



**MANUAL FOR THE COURSE**

# **Fuel Oil Quality**

**and**

# **Fuel Oil Treatment**

a joint course arranged by

**DNV Petroleum Services**

**and**

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## PREFACE

The aim of this course is to provide basic information regarding refinery processes, the blending and composition of marine fuel grades, the relationship between these factors and the properties of the fuels with respect to storage, handling, shipboard treatment and combustion.

Since the early 1970's there have been predictions that by the end of the twentieth century, the quality of marine fuel oils will have deteriorated to such an extent that it will no longer be possible to utilise conventional handling and treatment techniques on board vessels. Obviously these predictions were vastly incorrect.

The quality of marine fuels was, for many years, acceptable and fairly predictable, but due to improved refining techniques, the residual fuel quality suffered and the necessary blending has made the quality less predictable. However, we believe that the overall situation is not as desperate as some predicted a decade ago. The majority of fuel deliveries to vessels continue to pass without incident with ship owners finding they are able to obtain the quantity and quality of fuel needed for their vessels without too much trouble.

Unfortunately this is not always the case and occasionally vessels are delayed on voyage and/or suffer main or auxiliary machinery damage as a direct result of loading poor quality fuel oil. We believe that, as with the majority of machinery failures, fuel-related incidents are largely predictable, and can be avoided or their severity reduced if reasonable care is taken during the initial stages of the bunkering operation. Through this course the problems associated with the ordering, receiving, quantifying, handling, treating and burning of marine fuel oils will be addressed and some ideas put forward to help the ship owner and vessel operator to reduce the risks of voyage delays and machinery failures.

The course is directed towards participants with a broad background ranging from those directly involved in vessel operations and maintenance, to solicitors handling fuel oil quality disputes, and from marine engineering students to those connected with the business of marine insurance.

It is hoped that the course will be of assistance to those connected with all aspects of marine bunkering activities and particularly provide ship owners and operators with some basic ideas for the development of a fuel management programme which should form an integral part of a vessel's programme of planned maintenance and condition monitoring.

# **PETROLEUM**

# **GLOSSARY**



<b>Absorption</b>	Variation of peaks at specific wave lengths in FTIR (DIR), indicating deterioration, oxidation, nitration, reduction in additive concentration. See also "DIR" and "FTIR".
<b>Abrasive Wear</b>	Wear caused by abrasive particles
<b>ACEA</b>	Association des Constructeurs Europeens de l'Automobile (Association of European Automotive manufacturers)
<b>Acid</b>	Any substance containing hydrogen in combination with a non-metallic element(s) and capable of producing hydrogen ions in solution. An acid is capable of neutralising or being neutralised by a base.
<b>Acidity</b>	In lubricants, acidity denotes the presence of acidic constituents whose concentration is usually defined in terms of an acid number. The number denotes mg KOH consumed when 100g of the oil sample is titrated under the condition of the test method.
<b>Additives</b>	A chemical compound or compounds added to a lubricating oil for the purpose of imparting new properties or enhancing existing properties.
<b>Adhesive Wear</b>	Wear caused by metal to metal contact due to oil film break down eg scuffing
<b>Air/Fuel ratio</b>	Ratio of air mass to fuel mass present in cylinder at start of combustion.
<b>AN</b>	Acid Number, has replaced TAN (Total Acid Number)
<b>Aniline Point</b>	The lowest temperature at which a hydrocarbon fluid is completely miscible with an equal quantity of aniline. The higher the reading, the lower the aromatic content, and hence the smaller the effect on rubber.
<b>Antifoam Agent</b>	An additive used to suppress the foaming tendency of petroleum products in service. May be a silicone oil to break up surface bubbles or a polymer to decrease the number of small entrained bubbles.
<b>Antiwear Agent</b>	Additives or their reaction products which form thin, tenacious films on highly loaded parts to prevent metal-to-metal contact.
<b>API</b>	American Petroleum Institute
<b>API Gravity</b>	In the USA an arbitrary scale known as the API degree is used for reporting the gravity of a petroleum product. The degree API is related to the specific gravity scale (60°F/60°F) by the formula:  $\text{Degree API} = \frac{141.5}{\text{Sp.GR.}_{60^{\circ}\text{F}/60^{\circ}\text{F}}} - 131.5$
<b>Aromatics</b>	Hydrocarbons of ring structure having the smallest hydrogen to carbon ratio.
<b>Ash</b>	Inorganic, non combustible solid residue remaining after combustion. Some additives, particularly conventional detergent additives, leave behind a powdery residue after combustion.  For petroleum fuels, the ash content quoted is normally that obtained by simple high temperature combustion, sometimes called "oxide ash".  For lubricants, the ash is treated with sulphuric acid after partial combustion, and the final result is in terms of "sulphated ash".  Excess ash can cause engine malfunction if allowed to build up in the combustion chamber, cylinder liner ports and turbochargers.
<b>Ash (Sulphated)</b>	The ash content of an oil, determined by burning the oil and complexing the metals in the residue with sulphuric acid. Expressed as % by mass.
<b>Asphaltenes</b>	Components of asphalt which are insoluble in petroleum naphtha but are soluble in aromatic solvents. They are made up largely of high molecular weight polynuclear hydrocarbon derivatives containing carbon, hydrogen, sulphur, nitrogen, oxygen and usually nickel, iron and vanadium.
<b>ASTM :</b>	American Society for Testing Materials
<b>Bactericide</b>	A biocide specifically formulated to kill bacteria.
<b>Barrel</b>	A unit of volume measurement used for petroleum and petroleum products. a barrel = 42 US Gallons, = 35 Imperial Gallons or = 159 litres.
<b>Base</b>	A compound which reacts with an acid to produce a salt plus water.
<b>Base Number</b>	A measure of the acid-neutralising power in a lubricating oil, also known as Total Base

	Number.
<b>Base Stock(Base Oil)</b>	Refined petroleum oil used in the production of lubricants and other products. The base stock may be used alone or blended with other base stocks and/or additives, to manufacture a finished lubricant.
<b>Beta Value</b>	Defined as the number of particles bigger than the specified size after filter. See ISO 4572.
<b>BFOC</b>	See "SFOC" - the preferred term.
<b>Biogas</b>	Gases derived from microbial or biochemical decomposition processes. Main components : methane, carbon dioxide, often H <sub>2</sub> S.
<b>Bitumen</b>	A viscous liquid or solid consisting of hydrocarbons and their derivatives which is soluble in an aromatic solvent such as benzene. It is non volatile and softens when heated. Bitumen may be black or brown in colour and possesses waterproofing and adhesive properties. It is obtained from refinery processes but is also found as a natural deposit.
<b>Black Oils</b>	Asphaltic materials are added to lubricants used for open gears and steel cables to impart extra adhesiveness, giving them the characteristic black colour.
<b>Blending</b>	The intimate mixing of various components, including base oils and additives, in the preparation of a product of specified properties.
<b>Blended Fuel Oil</b>	A mixture of residual and distillate fuel oils.
<b>Blow-by</b>	Passage of combustion gases past the piston rings of internal combustion engines, resulting in contamination of the crankcase oil.
<b>Boundary Lubrication</b>	Lubrication between two rubbing surfaces without the development of a full fluid lubricating film. It occurs under high loads and requires the use of antiwear or EP additives to prevent metal-to-metal contact.
<b>BSOC</b>	See "SLOC" - the preferred term.
<b>Bulk Modulus</b>	The reciprocal of the compressibility of an oil. The higher the Bulk Modulus of a fluid, the greater its incompressibility.
<b>Bunker C</b>	A term used by some bunker suppliers to describe a high viscosity marine fuel oil.
<b>Calorific Value</b>	The heat liberated by combustion of a fuel. Also termed specific energy, heat energy, and heat of combustion. Gross (upper) value usually quoted, but net (lower) value also used in many calculations.
<b>Cams</b>	Eccentric lobes attached to a camshaft and driven by a crankshaft which are used in most internal combustion engines to open and close valves and sometimes operate fuel pumps.
<b>CARB</b>	California Air Resources Board.
<b>Carbon Residue</b>	Coked material remaining after an oil has been exposed to high temperatures (without oxygen) under controlled test conditions. Carbon residue is thus an indicator of the coke forming tendencies of an oil. It can be expressed as Conradson (CCR), Ramsbottom (RCR) or Micro-Carbon Residue (MCR).
<b>Catalyst Fines</b>	Small (typically less than 50 micron) particles of aluminium silicate used as a catalyst in catalytic cracking (cat cracker) refineries. They are sometimes carried over in the refinery process and can be found in residual fuels. They are very abrasive and can cause excessive wear in engine parts - particularly fuel pumps, injectors, cylinder liners and piston rings.
<b>Catalytic Cracking</b>	Process of breaking down the larger molecules of heavy oils into smaller ones by the action of heat, with the aid of a catalyst. In this way heavy oils can be converted into lighter and more valuable products. It is commonly referred to as cat cracking.
<b>Centipoise (cP)</b>	See Poise
<b>Centistoke (cSt)</b>	See Stoke
<b>Cetane Index</b>	A measure of the ignition quality of a distillate fuel, that is the relative ease with which the fuel will ignite when injected into a compression - ignition engine. Cetane Index is <u>calculated</u> from the API gravity and the mid boiling point of the fuel. High Cetane Indices indicate shorter ignition delays and are associated with better combustion performances.
<b>Cetane Number</b>	Similar to Cetane Index but is derived from a standard <u>engine test</u> rather than by calculation.
<b>Chemisorption</b>	Many gases react with surfaces by chemically bonding. In contrast to physisorption, chemical adsorption (chemisorption) involves the formation of strong chemical bonds between adsorbate molecules and specific surface locations known as chemically active sites. Chemisorption is thus used primarily to count the number of surface active sites which are likely to promote chemical and catalytic reactions.
<b>CHP</b>	Combined Heat & Power. Term for all engines generating heat and power ( co-generation )

<b>Cloud Point</b>	The temperature at which a cloud or haze begins to appear when an oil, which has been previously dried, is cooled under prescribed conditions. Such a cloud or haze is usually due to the separation of wax from the oil.
<b>COC</b>	Flash point measured by Cleveland Open-cup
<b>Cold Filter Plugging Point(CFPP)</b>	A measure of the ability of diesel fuels to flow at low temperature. A fuel with a low CFPP is capable of being used satisfactorily at low ambient temperatures and not cause blockages in fuel systems through the precipitation of wax particles.
<b>Compatibility</b>	Refers to the sediment-forming tendency of a manufactured fuel when mixed with another fuel.
<b>Copper Strip Corrosion</b>	A qualitative measure of the tendency of a petroleum product to corrode pure copper.
<b>Corrosion Inhibitor</b>	A substance added to a lubricant to protect against metal corrosion.
<b>Cracking</b>	Process whereby the large molecules of heavier oils are converted into smaller molecules. When this is brought about by heat alone, the process is known as thermal cracking. If a catalyst is also used the process is referred to as catalytic cracking or hydrocracking if the process is conducted over special catalysts in a hydrogen atmosphere.
<b>Crosshead Diesel Engine</b>	Slow-speed marine diesel engine with separate lubrication systems for cylinders and crankcase. Invariably operating on the 2-stroke cycle these engines derive their name from the crosshead bearing which couples the piston rod and the connecting rod.
<b>Crown</b>	The top of the piston of an internal combustion engine above the firing ring which is exposed to direct flame impingement.
<b>CSR</b>	Continuous Service Rating – typically 80-90% MCR
<b>Cutback</b>	Reducing viscosity by blending.
<b>Cylinder Oil</b>	Lubricating oil having a high BN for the lubrication of the cylinders of crosshead marine diesel engines and some types of trunk piston engines.
<b>Demulsibility</b>	The ability of lubricant to withstand the formation of an emulsion with water. This property is measured by a test which times the separation of a well-mixed sample of oil and water, and gives a 'demulsification Number' or 'Value'.
<b>Density</b>	The mass (weight in vacuum) of a liquid per unit volume. The temperature must be specified, usually 15°C for petroleum products. The preferred S.I. units are kg/m <sup>3</sup> . However, it is frequently referred to in kg/l or g/ml. This has largely replaced relative density (specific gravity) which is the ratio of the mass of a given volume of liquid at one temperature to the mass of an equal volume of pure water at the same or another temperature.
<b>Detergent</b>	A substance added to a lubricant to keep engine parts clean. In engine oil formulations, the detergents most commonly used are metallic soaps with a reserve of basicity to neutralise acids formed during combustion.
<b>Detonation</b>	Uncontrolled ignition/combustion with very high flame speed. Severe pressure waves with hard noise known as knocking. High risk of mechanical/thermal damage.
<b>Dew Point</b>	The temperature at which water vapour in the air starts to condense to liquid.
<b>Diesel Fuel</b>	Usually defines a heavy distillate that can contain small amounts of a residual fuel. Commonly known as marine diesel fuel (MDF) or marine diesel oil (MDO). Should not be confused with Gas Oil (MGO).
<b>Diesel Index</b>	A calculated indicator of the ignition quality of a diesel fuel using the relative density and aniline point. Although of the same order as cetane number/index, it may differ widely and should be accepted with reserve.
<b>Differential Infrared Spectroscopy (DIR)</b>	Method to compare fresh and used oils by showing different peaks at different wavelengths. Used to determine deterioration of engine oils with reference to oxidation, and nitration. See FTIR.
<b>Differential Infrared Spectroscopy (DIR)</b>	Method comparing fresh and used oil by showing different peaks at specific wave lengths. Method widely used to assess deterioration of gas engine oils with reference to oxidation and nitration.
<b>Digester Gas</b>	See "Sewage Gas".
<b>Dilution of Engine Oil</b>	Contamination of crankcase oil by unburnt fuel leading to reduced viscosity and flash point.
<b>Dispersant</b>	An additive designed to disperse oil insoluble sludge in suspension, thus preventing harmful deposition in oilways.

