CARB
April 2010 California

Low sulphur fuel operation.

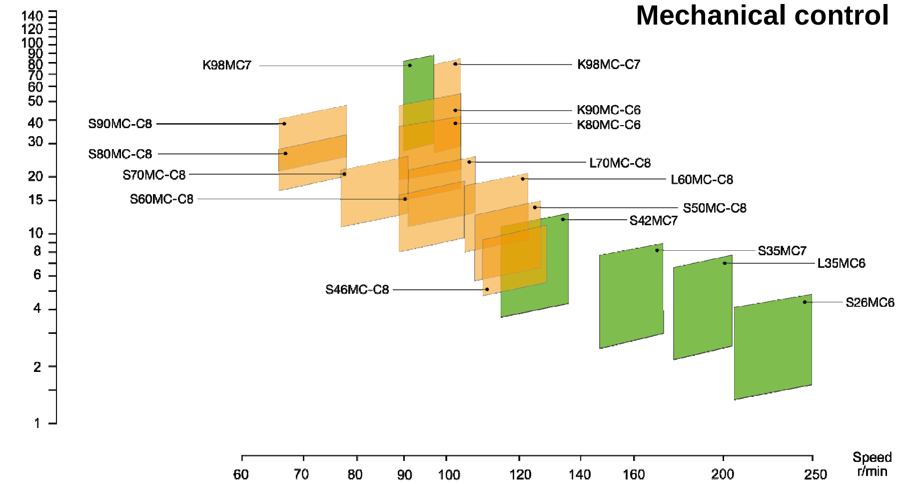
Kjeld Aabo
Director of the Promotion Department.
Marine Low Speed

The Challenge: Emission

- **Half of the world transport of goods is transported by MD two-stroke engines**
- **MD has 15.000 engines in order or in operation**
- **Engines with total power more than 200 GW – or equivalent to ~25% of the European power plant supply!**
- **The total HFO consumption for sea going vessels are more than 250 mill. ton yearly– about 3-4% of the world CO_2 emission!**

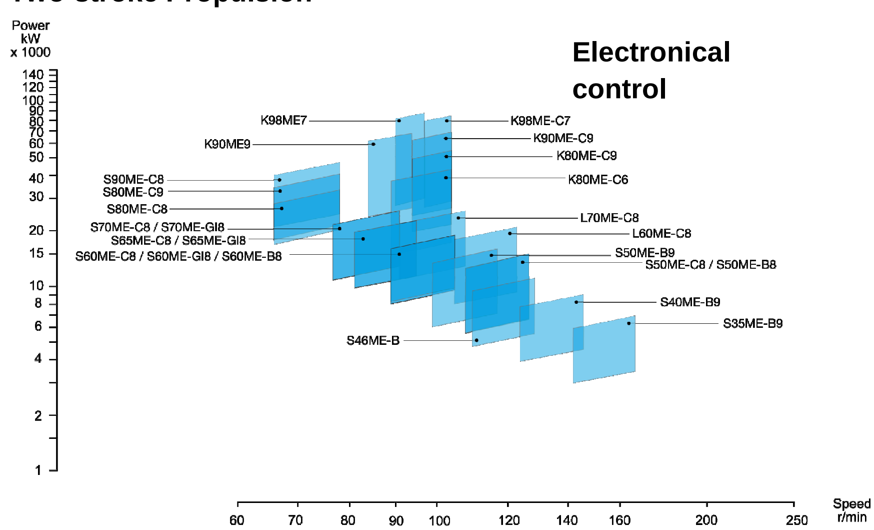
Marine Engine Programme
Preferred for Tier II Compliance

Two-stroke Propulsion



Marine Engine Programme 2009
Preferred for Tier II Compliance

Two-stroke Propulsion



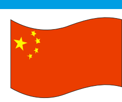
Reference List
MAN B&W Two-stroke Engines

MAN B&W MC & ME Programme

Type	On order/delivered	Total MW
98	716	44,784
90	785	130,129
80	921	22,374
70	2,197	38,532
65	17	317
60	3,738	47,223
50	4,725	43,839
46	443	53,503
42	1,002	6,375
40	44	300
35	2,348	9,963
26	223	518
Total	**17,159**	**247,856 MW**

