Technical Considerations of Fuel Switching Practices

API Technical Issues Workgroup

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I. Introduction

API and its members recognize that the burning of cleaner fuels in the main engine of ships while coming into regulated waters is likely to become widespread. California plans to implement legislation for its coast effective July 2009, and the US and Canada have proposed a North American Emission Control Area that will most likely become effective in mid-2012.

In March 2007, the California Air Resources Board (CARB) held its first workshop to introduce the concept of cleaner fuels in the main engine of ships while coming into California waters. Concerns were expressed that the fuel switching process would introduce a risk of a vessel's main or auxiliary engines shutting down while it was entering restricted waters. Subsequently, an API Marine Engine Technical Issues Working Group was formed to investigate potential concerns when switching from residual fuel to distillate, and vice versa, in slow and medium speed diesel engine powered vessels.

The Working Group's review found that an unscheduled shut down of the main or auxiliary engine(s) could occur as a result of one or more of the following events

- Fuel temperature during change over causing sticking/scuffing of high pressure fuel injection components as a result of thermal shock and reduced fuel oil viscosity and lubricity at the high pressure fuel pump inlet.
- Prolonged service with mismatched crankcase or cylinder lubricating oil resulting in accelerated piston ring/liner wear.
- The incompatibility of the fuels being switched causing sticking/scuffing of high pressure fuel injection components, or complete fuel pump seizure.
- Liner lacquering resulting in difficulties maintaining a sufficient oil film thickness

Incidents caused by temperature, mismatched lubricating oils and liner lacquering can be avoided or controlled onboard by understanding and mitigating the risk using defined and proven change over procedures. Fuel incompatibility issues are more difficult to identify so onboard personnel should be aware of these issues. Industry is working to improve the handling of bunkers, including better control of fuel quality, the provision of more rigorous quality assurance, and greater oversight of fuel suppliers.

Scope

- These guidance notes are intended for the use of vessel operators with main diesel engines normally running on residual fuel oil that need to change over to low sulphur distillate to meet regulatory requirements.
- When available, applicable engine manufacture's instructions should be followed.

- In order to make the changeover process simpler and secure, the use of an automatic control system is preferable. However, not all vessels are fitted with an automated system and generic change-over procedures are given.
- For the purpose of these notes Heavy Fuel Oil (HFO) and Intermediate Fuel Oil (IFO) are referred to as residual fuels and are assumed to have higher sulphur content. Marine Diesel Oil (MDO) and Marine Gas Oil (MGO) are referred to as distillate fuels and are assumed to have lower sulphur content.

II. Operational Concerns

Crankcase and Cylinder lubricating oil

- In addition to necessary mechanical lubrication, the cylinder oil of slow speed engines and crankcase oil of medium speed engines contains base (also called alkalinity) which neutralizes any acid formed. The base consists primarily of calcium carbonate (limestone – $CaCO_3$) and is measured by the base number (BN). After reaction with acid, calcium sulphate (gypsum – $CaSO_4$) is formed.

  In the slow speed engine unreacted base ($CaCO_3$) can form a very hard deposit on the piston crown. If excess deposit is formed, the lubricant film can be disrupted and scuffing or sudden severe wear may take place.

  Although neutralization is important, some engine designers believe that a degree of corrosion is not entirely bad for an engine. A limited degree of corrosion keeps the metal micro-structure of the cylinder liner surface open which enables the lubricating oil to better adhere to the surface ensuring a good oil film.

  For the above reasons, it is important that a proper balance is maintained between the base coming from the lube oil and the fuel sulphur level in order to avoid excessive deposit and to keep the cylinder liner metal structure open.
- With engines that do not operate permanently on distillate fuel oil (i.e. only during maneuvering or port stays), the lube oil should be selected on the basis of the highest sulphur content of the fuels used (this is normally BN70)
- Continuous operation with residual fuel oil is recommended for engines and plants designed for running on residual fuel oil. Changing to distillate is only recommended when absolutely necessary, for example:
  - For flushing the engine before maintenance.
  - When the heating plant is not available.
  - Due to regulatory reasons when entering waters with regulated fuel requirements.
- When distillate fuel oil (MDO or MGO) is to be used only for temporary engine operation (e.g. in port) continued use of higher Total Base Number (TBN) oil used for residual fuel oil should not present any problems. Manufactures guidance of an acceptable period of temporary operation can vary from 3 to 14 days.
  In addition, some engine manufactures recommend a reduction of the cylinder lubricating oil feed rate during this period to minimize the effects of the mismatch of fuel sulphur content (acidity) and cylinder lubricating oil TBN (alkalinity).