<b>Distillate</b>	An product obtained by condensing the vapours distilled from petroleum or its products.
<b>Distillate Fuel Oil</b>	A fuel oil containing only fractions removed as vapour and condensed.
<b>Distillation Range</b>	The range of temperatures, usually determined at atmospheric pressure by standard apparatus, over which boiling, or distillation, of a liquid proceeds. Only a pure substance has one definite boiling point at a particular pressure. Petroleum have a range of boiling points because of their varying complex range of hydrocarbon compounds.
<b>Drop Point</b>	The temperature at which a grease passes from a semi-solid to a liquid under specified test conditions.
<b>Dry Gas</b>	Natural gas containing no hydrocarbons heavier than butane and pentane. Can contain up to 99 % methane.
<b>Dry Sump</b>	Engine lube oil system with an external tank reservoir.
<b>Dual Fuel</b>	Term used for gas engines running on combustible gas ignited by controlled "pilot" injection of 1 – 10 % fuel with adequate ignition quality, i.e., gas oil or heavy fuel oil.
<b>Dumb bell Blend</b>	A blend of (usually two) components with an extreme of a particular blend parameter, such as viscosity, density, distillation curve.
<b>Emulsibility</b>	The ease in ability of fluids to form emulsion (see emulsion)
<b>Emulsifier</b>	A type of surfactant effective at producing stable emulsions.
<b>Emulsion</b>	An intimate mixture of fluids which are non soluble in each other. An emulsion is said to "break" when the fluids separate.
<b>End Point (final Boiling Point)</b>	The highest temperature indicated on the distillation thermometer when a light distillate is subjected to one of the standard laboratory methods of distillation.
<b>Engine Deposits</b>	Accumulations of sludge, varnish and carbonaceous residues on engine components.
<b>Engine Test</b>	Use of an internal combustion engine to evaluate lubricants. Parameters such as piston ring groove fill (by deposits), piston varnish, component wear, oil viscosity etc. are measured - to apply a performance rating.
<b>Esters</b>	Compounds of alcohols and fatty acids which form the major constituent of many synthetic lubricating oils.
<b>Eutectic</b>	A mixture of compounds (e.g. vanadium and sodium) resulting in a low melting point
<b>Extreme Pressure (EP) Lubricants</b>	EP oils and greases contain additives which, under the effects of high temperature and pressure, form a protective film on metallic surfaces, preventing metal-to-metal contact if the normal hydrodynamic film breaks down under high pressure.
<b>FCC Fine</b>	See catalyst fines
<b>Ferrography</b>	Ferrographic Analysis. A method for detecting wear metal particles "graded" by a magnetic field for further study using photo sensor or a microscope.
<b>Fire Point</b>	The lowest temperature at which an oil vaporises rapidly enough to burn for at least five seconds after ignition under standard conditions.
<b>Flash Point</b>	The lowest temperature to which a combustible liquid must be heated to give off sufficient vapour to form a momentarily flammable mixture with air when ignited under specified conditions.
<b>Floc Point</b>	A measure of the tendency of an oil to flocculate - or precipitate wax - under prescribed conditions. It is mainly applicable to refrigeration oils.
<b>Four Ball EP Test</b>	Method for determining extreme pressure (EP) properties of fluids. One steel ball under load rotates against three stationary balls in the form of a cradle. Heated test fluid is subjected to a series of timed tests at increasing loads until welding occurs. Wear is described by scar diameter plus load to weld in kg.
<b>Friction</b>	The resisting force encountered at the common boundary between two bodies when, under the action of an external force, one body moves, or tends to move, relative to the other.
<b>FTIR</b>	Fourier Transformation of InfraRed spectroscopy. Digital generation of spectral information. See DIR.
<b>FTIR</b>	Fourier Transformation InfraRed Spectroscopy
<b>FZG Gear Test Rig</b>	A method for determining the load carrying ability of lubricants. Calibrated spur gears are operated at fixed speed and controlled initial oil temperatures for 15 minute stages. The load on the gear teeth is increased after each stage. Performance is judged by the number of stages run up to a defined weight loss of the test gears or visual assessment of damage to the tooth flanks. Maximum number of stages is 12. Normal reporting format is to quote the failed stage.

<b>Gas Oil</b>	A petroleum distillate having a viscosity and distillation range between those of kerosene and light lubricating oil. The distillation range of gas oils usually extends from 200°C to 380°C. Gas oil is used as a fuel in medium and high speed diesel engines and as a burner fuel in heating installations.
<b>GPC</b>	Gel Permeation Chromatography
<b>Grease</b>	A lubricant composed of an oil, or oils, thickened with a soap or other thickener, to a semi-solid or to a solid consistency.
<b>H<sub>2</sub>S</b>	Hydrogen Sulphide, acidic, poisonous, flammable gas found in bio and natural gases. Disagreeable odour. Robust alkalinity of gas engine lubricant required when present.
<b>Hot Corrosion</b>	Corrosion phenomena of hot components (piston crown, exhaust valve etc) by the combination of vanadium and sodium compounds at critical ratios and high temperature.
<b>Hydrocarbons</b>	Chemical compounds which consist entirely of carbon and hydrogen. They form the basic composition of all fuels and lubricants derived from petroleum.
<b>ICP (or PES)</b>	Inductively Coupled Plasma Emission Spectrochemical Analysis. A method for detecting elements (mainly metals) in oil at ppm level by using plasma emissions
<b>Ignition Quality</b>	The ability of a fuel to ignite; measured as the delay between the start of injection and the start of the combustion. See cetane number and diesel index.
<b>Immiscible</b>	Liquids incapable of forming homogeneous mixture, eg. oil plus water.
<b>Inhibitor</b>	A substance which is added in a small proportion to a lubricant to prevent or retard undesirable changes in the quality of the lubricant, or in the condition of the equipment in which the lubricant is used.
<b>Insolubles</b>	Contaminants found in used oils due to dust, dirt, wear particles, oxidation products, combustion product etc often measured as pentane/heptane or toluene insolubles to reflect insoluble character.
<b>IP</b>	Institute of Petroleum
<b>JIS</b>	Japanese Industrial Standard
<b>Kinematic Viscosity</b>	Measure of a fluid's resistance to flow under gravity at a specific temperature (usually 40°C or 100°C)
<b>Knocking</b>	Hard metallic noise heard when engine fires in uncontrolled mode. See "Detonation".
<b>Lambda Value</b>	Ratio of combustion air actually charged to combustion air theoretically required. LV = 1 is defined as "stoichiometric condition". Lean burn engines run at LV > 1.
<b>Landfill gas</b>	Produced by anaerobic decomposition of household and industrial waste. Generally contains 40 – 60 % methane, 40 – 50 % CO <sub>2</sub> , and 10 % N <sub>2</sub> . May also contain H <sub>2</sub> S, chlorinated hydrocarbons and silicon compounds.
<b>Lands</b>	The vertical surfaces of the piston crown and the areas between the piston rings.
<b>Lean Burn Engine</b>	Gas engines running on air excess, except in pre-chambers where gas is ignited. See also "Lambda Value" and "Stoichiometric Condition".
<b>Liner Lacquers</b>	Hard resin like coatings formed on the surface of liners filling the honing grooves. Such lacquers may lead to increased oil consumption.
<b>LPG</b>	Liquefied Petroleum Gas. Consists mainly of propane or butane or mixtures thereof. Liquid at ambient temperature when kept under pressure.
<b>Lubricant</b>	Any substance reducing friction between moving surfaces.
<b>Marine Gas Oil</b>	Lighter fraction and better quality fuel than diesel fuel, controlled to an ignition quality more appropriate to high speed diesel engines.
<b>MCR</b>	Maximum continuous rating (of an engine ). The rating at which the manufacturer sets for operation at 100% loading
<b>Metal Content</b>	Any metallic contaminants present in residual fuels.
<b>Methane No. (MN)</b>	Figure rating the anti-knock performance of a gaseous fuel. Pure methane was given the methane number 100, hydrogen has 0. Other gases may have higher or lower MNs. Gas mixtures may have wide ranges due to changes in composition.
<b>MIL-</b>	US Military specifications
<b>Mineral Oil</b>	Oil derived from mineral sources, notably petroleum.
<b>Miscible</b>	Opposite of Immiscible. See "Immiscible".
<b>Multigrade</b>	'Multigrade' is a term used to describe an oil with low temperature and high temperature

