Technical Session 3 – Sulphur Cap

What are problems of compliant fuels from 2020 ?

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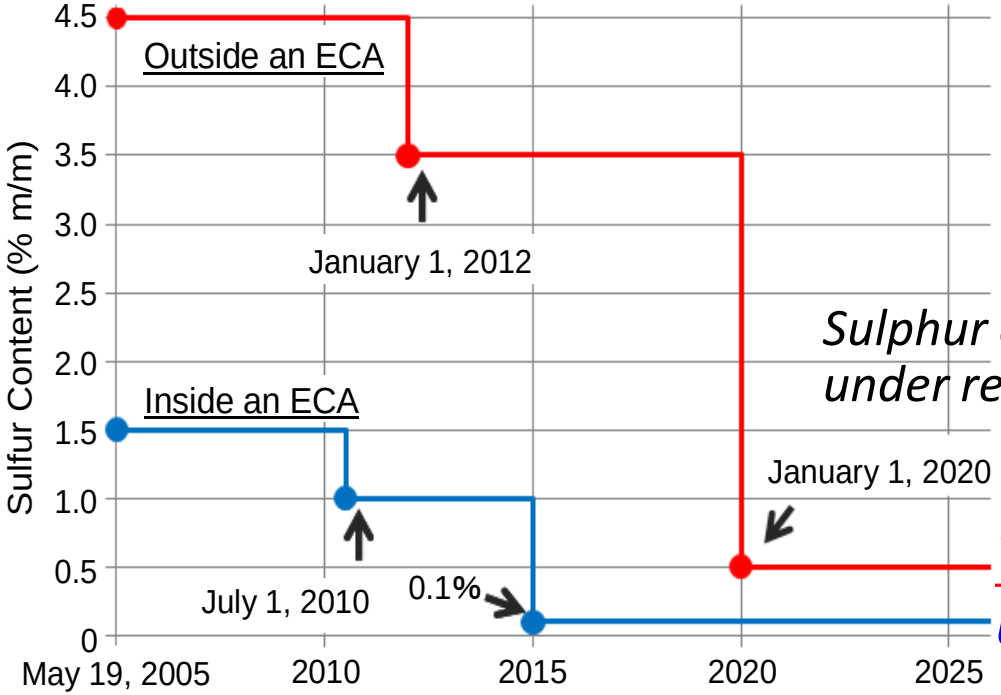
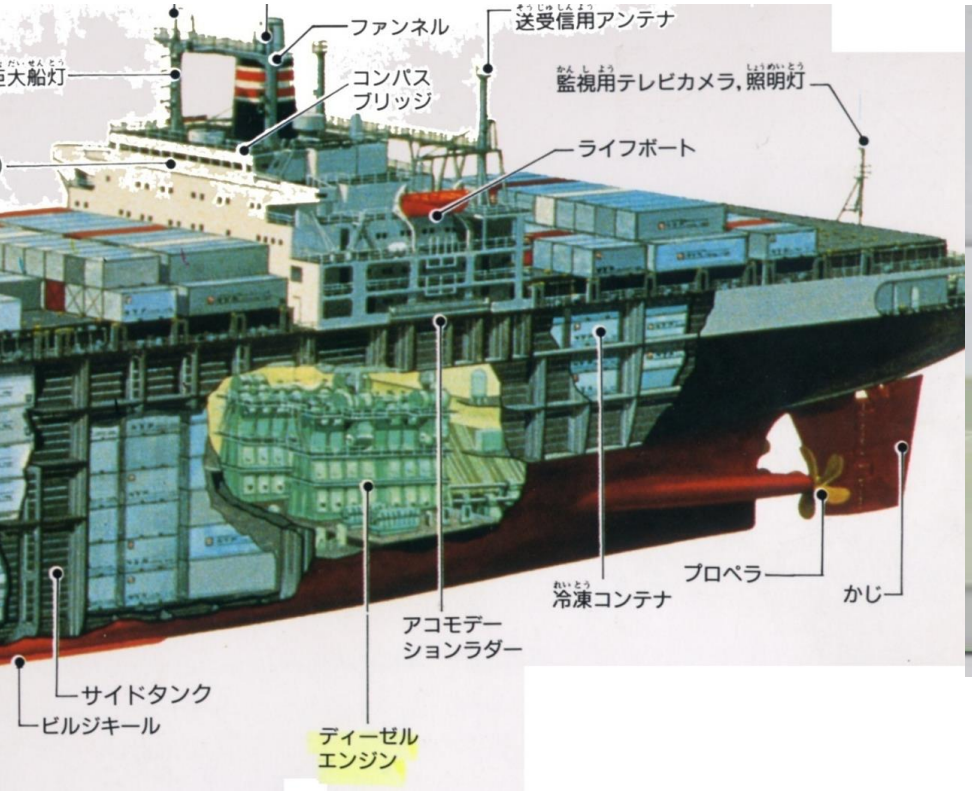


Sulphur content limits prescribed under revised Annex VI

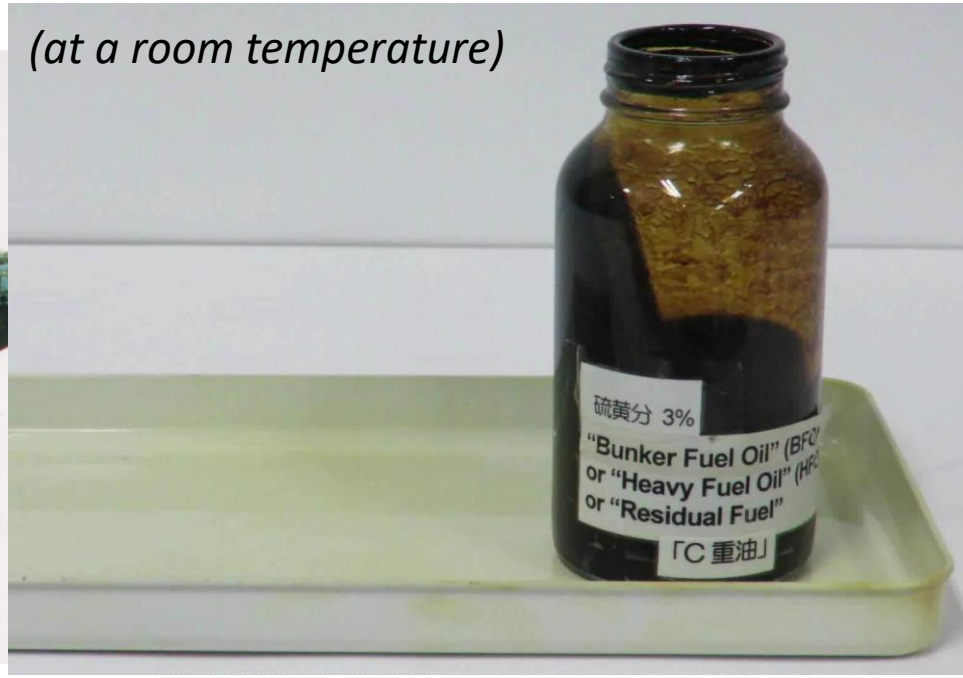
***V**ery Low Sulfur Fuel Oil (**V**LSFO)*

***U**ltra Low Sulfur Fuel Oil (**U**LSFO)*

The presenter has been dealing with marine engines and marine fuels last 40 years. His first job at a shipyard and engine works was concerning the conversion of main engine for a container ship from steam turbine to diesel.
There was such a change of main engines for container ships and VLCCs 40 years ago. However, fuel was not changed. The same Heavy Fuel Oil (HFO) has been used.



Container ship 'Kasuga-maru' after the main engine conversion from steam turbine to diesel (1979)



Conventional Residual Fuel Oil, HFO (Heavy Fuel Oil)
Containing much residue from oil refinery and 3.5% Sulfur at maximum.

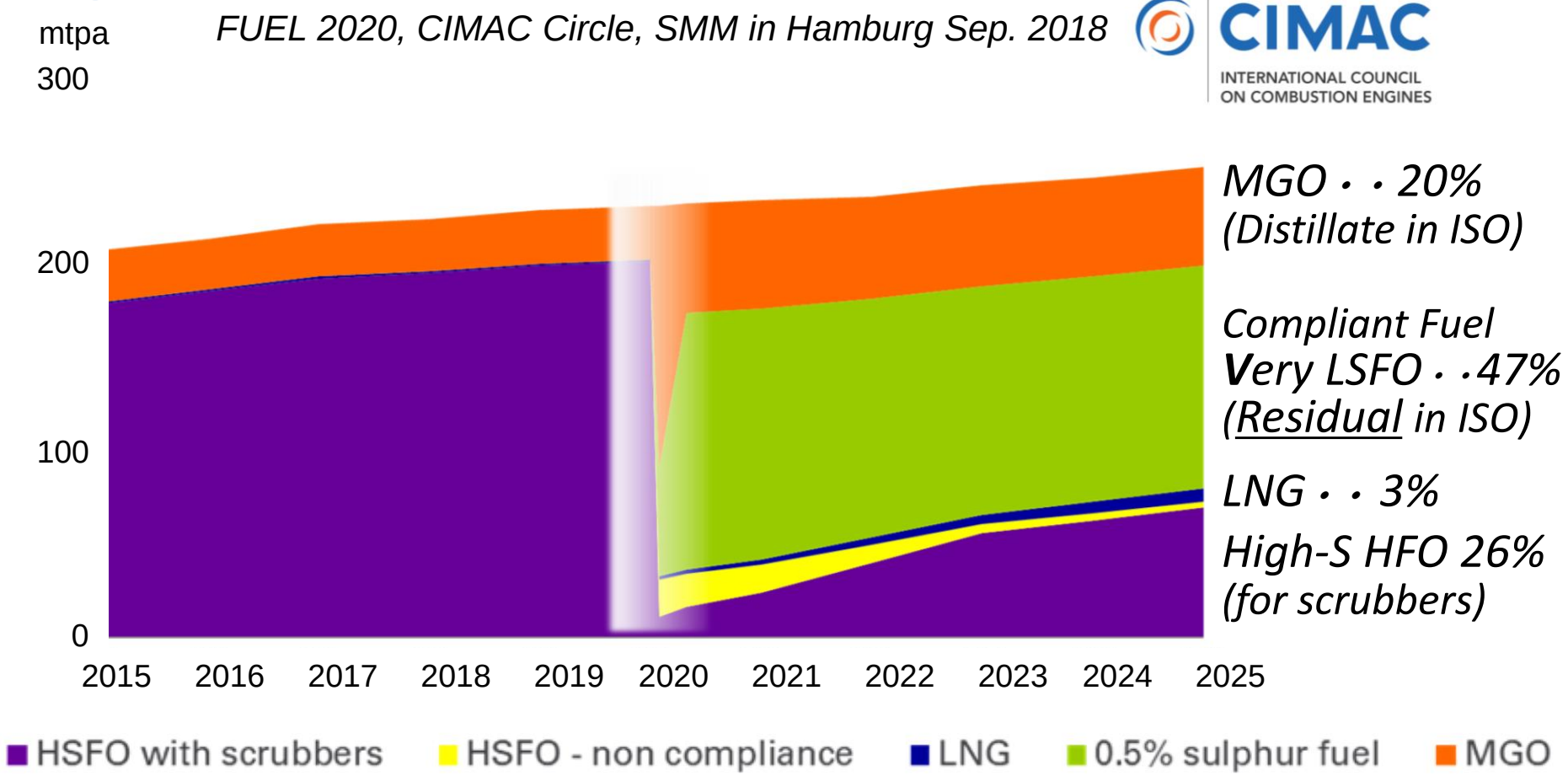
*Compliant **V**LSFO from 2020* • • *Sulfur < 0.5%* • •