- A lower TBN crankcase oil for medium speed engines or cylinder lube oil for slow speed engines should be selected only if a distillate fuel is going to be used permanently or for prolong periods of time.
- If a vessel engages in trade where frequent fuel changes must be made, consideration should be given to providing for a second grade of cylinder oil that has a lower base number than the first.

Reduced Viscosity and Lubricity of low Sulphur Distillate oil

- The sulphur content of residual fuel oil has a lubricating effect. Poor lubricity of low sulphur distillate fuel was not considered a problem for fuel injection components as long as the sulphur content was above 100ppm (=0.01%) S-content. Unfortunately, there had been little industry experience of operating engines for prolonged periods on distillate fuel with such low sulphur content. However, it is understood that there has recently been incidents of poor lubrication reported within vessels that operate medium speed engines on distillate fuel with sulphur content below 0.05% for prolonged periods. Such cases may require the fitting of a fuel pump plunger/barrel lubrication system for regular continued operation with the ultra low sulphur distillate fuel. The modification if required would add both mechanical complication and cost for the engines continued operation.
- Most modern marine diesel engines are suitable for continuous operation on distillate with viscosity down to 2.0 to 2.5 cSt. However, the minimum kinematic viscosity at 40°C as per ISO8217 is 1.5 mm/s^2(cSt) for DMA type distillate fuel and in the Shipping Industry an average value of about 4.0 would normally be expected for DMB, see Appendix 3.
- The use of distillate fuel with low sulphur content and, at the same time, low viscosity might cause fuel pump and fuel valve wear and, consequently, the risk of sticking. However, from the hydrodynamic lubrication point of view, if the viscosity is high enough and, thereby, the oil film is thick enough, low-sulphur fuel can be used.
- The temperature of distillate fuel service tanks within the engine-room can rise as a result of heat transfer from adjacent heated residual oil tanks and/or an elevated surrounding air temperature. Consequently, it may be necessary to cool lower viscosity distillate fuel to increase the viscosity above 2.0 mm/s^2(cSt).
- Older engines that have been operating quite satisfactorily on higher viscosity residual fuel oil may suffer leakage and decreased fuel pump efficiency when operating on lower viscosity distillate fuel oil due to wear in the injection pumps.

Reduced Density of Distillate oil

- Distillate fuel normally has a higher calorific value and a lower density than residual fuel. This can result in an increased fuel rack position to deliver the same specific energy per stroke, which may result in the fuel pump reaching its capacity at a lower power output than when operating on residual fuel. For most vessels this will not be an issue as there is sufficient margin in the fuel pump capacity.

Temperature

- When switching from residual to distillate fuel, changing the fuel temperature too quickly or uneven temperature changes may cause thermal shock causing uncontrolled clearance adaptation which can result in sticking/scuffing of the fuel valves, fuel pump plungers and suction valves.