<b>Distillate</b>	An product obtained by condensing the vapours distilled from petroleum or its products.
<b>Distillate Fuel Oil</b>	A fuel oil containing only fractions removed as vapour and condensed.
<b>Distillation Range</b>	The range of temperatures, usually determined at atmospheric pressure by standard apparatus, over which boiling, or distillation, of a liquid proceeds. Only a pure substance has one definite boiling point at a particular pressure. Petroleum have a range of boiling points because of their varying complex range of hydrocarbon compounds.
<b>Drop Point</b>	The temperature at which a grease passes from a semi-solid to a liquid under specified test conditions.
<b>Dry Gas</b>	Natural gas containing no hydrocarbons heavier than butane and pentane. Can contain up to 99 % methane.
<b>Dry Sump</b>	Engine lube oil system with an external tank reservoir.
<b>Dual Fuel</b>	Term used for gas engines running on combustible gas ignited by controlled "pilot" injection of 1 – 10 % fuel with adequate ignition quality, i.e., gas oil or heavy fuel oil.
<b>Dumb bell Blend</b>	A blend of (usually two) components with an extreme of a particular blend parameter, such as viscosity, density, distillation curve.
<b>Emulsibility</b>	The ease in ability of fluids to form emulsion (see emulsion)
<b>Emulsifier</b>	A type of surfactant effective at producing stable emulsions.
<b>Emulsion</b>	An intimate mixture of fluids which are non soluble in each other. An emulsion is said to "break" when the fluids separate.
<b>End Point (final Boiling Point)</b>	The highest temperature indicated on the distillation thermometer when a light distillate is subjected to one of the standard laboratory methods of distillation.
<b>Engine Deposits</b>	Accumulations of sludge, varnish and carbonaceous residues on engine components.
<b>Engine Test</b>	Use of an internal combustion engine to evaluate lubricants. Parameters such as piston ring groove fill (by deposits), piston varnish, component wear, oil viscosity etc. are measured - to apply a performance rating.
<b>Esters</b>	Compounds of alcohols and fatty acids which form the major constituent of many synthetic lubricating oils.
<b>Eutectic</b>	A mixture of compounds (e.g. vanadium and sodium) resulting in a low melting point
<b>Extreme Pressure (EP) Lubricants</b>	EP oils and greases contain additives which, under the effects of high temperature and pressure, form a protective film on metallic surfaces, preventing metal-to-metal contact if the normal hydrodynamic film breaks down under high pressure.
<b>FCC Fine</b>	See catalyst fines
<b>Ferrography</b>	Ferrographic Analysis. A method for detecting wear metal particles "graded" by a magnetic field for further study using photo sensor or a microscope.
<b>Fire Point</b>	The lowest temperature at which an oil vaporises rapidly enough to burn for at least five seconds after ignition under standard conditions.
<b>Flash Point</b>	The lowest temperature to which a combustible liquid must be heated to give off sufficient vapour to form a momentarily flammable mixture with air when ignited under specified conditions.
<b>Floc Point</b>	A measure of the tendency of an oil to flocculate - or precipitate wax - under prescribed conditions. It is mainly applicable to refrigeration oils.
<b>Four Ball EP Test</b>	Method for determining extreme pressure (EP) properties of fluids. One steel ball under load rotates against three stationary balls in the form of a cradle. Heated test fluid is subjected to a series of timed tests at increasing loads until welding occurs. Wear is described by scar diameter plus load to weld in kg.
<b>Friction</b>	The resisting force encountered at the common boundary between two bodies when, under the action of an external force, one body moves, or tends to move, relative to the other.
<b>FTIR</b>	Fourier Transformation of InfraRed spectroscopy. Digital generation of spectral information. See DIR.
<b>FTIR</b>	Fourier Transformation InfraRed Spectroscopy
<b>FZG Gear Test Rig</b>	A method for determining the load carrying ability of lubricants. Calibrated spur gears are operated at fixed speed and controlled initial oil temperatures for 15 minute stages. The load on the gear teeth is increased after each stage. Performance is judged by the number of stages run up to a defined weight loss of the test gears or visual assessment of damage to the tooth flanks. Maximum number of stages is 12. Normal reporting format is to quote the failed stage.

<b>Pour Point Depressant</b>	An additive used in a small proportion to lower the pour point of a lubricant by modifying the formation of wax crystals so that they do not agglomerate.
<b>Precipitation</b>	Dropping out of solids from solution
<b>Pumpability</b>	The characteristics of an oil that permit satisfactory flow to and from the engine oil pump and subsequent lubrication of moving components.
<b>Redwood 1 (RW1)</b>	An obsolete instrument for measuring viscosity. It is still quoted occasionally, but is calculated from measured kinematic viscosity.
<b>Refining</b>	Series of processes for converting crude oil and its fractions to finished petroleum products, including thermal cracking, catalytic cracking, polymerisation, alkylation, reforming, hydrocracking, hydroforming, hydrogenation, hydrogen treating, solvent extraction, dewaxing, deoiling, acid treating, clay filtration and de-asphalting.
<b>Residual Fuel Oil</b>	Heavy fuel oils produced from the residue of the fractional distillation process rather than from the distilled fractions. Fuels sold as MFO, IFO, IF and TFO.
<b>Ring Sticking</b>	Resistance to free ring movement due to deposits.
<b>Rings</b>	The circular metallic elements that ride in the grooves of a piston and provide compression sealing during combustion. Also used to spread oil for lubrication of the cylinder liners.
<b>Rust Preventive / Rust Inhibitor</b>	Additive for coating metal surfaces with a film that protects against rust.
<b>S.I.P.W.A</b>	Sulzer Integrated Piston Ring Wear-detecting Arrangement. This equipment monitors the rate at which piston rings wear in crosshead engines.
<b>SAE :</b>	Society of Automotive Engineers
<b>Sampling cock/tap</b>	Cock/tap at a suitable, <u>representative</u> point of a lube or fuel system for taking representative samples.
<b>Scuffing</b>	Abnormal wear occurring in engines due to localised metal to metal contact. It can be prevented through the use of antiwear, extreme pressure and friction modifier additives.
<b>Selective Catalytic Reduction (SCR)</b>	Exhaust gas treatment system with urea or ammonia injected into exhaust gas to reduce NO <sub>x</sub> . Catalyst poisoned by sulphur.
<b>Semi-synthetic</b>	Blend of mineral and synthetic base oils
<b>Sewage gas</b>	Particular form of biogas generated by bacterial decomposition of sludges from sewage. Generally contains 50 – 70 % methane, 20 – 30 % CO <sub>2</sub> and often H <sub>2</sub> S.
<b>SFOC</b>	Specific fuel oil consumption, based on g/kWh or g/bhph
<b>Shear Stability</b>	The property of resisting physical change under high rates of shear when applied to a Viscosity Index Improver. It is the ability of the VI improver molecules to withstand breakdown into smaller molecules.
<b>Silica</b>	Abrasive contaminant e.g. catalytic fines, dust particles (e.g from landfill gas). Very abrasive, resulting in excessive wear.
<b>SLOC</b>	Specific lube oil consumption, based on g/kWh or g/bhph
<b>Sludge</b>	Oil insoluble products formed from lubricants and/or fuels used in internal combustion engines, and deposited on engine parts other than those in contact with the combustion space.
<b>Solvent Extraction</b>	Refining process used to separate reactive components (unsaturated hydrocarbons) from lube distillates in order to improve the oils oxidation stability, viscosity index and response to additives.
<b>Sour gas</b>	Natural gas that contains a significant amount of H <sub>2</sub> S ( up to 5 %).
<b>Spark Ignited</b>	Term used for gas engines in which the air/ fuel charge is ignited by spark plugs.
<b>Stoichiometric Condition</b>	The theoretically exact amount of air needed for complete combustion of the fuel.
<b>Stoke (St)</b>	The unit of kinematic viscosity, ie, the measurement of a fluid's resistance to flow defined by the ratio of the fluid's dynamic viscosity to its density; usually quoted as centistokes (cSt).
<b>Straight Run</b>	Fuels produced by distillation without cracking or alteration to the structure of the constituent hydrocarbons.
<b>Sulphur Conversion Ratio</b>	See [Rec 13, p.37]. The ratio of : <u>sulphur which condensed as sulphuric acid</u> the total sulfur ingested with the fuel
<b>Surfactant</b>	A compound able to reduce surface tension and commonly used to achieve emulsification, wetting or detergency.
<b>Sweet gas</b>	Natural gas containing less than 10 ppm H <sub>2</sub> S.

<b>Thermal Cracking (Visbreaking)</b>	An oil refinery process in which the reaction is produced by the action of heat and pressure.
<b>Thermophoresis</b>	Describes the interaction of heat and particles of various sizes.
<b>Three Way Catalyst</b>	Generally used in stoichiometric engines to convert harmful combustion components to H <sub>2</sub> O, CO <sub>2</sub> and N <sub>2</sub> .
<b>Timken OK load</b>	Measure of the EP properties of a lubricant. Lubricated by the product under investigation, a standard steel roller rotates against a block. Timken OK load is the heaviest load that can be carried without scoring.
<b>Tribology</b>	The science of lubrication, friction and wear.
<b>Trunk Piston Diesel Engine</b>	Medium-Speed, or High-speed engine generally using the same oil for both cylinder and crankcase lubrication, and utilising connecting rods to transmit piston power directly to the crankshaft rather than through a crosshead.
<b>Turbine</b>	A piece of equipment in which a shaft is steadily rotated by the impact of a current of steam, air, water, or other fluid directed from jets or nozzles upon blades of a wheel or series of wheels.
<b>Turbocharger</b>	Compressor driven by exhaust gas driven turbine supplying air at higher pressure to the engine to increase power.
<b>Valve Guttering and Torching</b>	Damage to exhaust valves due to high temperature corrosion and erosion.
<b>Valve Recession</b>	Excessive wear of valve seat and face caused by combined effects of metal abrasion, high temperature corrosion, functional sliding and adhesion.
<b>Viscosity</b>	Viscosity is defined as the resistance of a fuel to flow. When viscosity is used to classify a fluid for example fuels, lubricants etc., it is necessary to report the viscosity at a reference or standard temperature, for example 380 mm <sup>2</sup> /s (cSt) at 50°C. Note: Different reference temperatures are used depending upon: The viscosity scale used and the type of fuel being measured e.g. lubricants, distillate fuels, residual fuel etc.
<b>Viscosity Breaking</b>	A thermal cracking process aimed specifically at reducing the viscosity of long or short residues.
<b>Viscosity Index (VI)</b>	A value indicating a fluid's change of viscosity with temperature. Normally used for lubricating oils only. The viscosity of an oil decreases with a rise in temperatures but to a varying degree depending on the type of crude from which it is derived and the treatment it has undergone
<b>Viscosity Index Improver</b>	An additive employed to raise the VI of a mineral oil and other products.
<b>Volatility</b>	Amount distils off or vaporises with temperature - highly volatile means large amount
<b>Wet Gas</b>	Natural Gas containing heavier hydrocarbons like ethane, propane, butane plus small quantities of hydrocarbons liquid at ambient temperatures.
<b>Wet Sump</b>	Engine lube oil system in which the crankcase serves as the oil tank; a system without an external tank reservoir; common in smaller 4-stroke engines.
<b>Wobbe Index</b>	Ratio of a gas's calorific value to the square root of it's specific gravity. Indicates thermal input provided by gas at given temperature.
<b>Zeppelin</b>	Big gas container carrying militant non-smokers.
<b>Zinc (ZDDP/ZDTP)</b>	Commonly used name for zinc phosphorous compound used as anti-wear and anti-oxidation inhibitor..



**1**

**CRUDE OIL**

**AND**

**REFINERY PROCESS**

## 1.1 Composition and Classification of Crude Oil

### Composition of Crude Oil

Analysis of a crude oil shows that it consists of 83-87 % carbon (C), 11-14 % hydrogen (H) and 0.1-4.5 % sulphur (S). From the chemistry we know that carbon and hydrogen are able to compose the most extraordinary molecular combinations. The common name for all these compounds is hydrocarbons. Carbon has the ability to join into long chains with all imaginable kinds of side chains, and into circular compounds, as well as combinations of chains and circular compounds. Carbon molecules constitute the “backbone” of the molecules while hydrogen molecules “fill in the vacancies”.

Carbon has 4 “arms”, with which it can form chemical bonds. The simplest chemical compound formed from carbon and hydrogen is methane, consisting of one C-atom and four H-atoms. Methane, also called marshgas, is produced by the slow, anaerobic decomposition of organic material. Methane can be present in considerable amounts in oilfields and is usually the major component of natural gas. After methane comes ethane with two joints C-atoms and 6 H-atoms at the vacant “arms”. This trend (adding a C-atom and two H-atoms) continues with propane ( $C_3H_8$ ) and butane ( $C_4H_{10}$ ), of which propane is probably the best known.

Next in line after butane comes pentane, a highly volatile liquid with a boiling point of 30°C. When the number of C-atoms exceeds 8 or 9, the number of possible combinations with different side chains increases considerably. If the molecule contains more than 15 or 16 C-atoms the pure compound will be in a solid state, but in crude oil they are dissolved in the liquid hydrocarbons. The most complex and high molecular compounds in the crude oil will after refining emerge as paraffinic waxes or asphaltenic tar components.

### Classification of Crude Oil

Crude oils from different locations in the world have surprisingly similar composition, but with the special

requirements for the various oil products as delivered from the refineries; the small differences are of utmost importance to the oil chemists and refinery personnel.

The number of chemical combinations is, as previously mentioned significant. Therefore, the hydrocarbons are divided into three main categories:

- Paraffinic hydrocarbons.
- Naphtenic hydrocarbons.
- Aromatic hydrocarbons.