*Compliant fuels (named as **V**ery Low Sulfur Fuel Oil) would have lower viscosity and lower density than the conventional HFO, However, they are still in the category of Residual fuel oil.* • • *What would be problems?*

BP prediction of fuel in the future

FUEL 2020, CIMAC Circle, SMM in Hamburg Sep. 2018

CIMAC INTERNATIONAL COUNCIL ON COMBUSTION ENGINES

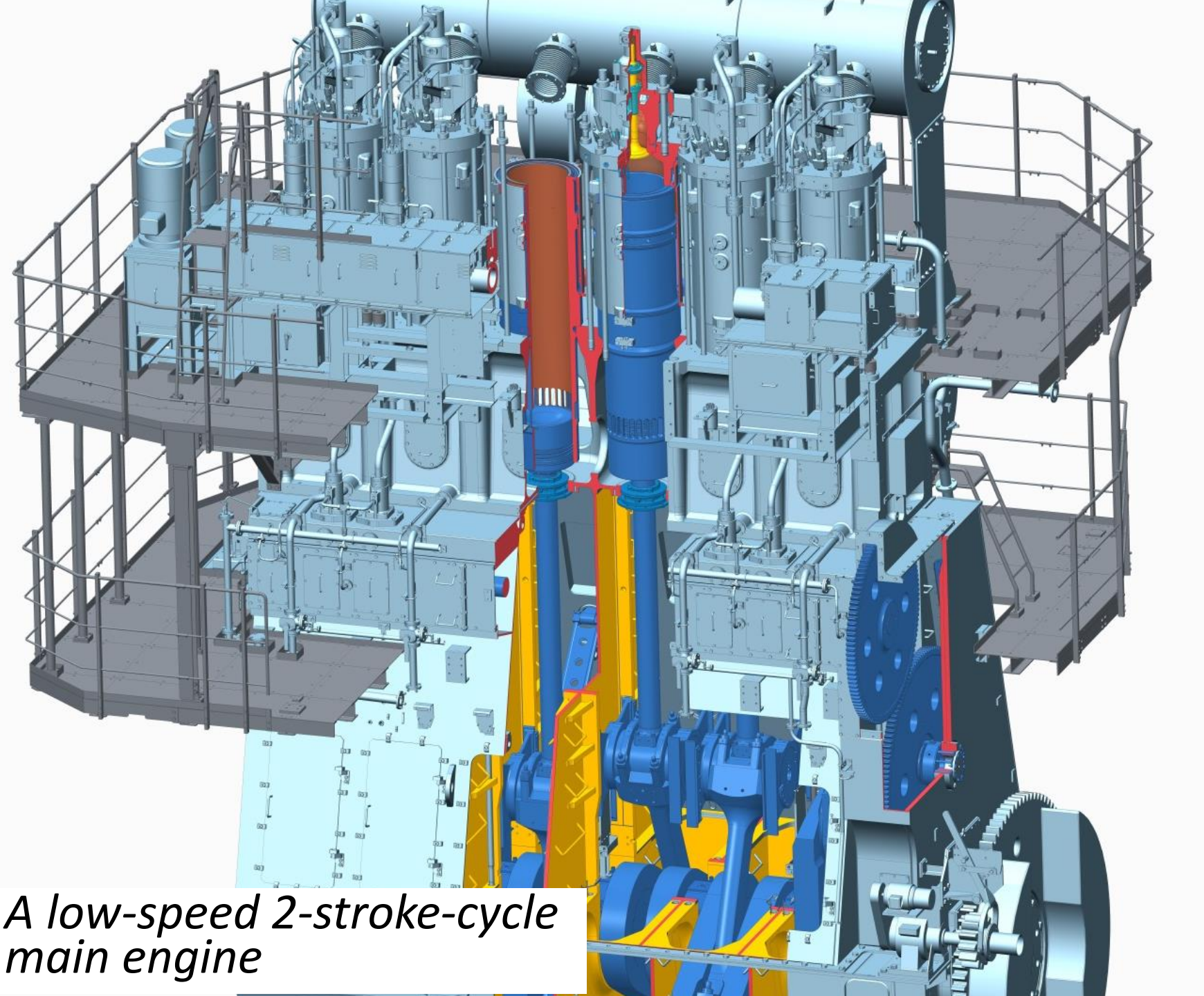


MGO • • 20%
(Distillate in ISO)

Compliant Fuel
***V**ery LSFO • •47%*
(Residual in ISO)

LNG • • 3%

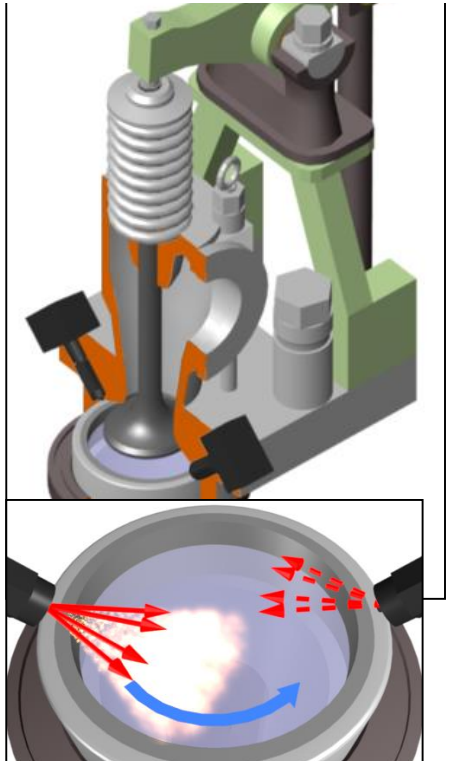
High-S HFO 26%
(for scrubbers)



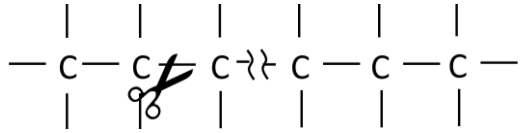
A low-speed 2-stroke-cycle main engine

How fuel sprays burn in a marine engine?

Visual Test Engine
Bore /Stroke :
190 mm /350 mm
Two-stroke, Super-charged,
Engine speed ：500 rpm