- To protect the injection equipment against rapid temperature changes the changeover from residual to distillate must be carried out slowly in order to allow the temperature of the fuel pumps to decrease from up to 150°C in residual fuel operation to a maximum 50°C (MGO) – 60°C (MDO) in distillate fuel operation. This is essential in order to avoid pump seizure due to the low viscosity of the diesel fuel and thermal shock.
- Engine manufactures indicate that the temperature should not change by more than 2°C/min resulting in a change over time of about 50 minutes. This needs to be factored into voyage planning to ensure that the engine department is not rushed to meet a change-over requirement before entering regulated waters. OPA'90 and STCW working hour requirements, weather, etc., and now fuel switching must be dealt with by the vessel in the process of making arrival.
- There is risk that with prolonged operation on distillate fuel oil the maximum admissible fuel temperature may be exceeded due to the system heating the fuel and the hot fuel being re-circulated into the mixing tank. An elevated distillate/residual mix may result in the distillate vaporizing and "gassing-up" the booster pumps causing the engine to stop. In this instance the shut-off valves in the return pipe may have to be switched so that the distillate fuel oil is returned to the service tank instead of the mixing tank. To avoid possible incompatibility issues returning distillate to the residual fuel service tank should be kept to a minimum.
- For engines designed to operate predominantly on residual fuel, injection valve cooling in operation is common. In order to prevent over-cooling when operating on distillate fuel exceeding 72hrs the engine manufacture may recommend that nozzle cooling is to be switched off and the supply line closed, however, the return pipe is to remain open.
- At all times, whether operated on distillate or residual fuels, the engine and its components are to be maintained at normal service temperature.
- Care should be taken that the residual fuel oil service and settling tanks are maintained at their normal temperature, i.e. tank heating and oil purification must be monitored.

<u>Incompatibility of fuels</u>

- A successful transition from residual to distillate fuel is dependent upon the compatibility between the products.
- Most commonly available distillates are compatible with most residual fuel oils. However, the low sulphur content of a distillate fuel oil with low aromatic hydrocarbon content often correlates with poor solubility of asphaltenes and may be incompatible with residuals that are rich in asphaltenes.
- ISO 8217:2005 has no specific testing requirements for determining the propensity for asphaltenes to precipitate out of a residual fuel, or for determining the interaction between asphaltenes and distillate fuels.
- The changeover procedure can be time consuming. Throughout the procedure, there will be a mix of the two very different fuels for an extended period of time. During this phase, asphaltenes of the residual fuel are likely to precipitate out of the mixture as heavy sludge, which in turn may cause clogging of fuel filters and separators, sticking

of fuel injection pumps (asphaltene deposits on plunger and barrel), and plugged fuel nozzles.

- Testing and analysis of an externally contaminated residual fuel from the US Gulf region revealed it had an acid number above the global average. Further investigation confirmed that the external contamination is linked to fatty acids, such as hexadecanoic and octadecanoic acids. Other compounds found in the fuel samples included heptanol, dioxane, phenol, phenoxy ethanol, trimethyl norborane, phenyl ethanol and phenoxy propanol, which are used as chemical intermediates, solvents and in the cosmetics, flavorings and fragrance industries. Use of low quality fuel such as these may exacerbate incompatibility problems when mixed with other fuels. Annex VI prohibits the presence of these materials in bunker fuels. However, there are no tests in ISO 8217:2005 to detect the presence of materials of this nature. Compliance is on the "honor system" by the fuel suppliers.
- As residual fuel quality diminishes over time and as fuel blending becomes a necessity to meet viscosity and sulfur requirements, the possibility of receiving residuals that are high in asphaltenes and are susceptible to separating increases.
- It is important to note that because there are no specific tests associated with ISO 8217:2005 regarding compatibility of residual fuels and distillates, the ship's engineers are often limited to spot testing. Onboard spot testing of fuels to identify potential problems may be of limited value, often providing engine room personnel with less than satisfactory results.
- Theoretically, residual fuels and distillates should be compatible based on commonly available bunkers and distillates. However, because compatibility is often linked to the crude oil from which the end product is derived, a vessel that takes its residual fuel in the Far East and its distillate on the U.S. West Coast could have an inherent issue that is not readily apparent.

Liner lacquering

- Liner lacquering has been observed on four-stroke engines operating on low sulphur (mainly distillate) fuels. The lacquer fills in the honing grooves of the liner which results in difficulties in maintaining a good oil film. This can result in high lubricating oil consumption.

III. Possible Procedure for Changeover between High and Low-Viscosity Fuels

NOTE: The following is a generic description of a fuel system. Fuel systems may vary from vessel to vessel.

