesel Oil
=
« Living » Product not Necessarily Treated with H2

6 Weeks for Settling for this Concentrated Sample



Operational Issues – Case 1: Heavy Pollution



Operational Issues – Case 2: Inability to Run with 20-Micron Filter

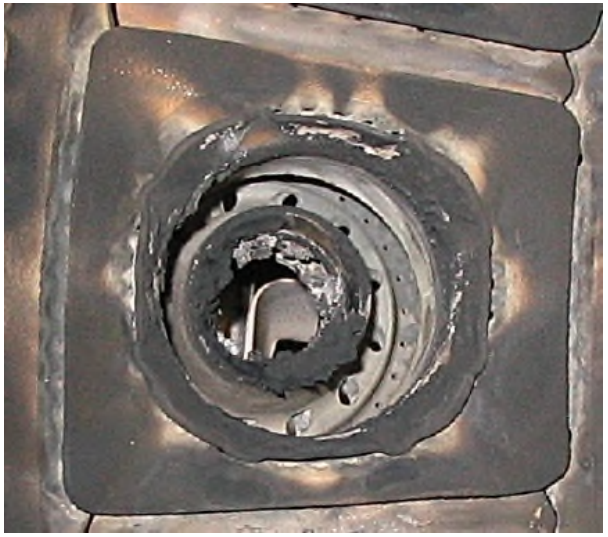
Parameters	Units	Certificate 1	Certificate 2	Certificate 3	Certificate 4	Certificate 5	Certificate 6
Specific Gravity @ 15°C	(kg/m3)	863,7	858,0	858,0	858,1	841,1	848,7
Color	/	1,5	1,0	2,5	2,5	L1,0	L1,0
Appearance	/	Clear and Bright	Clear	Not Reported	Not Reported	Not Reported	Not Reported
Cetane Index	/	46,7	49,1	47,5	47,3	52,8	54,3
Sulfur	%	0,147	0,1795	0,2372	0,2852	0,1565	0,16
Water	ppm	208	115	240	115	151	Not Reported
Cloud Point	°C	-2	-0,9	4,5	-2	1,5	Not Reported
Pour Point	°C	-6	-4	-3	-6	-19	+3

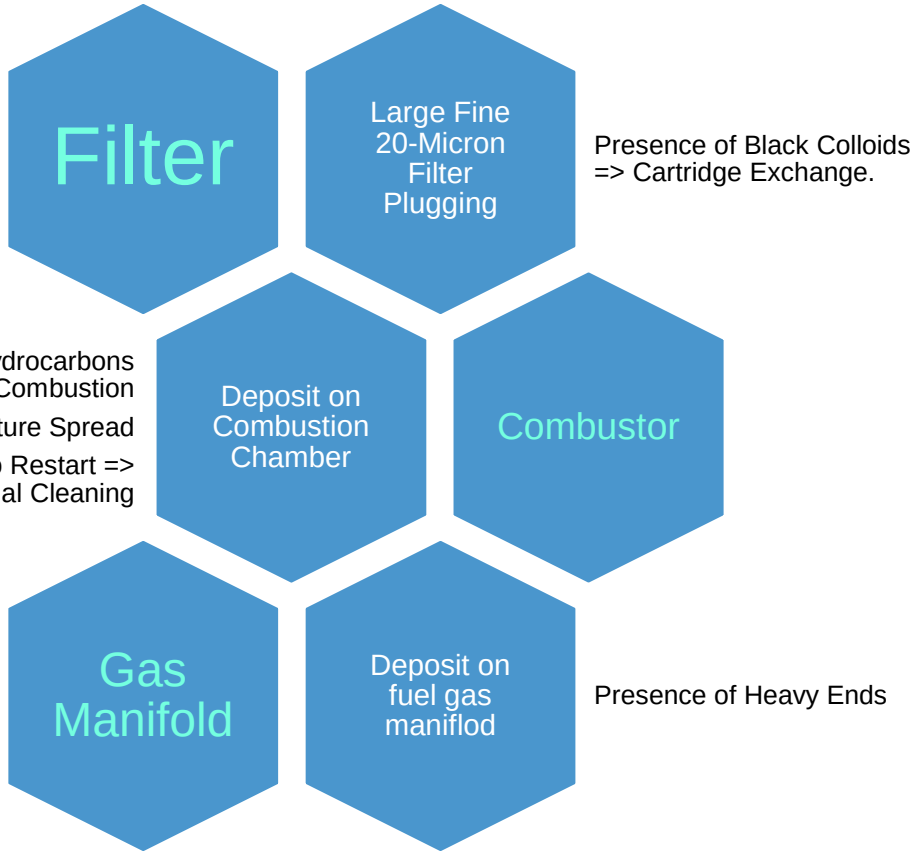
Certificates for Marine Distillate, DMA according to ISO 8217