### Aliphatic or Paraffinic Hydrocarbons

Aliphatic, also called paraffinic, hydrocarbons have a chainlike structure where an increasing number of carbon atoms in the molecule will generally result in:

- higher density
- gaseous molecules become less volatile
- increased boiling temperature for liquid molecules
- the melting temperature increases for solid compounds

Paraffinic hydrocarbons are chemically stable, but are less thermally stable, i.e. crack easily during heat treatment (thermal cracking). Crude oil consisting mainly of paraffinic hydrocarbons (called paraffinic oil) will have a high content of paraffinic wax, which has to be taken into account when refining the oil. Crude oil from North Africa usually is of this type.

### Naphtenic Hydrocarbons

Naphtenic hydrocarbons can be regarded as paraffinic hydrocarbons with a circular structure. In naphtenic hydrocarbons the H-atoms at the ends are eliminated, thereby increasing the carbon/hydrogen ratio. As C-atoms are heavier than the H-atoms the specific gravity of the molecule increases. Naphtenic hydrocarbons are chemically less stable than the aliphatic components, but are more thermally stable. The liquid naphtenic hydrocarbons exhibit above all a decrease in the point of solidification compared to the paraffinic hydrocarbons. Crude oils consisting mainly of naphtenic hydrocarbons are said to be on a naphtic

basis. Typical examples of such crude oils are Venezuelan and some Middle East crude oils.

### Aromatic Hydrocarbons

Aromatic hydrocarbons also have a circular structure but with fewer H-atoms. This means that their density is even higher than for naphthenic and paraffinic hydrocarbons. In order for the molecule to contain a limited number of H-atoms, a structural change is needed. This is best illustrated by the “arms”-model: Two of the C-atom’s four “arms” occupies two “arms” of the neighbouring carbon atom, thereby creating what is known as a double bond. The aromatic hydrocarbons are chemically less stable than saturated hydrocarbons, thermally stable and the point of solidification is low. They also exhibit a strong smell.

Crude oil does not contain free sulphur, but it does contain sulphur chemically bound to the hydrocarbons. One example of this is the mercaptans, smelly compounds that are often the major component causing the pungent smell from pulp and paper industry processes.

The composition and structure of the hydrocarbons in the crude oil are to a certain extent, responsible for the properties of the final products after refining. In a modern refinery however, it is possible to modify the molecules substantially, thus creating products with favourable properties.

The characteristics of the various hydrocarbon types are listed below, from which it is clear how chemical composition controls a number of aspects of fuel performance.

### Hydrocarbon Properties:

- Paraffins: Highest cetane number. Lowest density. High gravimetric calorific value. Low volumetric calorific value. Low black smoking tendency. High pour point. (wax)
- Isoparaffins: Lower cetane number. Lower pour point. Somewhat higher density. Other properties as for paraffins.
- Naphthenes: Intermediate cetane number. Moderately high density. High

gravimetric calorific value. Moderately high volumetric calorific value. Moderately high black smoking tendency. Lower pour point.

- Aromatics: Lowest cetane number. Highest density. Low gravimetric calorific value. High volumetric calorific value. High black smoking tendency. Moderately high pour point.
- Olefines: Similar to isoparaffins but slightly higher black smoking tendency.

### Properties of the Crude Oil

Crude oil is a very complex mixture of different hydrocarbons, and it is difficult and time consuming to determine all of the compounds in the mixture.

On the other hand there are a number of simple analytical tests that can be performed on crude oil, in order to help assessment of its value and usefulness to the different refineries.

## 1.2 Crude Oil analysis

### Density

The density of a crude oil is occasionally given in degrees API. The higher the density is, the lower the API-value is. Formula for the calculation of °API:

$$(141.5/\text{rel.dens.}) - 131.5 = \text{°API}$$

Where the relative density is given at 15°C and API is given at 60°F (or 15.5°C).

### Sulphur

The sulphur content, along with the density, are the two properties that have a significant influence on the value of a crude oil. Sulphur content is given in weight percentage and varies from below 0.1% to over 4.5%. Crude oils with more than 0.5% sulphur (denoted “sour” crude oil) usually require more extensive refinery processing than the ones with less sulphur. Crude oils with less than 0.5% sulphur are called “sweet”.

### Pour Point

The pour point of a crude oil is an indicator of the content of aliphatic/paraffinic

compounds present in the crude oil, and of the content of aromatic compounds.

### Carbon Residue

The carbon residue is determined by thermal “distillation” of the crude oil without addition of air, until only coke remains. Carbon residue is roughly related to the content of asphaltenes in the crude oil.

### Salt Content

If the salt content of the crude oil is too high, it must pass through a desalting unit before entering the refinery process. This is done in order to avoid corrosion problems in the downstream refinery units.

### Characterisation Factors

There are several different ways to characterise a given crude oil and to indicate the output from a refinery based on its content of paraffinic and aromatic hydrocarbons. In this context we will only mention UOP or Watson Characterisation Factor (K-factor) as well as the U.S. Bureau of Mines’ Correlation Index.

### Nitrogen Content

A crude oil with a high content of nitrogen compounds is unfavourable because it can poison the catalyst in the later steps of the refining. Products produced from these crude oils are therefore subjected to a special process in order to reduce the nitrogen content.

### Boiling Point Interval

The boiling point interval of a crude oil gives an indication of its composition. The

most usable form of distillation in this context is known as TBP-distillation, which distinguishes quite well between the different distillation intervals. There is no special ASTM-method for a TBP-distillation, but there are methods being used by most laboratories, for instance ASTM D 285. None of the most used methods specify the number of theoretical plates or the return ratio, but quite a few perform the distillation with a return ratio (reflux) of 1:5 and with 15 theoretical plates in the column. The TBP-interval must relate to the ASTM method D 86 because most products are specified according to this method.

### Metal Content

The metal content in a crude oil can vary from a few mg/kg to more than 1000 mg/kg, and is, in spite of the low concentrations, of major importance. Small amounts of certain metals can severely affect the performance of a catalyst and result in a decrease in the output of certain processes. A concentration of vanadium, for instance, of 2 mg/kg can cause severe corrosion on the blade of a gas turbine. Distilling causes the concentration of metals to increase in the heavier parts of the oil, but some organometallic compounds can evaporate and thus be found in the lighter distillates. The amount of some metals can be reduced, for example by solvent extraction.

**Table 1 Boiling point interval for the most typical crude oil fractions:**

FRACTION	BOILING POINT INTERVAL ASTM °C	BOILING POINT INTERVAL TBP °C
Pentane & lighter		- 30
Light Gasoline	30 – 100	30 – 100
Heavy Gasoline	80 – 200	100 – 190
Kerosine (Paraffin)	165 – 280	190 – 270
Light Gas Oil	215 – 340	270 – 320
Heavy Gas Oil	290 – 440	320 – 425
Vacuum Gas Oil	400 – 565	425 – 565

In addition to hydrocarbons, crude oil contains organic sulphur and nitrogen compounds, acids, vanadium and nickel in amounts ranging from a few mg/kg and higher. They also contain other elements in lesser amounts.

**Table 2 Some typical properties of the crude oil:**

<b>Density</b>	<b>790 – 1000 kg/m<sup>3</sup> at 15<sup>0</sup>C</b>
<b>Initial Boiling Point</b>	<b>0 – 50<sup>0</sup>C</b>
<b>Kinematic Viscosity</b>	<b>4 – 15000 mm<sup>2</sup>/s at 37,8<sup>0</sup>C (100<sup>0</sup>F)</b>
<b>Pour Point</b>	<b>- 35 – 70<sup>0</sup>C</b>
<b>Sulphur</b>	<b>0.08 – 5.0 %m/m</b>
<b>Vanadium</b>	<b>1 – 1200 mg/kg</b>
<b>Wax</b>	<b>2 – 12 %m/m</b>
<b>Asphaltenes</b>	<b>0.05 – &gt;5.0 %m/m</b>

The products produced come from crude oil range over a wide area, from condensing gases via petrochemical raw materials, fuels, and lubricating oils, to asphalt/bitumen depending on the refining facilities.

Since crude oils display such a variety of properties, some products are easier to produce than others are. The refineries therefore select and combine crude oils so that the output of the desired product can be reached by optimised blending of different crude oils.

### 1.3 REFINERING AND COMPOSITION

Diesel-engine fuels comprise a variety of petroleum products ranging from gas oil, used mostly in high-speed and medium-speed auxiliary engines, to heavy marine fuel oil, used in low-speed main propulsion engines. They are distinguished by differences in viscosity, boiling range, combustion range, combustion characteristics, chemical composition, and

many other properties. Gas oil and heavy distillate fuel (Marine Diesel Fuel) are manufactured from crude oil by distillation and processing. Fuel oil consists mainly of the residue left after distillation of crude oil.

There is an important distinction between fuels derived from the distilled components, and the more viscous high-boiling fuel oils derived principally from residual fuel oil components. The former are known collectively as distillate fuels; they can be handled, stored and used directly. Residual fuels, on the other hand, are too viscous at normal temperatures to be used directly, and must be heated before they can be handled or injected into the combustion chamber. There is consequently a fairly sharp division in application, distillate fuels being used almost exclusively for high-speed and many medium-speed diesels, while residual fuels, or blends of residual and distillate fuels, are used in low-speed marine and stationary industrial diesel engines, and in medium-speed engines.

### 1.3.1 Available fuel grades

Marine Fuel Oil (MFO) is the designation commonly used by many suppliers to describe the cheapest available grade for marine application, though it is still sometimes referred to as "Bunker C" or "No. 6 Fuel". It can be of any viscosity up to a maximum that varies from one area to another, and sometimes even at different ports in the same country. Maxima of 460, 420 and 380 mm<sup>2</sup>/s at 50°C are usual at most major ports, decreasing to 180 mm<sup>2</sup>/s and lower elsewhere. A trend towards high-viscosity fuels of 500 and 700 mm<sup>2</sup>/s is becoming apparent in some areas.

### 1.3.2 Basic refinery processes

Fractional distillation at atmospheric pressure divides the crude oil into fractions of differing volatility (boiling range). The most important, in order of increasing boiling point, are gas, naphtha, kerosine, gas oil, and fuel oil, which are recovered as a residue. Distillate fractions with a wide boiling range are normally subdivided into a number of components. This reduces the boiling range of each component, with different chemical and physical characteristics.

The kerosine and gas-oil components may require further treatment, for example to reduce sulphur content or to remove chemical constituents that might prove harmful in service.

The residual material remaining after fractionation at atmospheric pressure is

Thin Fuel Oil (TFO), Intermediate Fuel Oil (IFO), Intermediate Fuel (IF), etc., are terms used by various suppliers to define the blended fuels supplied to specified viscosities. Their availability varies, but below table lists the principal viscosity grades supplied by most oil companies:

Distillate fuels fall into two categories. The heaviest distillate, Marine Diesel Fuel (MDF) or Marine Diesel Oil (MDO), as supplied at some Eastern ports, may contain a small proportion of residual fuel. Elsewhere it is a distillate product that may be delivered through lines and facilities used for MFO and so pick up sufficient residual traces to make it black in appearance. The other distillate, Gas Oil (GO), is a lighter fraction and is delivered through clean facilities.

known as the "long residue". Further distillates may be obtained from this by vacuum distillation. The vacuum distillates may be used as diesel-fuel components or as feedstock for producing lubricating oil. The residue from the process, known as the "short residue", can be used as a feedstock for further upgrading (i.e. by secondary conversion processes - see below); as feedstock for bitumen production, or as a fuel-oil component on its own.

