WÄRTSILÄ

TECHNICAL BULLETIN

Services, Wärtsilä Netherlands B.V.

Fuels, fuel preparation

Engine types

This bulletin applies to all D232, D234, D518, D601, D602, D603, D604(B), D616, D618, D620, D628, D640, D645 D716, D816 and D18/22 engines.

It applies in part to older engines which are no longer in the model range. Please contact your Wärtsilä Services Network Company if you have any questions.

Contents

1 Fuel types
1.1 Distillate fuel
1.2 Intermediate fuel
1.3 Residual oil
2 Notes on fuel
2.1 Ignition quality
2.2 Fuel mixtures
2.3 Influence of fuel on performance
2.4 Fuel temperature
2.4.1 Temperature required for fuel pumping
2.4.2 Separating temperature
2.4.3 Fuel temperature at injection pump inlet
2.5 Separation of fuels
2.6 Injector cooling system
2.7 Low-load operation with residual fuels
2.8 Shutting down and starting the engine for operation with residual fuel

Wärtsilä Netherlands B.V.
P.O. Box 10608
8000 GB Zwolle

Office: Hanzelaan 95
8017 JE Zwolle
The Netherlands

Telephone: +31 38 425 32 53
Telefax: +31 38 422 35 64
service.sales.nl@wartsila.com

1 Fuel types

The following table lists those fuels which are approved for Wärtsilä Deutz marine engines.

Permissible fuels		see enclosure	Approved for engines						
			D518 D618 D18/22	D232 D234 D616	D601 D602 D603 D604(B) D620	D716 D816	D628	D640	D645
Distil-late fuels	**Diesel fuels to:** EN 590	4							
	Marine distillate fuels to: ISO 8217:2005 DMA	5							
	ISO 8217:2005 DMX	5							
Inter-mediate fuels	**MDF mixed-fuel oil to:** ISO 8217:2005 DMB	5		Only constant speed engines					
	MDF mixed-fuel oil to: ISO 8217:2005 DMC	5							
Resi-dual oil (heavy oil)	**Residual oil to:** ISO 8217:2005 RMA30 / RMB30 RMD80 RME180 / RMF180 RMG380/RMH380/RMK380	6							
	RMH700/ RMK700								

With regard to fuels with specifications other than those listed above, please contact the Wärtsilä Services Network, submitting the relevant specification or a fuel sample.

1.1 Distillate fuel

Distillate fuels are all fuels not containing residual oil.

Pure distillates do not require any specific engine equipment.

- Low-sulphur diesel fuel with a sulphur content of < 0.05 % can be used.
  Sufficient lubricity must, however, be ensured through the use of additives.
  The fuel manufacturer is responsible for guaranteeing this.

1.2 Intermediate fuel

Intermediate fuels are distillate fuels to which small quantities of residual oil have been admixed.

If the cetane number is not specified or cannot be determined, the CCAI value applies (see nomogram, enclosure 3).

For D234, D616, D604B and D620 engines, intermediate fuels are only permitted for on-board assemblies (constant speed auxiliary application). Engine power must be reduced by 10 %.

When running an engine on intermediate fuel, it is important to make sure that the max. injection viscosity is not exceeded, see section 2.5.3. Otherwise there must be provision for fuel preheating.

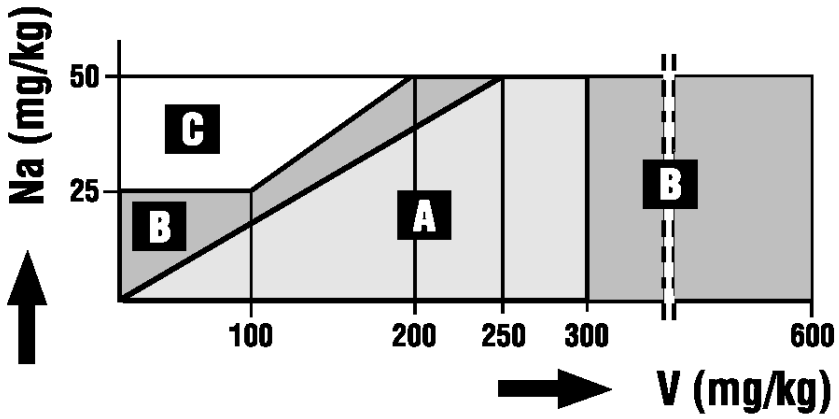
D628, D640 and D645 engines run on intermediate fuel to ISO 8217:2005 DMC are to be treated as for heavy-oil operation with regard to engine power and equipment.
There must be provision for fuel separation, see section 2.6.