Certificates as per Original

Nothing Wrong on Paper.
The limited number of parameters are met.

Operational Issues – Case 2: Inability to Run with 20-Micron Filter



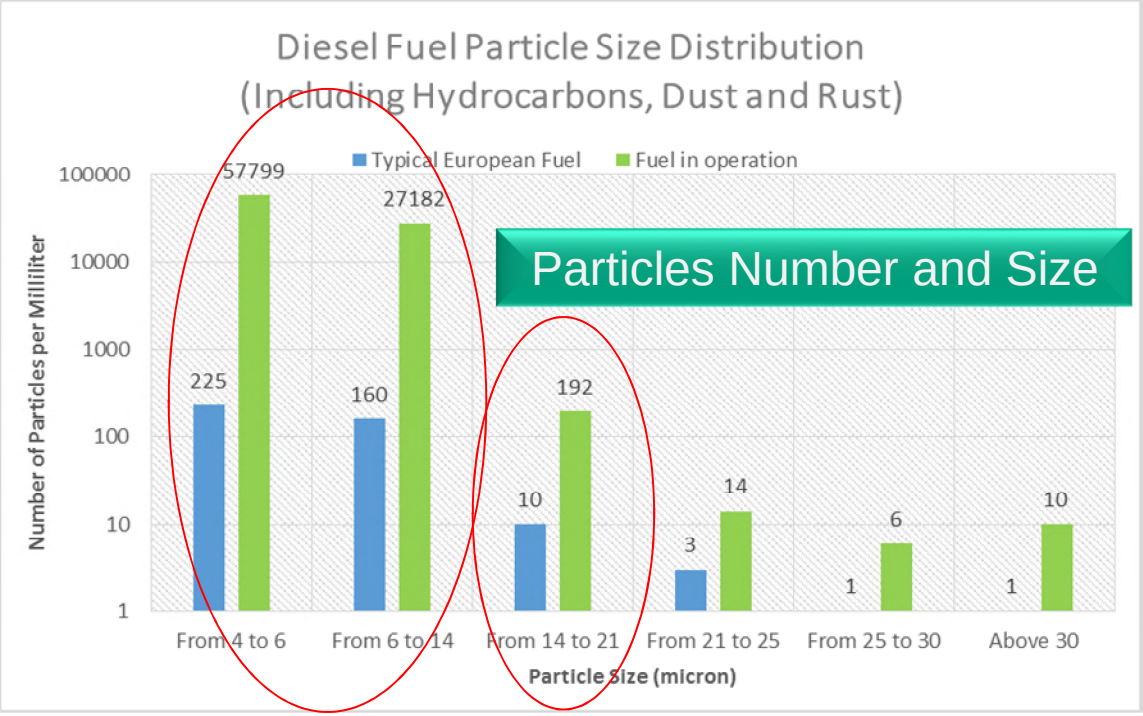


Operational Issues – Case 2: Inability to Run with 20-Micron Filter

Parameters	Method	Units	Laboratory Analysis of Fuel in Operation
Specific Gravity @ 15°C	ISO 12185	(kg/m3)	855
Color	ASTM D1500	/	L3,5
Sulfur	ASTM D2622	%	0,267
Water	Proprietary	ppm	67
Cloud Point	EN 23015	°C	4,1
90% Distillation	ISO 3405	°C	362,6