As at 2009.09.25 Totals: 336,898,320 BHP 247,855,645 kW 17,159 engines

Low-speed Licensees

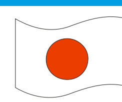


China

HHM	1980
DMD	1980
YMD	1989
CMD	2007
STX	2007
JAD	2007
ZJCME	2008
ZHD	2008
RPM	2008

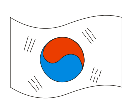
Croatia

Uljanik	1954
Split	1967



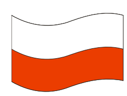
Japan

Mitsui	1926
▪ Makita	1981
Hitachi	1951
Kawasaki	1923



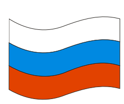
Korea

Hyundai	1976
Doosan	1983
STX	1984



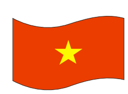
Poland

Cegielski 1959



Russia

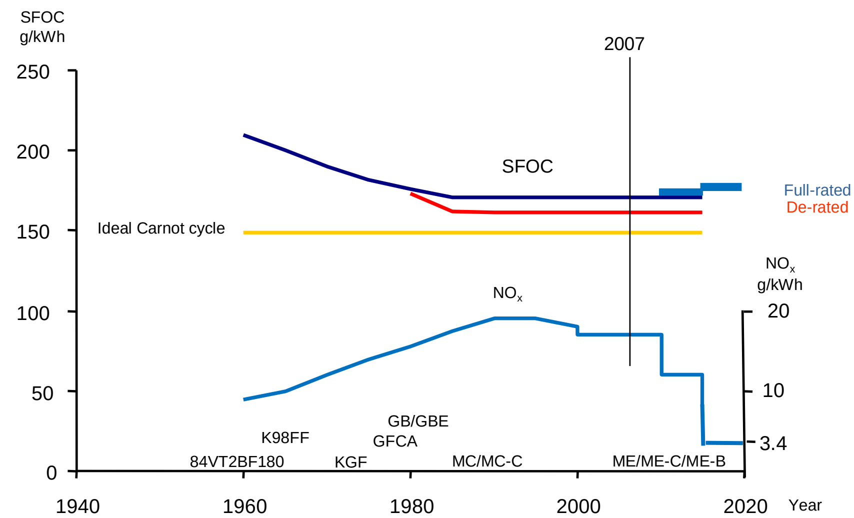
Bryansk 1959



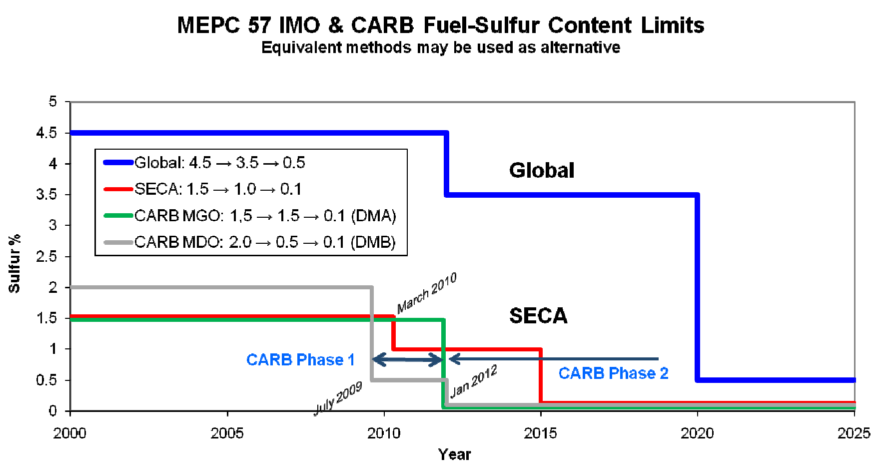
Vietnam

Vinashin 2004

History and Future for SFOC and NO_x

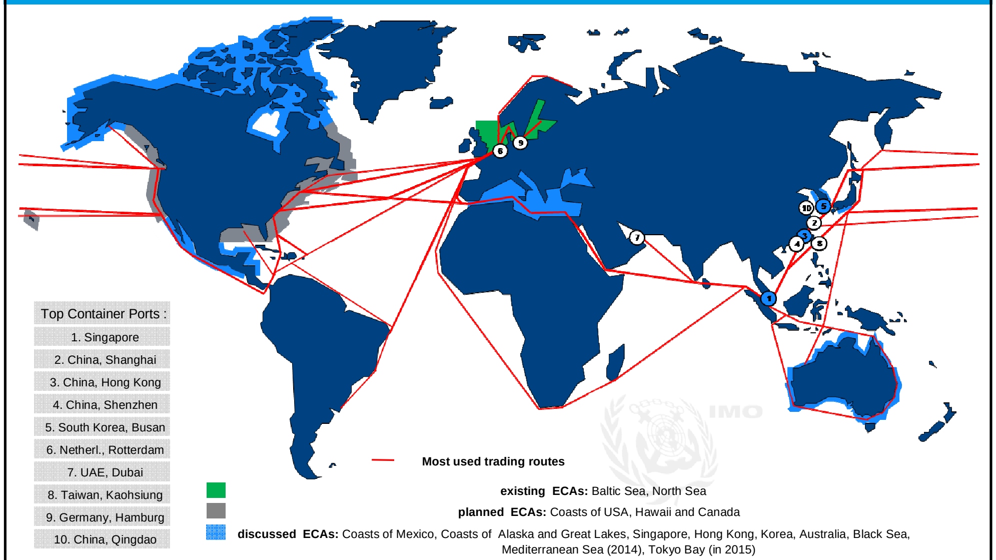


MEPC 57 Fuel-Sulfur Content Proposal

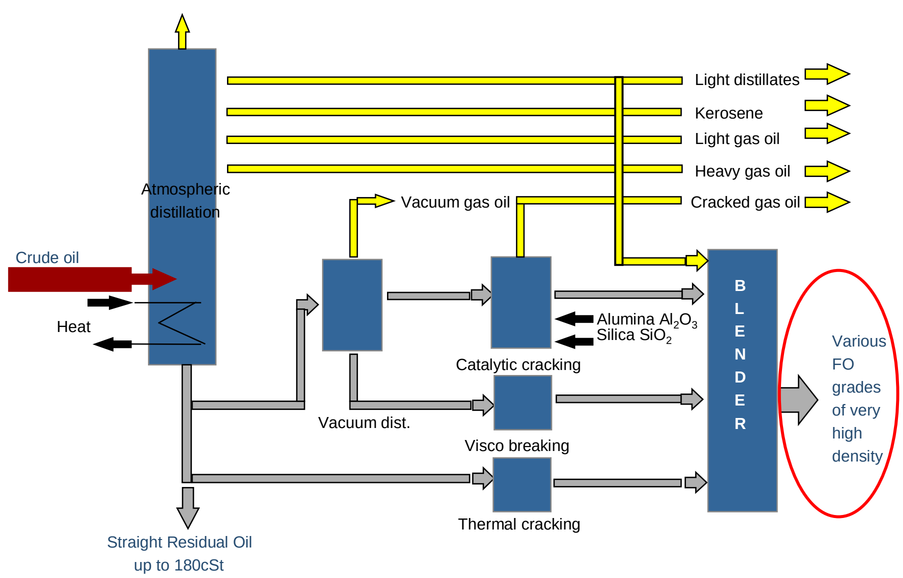


Emission Trend

Emission restricted areas by IMO – ECAs in 07/2009



Cat fines added at the production process.



Low sulphur fuel

- Use of low-sulphur crude oil, but limited availability
- Blending of fuels is a possibility, and is done today
- Desulphurisation of HFO

According to the major fuel companies : Much better investment to build high-efficient refineries that can produce more valuable products such as gasoline, diesel and LPG than to build desulphurisation plants for HFO.