### 1.3.3 Secondary conversion processes

Since the oil crises of the 1970s, there has been a marked change in the pattern of refining. This is due largely to the relatively reduced demand for residual fuels, and a corresponding increase in demand for distillate fuels, especially middle distillates. As a result, residual fuel components from the distillation processes already described, as well as certain heavy distillates, have to be converted to further distillate materials, by processes that

Viscosity - Kinematic mm <sup>2</sup> /s at 50 °C	Approximately - Kinematic mm <sup>2</sup> /s at °C	Equivalent - Kinematic mm <sup>2</sup> /s at °C	Viscosities Redwood secs at 100 °F
700	130	55	7000
500	100	45	5000
380	75	35	3500
180	45	25	1500
80	25	15	600
40	15	10	300

change the size and structure of the hydrocarbon molecules. In this respect, the conversion processes differ from physical separation processes, such as fractionation, in which there is no change in molecular structure, and no new compounds are formed.

The most widely used conversion process is cracking, which reduces the molecular size of the fuel-oil components. The main cracking processes are thermal cracking (including visbreaking) and catalytic cracking. They subject the feedstock to high temperatures in a reaction chamber - 450-500 °C in a thermal cracker, and 500-540 °C in a Fluidised Catalytic Cracking (FCC) Unit. In a FCC unit, hot feed, together with some steam, meets a stream of hot catalyst which heats the oil and so initiates cracking. The vapour for fractionation into new distillate components is formed initially by vaporisation and by cracking. After the cracking reaction, entrained catalyst is removed from the vapour by a cyclone.

The cracker converts the heavy feedstock into lighter distillate products that vary in molecular structure between gas and heavy gas oil. The residual product from the fractionator is called slurry oil and can be used as a fuel-oil component. Where a finished fuel oil is found to contain traces of catalyst fines, the slurry oil is the most likely source of contamination.

Residual components from thermal cracking and heavy distillates from catalytic cracking are commonly used in marine residual fuel. Their increased availability, resulting from the more widespread use of conversion process, has led to significant changes in the properties of marine fuels. The conversion processes themselves are not new; they have been used for many years, and cracked components have often been blended into marine fuels. As a result of the increasingly widespread use of such components, however, marine fuels may approach specification limits more closely than they did in the past.

A simplified configuration of distillation and cracking techniques is illustrated in figures below. A more detailed treatment of this complex subject may be found in numerous specialist books on refining.

### 1.3.4 Chemical composition

Crude oils are complex mixtures of many substances. Although they consist mainly of hydrocarbons, they also contain small amounts of sulphur, nitrogen and oxygen compounds, together with traces of sodium, potassium, iron, nickel and vanadium. The hydrocarbons themselves comprise a vast number of members of three different families, or series, called paraffins, naphthenes and aromatics. Every crude oil contains all three types, though in varying proportions. In cracked fuels, other hydrocarbons are formed; these are known generically as "unsaturated hydrocarbons" and include the olefins.

Each type of hydrocarbon is characterised by certain chemical and physical properties. For example, paraffins have high cetane numbers (80-110) and high pour points (-15 to +30 °C), while isoparaffins have low cetane numbers (20-80) and low pour points (-70 to -30 °C). These and other characteristics of the various hydrocarbon types are listed in Section 1, page 10, from which it is clear how chemical composition controls a number of aspects of fuel performance.

It is not possible to separate the individual hydrocarbons, of which there are may thousands, or even the hydrocarbon types, in a purely physical process such as distillation. But, in practice, there is no need to do so, since by controlling the distillation range of the component, the refiner has a certain degree control over its other physical properties, such as flash point, density, viscosity, and pour point. He can also control, within limits, the percentage yield of components whose composition, however, remains substantially unaffected, being determined only by the crude oil's origin and the boiling range of the component.

Kerosines are very largely mixtures of paraffins, isoparaffins, and naphthenes containing up to 18 per cent mass of aromatic compounds. Many kerosines have quite high cetane numbers (50 or greater) indicating high paraffin content, but many others have cetane numbers of 45 or less, reflecting an appreciable naphthene and/or aromatic content.

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Gas oils differ very widely in composition, especially in the relative proportions of paraffins, isoparaffins and naphthenes. Aromatics usually lie within a fairly narrow range, between 15 percent and 30 percent mass.

The proportion of total paraffins and naphthenes may vary from about 70 per cent and 4 per cent respectively in some Middle East oils to 25 per cent and 60 per cent respectively in Nigerian gas oils. These variations have a substantial effect on density, cetane number and pour point, as do variations in the n-paraffin/isoparaffin ratio.

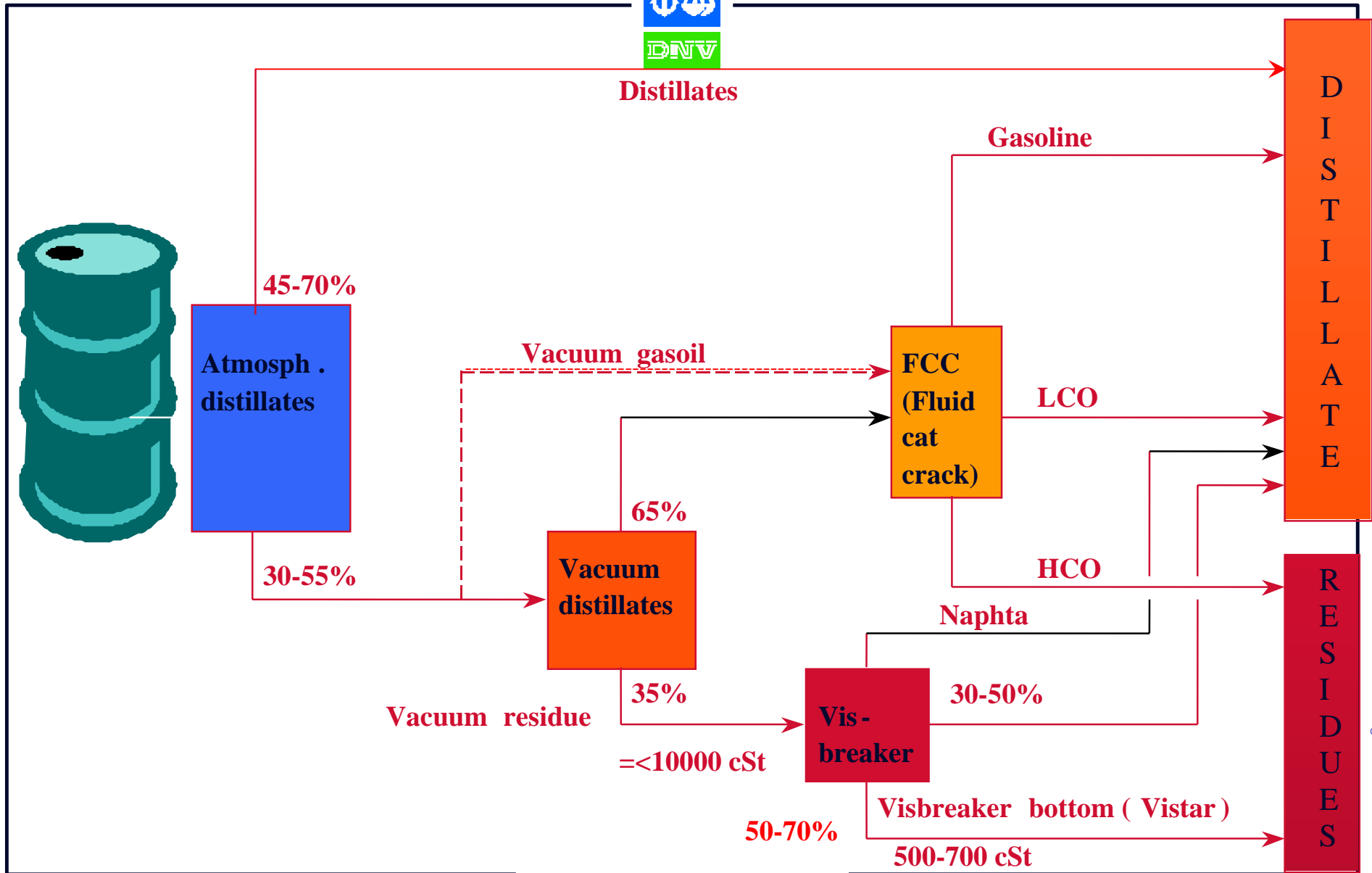
Residual fuel oils are extremely complex mixtures, but even so they can be roughly

divided into paraffinic and naphthenic/aromatic (asphaltic) types according to their crude oil origin. The paraffinic types have relatively high pour points (up to about 24 °C in marine use), whereas the corresponding asphaltic fuel oils may have pour points well below 0 °C.

As mentioned above much higher proportions of cracked material are now used in marine fuel oils than in the past. These components are highly aromatic and fuels containing them will have generally aromatic properties. In comparison with fuels based largely on components from fractional distillation, those containing cracked components have a higher carbon residue, and a smaller reserve of stability.

References:      Lubricants and Fuels in Ships  
Shell International Trading Company, London, 1989