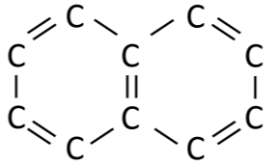


High-Paraffinic fuel
*(represented by **G**as **O**il)*



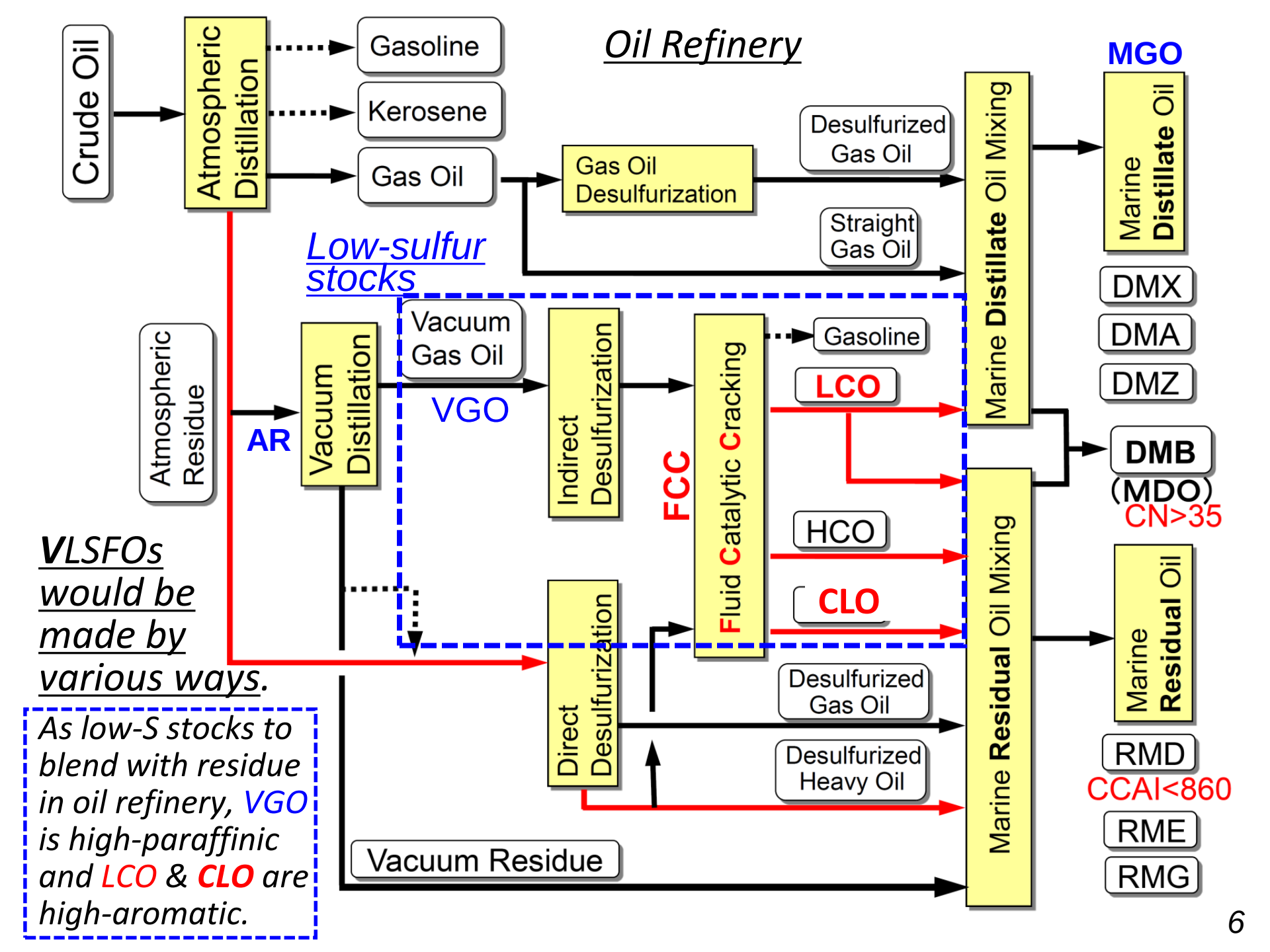
Molecule is easy to be cut

High-Aromatic fuel
*(represented by **LCO**)*



Molecule is rigid

Paraffinic portion ignites and burns well in engine. *However* • •


Oil Refinery
Crude Oil
Atmospheric Distillation
Gasoline
Kerosene
Gas Oil
Gas Oil Desulfurization
Desulfurized Gas Oil
Straight Gas Oil
Marine Distillate Oil Mixing
MGO
Marine Distillate Oil
DMX
DMA
DMZ
DMB
(MDO)
CN>35
Low-sulfur stocks
Atmospheric Residue
AR
Vacuum Distillation
Vacuum Gas Oil
VGO
Indirect Desulfurization
FCC
Fluid Catalytic Cracking
Gasoline
LCO
HCO
CLO
Direct Desulfurization
Desulfurized Gas Oil
Desulfurized Heavy Oil
Vacuum Residue
Marine Residual Oil Mixing
Marine Residual Oil
RMD
CCAI<860
RME
RMG
VLSFOs would be made by various ways.
As low-S stocks to blend with residue in oil refinery, VGO is high-paraffinic and LCO & CLO are high-aromatic.

Very Low Sulfur Fuel Oil：**V**LSFO（distinguished from **U**ltra LSFO (0.1% S) for ECA）

- Action of ISO & CIMAC WG *As VLSFOs would be made by various ways*

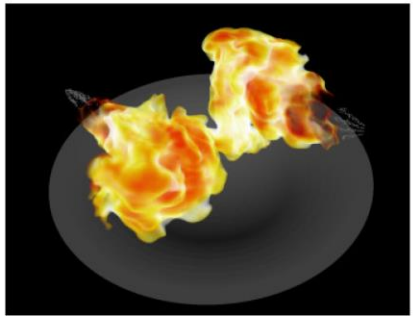
2020: Fuel and lube test plan

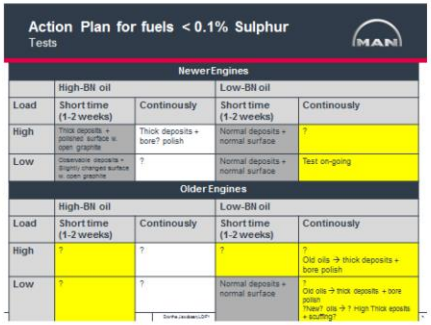
In order to prepare for the new types of 0.50%S fuels, test engine, service tests and lab tests will be carried out.

This will be done in collaboration with lube oil suppliers, fuel oil suppliers, ISO 8217 WG, CIMAC WG Fuels, ship owners and other relevant partners.

Potential challenges:

- Fuel:
  - a. Technical:
    - i. Stability
    - ii. Compatibility) before engine
    - iii. Ignition – knocking
    - iv. Burn out – deposits) in engine
  - b. Commercial:
    - i. ISO 8217 -> ISO/PAS or CIMAC
- Lube:
  - a. Deposit : detergency of Lub. Oil is important.
  - b. Corrosion – how much?
  - c. Smearing




Action Plan for fuels < 0.1% Sulphur
Tests

Newer Engines				
	High-BN oil		Low-BN oil	
Load	Short time (1-2 weeks)	Continously	Short time (1-2 weeks)	Continously
High	Thick deposits + polished surface w. open graphite	Thick deposits + bore? polish	Normal deposits + normal surface	?
Low	Observable deposits + slightly changed surface w. open graphite	?	Normal deposits + normal surface	Test on-going

Older Engines				
	High-BN oil		Low-BN oil	
Load	Short time (1-2 weeks)	Continously	Short time (1-2 weeks)	Continously
High	?	?	?	? Old oils → thick deposits + bore polish
Low	?	?	Normal deposits + normal surface	? Old oils → thick deposits + bore polish These? oils → ? High Thick epoxis + stuffing?

＋ *Cat-fine problem*

Feedback from market?

ISO/PAS 23263:2019
Specific considerations for 0,50% S marine fuels

Addresses considerations that may apply to **particular 0,50 mass % S fuels**

Included in ISO 8217

- Kinematic viscosity
- Cold flow properties: Cloud point, CFPP, PP
- Stability: total sediment aged of 0,10 % m/m max.
- CCAI
- Catalyst fines

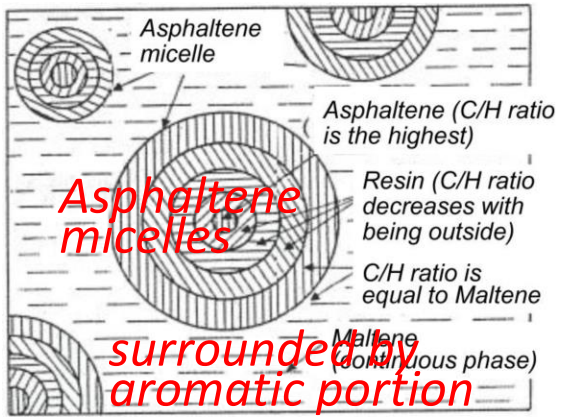
Concern on potential incompatibility of fuels:

- Suppliers can not guarantee compatibility without testing
- CONCAWE sponsored ISO/TC 28/SC 4/WG6 study to evaluate testing methodologies to obtain indication of degree of compatibility between marine fuels without having to mix the fuels

*(At this moment, it is announced that much high-paraffinic **V**LSFOs would be supplied by oil-majors side.)*

quoted from Symposium on IMO 2020 and Alternative Fuels on 17.and 18. Oct. 2019

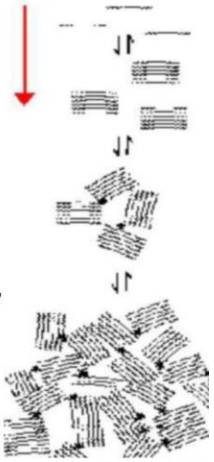
- *Stability, Compatibility and Cold flow property are related to troubles 'in tank' or 'before engine'.*
- *There is a contradiction between 'before engine' and 'in engine'.*
- *Paraffin-rich fuels have tendency to cause stability problems (Asphaltene sludge or wax formation).*
- *Aroma-rich VLSFOs are rather stable and convenient to avoid such troubles.*



Schematic (microscopic) structure of asphaltene micelle (stable)

Compatibility

VLSFO, residual fuel contains asphaltene, normally stable as a colloid state by the function of surrounding resin and aromatics. (figure left)



If that state becomes unstable, for example, by mixing a paraffin-rich fuel, asphaltene agglomerates and forms sludge. (figures right)