CIMAC recommendation for residual fuel

Characteristics[1]	Unit	Limit	CIMAC A 30	CIMAC B 30	CIMAC D 80	CIMAC E 180	CIMAC F 180	CIMAC G 380	CIMAC H 380	CIMAC K 380	CIMAC H 700	CIMAC K 700	Test method reference
Density at 15 ℃,	kg/m³	max.	960,0	975,0	980,0	991,0		991,0		1010,0	991,0	1010,0	ISO 3675 or ISO 12185 (see also 6.1)
Kinematic viscosity at 50 ℃	mm²/s [2]	max.	30,0		80,0	180,0		380,0			700,0		ISO 3104
		min. [3]	22,0		-	-		-			-		ISO 3104
Flash point,	℃	min.	60		60	60		60			60		ISO 2719 (see also 6.2)
Pour point (upper)	℃												
- winter quality		max.	0	24	30	30		30			30		ISO 3016
- summer quality		max.	6	24	30	30		30			30		ISO 3016
Carbon residue	% *(m/m)*	max.	10		14	15	20	18	22		22		ISO 10370
Ash	% *(m/m)*	max.	0,10		0,10	0,10	0,15	0,15			0,15		ISO 6245
Water	% *(V/V)*	max.	0,5		0,5	0,5		0,5			0,5		ISO 3733
Sulfur [4]	% *(m/m)*	max.	3,50		4,00	4,50		4,50			4,50		ISO 14596 or ISO 8754 (see also 6.3)
Vanadium	mg/kg	max.	150		350	200	500	300	600		600		ISO 14597 or IP 501 (see also 6.8)
Total sediment potential	% *(m/m)*	max.	0,10		0,10	0,10		0,10			0,10		ISO 10307-2 (see also 6.6)
Aluminium plus silicon [5]	mg/kg	max.	80		80	80		80			80		ISO 10478
Used lubricating oil (ULO)			**The fuel shall be free of ULO.** A fuel shall be considered to be free of ULO if one or more of the elements Zinc, Phosphorus and Calcium are below or at the specified limits. <u>All</u> three elements must exceed the same limits before a fuel shall be deemed to contain ULO.										
Zinc	mg/kg	-	15										IP 501 or IP 470
Phosphorus	mg/kg	-	15										IP 501 or IP 500
Calcium	mg/kg	-	30										IP 501 or IP 470 (see also 6.7)

1) See General Recommendations paragraph 3 for additional characteristics not included in this table
2) 1 mm²/s = 1 cSt
3) Fuels with density close to the *maximum*, but with very low viscosity, may exhibit poor ignition quality. See Annex 6.
4) A sulphur limit of 1.5% m/m will apply in SOx Emission Control Areas designated by the IMO, when its relevant Protocol comes into force. There may be local variations.
5) See Annex 3.

What is expected changes for the new ISO 8217

Requirements for distillate and residual fuels

•The hydrogen sulfide, H2S, concentration listed.

• Acidity specified

Requirements for distillate fuels

- Oxidation stability specified. (fatty acid methyl esters (FAMEs)
- The lubricity specified for distillate fuels with a sulfur content below 500 mg/kg. The lubricity limit is based on the existing requirements for high-speed automotive and heavy-duty industrial diesel engines.

Requirements for residual fuels

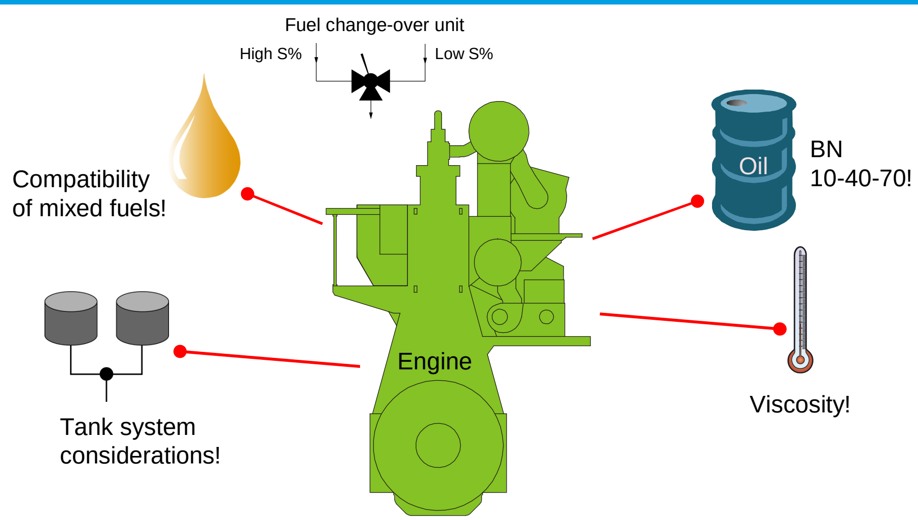
- Ignition characteristics specified as CCAI
- The sodium concentration included due to concerns regarding the influences of metals in fuels on ash deposition and high-temperature corrosion

Additive added to HFO and distillates to protect against H2S and for other changes of fuel properties.

Attack at Fuel separator parts.

Attack at o-rings in fuel injection equipment

Low-sulphur Fuel Operation



Compatibility of fuels

Expected that most ships will switch from high sulphur fuel in open sea to low sulphur fuel in restricted areas

- When switching from HFO to a distillate fuel with low aromatic hydrocarbon there is a risk of incompatibility.
- The asphaltenes of the HFO are likely to precipitate as heavy sludge with clogging filters as a result.
- Use of test compatibility kit on board or guarantee from fuel supplier that fuels used can be blended

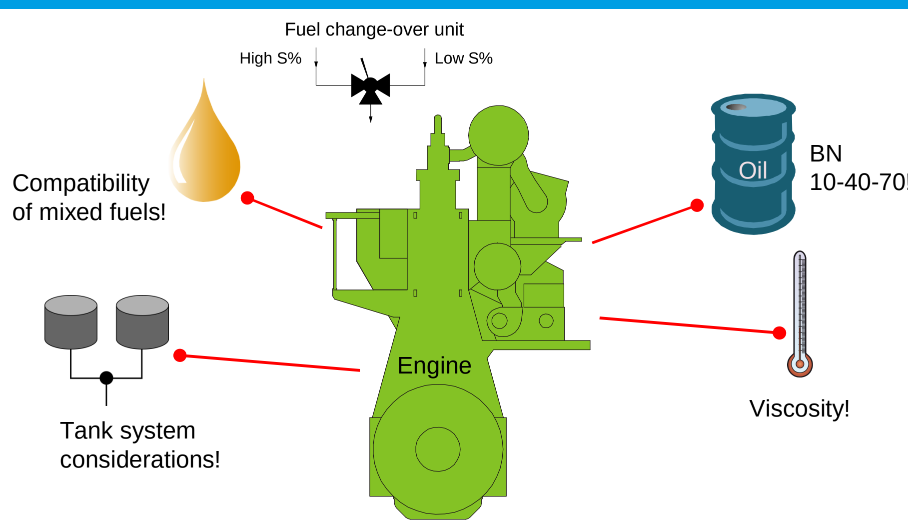
Mixing Two Different Fuels
Case story

	Before separator	Bunker sample
Density @ 15C	**928.0**	**932.4**
Viscosity @ 50℃	**19.5**	**22.1**
Water	**0.2**	**<0.10**
MCR	**9**	**10**
Sulphur	**1.24**	**1.54**
TSP	**0.34**	**0.01**
Total sediment accelerated	**U/F**	**0.60**
Vanadium	**92**	**100**