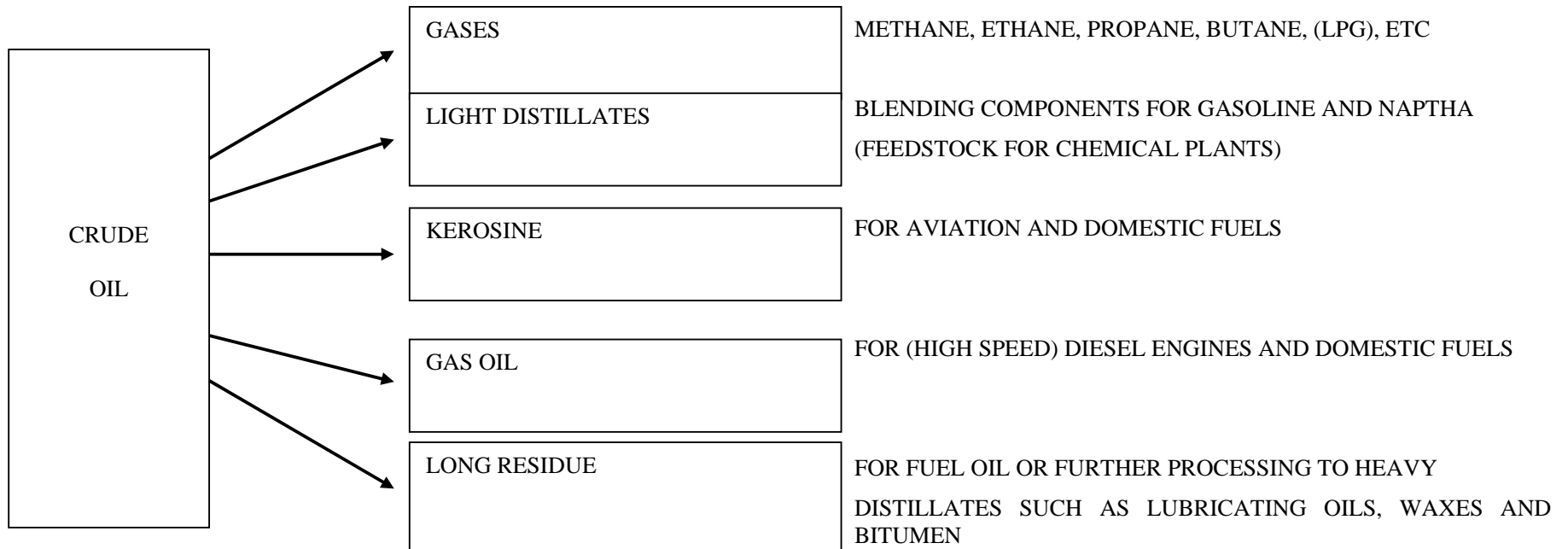




## 1.4 Atmospheric Distillation

CONVERTS

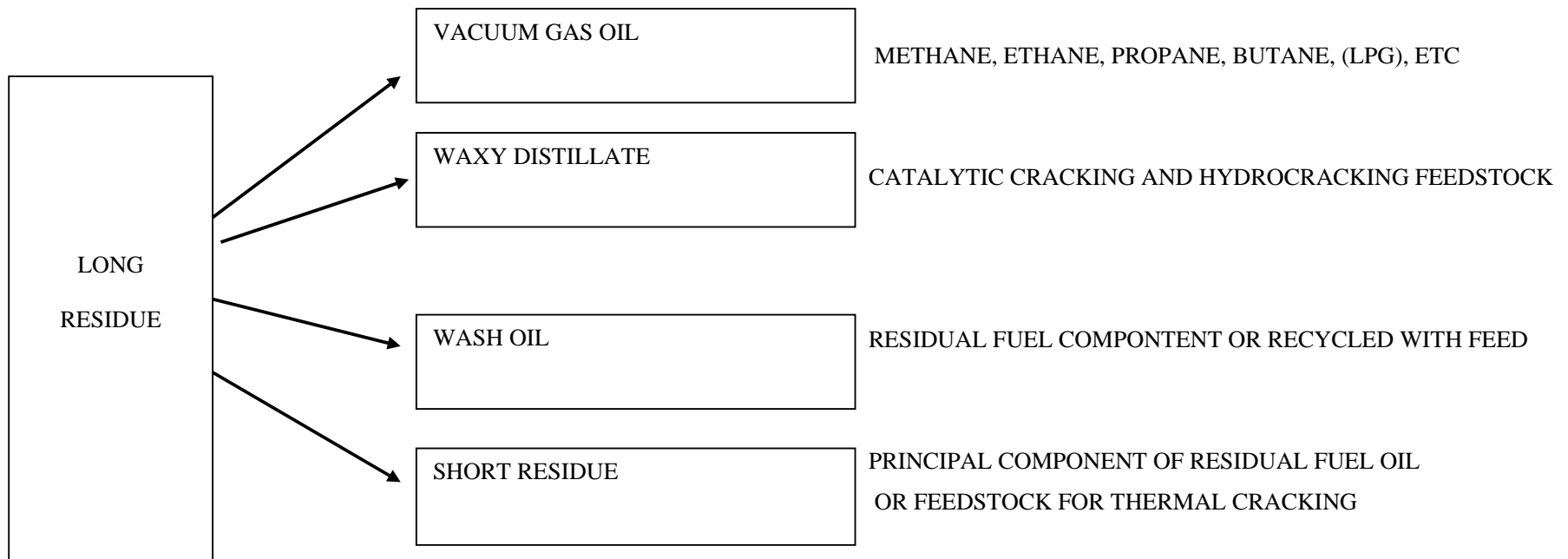
INTO



## 1.5 Vacuum Distillation

CONVERTS

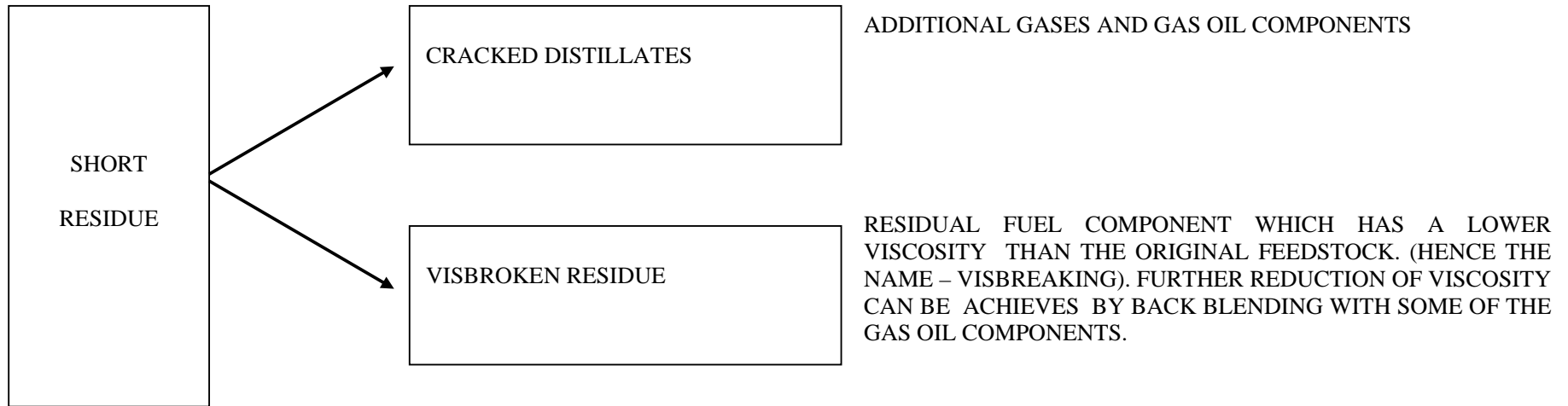
INTO



## 1.6 Visbreaking (Thermal Cracking)

CONVERTS

INTO

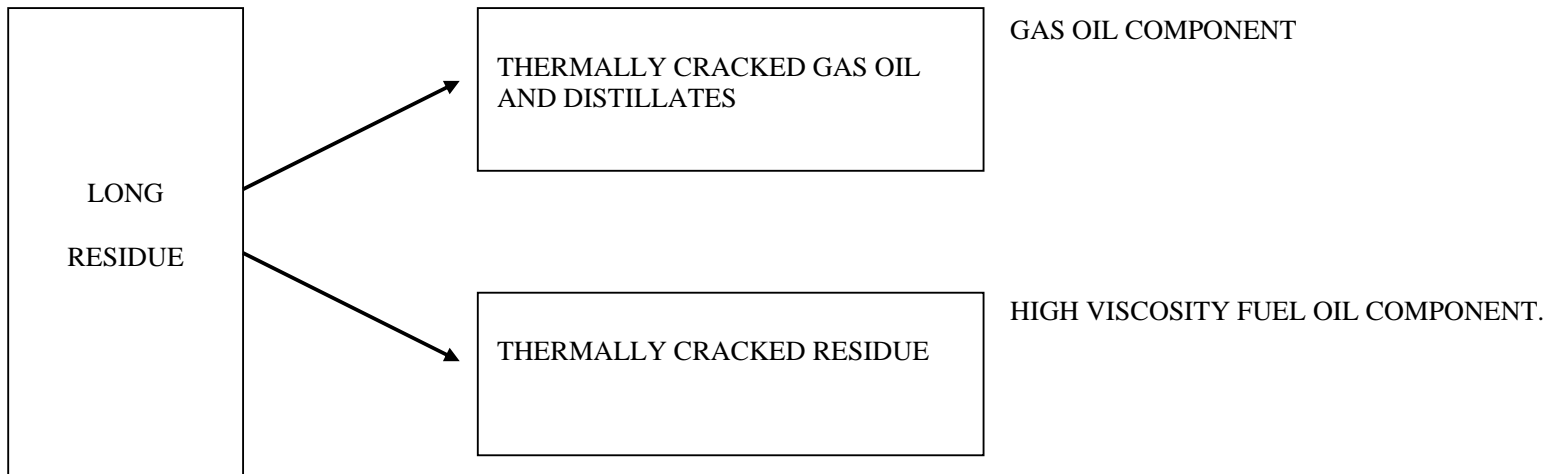


## 1.7 Thermal Gas Oil Unit (TGU)

### (Thermal Cracking)

CONVERTS

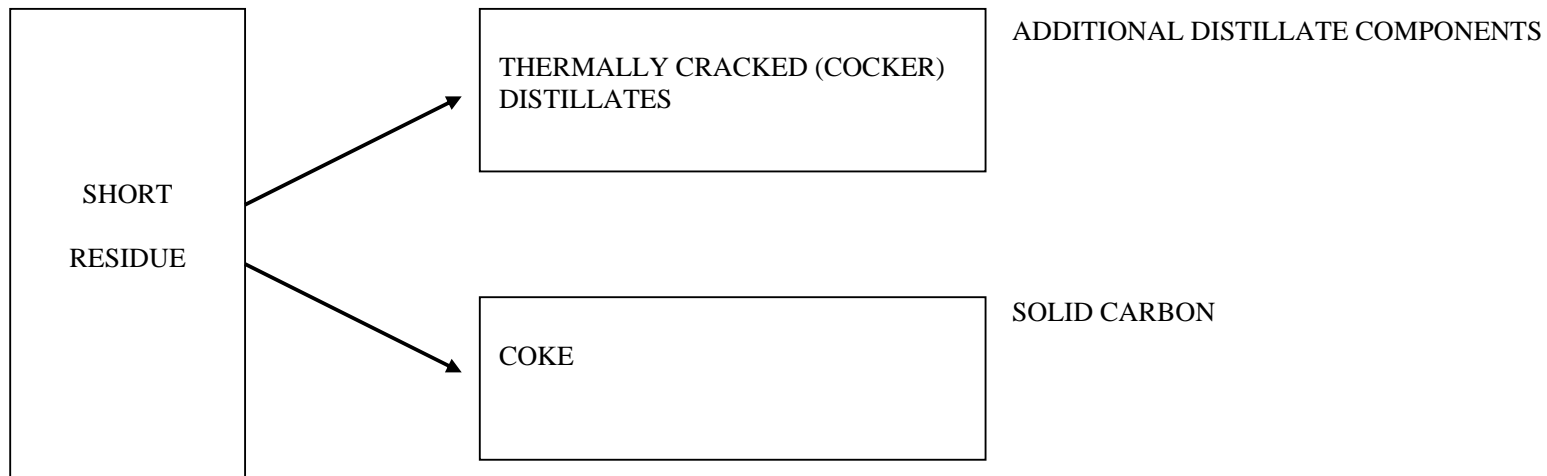
INTO



## 1.8 Coker (Severe thermal cracking)

CONVERTS

INTO

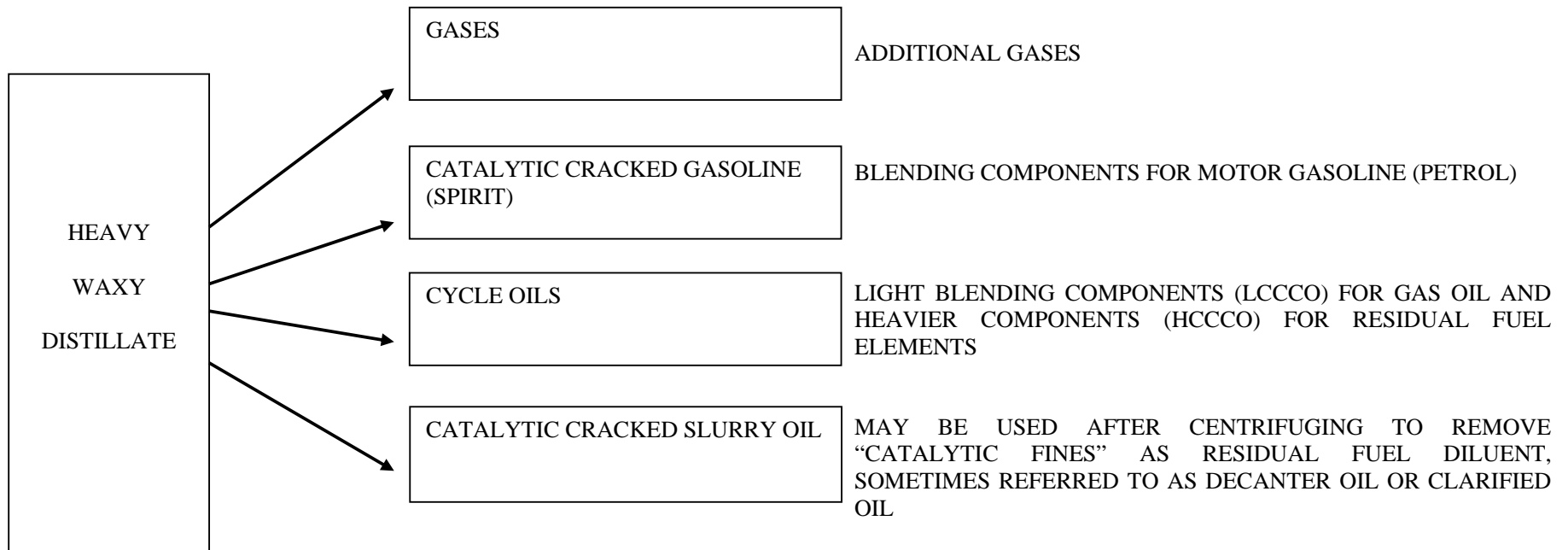


## 1.9 CATALYTIC CRACKING

(Fluid bed catalytic cracker – FCCU)