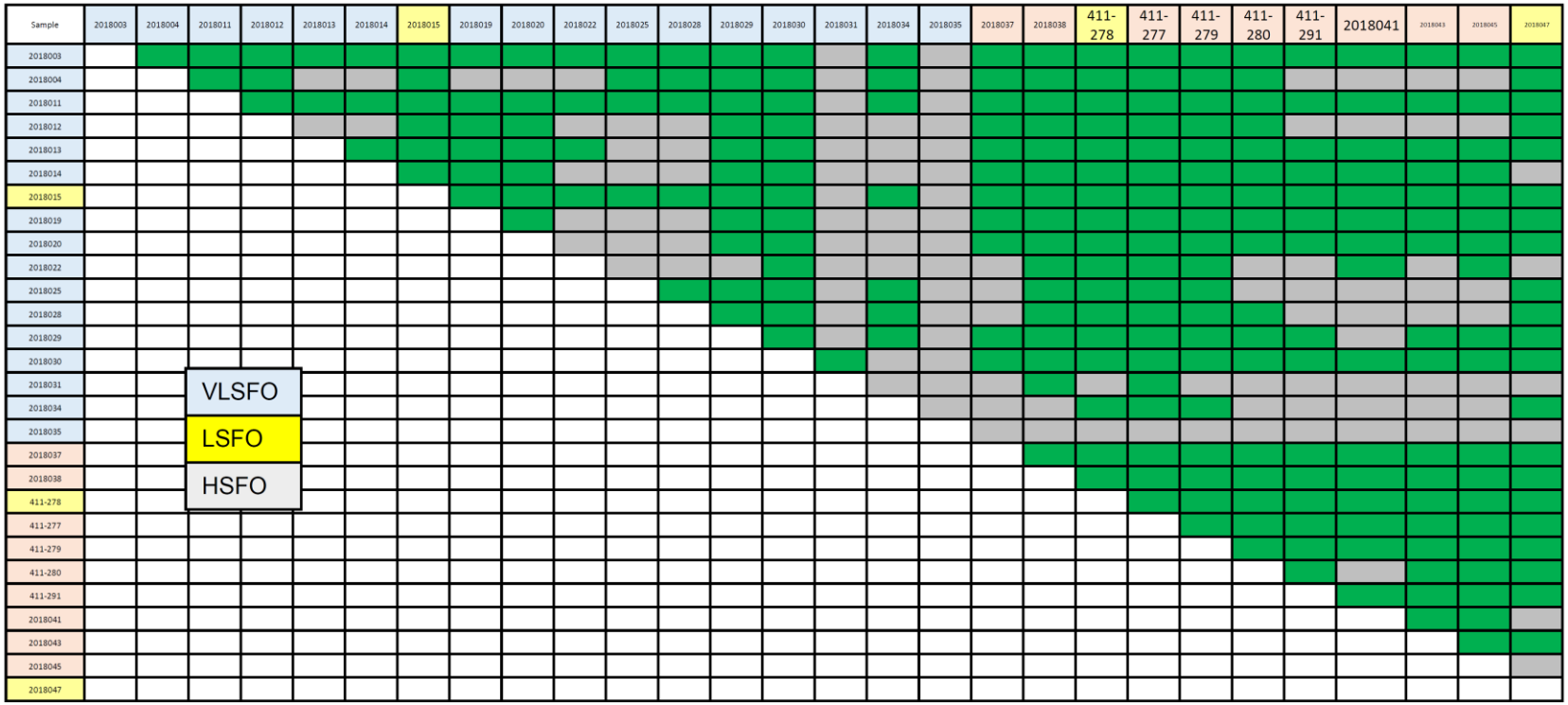
Asphaltene micelles are stable when surrounded by aromatic portion. If aromatic is reduced by mixing with high-paraffinic fuel, it is possible that agglomeration of asphaltene would start and form 'asphaltene sludge'. It is called as 'incompatible'.

ISO/CONCAWE study

Example compatibility prediction model:

- Green shaded cells: compatible over the entire 0-100 % commingling range
- Grey shaded cells: compatible at specific commingling ratio

(= Incompatible at some mixing ratio)



quoted from Symposium on IMO 2020 and Alternative Fuels on 17.and 18. Oct. 2019

ISO/CONCAWE study
Conclusion

- Prediction methodologies predict 65-69% of all possible fuel combinations to give stable blends whatever the mixing ratio is
  - ±50% of the possible fuel combinations that are predicted to be always stable whatever the mixing ratio is, are common for all 3 test methods
- Prediction methodology can only be applied to fuels that have been tested with the same test method
- Recommendation to use TSP (Potential Total Sediment) to guarantee total sediment aged of a fuel meets specification of 0,10 % mass max.

(Actually, 'only 65-69% of combination of VLSFOs are fully compatible' is surprisingly low rate.)

quoted from Symposium on IMO 2020 and Alternative Fuels on 17.and 18. Oct. 2019

• *Compatibility is not referred to in ISO.*

To avoid the sludge formation by low compatibility, multi-tank system for two fuels not to mix is recommended (figure right). (Actually, absolutely no mixing is difficult.)

MAN • • CIMAC 2019, Paper No.374.

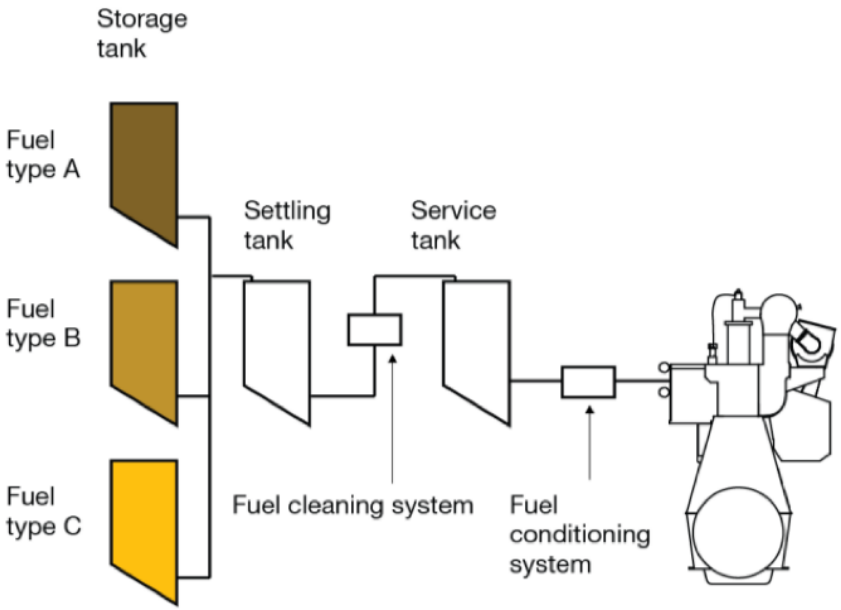


Figure 24. Schematic: Simple fuel system. Attention has to be paid to the fuel handling when changing fuels, because of the commingling in tanks. The settling and service tanks must be emptied before new fuel is added.

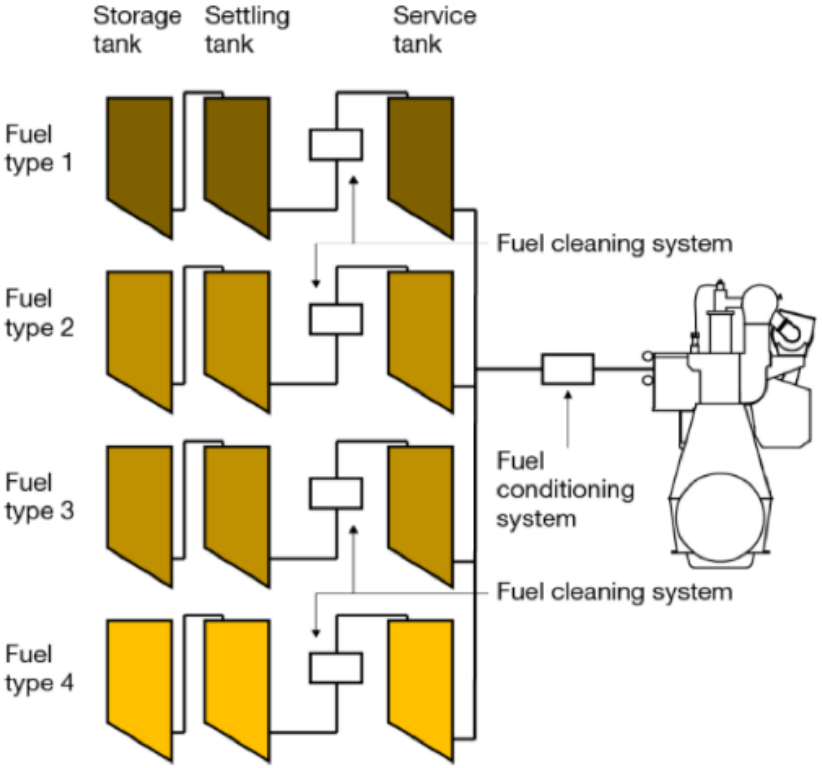


Figure 23. Schematic: Flexible fuel system. This system makes it easier to handle and change between different fuel types that might be incompatible.

Guidance for onboard use of Compliant Fuel with SOx regulation from 2020 *was issued by ClassNK in March 2019, the following five properties are considered when using compliant fuel.*