~ A fuels stabillity reserve

Source: DNVPS

Low-sulphur Fuel Operation



DIESEL*switch*

Advantages:

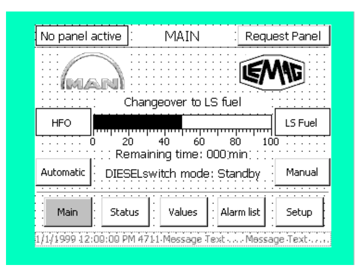
- **Safety controlled change over process**

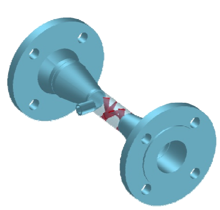
  minimized risk of damaged fuel injection parts due to abrupt temperature changes+

- **Change over running at full load possible**

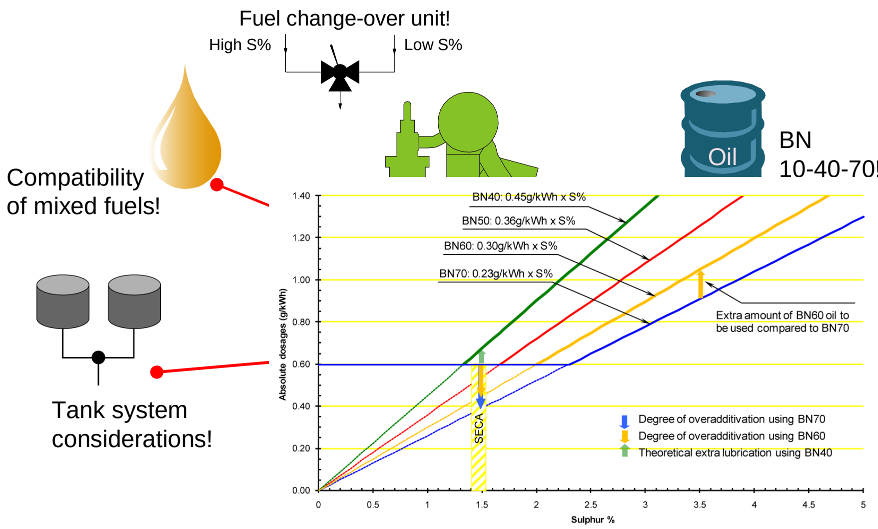
  No need to run engine with lowest power for change over process

DIESEL*switch* „S“





Low-sulphur Fuel Operation



Lube Oil Properties
related to Low Sulphur Fuels

- History Two-stroke:
  - Low sulphur fuel with high alkaline lubricants was not an issue (BN 70 CLO)
  - Excessive lubrication apparently gave no operational problems.

- Current Two-stroke:
  - Recent problems with $CaCO_3$ deposits and scuffing due to continuous low sulphur fuel operation with BN 70 CLO and high feedrate.

Scuffing and lube Oil Properties related to Low Sulphur Fuels

Liner scuffing:

- Excess lube oil ($CaCO_3$ additive) not used due to lack of S (less acid to neutralise) forms hard deposits on piston crowns
- Lack of controlled corrosion – sulphuric acid, adds to "holding pockets" for lube oil film (preventing bore polish)

Cylinder Liner Surface

'Open' graphite structure with good tribological abilities

1.6 mm

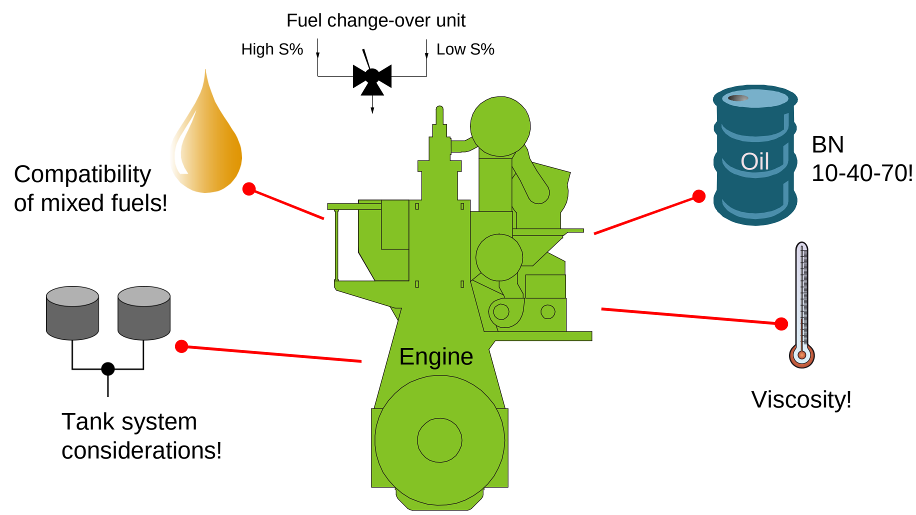
'Closed' graphite structure with reduced tribological abilities