1.3 Residual oil

Residual oils (heavy oil) are mixtures and specified to ISO 8217:2005. They are approved for D640 and D645 engines up to RMK700, for D628 engines only up to RMK 380.

Additional Wärtsilä Deutz requirements for the use of residual oils to ISO 8217:2005:

Specification	Limit	Test method
Asphaltene content:	Max. 14% by mass	DIN 51595
CCAI value:	≤ 860	calculated value based on density and viscosity
Sodium content:	depends on vanadium content, see diagram. Range A is safe range Range C must by avoided	ICP (**I**nductively **C**oupled **P**lasma)



- Additives on a non-mineral basis are not permitted (used lubricating oil, bituminous shale, coal oil, vegetable oil, solvents, and waste from the chem. industry).
- State-of-the art separator systems and the manufacturer's approval are necessary for densities over 991 [kg/m^3].
- Requirements and test methods for fuel before entering the engine.

Characteristic		Dimension	Limit	Value	Test method
Inorganic additives	Total	[mg/kg]	max.	**20 *1**	
	Al only	[mg/kg]	max.	**5 *1**	ICP or AAS *2
Water		% by volume	max.	**0,2**	ISO 3733

*1 Particle size < 5 [µm]
*2 ICP = **I**nductively **C**oupled **P**lasma
AAS = **A**tomic **A**bsorption **S**pectroscopy

Operation with residual oil requires specific engine and plant equipment, the main features of which are as follows:

- Twin fuel filter with heating (indicator filter, mesh width 34 [µm] ball passage)
- Separately installed fuel pump for D628, D640 and D645
- Closed fuel system
- Automatic fuel back flush-filter (in the plant, mesh width 10 [µm] ball passage)
- Fuel preheating with viscosity-dependent control
- Automatic lubricant back flush-filter (in the plant, mesh width 34 [µm] ball passage) (not required for D628 burning fuel RMA30 and RMB30)
- Cooled injectors above residual RME180 (≥ 80 [mm^2/s] at 100 °C)

2 Notes on fuel

2.1 Ignition quality

For distillate fuels and some intermediate fuels, ignition quality is specified together with the cetane number and limited to ≥ 40 for Wärtsilä Deutz engines. A cetane number which is too low may cause starting difficulties, the formation of white smoke and higher HC emissions due to the long ignition delay. Damage may also occur as a result of thermal and mechanical overloading.

If the cetane number is not specified (in the case of some intermediate fuels and residual oil), ignition quality is determined by the CCAI value. This can be calculated based on the density ([kg/m^3] at 15 °C) and kinematic viscosity ([mm^2/s] at 50 °C) using the following nomogram.

The following limits apply:

Engine	Permissible CCAI value
D234, D616, D604B, D620, D816	830 - 860
D628, D640, D645	≤ 860

2.2 Fuel mixtures

When mixing residual fuels of different origin or bunkers, there is the risk of precipitations or sediments. Fuels from different bunkers should therefore be kept apart.

2.3 Influence of fuel on performance

Non-distilled fuels almost always have a higher density than distillate fuels. This higher density would - assuming a constant control rod/unchanged pump setting - lead to an (excessively) high power output. Therefore the injection pump has to be readjust if a fuel is to be used which has a higher density than on which the factory setting was based.

The work may only be carried out by Wärtsilä Services or an authorised representative. Independent modification of the injection settings will render any warranty claims invalid.

2.4 Fuel temperature

Depending on the type of fuel, preheating may be necessary:

- To ensure fuel pumping.
- To optimise fuel separation.
- To ensure proper injection viscosity.

2.4.1 Temperature required for fuel pumping

No particular measures are required for pure distillate fuels and intermediate fuel with regard to fuel pumping qualities.

Distillates containing residual fuels need to be preheated to ensure pump ability. The fuel should be heated so that it is at least 10 °C above the pour point, as otherwise there will be difficulties with pumping.

The limit value for economical pumping (driving power, wear) of residual fuels is approx. 1000 [mm^2/s].

2.4.2 Separating temperature

See section 2.6

2.4.3 Fuel temperature at injection pump inlet

Permitted maximum injection viscosity:

Engine	Injection viscosity
D234, D616, D604B, D620, D816	max. 5 [mm^2/s]
D628	15-17 [mm^2/s]
D640, D645	9.5 - 12.0 [mm^2/s]

Distillate fuels should enter the injection pump at a minimum temperature of 30 °C. Special preheating is not normally required. If it is to be expected that (for example if the fuel is exposed to low outside temperatures) the fuel viscosity in the mixing tank will be higher than the permitted injection viscosity, the fuel should be preheated.