March 2019

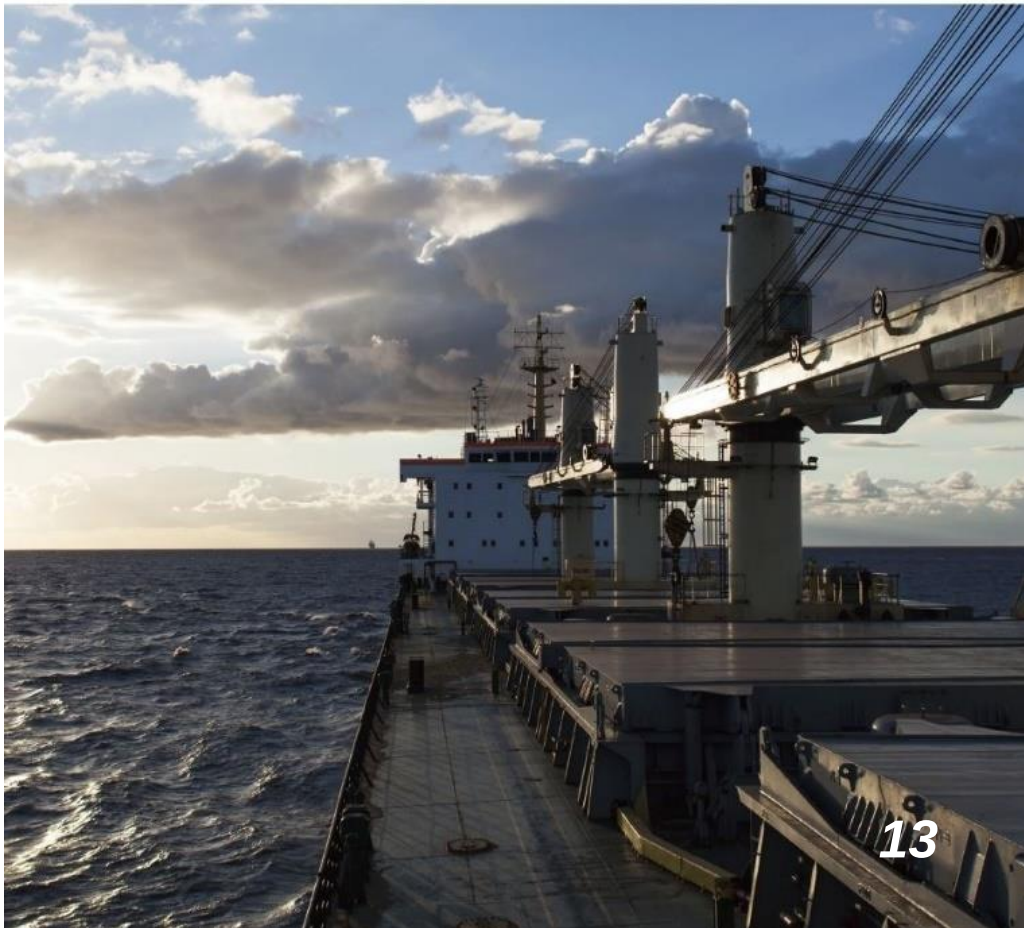
ClassNK

Guidance for onboard use of Compliant Fuel Oil with SOx regulation from 2020

[English]

- *Compatibility*
- *Low viscosity*
- *Cold flow properties*
- *Cat-fines (content of Al and Si)*
- *Ignition and combustion quality*

At first, 'compatibility' and 'cold flow properties' are explained in this presentation.

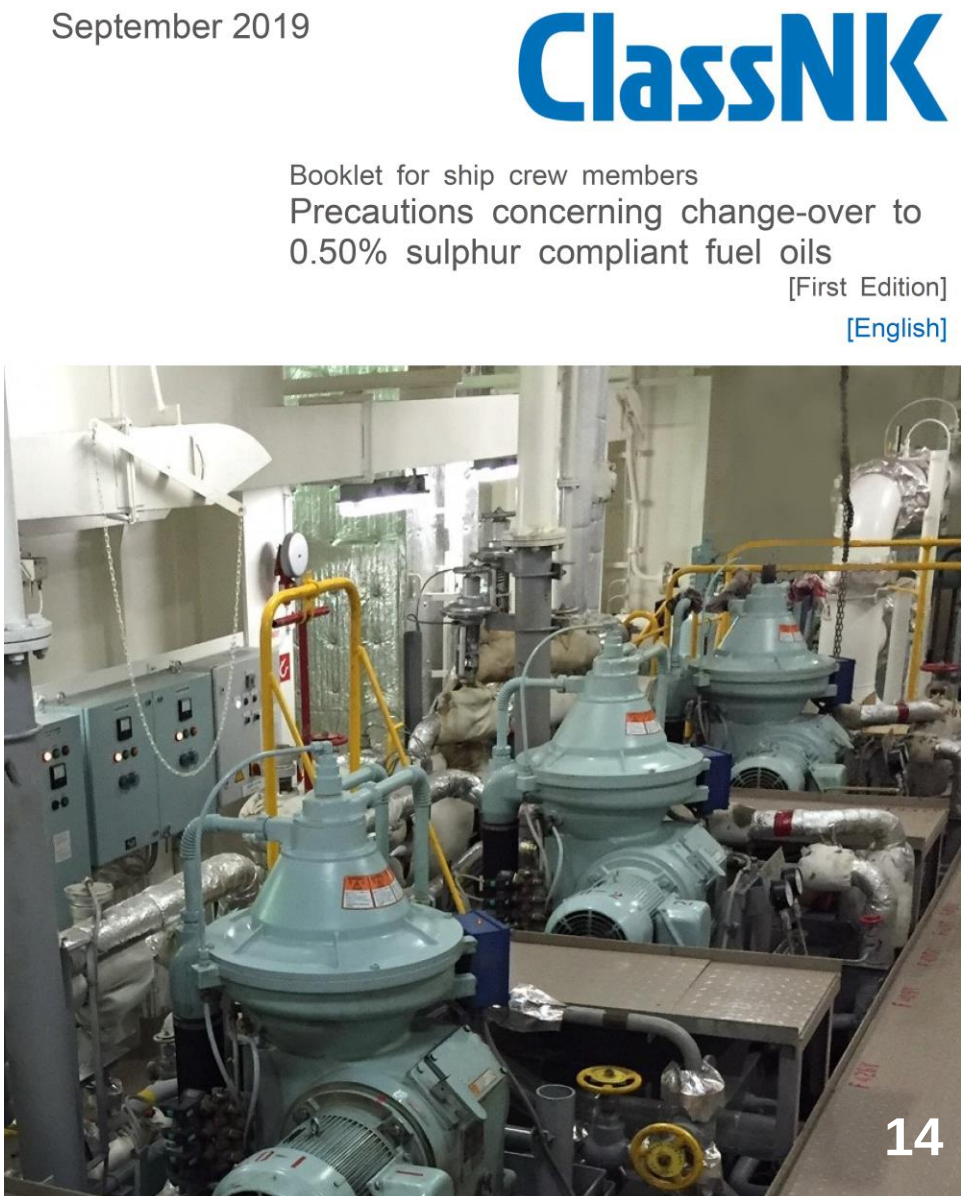


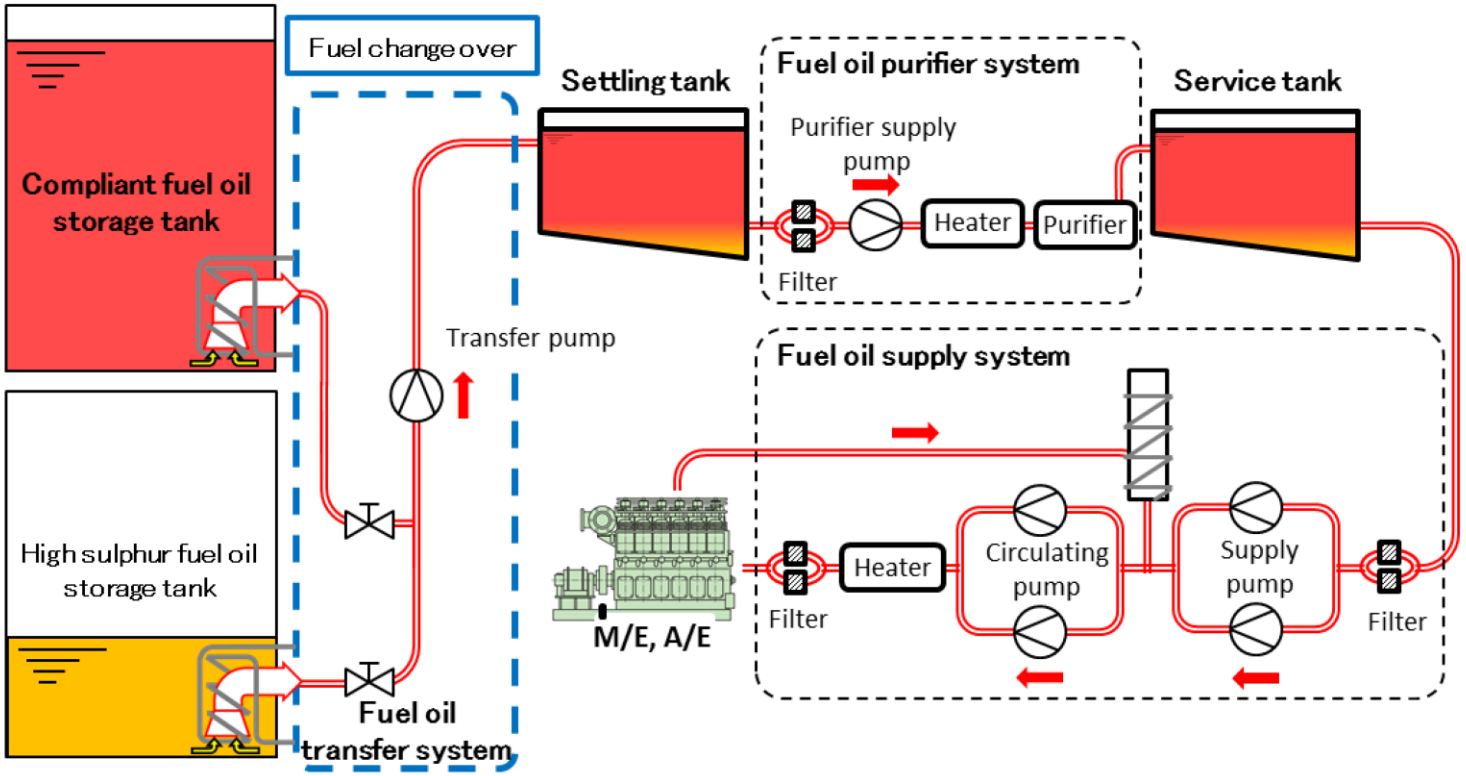
Booklet for ship crew members - Precautions concerning change-over to 0.50% sulfur compliant fuel oils (First Edition) was published by ClassNK in Sept..

'Change-over' means the first change of fuel from high-sulfur HFO to VLSFO. (must be carried out by the end of this year.)