1.6 mm

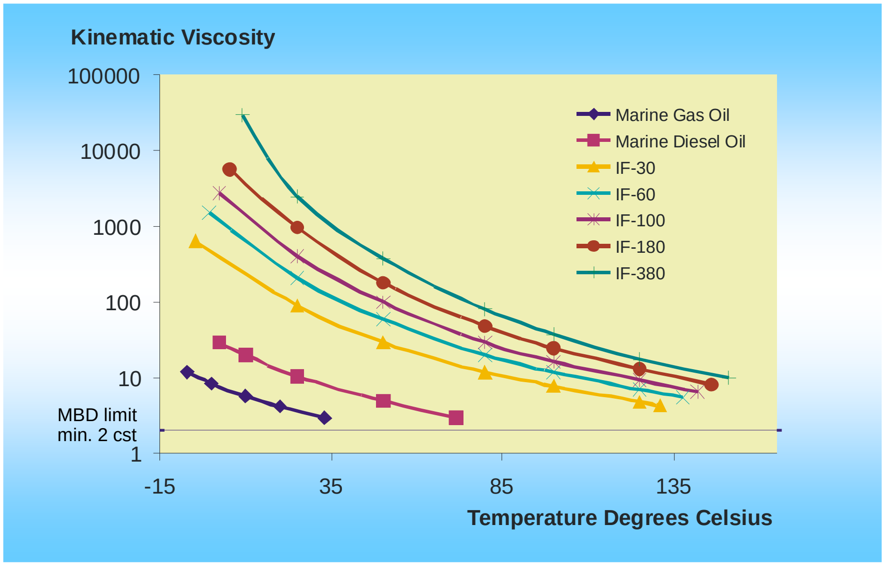
Cylinder oil

Lubricating oils					
	Low speed main engines			Auxiliary engines L23/30 & L28/32	Auxiliary engines L16/24, L21/31 & L27/38
Type	Circulating oil	Cylinder oil		Circulating oil	Circulating oil
Requirement	SAE30/BN 5-10	SAE50/BN 60-80	SAE50/BN 40-50	SAE30/BN 20-25	SAE40/BN 20-40
Oil company					
BP	OE-HT 30	CLO-50M CL 605	CL 505 / CL-DX 405	IC-HFX 203	IC-HFX 204/304/404
Castrol	CDX 30	Cyltech 70/80AW	Cyltech 40SX/50S	TLX Plus 203	TLX Plus 204/304/404
Chevron (FAMM, Texaco, Caltex)	Veritas 800 Marine 30 Doro AR30	Taro Special HT 70	Taro Special 50 Taro Special HT LS 40	Taro 20 DP 30 Delo 2000 Marine 30	Taro 20 DP 40 Taro 30 DP 40 Taro 40 XL 40 Delo 2000 Marine 40 Delo 3000 Marine 40 Delo 3400 Marine 40
Total	Atlanta Marine D3005	Talusia HR 70	Talusia LS 40	Aurella 3020	Aurella 4020 – 4030
Exxon	Exxmar XA	Exxmar X70	Mobilgard L540	Exxmar 24 TP30	Exxmar 30 TP40
Mobil	Mobilgard 300	Mobilgard 570	Mobilgard L540	Mobilgard (TB 25)	Mobilgard M430-M440
Shell	Melina 30/30S	Alexia 50	Alexia LS	Argina oil S30	Argina oil S40

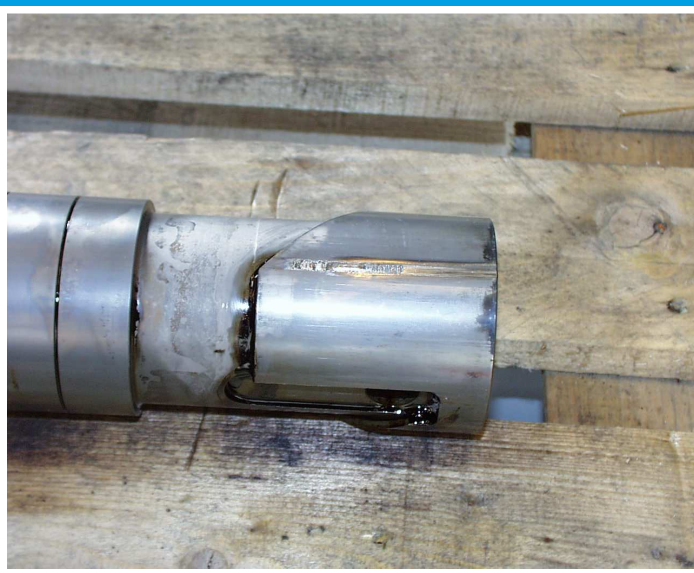
Low-sulphur Fuel Operation



Marine Fuels



Damage to Fuel Pump Plunger



Low Sulphur / Viscosity fuels

Viscosity and lubricity of fuels

Viscosity
The engine fuel pump is designed for high viscosity heavy fuel operation the majority of its operation hours.

The low viscosity challenges are the risk of excessive wear as well as the ability to keep proper injection pressure in the fuel pump - especially during low load, start and low rpm.

In worn pumps, the internal leakage can increase to a level where starting the engine is impossible because a proper injection pressure cannot be achieved.

Lubricity

Lubricity
MAN Diesel recommends that, prior to using distillates fuels with less than 0.05% sulphur, the lubricity is tested.
Lubricity can be tested by an HFRR (High-Frequency Reciprocating Rig) test (according to ISO12156-1) which can be performed by an independent lab. According to ISO12156-1 the maximum wear scar diameter should not exceed 460 micro m.

Different individual factors on engines and ex. Fuel system, have an influence on capability to operate on low viscosity fuels.

- **Fuel pump high pressure leakage mainly generated at cut off holes**

Design of fuel pumps

Wear of Plunger and Barrel

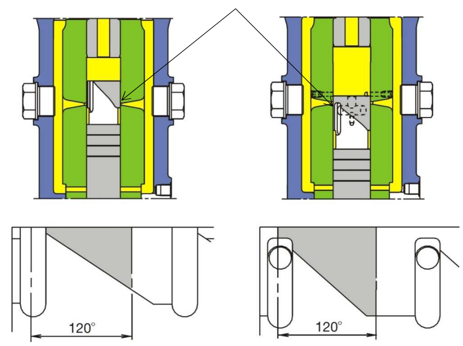
Fuel Volume of the ex. fuel system

Isolation of the fuel system

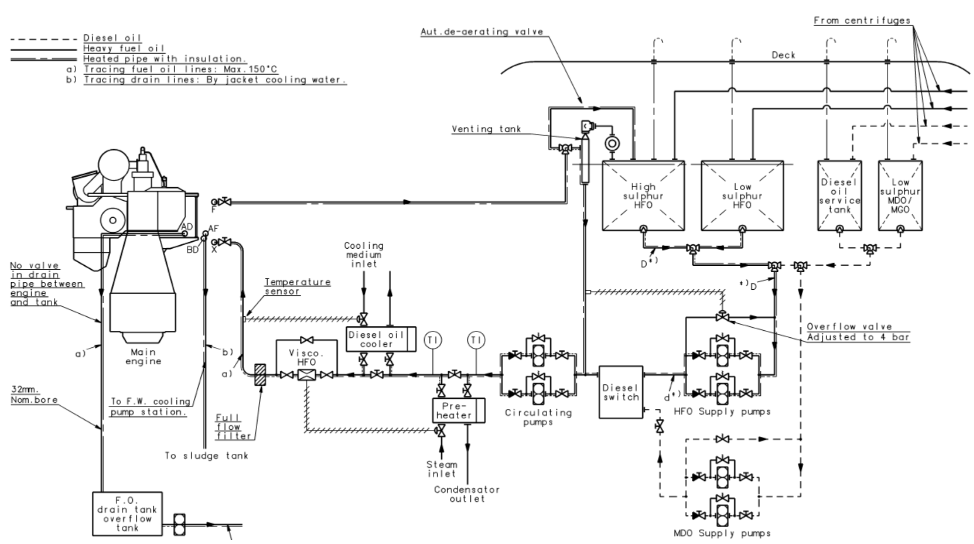
Design of external fuel pumps

Conclusion ;

Each ship needs to test sensitivity to fuel viscosity above the min. 2 cSt.