Intermediate fuels should always be preheated to reach the injection viscosity. With the engines D628, D640 and D645, preheating is not required if intermediate fuel in accordance with DMB is used, assuming that the temperature of the injection pump is at least 40 °C.

Residual fuels should always be preheated.

Preheating may be done

- Electrically with electric final pre-heater
  (as many heating stages as possible, heat transfer per unit surface max. 1.1 [W/cm^2])
- With steam through heat exchanger controlled by steam regulating valve
- With heat carrier oil via heat exchanger

Note for engines D234, D616, D604B, D620, and D816:

The injection pump of these engines permits a maximum outlet temperature of 80 °C. This means with a Δt in the injection pump (inlet/outlet) of 30 °C a permissible inlet temperature of 50 °C.

2.5 Separation of fuels

Intermediate fuels must be separated. For marine applications separation of distillate fuels is recommended with regard to water and sludge content.

Only the new generation of self-cleaning fuel separators should be used. These are highly effective across a wide density spectrum and can effectively separate residual fuels up to a density of 1010 [kg/m^3] at 15 °C. The separating effect is automatically monitored and the density-dependent regulation occurs automatically.

Two separators are always required for fuel treatment (one of which is a reserve separator), whereby each separator should be designed for 100% throughput. Single-stage and two-stage separation is possible.

Required separating temperature:

Distillate fuels	**Intermediate fuels**	**Residual fuels**				
DMA	DMB DMC	RMA 30 RMB 30	RMD 80	RME 180 RMF 180	RMG 380 RMH 380	RMH 700 RMK 700
20-40 °C	40-60 °C	75-98 °C	80-98 °C	90-98 °C	98 °C	98 °C

On principle, separators should be generously dimensioned in view of deteriorating fuel qualities.

If separators from Wärtsilä Deutz are supplied, optimum suitability is guaranteed. If the separators are provided by the customer, the separator plant must be set up in consultation with the supplier.

2.6 Injector cooling system

The following engines are equipped with an injector cooling system:

D628 for operation with residual fuel from ISO 8217 RME180 (>80 [mm^2/s] at 50 °C)
coolant pump, heat exchanger, tank and control installed separately.
For Wärtsilä Deutz D628 rebuild engines the injector cooling is omitted.

D640 for operation with residual fuel from ISO 8217 RME180 (>80 [mm^2/s] at 50 °C)
n = constant: connected to the lube oil circuit of the engine
n = variable: coolant pump, heat exchanger, tank and control installed separately.

D645 for operation with intermediate fuel and residual fuel, connected to the lube oil circuit of the engine.

In case of separate installation, observe the following:

- In the case of multi-engine plants, each engine should be provided with its own injector cooling system.
- The cooling agent is lubricating oil
- In view of the high temperature level, a pressure system design is required.
- If engines are shut down without switching to distillate fuel (e.g. pier-to-pier operation) the injector cooling system must remain switched on during the engine preheating phase.

2.7 Low-load operation with residual fuels

If highly supercharged engines are operated with residual fuels for a longer period of time - without preventative measures being taken - below 20 % of the rated load, deposits can occur in the combustion chambers, the exhaust area (as a result of incomplete combustion) and in the inlet area (as a result of inward acting exhaust emissions). Contamination of the lubricating oil is a further consequence.

These impairments can be avoided by limiting the amount of time that the engine is operated at low load.

Limit curve applicable for generator and propeller operation

If the engine is operated below 20 % of its rated output in the regulated range, it can be seen that the sum of the daily low-load operating periods does not exceed the amount shown in the diagram.