In this booklet, many practical cautions such as
'Do not carry out the changing over while the ship is operating in congested sea area or narrow water channels' are announced.

In critical case that a high-paraffinic VLSFO is mixed to a high-sulfur HFO that contains much asphaltene, it is possible that asphaltene in the HFO would form the sludge.
(= incompatible case)





Fuel oil piping diagram (quoted from the Booklet for ship crew members – Precautions concerning change-over to 0.50% sulfur compliant fuel oils, Sept. 2019, ClassNK)

・Sludge formation must be prevented at changing over not only in fuel oil storage tanks but also in fuel oil pipelines.

・If mixing within storage tanks cannot be avoided, to check compatibility by spot test (figure right) whenever possible at bunker time is recommended.

No.1 No.2 No.3 No.4 No.5

Low compatibility

Source: Guide for use of 2020 SOx regulation compliant fuel oils (Maritime Bureau of the Ministry of Land, Infrastructure, Transport and Tourism of Japan)

Cold flow properties

In case where compliant fuel oils are high-paraffinic, their pour point becomes higher and wax may therefore form in cold climate, if storage tanks are not provided with heating equipment.

Wax formation is not associated with asphaltene. Wax is different from asphaltene sludge, and is also referred as 'wax sludge'.

Heating the fuel oil at least 10℃ above the PP : pour point is recommended.
(The upper limit of PP for residual fuel oil is 30℃ in ISO.)

Filter blocked due to wax deposit
Source: 01|2015 CIMAC Guideline

Wax collected in a metal scoop
Source: Guide for use of 2020 SOx regulation compliant fuel oils (Maritime Bureau of the Ministry of Land, Infrastructure, Transport and Tourism of Japan)

▪(too) Low viscosity

Some VLSFOs with surprisingly low viscosity like lower than 20 cSt. (at 50 ℃) could appear. To keep an adequate viscosity for injection system lubrication, sometimes both the fuel cooler and heater should be used.
(CIMAC 2019 Paper, No. 374, MAN)

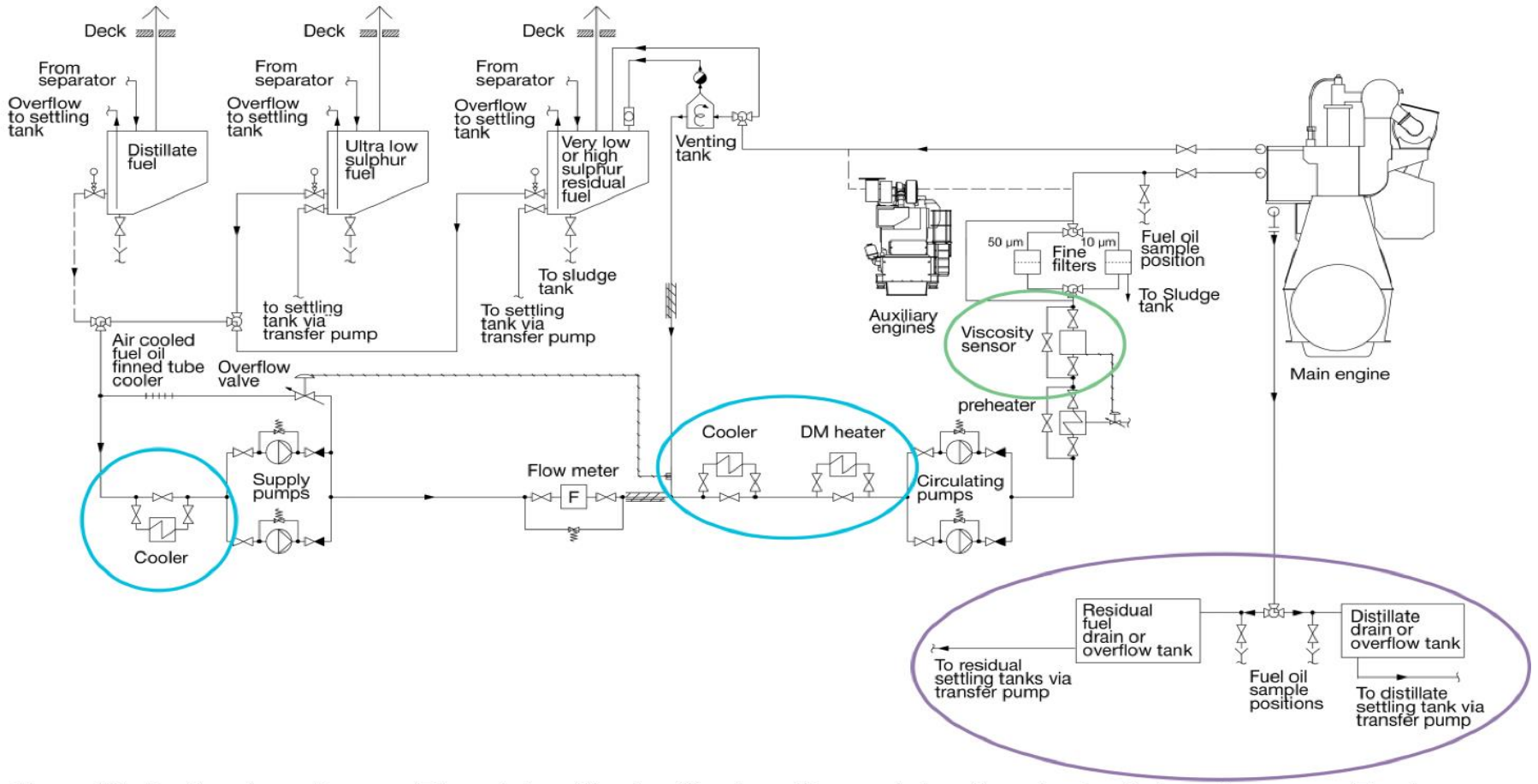


Figure 25. Fuel system diagram. Blue circles: Heaters/Coolers. Green circle: viscosimeter / viscosity sensor. Purple circle: fuel pump drain overflow tanks.

Cat-fines (content of Al and Si)

'FCC cat-fines', Al and Si particles (5-25 micron dia.) remaining in the fuel is a cause for the tribological problems. To make matters worse, damage like abnormal wear by cat-fines spreads from fuel injection pump to piston ring, cylinder liner and other engine parts.

*From 2020, it is possible that a low-sulfur stock in oil refinery named **CLO**: Clarified Oil would be mixed more to **V**LSFO. As **CLO**, originally named 'FCC slurry oil' may sometimes contain much cat-fines, it is possible that the **V**LSFO with more cat-fines than now would appear in the market.*

(Figure below) A data from MAN that low Sulphur HFO contains more cat-fines. (Upper limit of cat-fines is 60 ppm inISO8217/2015.)