CONVERTS

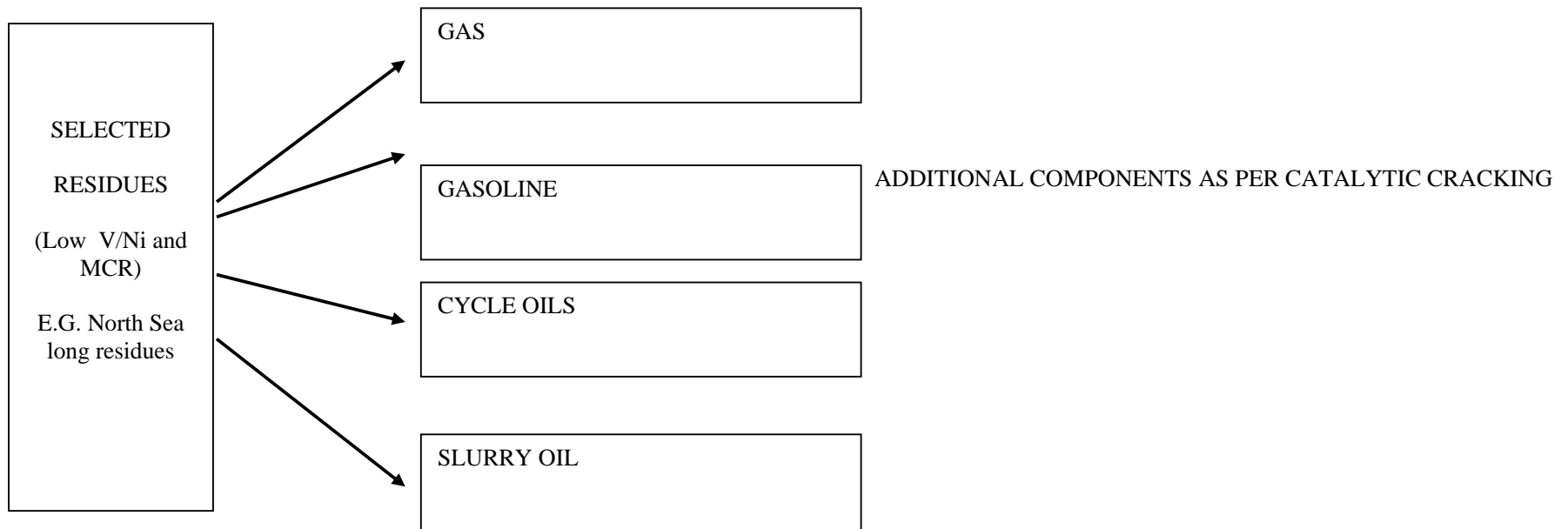
INTO



## 1.10 Long Residue Catalytic Cracking

CONVERTS

INTO





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## 1.11 Other Processes

HYDROTREATING

IS THE TERM APPLIED TO THE PROCESS OF DUCING CONTAMINANTS, PARTICULARY, SULPHUR AND NITROGEN COMPUNDS FROM A FEEDSTOCK PRIOR TO PROCESSING, OR TO PREPARE A PRODUCT TO MEET MARKET SPECIFICATIONS EG. HYDRO DESULPHURISATION.

HYDROCRACKING

IS USED MAINLY TO PRODUCE NAPHTHAS, KEROSINE AND DIESEL FUEL FOR CARS, ALSO CALLED LIGHT DISTILLATES, FROM HEAVIER DISTILLATE (EG. WAXY DISTILLATED FROM VACUUM DISTILLATION) AND THUS IS A VERY COMPATITIVE ROUTE FOR CATALYTIC CRACKING AND BECOMING INCREASINGLY POPULAR.

SOLVENT EXTRACTION

SOLVENTS SUCH AS BUTANE AND PROPANE ARE USED TO REMOVE HEAVIER COMPONENTS (ASPHALTENES) FROM RESIDUES TO PREPARE FEEDSTOCKS EG. PROPANE DEASPHALTED OIL (PDAO) FOR LUBRICANT MANUFACTURE. THE RESIDUE MIGHT BE IDENTIFIED AS PROPANE, ASHALT ETC.

## 1.12 Summary of Refinery Processes

A modern refinery is a very complex entity and incorporates additional processes to those considered here. The processes that are significant with respect to marine residual fuel oils may be described as follows:

The diagrams in Section 4 - "Refinery", provide a simple description of each of these processes.

### Distillation

- Atmospheric Distillation
- Vacuum Distillation

### Thermal Cracking

- Visbreaking
- Thermal Gas Oil Unit
- Coking

### Catalytic Cracking

- Distillate Cracking
- Residual Cracking

### Other Processes

- Hydrotreating
- Hydrocracking
- Solvent extraction

### Types of Refineries

To utilise fully the potential of crude oil, it is necessary to separate its constituents into a number of fractions; this is the object of oil refining. Refineries themselves can be divided into three different categories: simple, semi-complex and complex.

The basic configuration of a simple refinery is shown in Section 4. The foundation of the refinery is the atmospheric distillation unit, which physically separates crude oil into fractions of different boiling point. The residual fraction is, by definition, the material that will not boil at atmospheric pressure. The drawback of simple refining is that there is limited scope to vary the proportions of the resultant products; in particular, the ratio of residual to distillate material is governed almost entirely by the composition of the crude oil feedstock. Unless the product demand pattern is entirely compatible with the properties of the crude oil, an

unacceptable imbalance will exist with too much of one product and not enough of another. Generally, this will be the case as figure in Section 4, demonstrates; this figure compares the WOCA (World Outside Communist Areas) demand barrel with the fractions available from the simple distillation of a range of crude oils. It will be evident that, in all cases, residue availability exceeds demand, typically by a factor of two.

In order to match production with the market demand, it is necessary to go to complex refining. A complex refinery uses a combination of physical separation processes and chemical conversion processes that change the concentration, and to some extent the type, of hydrocarbons relative to those originally present in the crude oil. Both residues and heavy distillates are processed in conversion units. Conversion of a heavy feedstock involves reducing its carbon to hydrogen ratio. This is achieved either by removing carbon or by adding hydrogen. Carbon removal forms the basis of thermal cracking which is the oldest and simplest conversion process; the process is designed to reduce the molecular size of a portion of the feedstock by the application of heat. A particular type of thermal cracker, known as a thermal gas oil unit, is used in a semi-complex distillation unit to produce additional distillate (see Section 4).

Visbreaking and coking are also thermal cracking processes; they find application in fully complex refineries. In such a refinery, the residue from the atmospheric distillation unit is not fed directly to the conversion units, but is first processed in a vacuum distillation column. Here additional distillate material is extracted by carrying out a second distillation at reduced pressure; this promotes the boiling of heavier hydrocarbons. The residual stream is subsequently fed to the thermal cracking units while some of the distillate stream is generally upgraded further in the catalytic cracker (see Section 4).

Catalytic cracking is also a chemical conversion process that involves carbon removal; but, as the name implies, a catalyst is used to speed up the reaction rate.

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An alternative way of upgrading distillate material is to hydrocrack it. Here, the carbon to hydrogen ratio of the feedstock is reduced by the addition of hydrogen in the presence of catalyst; in this respect, the process is fundamentally different from catalytic and thermal cracking.

A fully complex refinery has all the processes shown in Section 4, thus a wide range of residues and diluents are available. However, fuel oil will usually consist of visbroken residue (that is a combination of residue and gas oil from the thermal cracker) diluted with cycle oils, cycle oil slurry and smaller amounts of

other distillates. If the refinery does not possess a thermal cracker, then the fuel oil has to be based on long and short residue.

It should be recognised that, particularly in a complex refinery, other streams are incorporated into the fuel oil pool to a lesser degree. There is some evidence to indicate that the less scrupulous refiners or bunker fuel suppliers may use the marine bunker fuel pool as a dump for waste products, which are otherwise difficult to dispose of - for example waste lubricating oils.

# 2

# Fuel Oil Composition and Blending

## 2.1 Composition

It should be remembered that the aim of the refiner is to produce the most valuable components possible, using the cheapest crude oil available, given the constraints of the product specifications and the processing equipment existing in the refinery.

The dominant market demand is for distillates such as gasoline and diesel fuel for road, the transport markets, aviation fuel and feedstock for chemical manufacturing plants.

Thus any residual fuel offered to the market would be essentially the unavoidable “waste product” arising from the main refinery activity.

Crude oils are complex mixtures of hydrocarbons and small amounts of other substances, and there are considerable variations in the composition and properties of crude oils from different sources.

Refining to produce distillates is essentially a process of selecting the preferred components. This introduces a degree of commonality in the distillate fuels produced. Even so there are still considerable variations in the composition and property of distillate fuels from different crude oils. For example, gas oil derived from Middle East and Nigerian crude oils have significantly different values for density, cetane number, pour point, etc.

Residual fuels are considerably more complex and variable than distillate fuels. In addition to the variations resulting from the type of crude oils used and the different types of refinery plant, there will be short-term variations within each refinery

depending upon the availability of residual and diluents blending components.

Residual fuel oil remains similar to the parent crude oil except that the distillate fractions have been removed thus leaving a higher concentration of the heavier species in the residue, i.e. sulphur compounds, large complex hydrocarbons, nickel and vanadium, etc.

The principal elements in the residual fuel oil are carbon and hydrogen; nitrogen and oxygen are also present, but in lower concentrations. The elemental composition of a residual fuel oil will typically be:

- Carbon 84 - 86 % weight
- Hydrogen 10 - 12 % weight
- Sulphur 0 - 5 % weight
- Nitrogen 0 - 1 % weight
- Oxygen 0 - 1 % weight
- Plus trace elements.

Clearly, it will be necessary for the refiner to blend fuels so as to meet end-use performance and environmental specification limits. In general the use of the more expensive diluents components will be limited as far as this is practical. This is particularly true with respect to the marine market where the current lack of environmental constraints provides the refiner with the opportunity to utilise this market as the “sink” for contaminants which are less acceptable in the inland market for residual fuel oils.

In any blending situation, the refiner will be required to meet one of the specification limits which impose a constraint for the particular set of circumstances, with the other properties and specification limits being more easily satisfied by the selected blend.

When blending for the inland market the dominant constraint will often be the sulphur content because of environmental legislation (which in future will be extended to the marine market). In the marine bunker fuel market, the dominant constraint is likely to be the need to meet limits for density, carbon residue and aluminium/silicon.

Viscosity is not a constraint to the refiner, other than the financial penalty of using

increased amounts of the more valuable distillates as diluents.

There is an additional constraint which the refiner should always meet but sometimes fails to achieve - that is to produce a blend which is STABLE (see Section 3 - "Stability and Compatibility").

## 2.2 PROPERTIES OF MARINE FUELS

Fuel samples are customarily analysed in control laboratories. Some tests are necessary only in special circumstances; others are always desirable. Five of the properties discussed below - density, viscosity, water content, sulphur and flash point - are those most often quoted on the delivery receipt and should be sufficient for quantity calculations and adjustment of fuel cleaning and treatment equipment. The other properties discussed have to be known if a complete assessment of fuel characteristics is required. Some, such as distillation range and cetane number, are relevant only to distillate fuels.

### 2.2.1 Density

Significance:

- Separability of water and solids
- CCAI calculation
- Quantity calculation
- Specific energy calculations

Knowledge of the fuel's density is needed for quantity calculations and to help determine the optimum size of gravity ring for purification. It is also the most significant parameter in order to be used to calculate the fuel's calorific value. Density alone gives no direct indication of fuel quality and there is no relationship between density and viscosity for fuels from different crude oils or blending components.