Change-over from Distillate Fuel Oil to Residual Fuel Oil.

- Open the steam supply or switch on the electrical supply to the fuel oil heater(s) and the trace heating.
- Swing the three-way cock on the service tank outlets from the Distillate Fuel to the Residual Fuel Oil operating position.
- Engine fuel pump fuel inlet temperature control:-
  - For those systems with automated viscosity control - the system should have been initially set in accordance with the engine manufactures recommendations and doesn't normally require adjustment.
  - For those systems without automated viscosity control - the fuel oil heater outlet temperature should be slowly increased in proportion to the amount of residual fuel in the system.

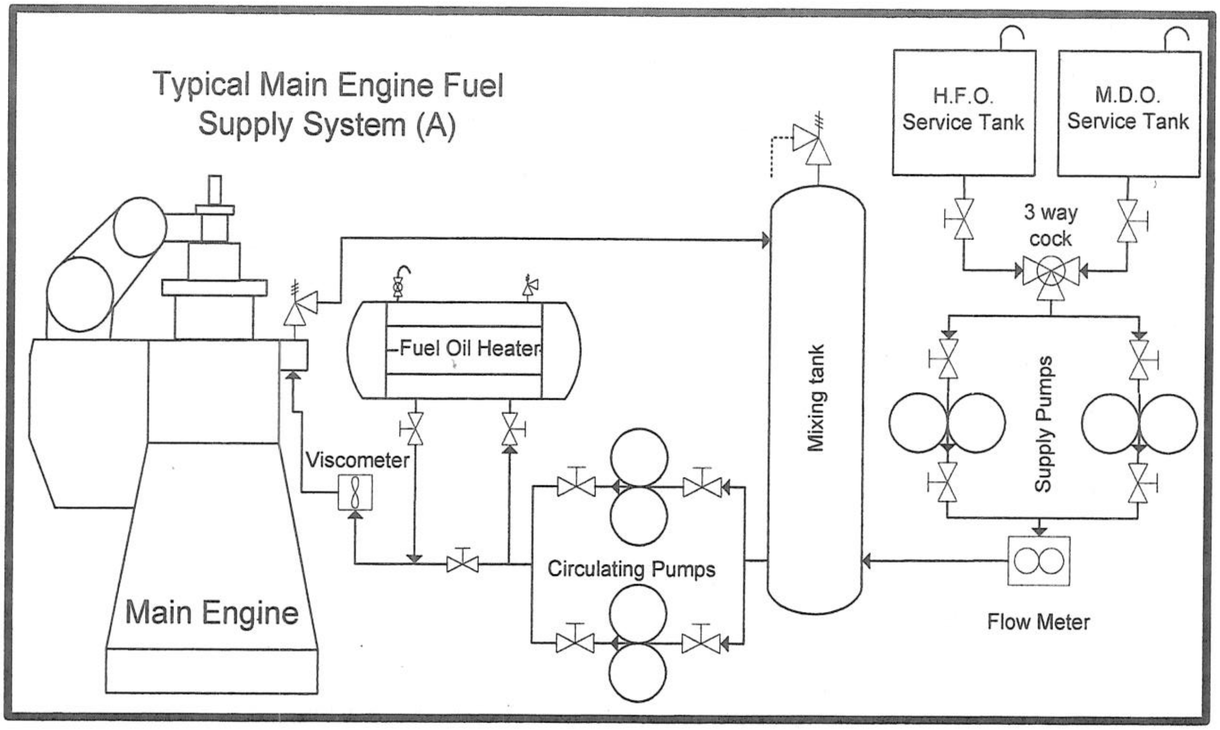
Change-over from Residual Fuel Oil to Distillate Fuel Oil.