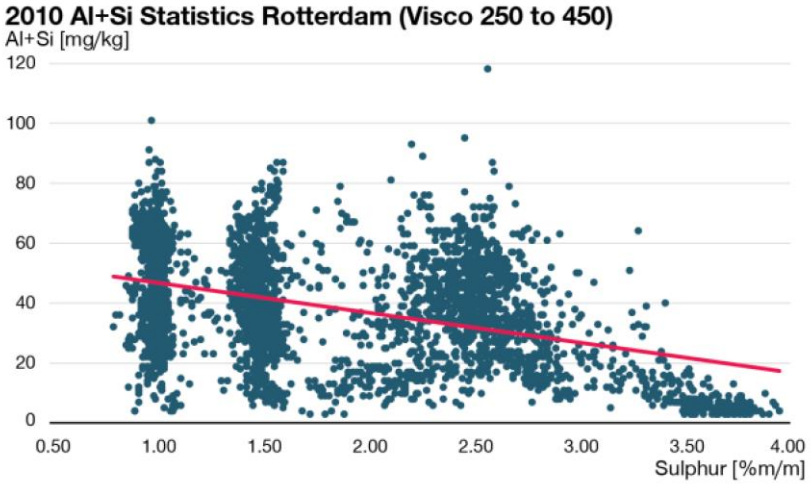
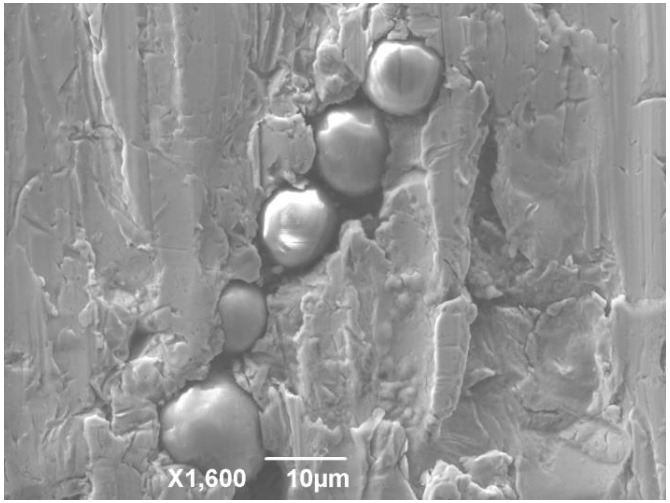
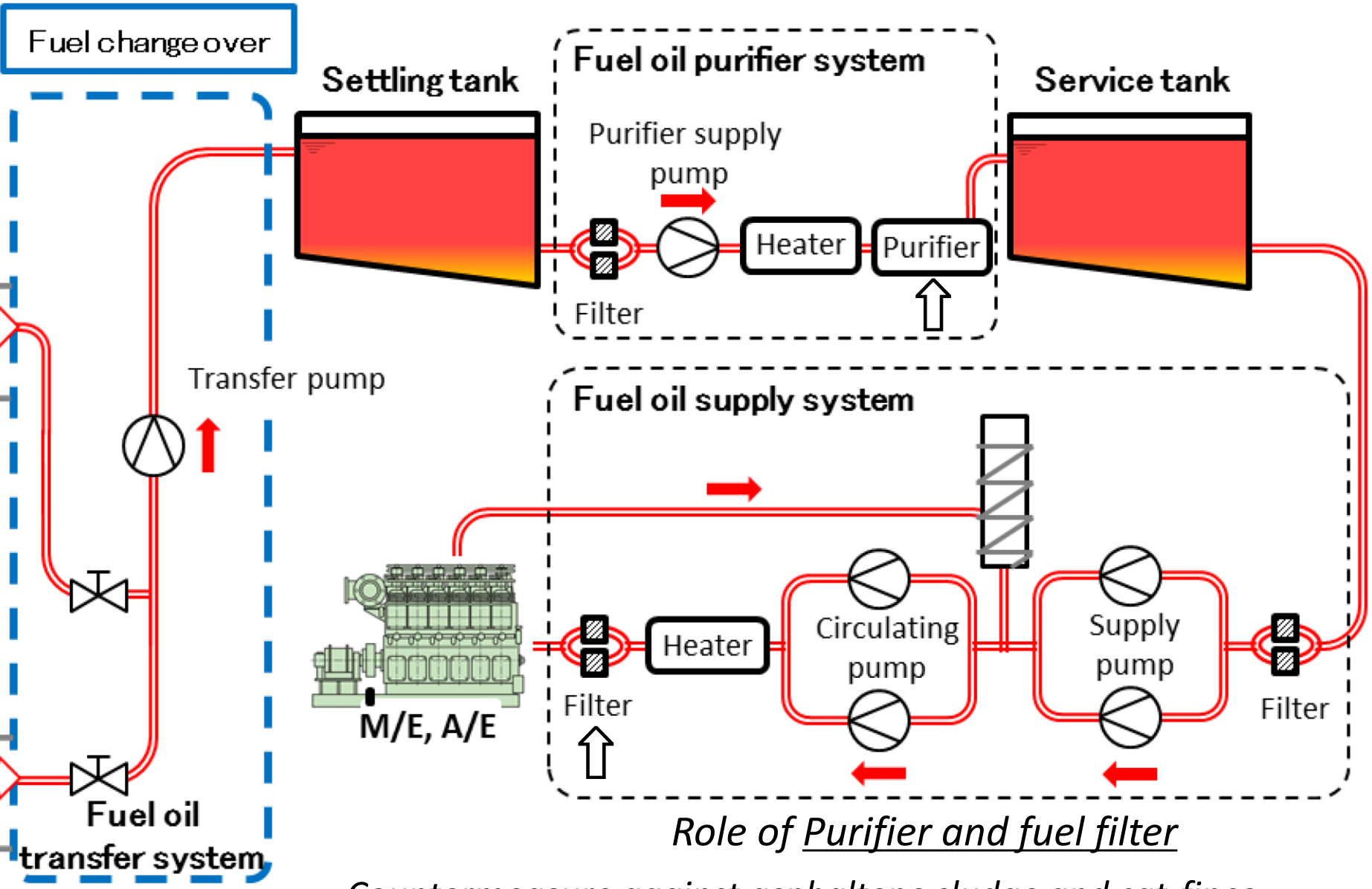


Figure 11. Cat fines content in relation to sulphur content in the fuel as bunkered. The data is from 2010 shows both SECA limits of max. 1.50% S and 1.00% S. Data from Rotterdam, visc: 250-450 cSt. Data courtesy: VPS, evaluation: MAN ES



Cat-fines embedded in the piston ring (Microscopic photo)



Role of Purifier and fuel filter

Countermeasure against asphaltene sludge and cat-fines:

- *Use of fine mesh filter*
- *Strengthen separation efficiency of purifier*

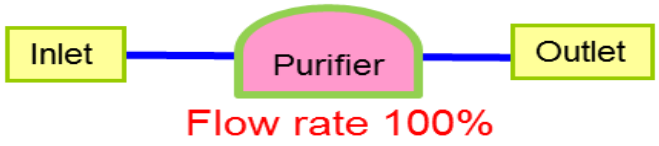
An example of safer operation of purifier ・・'Parallel operation'

If fuel oil presumed to include excess sludge or fuel oil with contamination by cat-fine is to be treated, a safer operation method would be to use a standby purifier so that purifying effect may be further enhanced.

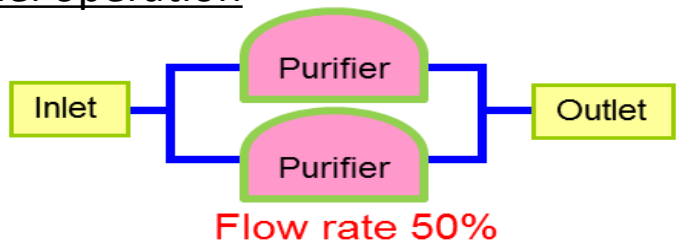
If two or more purifiers are operated, parallel operation is recommended which gives more satisfactory separation effect than series operation. Figure shows an example of systems for series and parallel operations and an example of the separation performance.

In the case of parallel operation, the fuel oil flow rate per one purifier reduces to half and separation efficiency becomes higher (point B) than the case of series operation (point C).

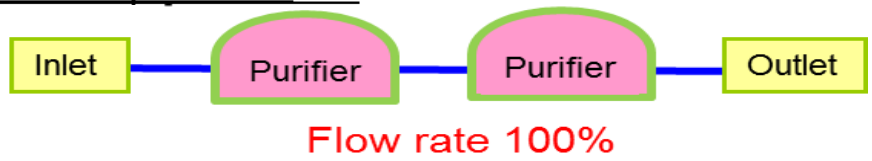
A. Single operation

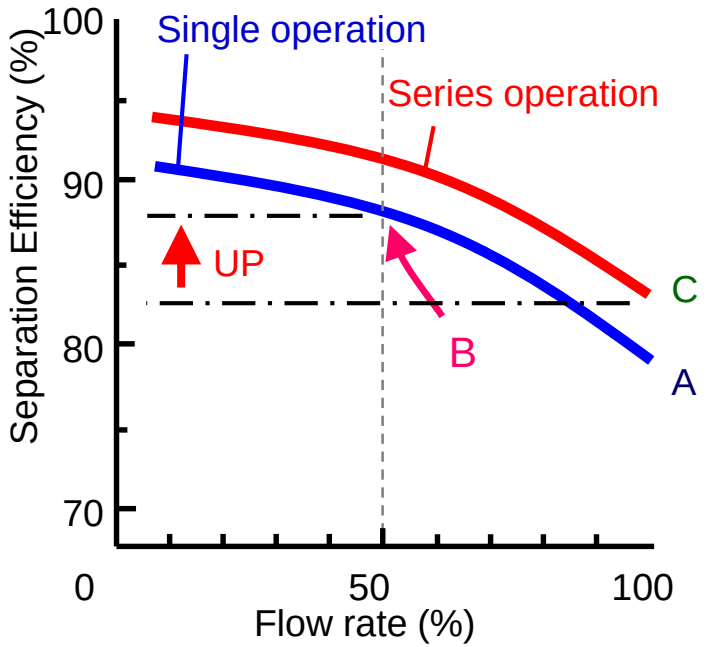


B. Parallel operation



C. Series operation





(quoted from 'Guidance for measures to cope with degraded marine heavy fuels, ver. Ⅱ, 2008, ClassNK)