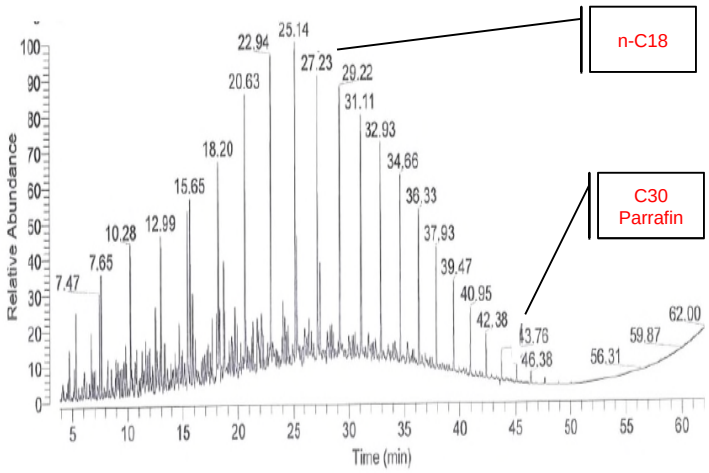
Compared to a typical European automotive diesel (EN-590 grade B), the fuel has up to 200 times more particles.

4 to 14 micron particle size is critical in quantity.

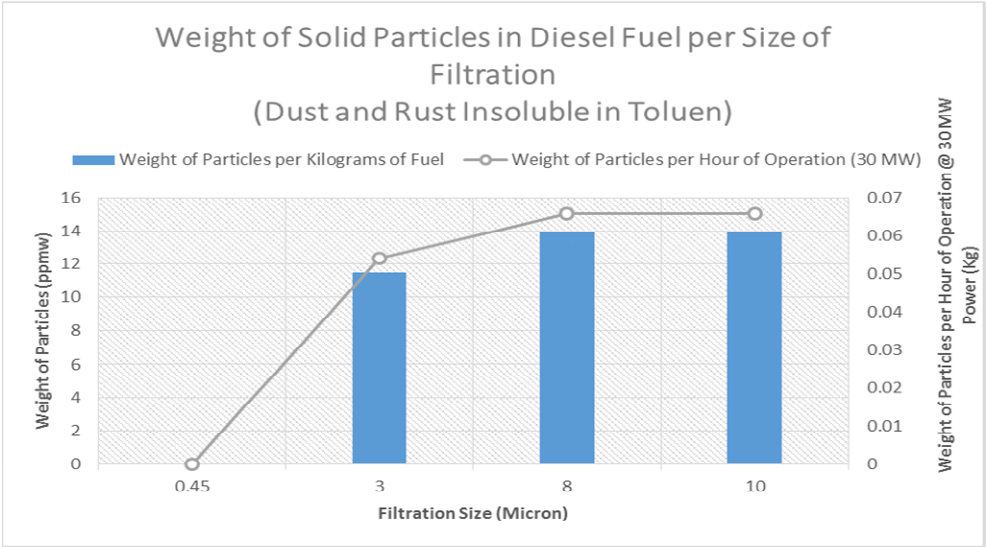


Operational Issues – Case 2: Inability to Run with 20-Micron Filter

Hydrocarbon Identification



Dust and Rust Weight

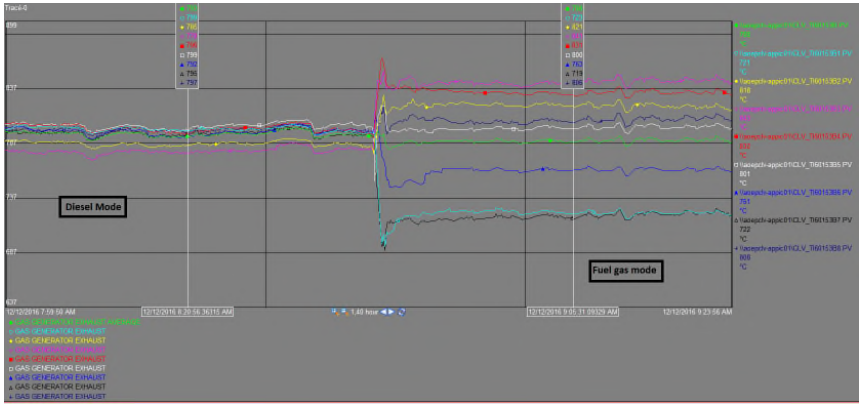


Dust and Rust <=> Organic deposit, Coke, Inorganic Deposit.