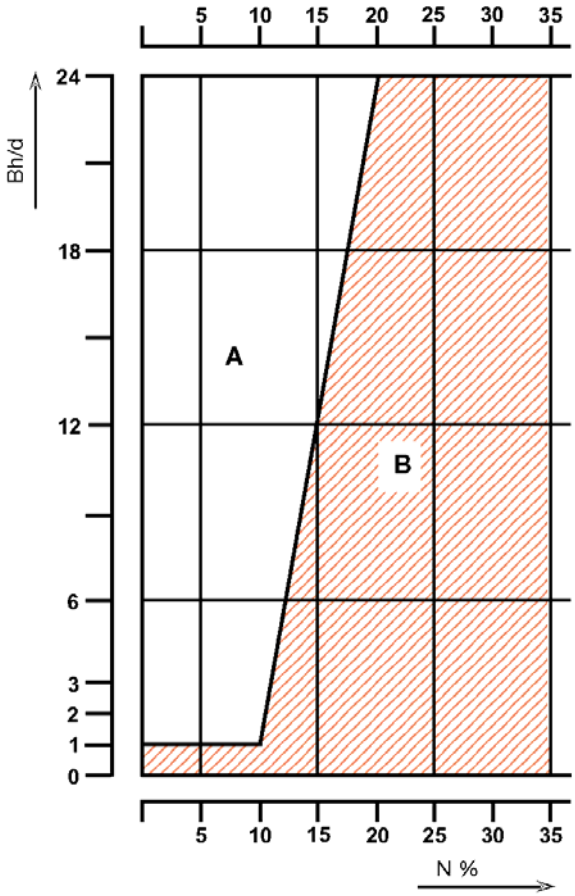
Immediately following low-load operation, the engine should be operated at 60 – 100 % of the rated output, whereby the engine should not be operated at full load for more than 1 hour per day.

A = Engine operation not permitted

B = Engine operation regulated

Bh/d = Operating hours per day

N % = Engine output as % of rated output



2.8 Shutting down and starting the engine for operation with residual fuel

Every effort should be made to stop and start the engine with residual fuel (pier-to-pier operation). It must be ensured, however, that the fuel treatment system continues in operation and that residual fuel is circulated in the low-pressure system. The separately installed injector cooling system must also continue in operation. The coolant must be heated up to at least 60 °C.

If repair work is planned on the fuel and injection system or if the engine is shut down for longer than 24 hours, the engine should be switched to distillate fuel before it is shut down. Distillate fuel should be selected early enough to ensure that the fuel system and injection lines remain free of residual oil.

If residual oil becomes cold in the system and is no longer able to flow, the following measures must be carried out with the fuel preheating system switched on:

- Remove the injection lines, heat up e.g. with hot air and clear using the injection valve washing device.
- Clear the fuel low-pressure system and the injection pump with distillate fuel using the fuel feeder pump or manual vane pump.

Ordering parts Contact your closest Wärtsilä Services Network. When ordering please specify the engine serial number and the material numbers.

Letter distribution The Wärtsilä Services Network and users/owners of engines concerned.

Feedback E-mail to: service.sales.nl@wartsila.com

Letter validity Until further notice.
Herewith Technical Bulletin 'TB00/99/2089' - issue 01 has been cancelled.

Enclosures

Enclosure 1:	Explanation of main fuel properties,
Enclosure 2:	Viscosity - Temperature sheet
Enclosure 3:	Nomogram for determining CCAI value
Enclosures 4-6:	Fuel specification

	Explanation of main fuel properties	Enclosure 1

Density
The density is normally specified in [kg/m^3] or kg/m^3 at 15°C and is important for converting fuel consumption from units of volume to units of mass. The higher the density, the greater the mass of the injected fuel. Assuming a constant control rod setting, the higher the density, the greater the engine output.

Boiling curve
The boiling curve specifies what volume % of the fuel distils over at a certain temperature. The greater the distillation residue (amount remaining after evaporation) the more combustion deposits can occur in the engine, particularly with low-load operation.

Viscosity
The figure specified is the kinematic viscosity in [mm2/s] at a specific temperature (1 [mm^2/s] = 1 cSt [centistokes]). For operation of the engine the viscosity must remain within certain limits. If the viscosity is too high, pre-heating is required.

Flash point
The flash point is of no significance to operation of the engine. It is used to determine the fire hazard and is important for grading the fuel in one of the hazard classes (important for storage, transportation and insurance).

Sulphur
High sulphur content and low component temperature can cause increased wear as a result of corrosion. The sulphur content affects the regularity at which the lubricant has to be changed.

Carbon residue
The carbon residue provides a reference point with regard to the tendency to form deposits in the combustion chamber.

Water
Too high a water content leads to corrosion and, in connection with corrosive products and sediments, to sludge. Faults in the fuel and injection systems are the result.

Sediments
Sediments are solids (dust, rust, scale) which cause wear in the injection system and combustion chamber as well as leaks in the valves.

Ash
Ash is carbon-free combustion residue which can become deposited in the engine and exhaust turbocharger, resulting in wear.