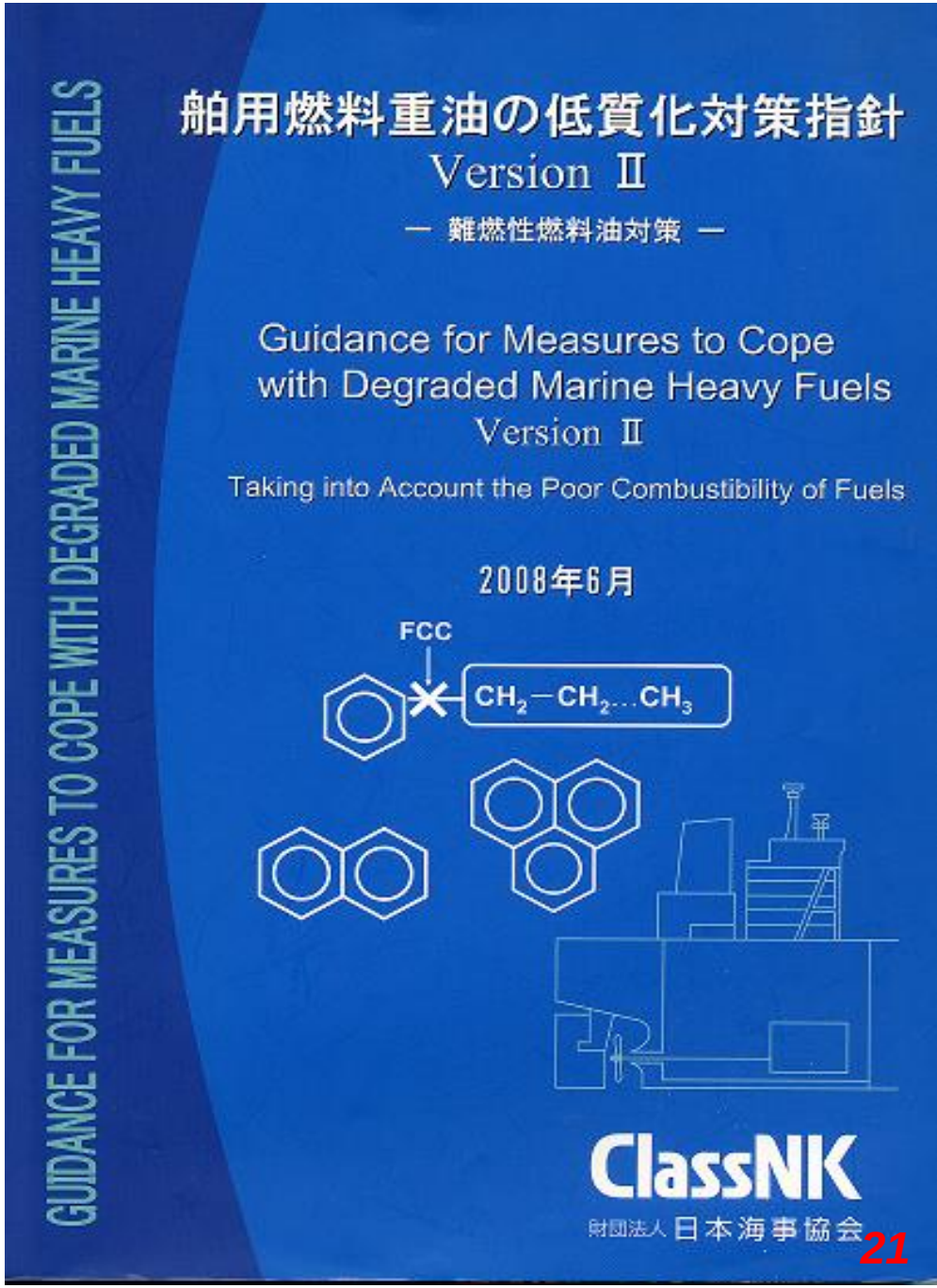
Ignition and combustion quality

*As **V**LSFOs will be made by various ways, it is also possible that **V**LSFOs from some area (for example, North America) would become high-aromatic.*

Too high-aromatic fuels show poor ignition and combustion quality.

In 2008, ClassNK published 'Guidance for measures to cope with degraded marine heavy fuels' (figure right).

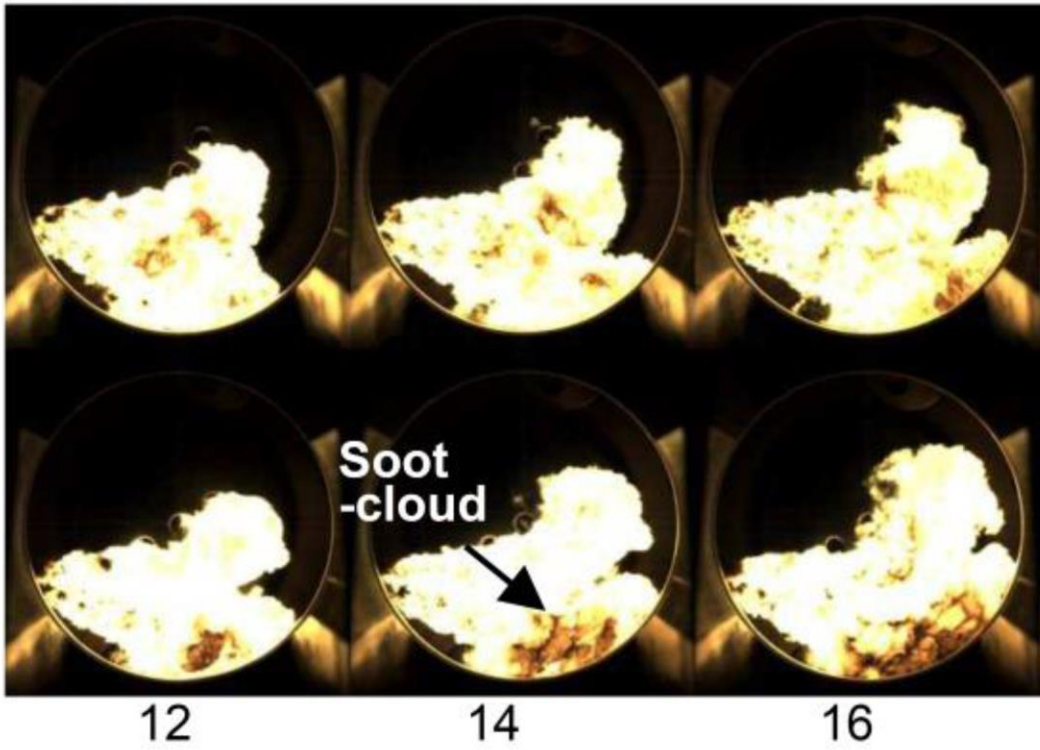
At that time, main issue was engine lubrication troubles between piston and cylinder caused by poor combustion.



Key Word ： Deposit
(formed by unburned fuel portion like soot + lubricating oil)

Fuel

Middle East HFO



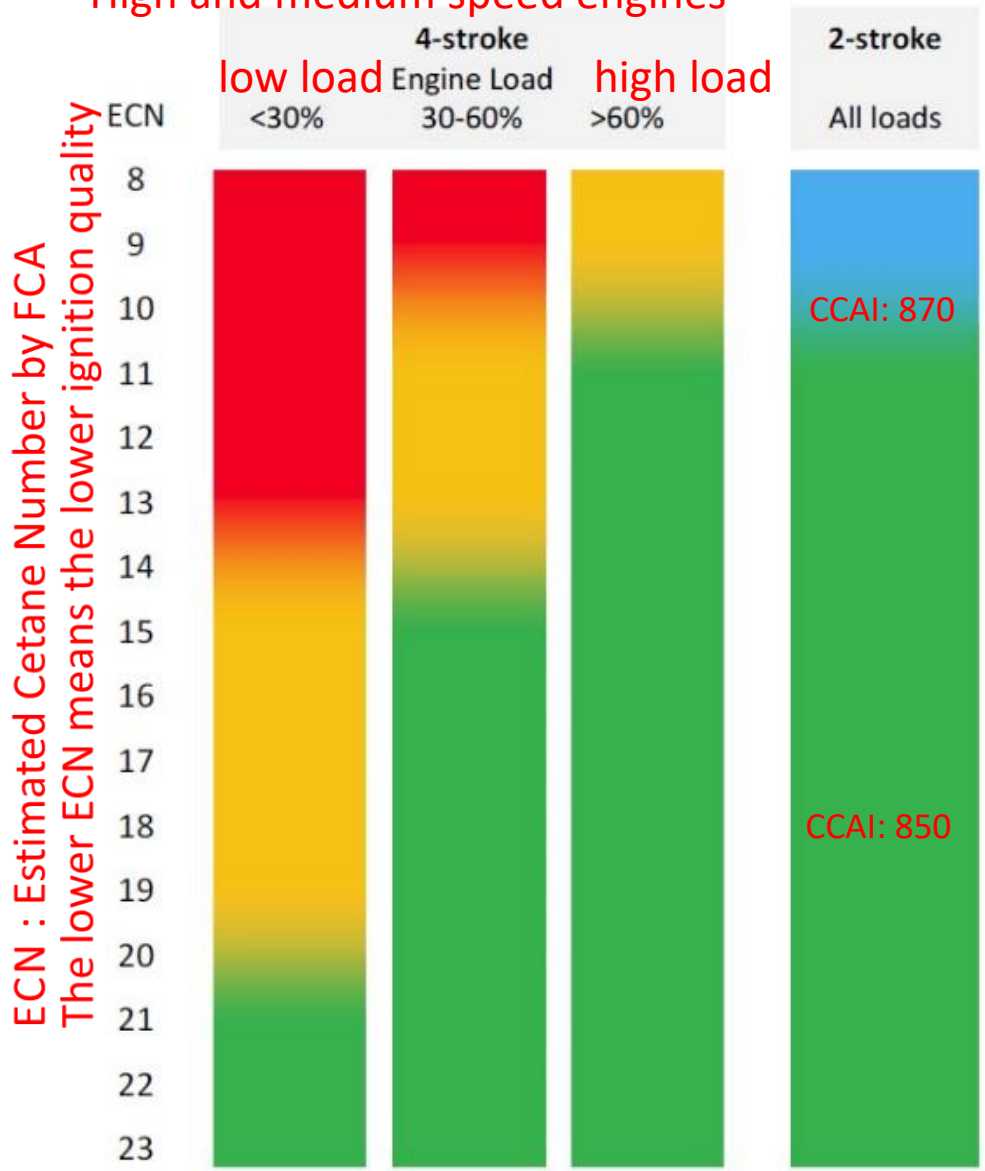
Crank angle deg.ATDC

Visual Test Engine ：
Bore /Stroke :
190 mm /350 mm
Two-stroke, Super-charged,
Engine speed ：500 rpm

CLO
(High-aroma)

- Recent engine modification (cylinder cover, liner and piston) mitigates the troubles.
- Recent reduced-speed (low load) operation hides the troubles.
  (Combustion problems of low-speed engines occur at higher load.)
- Low BN Lub. Oil with high detergency and high dispersibility is expected in combination with **V**LSFO to make the cylinder-inside always clean.

High and medium speed engines



Troubles at low-load :
Diesel-knock or soot emission

·*Ignition and combustion quality*

For high- and medium-speed engines, poor ignition quality by high-aromatic fuel directly hampers running at low-load unlike low-speed engines case.

Normal operation conditions expected

Difficulties may be encountered
Probability decreasing with recent engine technology (post 1995 design)

Risk of problems may increase up to engine damage after a short period of operations. Probability decrease with recent engine technology (post 1995 design)

Experience collected by the Japanese CIMAC Committee shows that some ship operators have experienced problems using fuels with low ECN values.

Reference : Recommended ECN Operational Reference Ranges[1]

(1) CIMAC "Fuel Quality Guide - Ignition and Combustion", 2011

What are problems of compliant fuels from 2020 ?

has been introduced.

It is helpful if information can be exchanged internationally from 2020.

Thank you for your kind attention

Research work will be continued.