Contain n-C35 whereas European Automotive Diesel Oils display up to n-C24 or n-C26

It may represent 60 grams per hour of « Dust and Rust » below 10 micron for a 30 MW engine.

Operational Issues – Case 3: Gas Manifold Contamination



High Spread, around 120°C, after running liquid and changing to gas

HP Turbine

T5

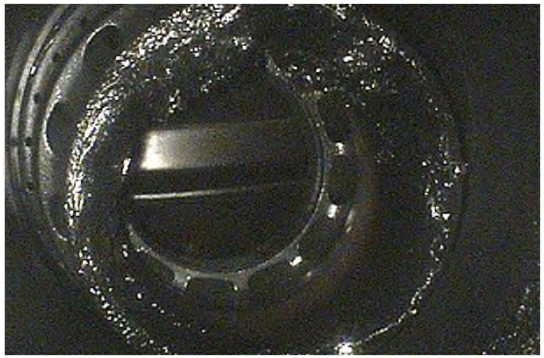
Coking built-up

Combustion Nozzle

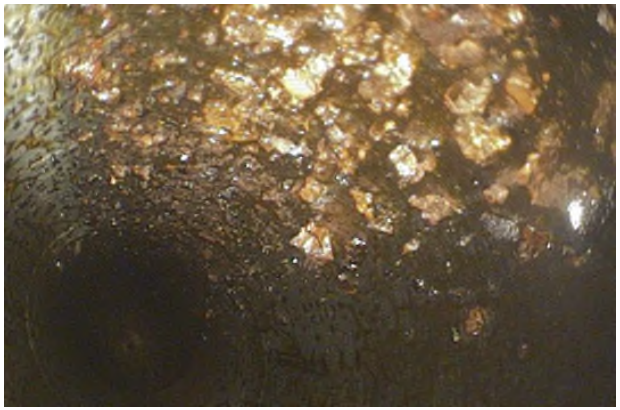
Combustor

Gas Network

Gas Manifold



Contamination in the form of long chain hydrocarbons (varnish) => Drainage of gas manifold is not properly achieved.



Operational Issues – Case 4: Impact of Calcium Stearate

Diesel issued from crude oil rich in naphtenic acids, having cycloaliphatic hydrocarbon arrangement as opposed to aromatic hydrocarbon arrangement.

At the time, OEM specified 40 microns last chance filter but 5 microns was installed.

2.7 ppmw of Calcium Stearate => change to 20 microns and add large filter of 10 microns

Gas turbine stopped after 12 minutes of operation

Guidelines for Fuel Treatment

Storage

Fixed Leg Platform.	Floating Unit (Settling is paramount of importance)			
Limited Issues	Capacity	Drainage	Suction	Vent
	Raw Diesel Tanks around 20 Days Treated Diesel Tanks around 3 Days	Conical Draining Point at the lowest location	Floating suction (not adopted by Shipyard for FPSO)	Equipped with 4-micron Coalescer

4 days settling is necessary in raw tanks (Typical)