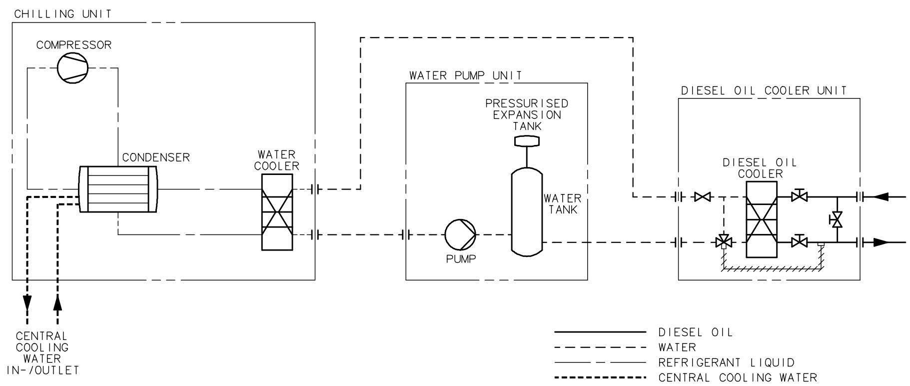


HFO system with MDO cooler

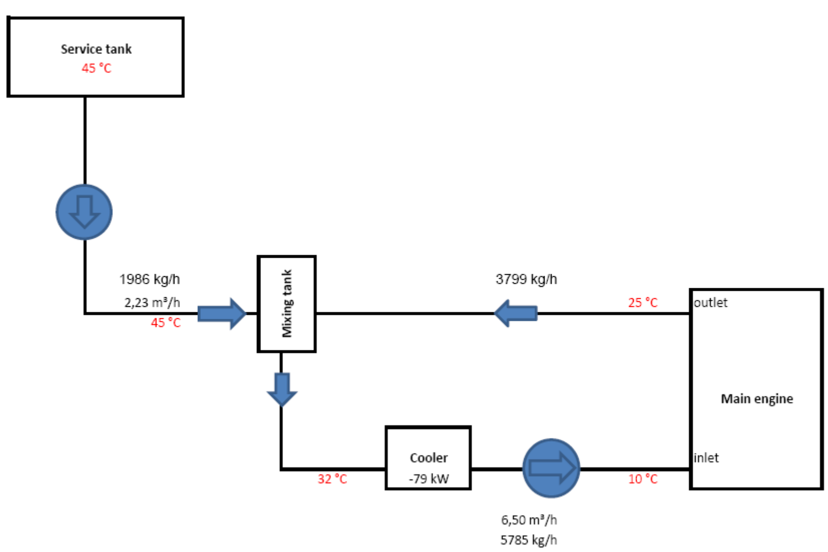


Auxiliary System
Diesel Oil Chiller in Fuel Oil System

Proposal to Chilling Cooling System for Diesel Oil Cooler



Heat dissipation example
7S50MC-C7 – 11,060 kW



Service Letter SL09-515/CXR

Action code: WHEN CONVENIENT

Guidelines on Operation on Distillate Fuels
Low-viscosity fuels

SL09-515/CXR
September 2009

Concerns
Owners and operators of MAN B&W two-stroke diesel engines.

Summary
Guidelines on low-viscosity fuel.
MAN Diesel recommends fuels with a viscosity of 2 cSt at engine inlet.

DIESELswitch for automatic change-over between HFO and MGO/MDO

Dear Sirs

With the introduction of new and tighter fuel sulphur content regulations by the EU and the California Air Resources Board, MAN B&W two-stroke engines will increasingly operate on distillate fuels, i.e. marine gas oil (MGO) and marine diesel oil (MDO) in such areas where required.

MAN B&W two-stroke engines are optimised to operate on heavy fuel. However, MGO/MDO fuels can be used when appropriate considerations are made to the following to ensure a safe and reliable performance, i.e.:

- the viscosity and lubricity of the fuel
- keeping a high fuel pump pressure
- the use of a cooler or chiller in an external fuel supply system
- other considerations, references for more information.

This service letter gives guidelines and recommendations on how to ensure a safe and reliable operation on low-viscosity distillate fuels.

For any questions or inquiries regarding the recommendations in this service letter, please contact our Operation Department at the e-mail address: *leo@mandiesel.com*

Yours faithfully

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MAN Diesel – a member of the MAN Group

Contents

Introduction

The lowest viscosity suitable for two-stroke diesel engines is 2 cSt at engine inlet. However, this viscosity limit cannot necessarily be used as a fuel specification for purchasing the fuel, as the viscosity in a purchase specification is tied to a reference temperature. This is due to the fact that the external fuel systems have an individual effect on the heating of the fuel and, thereby, the viscosity of the fuel when it reaches the engine inlet.

The external fuel oil systems on board today have been designed to keep a high temperature for HFO operation. This can make it difficult to keep the fuel system temperature as low as possible, and thereby as high a viscosity as possible, when changing to DO and GO operation. The crew must therefore make an individual test.

Many other factors influence viscosity and its influence on the engine, such as engine condition and maintenance, fuel pump wear, engine adjustment, actual fuel temperature in the fuel system, human factors, etc. Although achievable, it is difficult to optimise all of these factors at the same time. This complicates operation on viscosities in the lowest end of the viscosity range.

To build in some margin for safe and reliable operation, MAN Diesel recommends operators to test the engine's and external systems' sensitivity to low viscosity. Furthermore, the necessity for installation of a cooler or cooler & chiller should be evaluated before purchasing fuels with the minimum level of viscosity necessary.