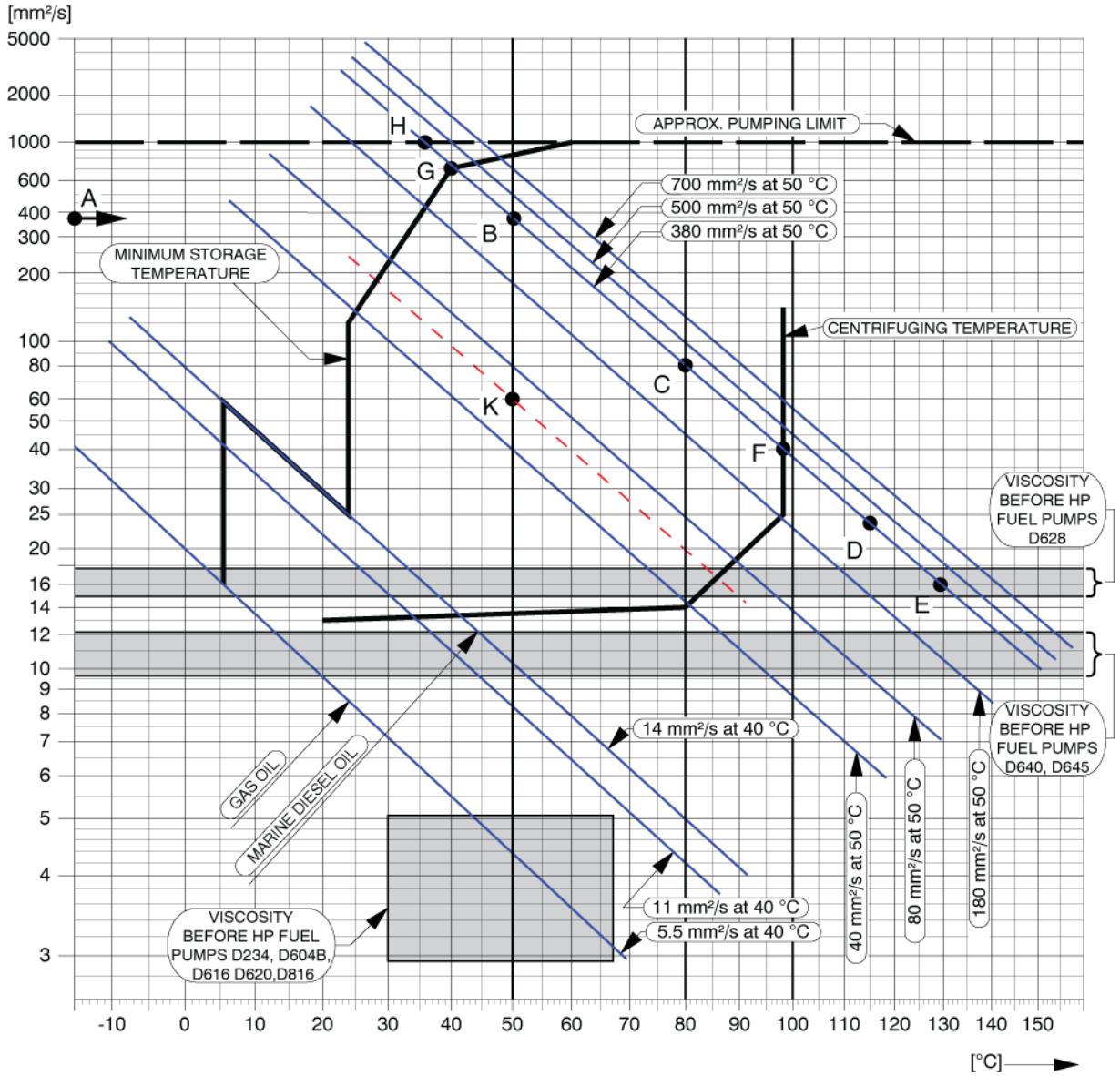
Low-temperature behaviour
The following values give an indication of the suitability of the fuel for use at low temperatures.

- The solidification point specifies at which temperature the fuel will no longer flow under its own weight.
- The pour point is approx. 3°C above the solidification point.
- The cloud point specifies at which temperature solid separations (paraffin) become visible.
- The limit value of filterability specifies at which temperature clogging of the filter and pipelines can occur.