Guidelines for Fuel Treatment

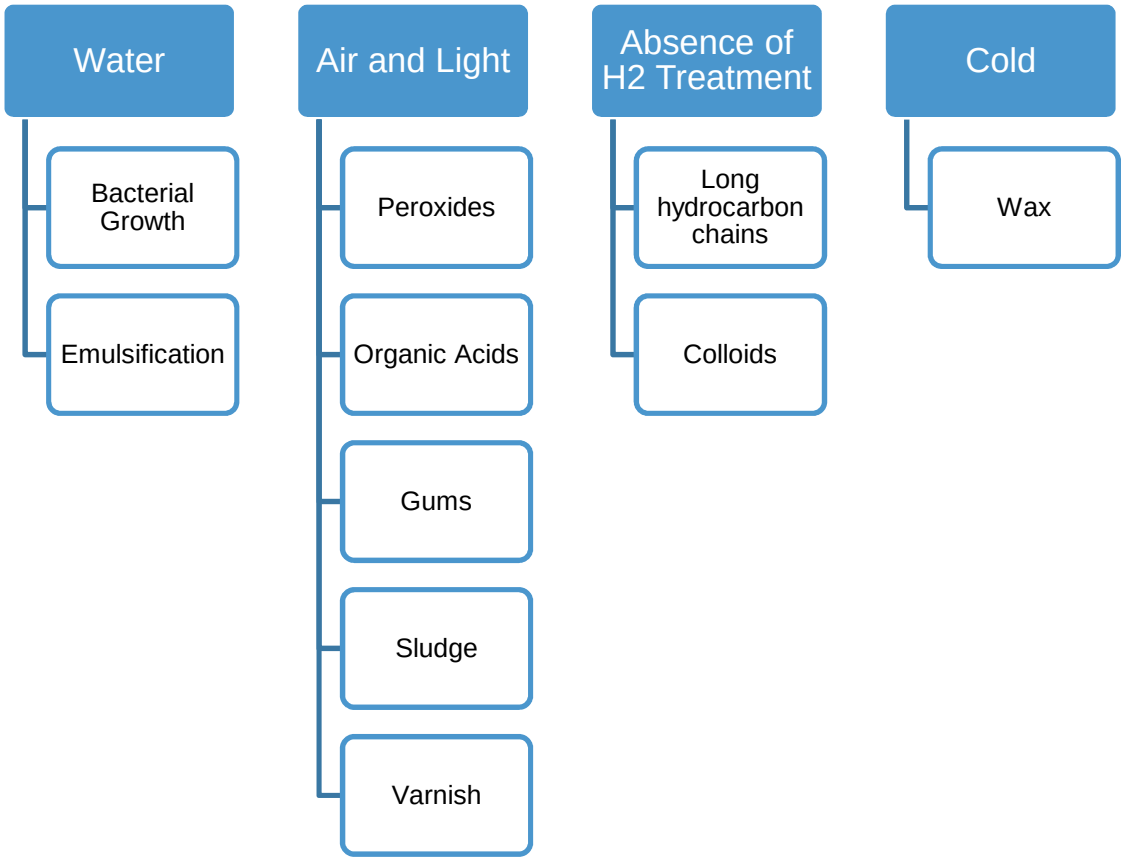
Filtration

« Raw Fuel »	« Treated Fuel »		« Fuel to Turbines »	
Loading Filter	Filter	Centrifugal Separator	Large Fine Filter	Last Chance Filter
100 microns 99% Eff. Beta 100	70 microns 99.5% Eff. Beta 200		10 microns 99.5% Eff. Beta 200	10 microns 90% Eff. Beta 10

OEM asked for 3 to 5 microns

Operational Recommendations

Adverse conditions impact diesel oils, that is a living substance



Operational Recommendations

Ensure supply boats are used to deliver Diesel fuel exclusively in dedicated tanks.

Tank recently loaded shall be kept unused for few days.

Bottom of the tanks shall be drained through a rigorous tank housekeeping.

Samples to be taken at drain locations.

- Appearance.
- Water Content.
- Color against ASTM D1500.
- Density.

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Examples of Metal and Alkali Analysis

Property	Test Method	OEM Specification	At Refinery	At Off-shore Facility
Flash Point	ISO 2719	<93° c	84° C	85° C
Water	ISO 6296	<0,1 % Vol	54 ppm	46 ppm
Calcium	ISO 11885	<2 ppm	0,49 ppm	0,38 ppm
Copper	ISO 11885		<0,01 ppm	0,01 ppm
Potassium	ISO 11885	<0,2 ppm	0,09 ppm	0,12 ppm
Lithium	ISO 11885	<0,2 ppm	<0,03 ppm	<0,03 ppm
Sodium	ISO 11885	<0,2 ppm	0,26 ppm	0,14 ppm
Lead	ISO 11885	<1,0 ppm	<0,01 ppm	0,015 ppm
Vanadium	ISO 11885	<0,5 ppm	<0,01 ppm	<0,01 ppm
Total Sulphur	ISO 8754	<1 % pds	0,15 % pds	0,18 % pds
Residue at 500° C		<0,01 % pds	<0,01 % pds	<0,01 % pds

All values are within OEM specifications.