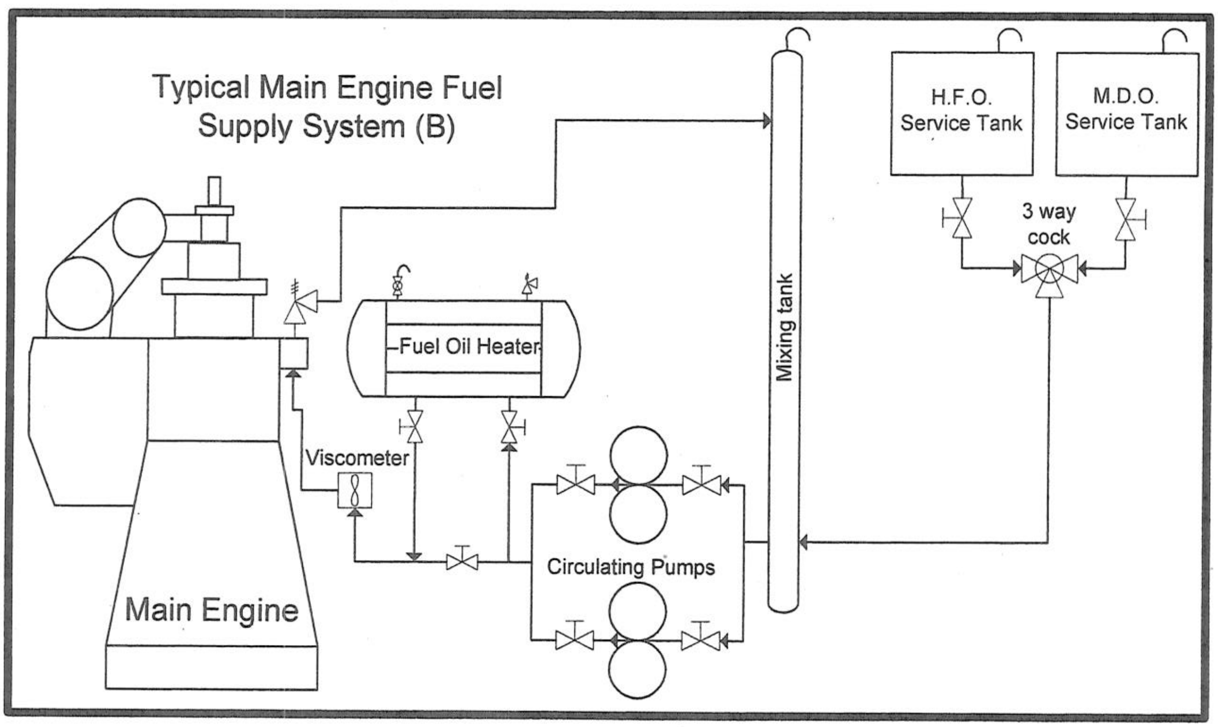
- When to change-over
  - Typically, the time the change-over should be started is governed by the manufactures recommended maximum temperature gradient and will normally be in the region of 35 to 45 minutes.
  - If the fuel system's capacity and the typical fuel consumptions are known, it is possible to calculate when the change-over should be started in order to ensure that all the residual fuel is consumed prior to arrival. Appendix 2 gives a spreadsheet function that can be used and some typical results. This can be confirmed by bleeding a sample of fuel at the engine fuel injectors or fuel pumps.
- Swing the three-way cock on the service tank outlets from the Residual Fuel Oil to the Distillate Fuel operating position.
- Engine fuel pump fuel inlet temperature control:
  - For those systems with automated viscosity control - the system was initially set in accordance with the engine manufactures recommendations and doesn't normally require adjustment.
  - For those systems without automated viscosity control - the fuel oil heater outlet temperature should be slowly decreased in proportion to the amount of residual fuel in the system.

    Note: With both arrangements, fuel injection equipment can be damaged and circulating pumps can "gas-up" if the change-over is carried out too quickly.
- Close the steam supply or switch off the electrical supply to the fuel oil heater(s) and the trace heating.

Appendix 1 shows two examples of common fuel system arrangements.