Ignition quality
The **cetane number** gives information on the ignition performance of the fuel. Too low a cetane number can, for example, cause starting difficulties, white smoke, increased HC emissions and thermal and mechanical overloading of the engine. The cetane number is calculated using a test engine.
If the cetane number is not specified the ignition quality is determined by the **CCAI value.** This is calculated using the density ([kg/m^3] at 15°C) and the kinematic viscosity ([mm^2/s] at 50°C).

Heat value
The lower heat value specifies the heat quantity released when 1 [kg] of fuel is burnt.

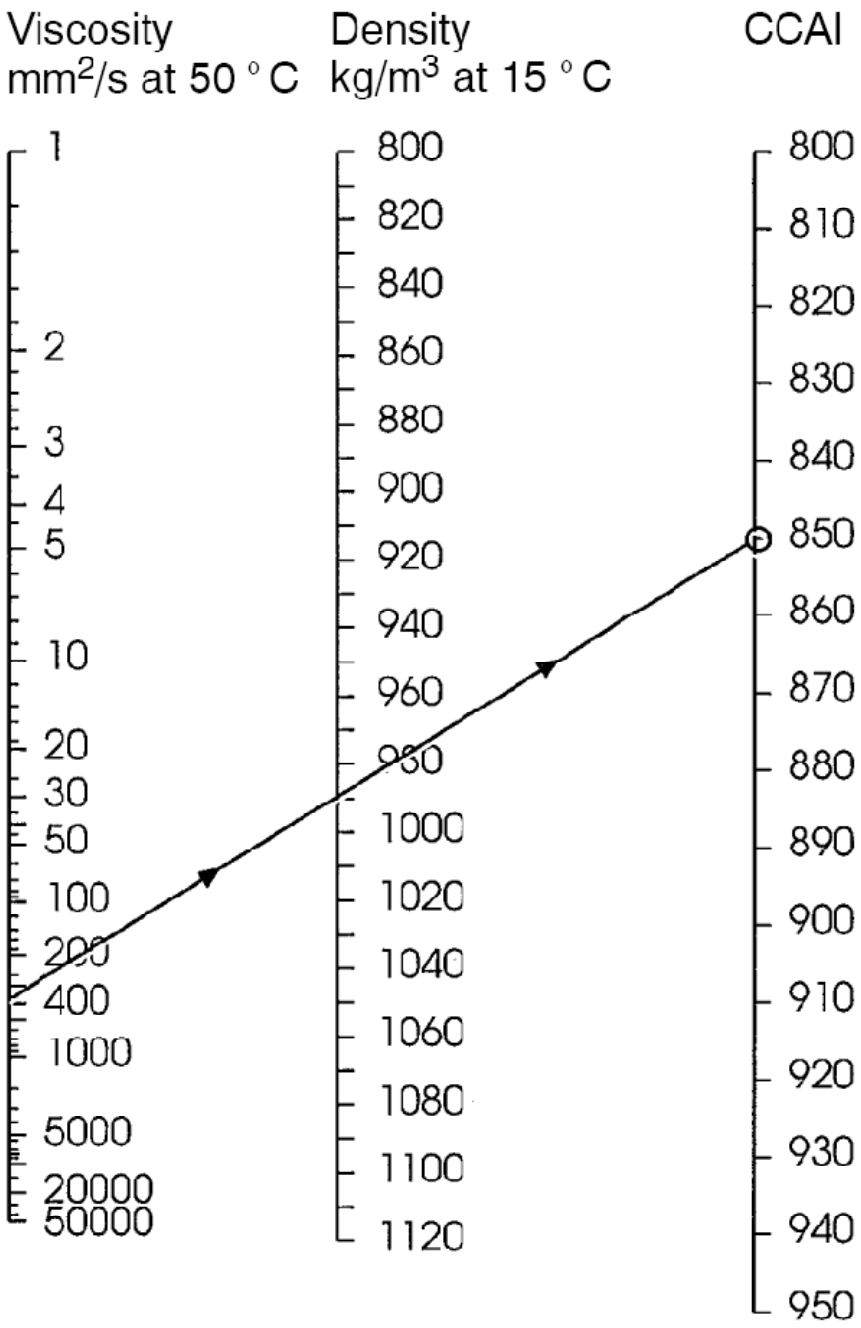
	Viscosity – Temperature sheet	Enclosure 2



The diagram shows:

- The viscosity-temperature lines for a number of viscosity grades.
  For residual fuels (ISO RM..) the viscosity is specified at 50 °C.
  For distillate fuels (ISO DM..) the viscosity is specified at 40 °C.
  The line for 380 [mm^2/s] at 50 °C fuel for instance is the one running through points H and E.
  Lines for fuels with other viscosities run parallel.
- The (horizontal) line at 1000 [mm^2/s] above which pumping is difficult.
- The line with sharp bends through point G, which shows the minimum storage temperature for all viscosity classes. For higher viscosity class fuels a higher storage viscosity is accepted to limit the heating demand.
- The line with sharp bends through point F, shows the required centrifuging temperature. For viscosity classes higher than 40 [mm^2/s] at 50 °C a higher centrifuging viscosity than 14 [mm^2/s] is accepted to save heating power. Finally the line turns vertical at 98 °C because boiling of the sealing and operating water in the centrifuge must be avoided. With further increase of viscosity the throughput through the centrifuge must be reduced for maintaining the required degree of purification.

	Nomogram for determining CCAI value	Enclosure 3



	Fuel specification (minimum requirements) Diesel fuel in accordance with **EN 590 : 1999**	**Enclosure 4**

Property	Unit	Limits		Test method [a]
		minimum	maximum	
Cetane number [c]		51,0	–	EN ISO 5165:1998
Cetane index		46,0	–	EN ISO 4264
Density at 15 °C [b]	kg/m^3	820	845	EN ISO 3675:1998 EN ISO 12185:1996
Polycyclic aromatic hydrocarbons [d, e]	% (*m/m*)	–	11	IP 391:1995
Sulfur content [b]	mg/kg	–	350	EN ISO 14596:1998 EN ISO 8754:1995 EN 24260:1994
Flash point	°C	above 55	–	EN 22719
Carbon residue [f] (on 10 % distillation residue)	% (*m/m*)	–	0,30	EN ISO 10370
Ash content	% (*m/m*)	–	0,01	EN ISO 6245
Water content	mg/kg	–	200	prEN ISO 12937:1996
Total contamination	mg/kg	–	24	EN 12662
Copper strip corrosion (3 h at 50 °C)	rating	class 1		EN ISO 2160
Oxidation stability	g/m^3	–	25	EN ISO 12205
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C	µm	–	460	ISO 12156-1
Viscosity at 40 °C	mm^2/s	2,00	4,50	EN ISO 3104
Distillation [g, h]				prEN ISO 3405:1998
% (*V/V*) recovered at 250 °C	% (*V/V*)		< 65	
% (*V/V*) recovered at 350 °C	% (*V/V*)	85		
95 % (*V/V*) recovered at	°C		360	

[a] See also 5.5.1

[b] See also 5.5.2.

[c] See also 5.5.3.

[d] For the purposes of this European Standard, polycyclic aromatic hydrocarbons are defined as the total aromatic hydrocarbon content less the mono-aromatic hydrocarbon content, both as determined by IP 391. IP 391 will be replaced by EN 12916 "Petroleum products – Determination of aromatic hydrocarbon types by high performance liquid chromatography with refractive index detection" upon publication.

[e] IP 391 is not able to distinguish between polycyclic aromatic hydrocarbons and fatty acid methyl esters (FAME). FAME, if present in diesel fuels, will give a bias which will increase the value for polycyclic aromatic hydrocarbons. An improved method for the determination of polycyclic aromatic hydrocarbons is under development by CEN/TC 19.

[f] See also 5.3.2.

[g] For the calculation of the cetane index the 10 %, 50 % and 90 % (*V/V*) recovery points are also needed.

[h] The limits for distillation at 250 °C and 350 °C are included for diesel fuel in line with EU Common Customs tariff.

	Fuel specification (minimum requirements) Distillate and intermediate fuel in accordance with **ISO 8217:2005**	**Enclosure 5**