In principle, fuels according to the specified grades DMX/DMA can be purchased, if the engine and external system are designed to keep a minimum viscosity of 2 cSt at engine inlet. If 3 cSt can be obtained, this is preferred to ensure a higher safety margin.

ISO 8217

According to ISO 8217, distillate grades DMX/DMA can be sold with a viscosity down to 1.4/1.5 cSt at 40°C. This will especially be the case if the DMX/DMA provided origins from automotive gas oil. The 1.4/1.5 cSt can only be applied if the distillate is cooled/chilled down correspondingly to reach the 2 cSt minimum viscosity at engine inlet.

Influence of lubricity and viscosity

Lubricity

The refinery processes intended to remove, e.g., sulphur from the oil result not only in low viscosity, but also impacts the lubricity enhancing components of the fuel. Too little lubricity may result in fuel pump seizures.

Although most refiners add lubricity-enhancing additives to distillates, MAN Diesel recommends testing the lubricity before using fuels with less than 0.05% sulphur. Independent fuel laboratories can test lubricity according to ISO12156-1 (High-Frequency Reciprocating Rig, HFRR). The HFRR wear scar limit is max 460 µm.

Viscosity

A low viscosity fuel oil challenge the function of the pump in three ways: 1. Breakdown of hydrodynamic oil film (resulting in seizures), 2. Insufficient injection pressure (resulting in difficulties during start and low-load operation), and 3. Insufficient fuel index margin resulting in limitation in acceleration.

Due to the design of conventional pumps versus the pressure booster, ME/ME-C/ME-B engines are more tolerant towards a low viscosity compared with the MC/MC-C engines. Many factors influence the viscosity tolerance during start and low-load operation:

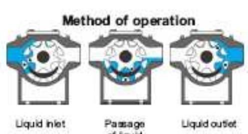
- Engine condition and maintenance
- Fuel pump wear
- Engine adjustment
- Actual fuel temperature in the fuel system
- Human factors, etc.

Although achievable, it is difficult to optimise all of these factors at the same time. This complicates operation on viscosities in the lowest end of the viscosity range. To build in some margin for safe and reliable operation, and availability of high-viscosity distillate fuels, it is expected that installation of coolers or cooler & chiller will be necessary for many operators.

Auxiliary System
Diesel Oil Cooler in Fuel Oil System

Pump which can operate with viscosity down to 1.5 cSt

DESMI - Rotan



KRAL Screw Spindle Pumps

Fuel parameters
Ignition delay and combustion qualities

Methods for determination of fuel qualities:

- ➢ CCAI / CII
  Calculation of fuel ignition quality by use of viscosity and density

- ➢ FIA (Fuel Ignition Analyser)
  Ignition delay
  Combustion quality (Rate of Heat Release ROHR)

FIA-100 FCA - Working Principle

Fuel is injected (x25) into warm and compressed air

- 45 bar
- 500˚C

Self-ignition of the fuel

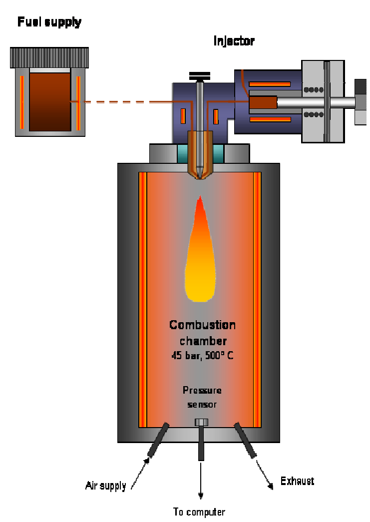
Pressure increase in the combustion chamber

The pressure change is measured and stored

Following parameters are measured/calculated

- Start of Main Combustion → Estimated Cetane Number ECN
- Combustion Period
- Rate of Heat Release etc..

Standard test method IP 541/06



Compliments from DNVPS

Fuel parameters - CCAI

MBD test of different fuels:

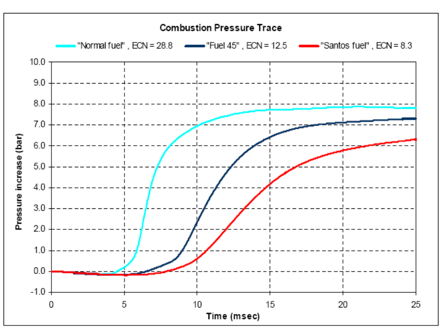
Fuel No	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Units
Viscosity	3.8	84	85	141	198	255	470	520	560	690	710	800	1200	50,000	-	cSt/50°C
Density	968	995	970	993	938	977	985	983	1,010	1,008	1,030	935	998	1,040	1.01	kg/m³ at 15°C
Flash point	98	84	80	103	100	106	90	95	90	79	84	>40	80	>60	>70	°C
Conradson Carbon	0.3	17.2	12.1	13.3	9.4	14.5	16.8	14.8	17.3	22.1	24.7	9.4	14,1	24.2	11.7	% weight
Asphalt	0.78	15.1	8.9	9.2	3.7	10.0	11.3	12.8	14.6	19.3	29.0	1.02	12	-	-	% weight
Sulphur	0.10	2.72	1.16	0.91	0.83	0.87	0.90	1.18	2.22	3.52	3.30	0.37	4	4.8	2.8	% weight
Water	0.01	0.01	0.01	0.00	0.01	0.02	0.02	0.01	0.00	0.00	0.00	-	0,65	0.05	-	% weight
Ash	0.00	0.065	0.025	0.03	0.03	0.025	0.03	0.035	0.04	0.07	0.09	0.043	-	0.035	0.18	% weight
Aluminium	-	-	-	-	-	-	-	-	-	-	-	-	12	2.0	1	mg/kg
Vanadium	0	220	20	23	12	17	24	45	122	300	370	415	312	149	-	mg/kg
Sodium	0	27	23	24	25	40	35	22	22	24	50	9	-	-	-	mg/kg
CCAI	912	874	849	866	807	843	844	841	868	864	885	-	-	-	-	-

FIA - 100 FCA

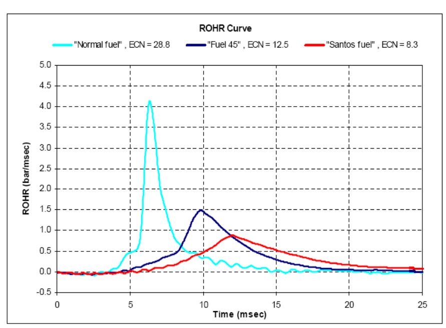
Constant volume spray combustion chamber:

- **Tinit = 800K,**
- **Pinit = 45bar**

Pressure trace

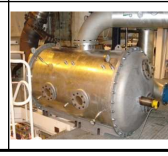


Heat release rate

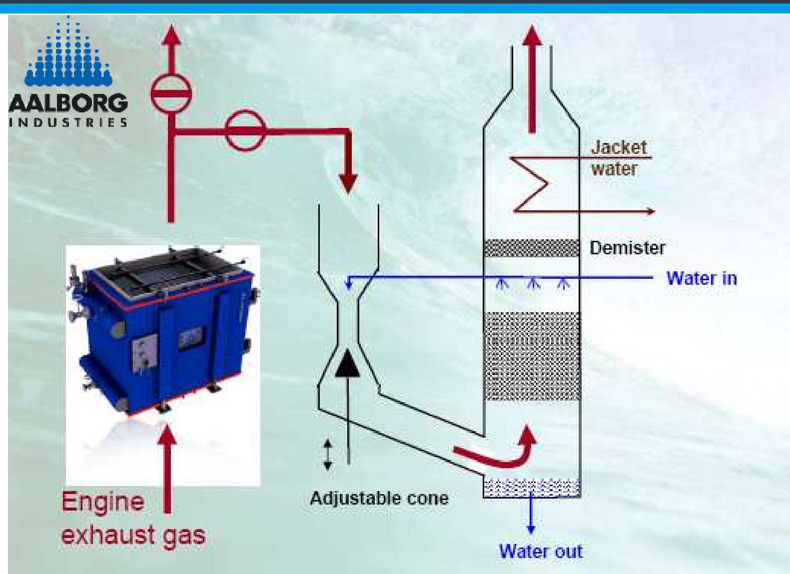


MAN Investigation in Scrubber Technology

Tests and future

Objectives	Participants	Scrubber	Goals	Test results	Ship test	Ship test
Development and test of scrubber for after-treatment	Clean Marine MAN Diesel		PM trapping: >90% SO_x removal: >67%	PM trapping: 35% 80% (salts add.) SO_x removal: 73% 95% (salts add.)	M.V. Banasol 7S50MC-C 9MW	
Development and test of scrubber for after-treatment	Aalborg Industries Alfa Laval DFDS MAN Diesel		PM trapping: >75% SO_x removal: >95%	PM trapping: 79% SO_x removal: 100% (NaOH)	Tor Ficaria 9L60MC-C 20MW	
Development and test of scrubber for after-treatment and EGR	APM MAN Diesel		PM trapping: >75% SO_x removal: >90%	PM trapping: 73% SO_x removal : 96% (NaOH)	Alexander 7S50MC 9MW	

Scrubber Principle Layout



Development Schedule

Test at MAN Diesel
2008

Ship installation July 2009

Service test Oct. 2009

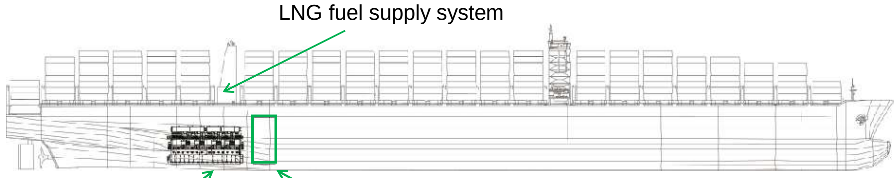
Aalborg Industries & DFDS
Exhaust gas scrubber retrofit project

- **20MW MAN B&W two-stroke engine**
- **Operating in SECA on MDO**
- **Exhaust gas scrubber permits HFO operation**
- **Expected payback time less than two years**

RO RO vessel M/V Tor Ficaria

AALBORG
INDUSTRIES

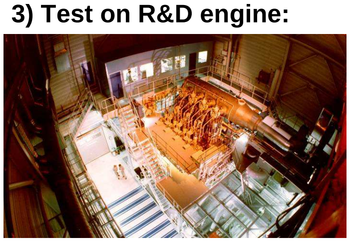
Emissions with Alternative Fuel
LNG ME-GI for Container Ship



	Reduction with ME-GI	Reduction with ME-GI + WHR	Reduction with ME-GI + WHR+EGR
CO_2 (gram per ton-mile)	23%	35%	33%
NO_x (gram per ton-mile)	13%	13%	80%
SO_x (gram per ton-mile)	92%	92%	94%
Energy (gram per kWh)	0%	12%	10%
Particulate matter (mg per m^3)	37%	37%	48%

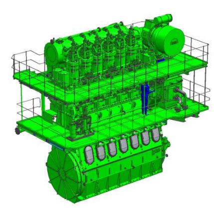
ME-GI
Development plan

3) Test on R&D engine:

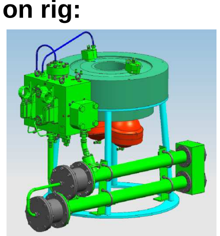


4) First production engine:

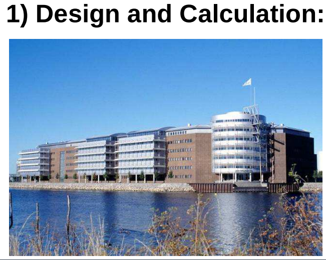
- Verification test and TAT



2) Test on rig:



1) Design and Calculation:



Let Nature Prevail.

CSNOx™ fro ECO-SPEC

System design

- The CSNOx™ System increases the pH value and alkalinity of freshwater or seawater without chemicals.
- Freshwater or seawater is first fed into the Ultra-Low Frequency Electrolysis System (ULFELS) to make it alkaline and ready for scrubbing.
- The alkaline water is then pumped through the exhaust stack to scrub the flue gas.
- The CSNOx™ treated water is highly reactive and effective in removing CO2, SO2 and NOx through absorption.
- The removed pollutants are converted into the harmless substances found naturally in the water.
- After scrubbing, the scrubbed water may pass through a solid-liquid separator to remove solid particles and undergo an integrated treatment to meet the discharge water standard.

Informed Performance ;

CO2 removal 77% CO2 + 66% NOx + 99% SO2 ! The world would welcome such system.

MAN Diesel Comments;

Are at this moment not able to see the chemical or energy balance working. Await explanation from Eco-spec.