Appendix 1 Common fuel system diagrams





Appendix 2 Change-over Time

	A	B	C	D	E
1				Cons. (m3/hr)	2
2	Time (mins)	% Residual	Residual Remaining (Ltrs)	System Capacity (Ltrs)	250
3	n	=ROUND(100*(1-($E$2-C3)/$E$2),0)	=E2		
4	n+1	=ROUND(100*(1-($E$2-C4)/$E$2),0)	=ROUND(C3-(C3*(1000*$E$1)/60)/$E$2),0)		
	0	100	250		
	1	87	217		
	2	75	188		
	3	65	163		
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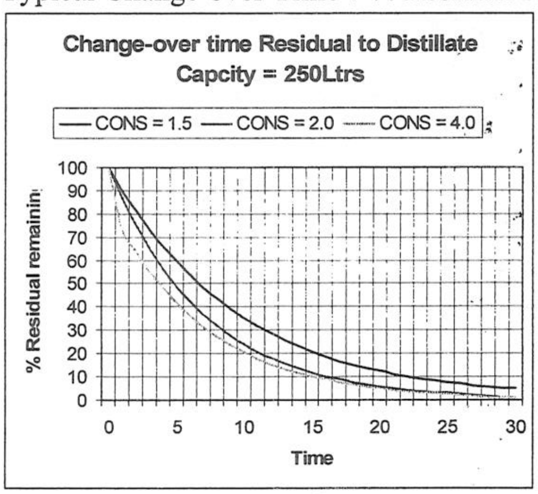
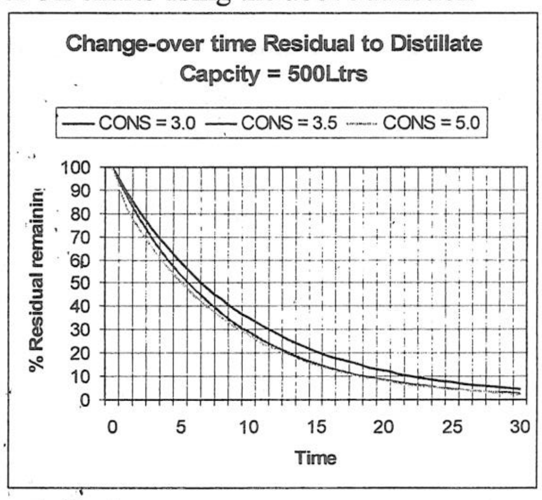
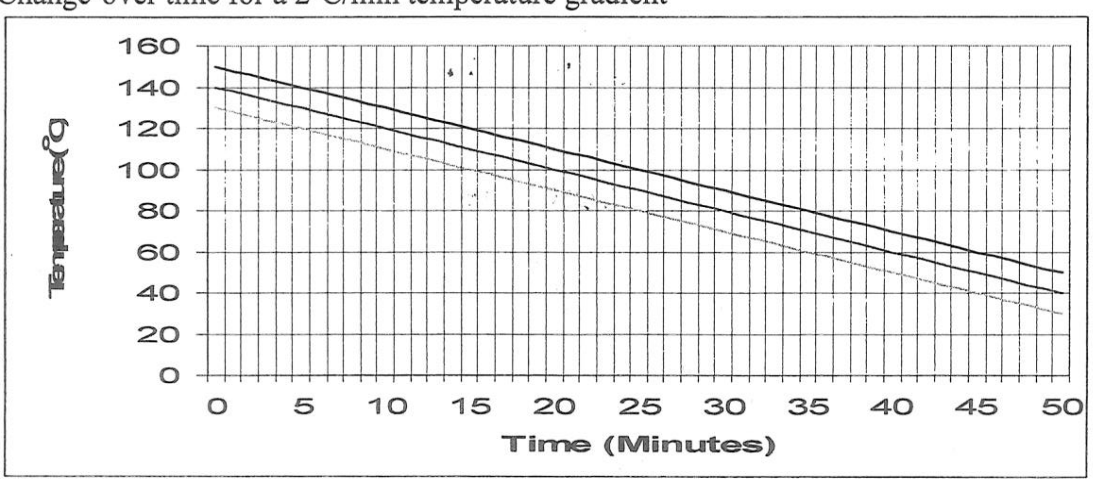
	28	2	3		
	29	1	3		
	30	1	3		