Characteristic	**Unit**	**Limit**	**Category ISO-F-**				**Test method reference**
			DMX	**DMA**	**DMB**	**DMC** [a]	
Density at 15 °C	kg/m^3	max.	—	890,0	900,0	920,0	ISO 3675 or ISO 12185
Viscosity at 40 °C	mm^2/s [b]	min. max.	1,40 5,50	1,50 6,00	— 11,0	— 14,0	ISO 3104 ISO 3104
Flash point	°C	min. min.	— 43	60 —	60 —	60 —	ISO 2719
Pour point (upper) [c] — winter quality — summer quality	°C	 max. max.	 — —	 - 6 0	 0 6	 0 6	 ISO 3016 ISO 3016
Cloud point	°C	max.	-16 [d]	—	—	—	ISO 3015
Sulfur	% *(m/m)*	max.	1,00	1,50	2,00 [e]	2,00 [e]	ISO 8754 or ISO 14596
Cetane index	—	min.	45	40	35	—	ISO 4264
Carbon residue on 10 % *(V/V)* distillation bottoms	% *(m/m)*	max.	0,30	0,30	—	—	ISO 10370
Carbon residue	% *(m/m)*	max.	—	—	0,30	2,50	ISO 10370
Ash	% *(m/m)*	max.	0,01	0,01	0,01	0,05	ISO 6245
Appearance [f]	—	—	Clear and bright		[f]	—	
Total sediment, existent	% *(m/m)*	max.	—	—	0,10 [f]	0,10	ISO 10307-1
Water	% *(V/V)*	max.	—	—	0,3 [f]	0,3	ISO 3733
Vanadium	mg/kg	max.	—	—	—	100	ISO 14597 or IP 501 or IP 470
Aluminium plus silicon	mg/kg	max.	—	—	—	25	ISO 10478 or IP 501 or IP 470
Used lubricating oil (ULO)						The fuel shall be free of ULO [g]	
- Zinc	mg/kg	max.	—	—	—	15	IP 501 or IP 470
- Phosphorus	mg/kg	max.	—	—	—	15	IP 501 or IP 500
- Calcium	mg/kg	max.	—	—	—	30	IP 501 or IP 470

[a] Note that although predominantly consisting of distillate fuel, the residual oil proportion can be significant.

[b] 1 mm^2/s = 1 cSt

[c] Purchasers should ensure that this pour point is suitable for the equipment on board, especially if the vessel operates in both the northern and southern hemispheres.

[d] This fuel is suitable for use without heating at ambient temperatures down to − 16 °C.

[e] A sulfur limit of 1,5 % *(m/m)* will apply in SO_x emission control areas designated by the International Maritime Organization, when its relevant protocol enters into force. There may be local variations, for example the EU requires that sulphur content of certain distillate grades be limited to 0,2 % *(m/m)* in certain applications.

[f] If the sample is clear and with no visible sediment or water, the total sediment existent and water tests shall not be required.

[g] A fuel shall be considered to be free of used lubricating oils (ULOs) if one or more of the elements zinc, phosphorus and calcium are below or at the specified limits. All three elements shall exceed the same limits before a fuel shall be deemed to contain ULOs.

Fuel specification
(minimum requirements)
Residual marine fuel in accordance with
ISO 8217:2005

Enclosure 6

Characteristic	Unit	Limit	Category ISO-F-										Test method reference
			RMA 30	**RMB 30**	**RMD 80**	**RME 180**	**RMF 180**	**RMG 380**	**RMH 380**	**RMK 380**	**RMH 700**	**RMK 700**	
Density at 15 °C	kg/m^3	max.	960,0	975,0	980,0	991,0		991,0		1010,0	991,0	1010,0	ISO 3675 or ISO 12185
Kinematic viscosity at 50 °C	mm^2/s [a]	max.	30,0		80,0	180,0		380,0			700,0		ISO 3104
Flash point	°C	min.	60		60	60		60			60		ISO 2719
Pour point (upper) [b] - winter quality - summer quality	°C	 max. max.	 0 6	 24 24	 30 30	 30 30		 30 30			 30 30		 ISO 3016 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 [c]	% *(m/m)*	max.	3,50		4,00	4,50		4,50			4,50		ISO 8754 or ISO 14596
Vanadium	mg/kg	max.	150		350	200	500	300	600		600		ISO 14597 or IP 501 or IP 470
Total sediment potential	% (*m/m*)	max.	0,10		0,10	0,10		0,10			0,10		ISO 10307-2
Aluminium plus silicon	mg/kg	max.	80		80	80		80			80		ISO 10478 or IP 501 or IP 470
Used lubricating oil (ULO) - Zinc - Phosphorus - Calcium	mg/kg	 max. max. max.	The fuel shall be free of ULO [d] 15 15 30										 IP 501 or IP 470 IP 501 or IP 500 IP 501 or IP 470

[a] Annex C gives a brief viscosity/temperature table, for information purposes only. 1 mm^2/s = 1 cSt

[b] Purchasers should ensure that this pour point is suitable for the equipment on board, especially if the vessel operates in both the northern and southern hemispheres.

[c] A sulfur limit of 1,5 % *(m/m)* will apply in SO_x emission control areas designated by the International Maritime Organization, when its relevant protocol comes into force. There may be local variations.

[d] 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. All three elements shall exceed the same limits before a fuel shall be deemed to contain ULO.