Typical Change-over Time v % Residual Fuel Oil charts using the above function

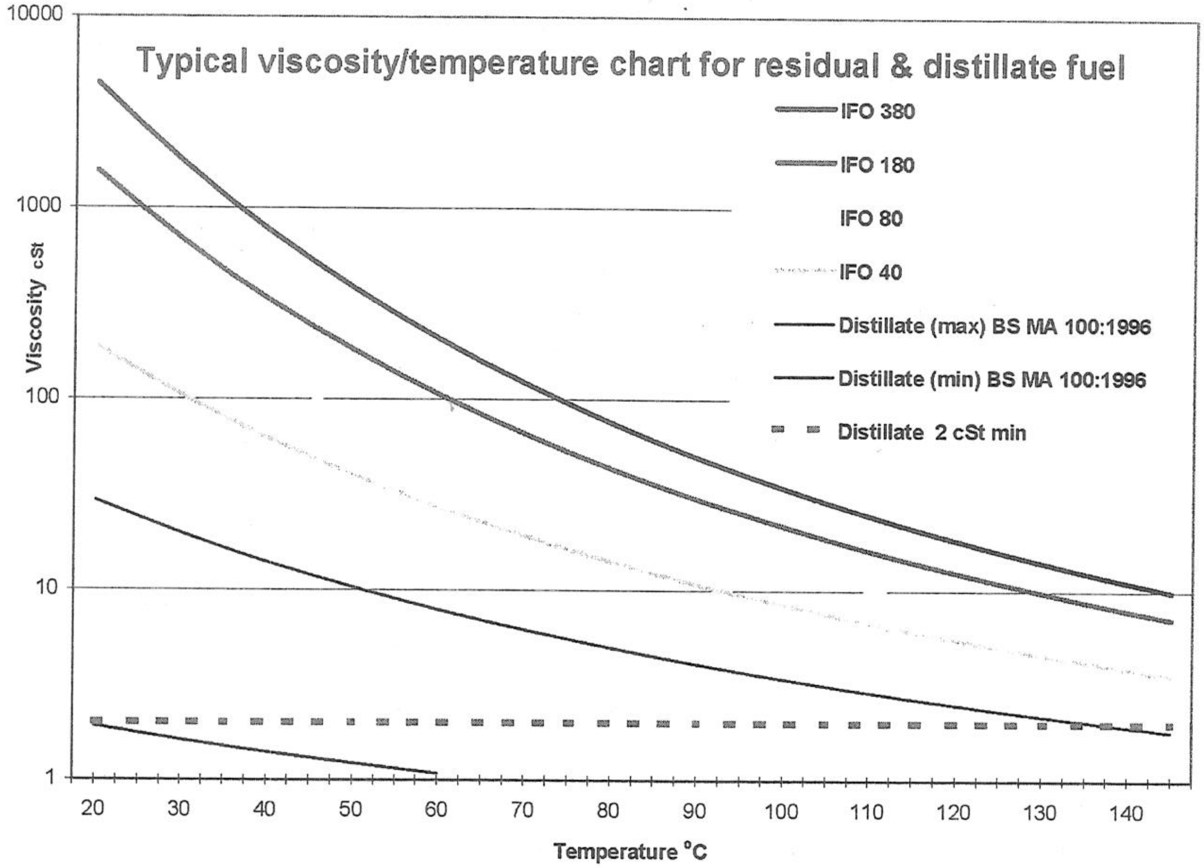




Change-over time for a 2°C/min temperature gradient



Appendix 3



References

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2. MAN B&W - Operation on Low-Sulphur Fuel Two-Stroke Engines
3. MAN - Diesel Customer Information – Operation of MAN Diesel medium-speed engines on low sulphur fuels
4. WARTSILA - Low Sulphur Guidelines
5. The International Council on Combustion Engines - Guidelines for Diesel Engine Lubrication – Impact of low sulphur fuel on lubrication of marine engines.
6. ISO 8217:2005
7. MARPOL Annex VI
8. BP Marine Bunker Fuels Calculator, version 1.2