Density is an absolute relationship between mass and volume at a stated temperature, in contrast to specific gravity (or relative density), which is related to the density of water at the same or a different reference temperature. Density is progressively becoming the universal parameter for fuel

description. The API gravity (Degrees API), which will eventually be replaced by density, is a function of specific gravity at 60/60 °F. API gravity is inversely proportional to specific gravity with 1.0 specific gravity equalling 10 degrees API.

There are several units for density. The SI unit is  $\text{kg/m}^3$ , and this is the form increasingly used. It gives numerical values in the range of 500-1050 for petroleum products. To give values related to units, SI allows only two alternatives:  $\text{kg/dm}^3$  or  $\text{mg/m}^3$ , neither of which is particularly familiar. The  $\text{dm}^3$  unit is exactly equal to the litre, however, and the kilogram per litre ( $\text{kg/l}$ ) unit is most commonly used at present.

Densities are measured over a range of temperatures, often those at which the fuel is stored. The correction to a density at 15°C, required by many excise authorities, can be made from standard tables. These are derived from density measurements of large numbers of samples representing worldwide fuel availability. Like viscosity/temperature characteristics, density/temperature characteristics can vary a little from one fuel to another.

Typical density range of fuels at 15°C is:

- |                     |                         |
|---------------------|-------------------------|
| • Kerosine          | 770-810 $\text{kg/m}^3$ |
| • Gas oil           | 820-880 $\text{kg/m}^3$ |
| • Heavy distillates | 840-920 $\text{kg/m}^3$ |
| • Heavy Fuel Oils   | >930 $\text{kg/m}^3$    |

The increasing use of cracking processes to obtain a larger proportion of distillates from crude oil has resulted in increases in the densities of residual fuels in many areas. Consequently, it has become necessary to control density where fuels that are to be centrifugal purified. A level of 990  $\text{kg/m}^3$  at 15°C, arrived at by tests carried out jointly by Shell and Alfa-Laval and published in the "Motor Ship" of April 1978, has become the accepted maximum for this purpose. This figure was derived from densities measured at 45-50°C and corrected back to 15°C by the measurement tables then in force. New standard measurement tables were published in 1980, and these show slightly different density/temperature characteristics from

those used historically. In practice, a fuel whose density measured at 40-60°C gave a corrected value of 990 kg/m<sup>3</sup> at 15°C by the former tables, gives approximately 991 kg/m<sup>3</sup> at 15°C when corrected by the new tables. The latter has become the standard for centrifuges operating with a gravity ring and water seal. The introduction of new centrifuge technology, for example Alfa-Laval's "ALCAP", permits a density limit of 1010 kg/m<sup>3</sup>.

For details about the definitions of relative density, specific gravity, API gravity, temperature conversion tables etc., please refer to Section 5 "Density - Volume/Weight"

### 2.2.2 Viscosity

Significance:

- Fluidity & heating needs for transfer and injection
- CCAI calculation
- Purchasing grade paid for

In practical operation, viscosity is the most important fuel characteristic. It is not in itself an indication of quality, but since the viscosity of fuel oils decreases as they are heated, knowledge of the rate at which viscosity changes makes it possible to estimate the temperature at which the fuel should be stored for pumping at the most convenient rate. The viscosity curve also enables the engineer to gauge the temperature at which residual fuels should be atomised.

Formerly, there were various methods for determining viscosity, such as Redwood, Saybolt and Engler, but all of these are now obsolete. Kinematics viscosity is now the generally accepted standard, expressed as "mm square per second" at a fixed temperature, usually 50°C for residual fuels and 40°C for distillates. A move to 100°C for residual fuels was expected since the introduction of the ISO marine fuel standard. It is believed, however, that fuels will continue to be priced and sold based on the viscosity in mm<sup>2</sup>/s at 50°C for many years to come. There is already a pressure on ISO to adopt 50°C instead of the 100°C. A temperature of 50°C is normally high enough to avoid wax formation, which at lower temperatures (depending on the Pour

Point) might result in a false viscosity reading.

Chart IV, viscosity/temperature relationships in Exxon's Conversion Tables and Charts (see Section 7) shows a range of viscosity/temperature curves for fuel oils, and includes comparable curves for gas oil and marine diesel fuel. The curves provide an estimate of the change in viscosity with temperature, and indicate the most suitable temperature for pumping and atomisation.

The figure shows, for example, that a 380 mm<sup>2</sup>/s at 50°C fuel will have a viscosity of approximately 1700 mm<sup>2</sup>/s at a storage temperature of 30°C. In estimating viscosities at low temperature, however, it is necessary to bear in mind that the extrapolated viscosity may not agree with the measured value. This is because wax formation may thicken the oil.

The figure also indicates the temperature at which each fuel will give the most efficient atomisation. Suppose, for example, that the injection equipment provides the best combustion when fuel is atomised at a viscosity of 15 mm<sup>2</sup>/s. The curves show that the appropriate atomisation temperature is approximately 88°C for fuel oil of 60 mm<sup>2</sup>/s at 50°C and approximately 128°C for a fuel oil of 380 mm<sup>2</sup>/s at 50°C.

The shaded portion of the figure shows the range over which most fuel injectors are designed to give the best atomisation.

Because different fuels may vary in their viscosity/temperature characteristics, it is strongly recommended that the final control of fuel heating should be viscometric rather than thermostatic. By means of a viscometer in the fuel line, the final viscosity of a blend of two different grades may be readily obtained before the mixture is delivered to the engine.

### 2.2.3 Water Content

Significance:

- Wet sludge
- Corrosion (esp. sea water)
- Possible ignition inference
- Displacement of fuel quantity
- Specific energy calculations

Water is the most common contaminant of fuel oil, and it is therefore customary to

conduct regular determinations of water content on fuels held in bulk storage. Apart from the fact that up to 1 per cent by volume of water is allowed in many of the specifications for heavy fuel oils, there is usually a likelihood of further contamination by water in customer storage. This can be caused by leakage of water into the tank in a badly designed or maintained fuel installation, but may more commonly result from condensation of water inside the tank as a consequence of "tank breathing" due to temperature variations. The water is generally in an emulsified form and settles - over a period dependent on the fuel's viscosity - thus contributing to the sludge at the bottom of the tank. Water reduces the fuel's net specific energy, and thus imposes a cost penalty on the operator. To keep this to a minimum, Shell companies have established a maximum water level of 0.3 per cent at certain major ports.

#### 2.2.4 Sulphur

Significance:

- Corrosive wears of cylinder liners and rings; however, adequate lubrication with modern lubricant means effectively no/small problems.
- Specific energy calculations

The sulphur content of a fuel oil is very important. It depends entirely on crude oil origin and the amount of distillate material removed. In practice it varies from around 1 per cent to 4 per cent mass, although up to 4.5 per cent is permitted in certain specifications for heavier grades.

When a fuel burn, any sulphur it contains is converted into sulphur oxides. These are not particularly harmful and would pass out through the exhaust system were there no water present. But they condense in the water which is present to form acids that may cause corrosion and wear of cylinder liners and piston rings. This is only one of several causes of wear, however, and has been overcome by the use of high-quality alkaline lubrication oils, and by running engines at temperatures above the condensation point of water and sulphur acids. In general, low-speed marine diesel engines run quite satisfactorily on fuels with sulphur content of up to 4 per cent.

Gas oils, which are 100 per cent distillate, normally have sulphur content not greater than 1 per cent mass. Marine diesel fuel, which is not necessarily completely distillate, may have sulphur content of 1.5 per cent, or even more, due to the presence of a small proportion of residual material.

#### 2.2.5 Carbon Residue and Asphaltenes

Significance:

Indication of tendency to formation of carbonaceous deposits. However, correlation to field performance is poor.

To estimate the coke-forming tendency of a diesel fuel, somewhat empirical carbonising tests are used, such as Ramsbottom or Conradson. A new test, Micro Carbon Residue (MCR) is becoming widely used in place of the Ramsbottom and Conradson residue tests. It correlates with the Conradson test, but is quicker and has better precision. Broadly speaking, these tests indicate the amount of residual matter present in the fuel. Values for pure distillate fuels are therefore very low, normally less than 0.05 per cent mass - so low that the test is often carried out on the 10 per cent residue of the fuel. Fuel oils give carbon values as high as 22 per cent mass, depending on viscosity grade and origin.

The carbon residue and asphaltene content are generally related, although the precise relationship varies considerably from one fuel oil to another.

Fuel containing a high proportion of cracked components may have a very high carbon residue and asphaltene content. So long as the asphaltene remain dispersed and the fuel is stable there are not necessarily any problems in handling or combustion, and high carbon residue may therefore be tolerated. The ISO 8217 Standard, for example, permits up to 22 per cent mass Carbon Residue for the heavier grades of fuel.

#### 2.2.6 Ash Content

Significance:

- Incombustible materials, which are metals, may form deposits on piston



rings, grooves, liners, exhaust valves, turbochargers.

- Specific energy calculations

The amount of ash-forming material in distillate fuel is extremely low and can usually be disregarded. During distillation in the refinery, the ash-forming constituents of the crude oil tend to be concentrated in the residue. Fuel oils, which are usually blends of this residue with a distillate, have measurable ash content, though this is rarely as high as 0.1 per cent mass. The nature of the fuel ash and its amount vary widely, being largely dependent on the source of the crude oil, but the amount may be increased by contamination with inorganic matter during handling before combustion. The main elements present in what might be termed the “natural” ash are usually aluminium, calcium, iron, nickel, silicon, sodium and vanadium. Contamination may introduce further quantities of sodium in seawater; iron from rusty storage tanks or pipelines; and aluminium and silicon are dust and dirt, or from catalyst fines derived from the refining process (see below). Nickel and vanadium are usually present only in oil-soluble forms. Metals such as calcium and zinc are typical for lubricating oils. Their presence in fuel is an indication of some lubricating oil having been mixed into the fuel

Insoluble matter and water-soluble salts (especially sodium salts) can usually be removed by centrifuging, a process that is obviously most effective if carried out immediately before combustion. Oil-soluble ash components, notably vanadium, cannot be removed by centrifuging or by any other method that is practical on board vessel.

Heavy ash deposits may be harmful to an engine, especially if they form on such critical areas as exhaust valve seating. Local breakaway of these deposits will allow gas blow-by and, owing to the high gas temperature and velocity, can lead to guttering of the valves.

In turbocharged engines, some ash can deposit on the turbine blading. These deposits often have high sodium content, and can be largely removed by regular

water washing. If they are not removed, their effect is cumulative, since any blockage of the turbine reduces the air throughput of the turbocharger. The exhaust gas temperature is thus raised and the rate of ash deposition increased.

### 2.2.7 Catalyst Fines (Al/Si)

Significance:

- Almost invariably an indication of catalyst fines which are highly abrasive. Even levels within specification can and must be adequately reduced before use.

The more widespread use of secondary conversion processes means that increased volumes of cracked material, including components from catalytic crackers, are now incorporated in heavy fuels. These trends causes some concern because of the consequent risk that disintegrated catalyst, known as catalyst fines, may be carried over into the fuel component. The catalyst is normally an alumina-silica compound. It is very hard and abrasive and, if present in sufficient quantity, could result in high wear of various engine components (especially fuel pumps/injectors and cylinder liners and piston rings). Most of the catalyst fines are usually recovered after the cracking process and then recycled. Occasionally, perhaps because of some fault in the recovery process, the level of catalyst fines left in the fuel is unacceptably high. Alternatively too much of the component containing catalyst (slurry oil) is used for blending into the fuel.

Under normal circumstances, the final concentrations of catalyst fines in a finished fuel containing cracked components are low, less than 120 mg/kg. Even where higher concentrations are present, efficiently operated centrifuges on board vessel can reduce fines to a level that will not seriously increase engine wear.

The ISO 8217 Standards for marine fuels indicate a maximum limit for aluminium plus silicon in the fuel of 80 mg/kg, corresponding to about 160 mg/kg of total catalyst. The combined aluminium and silicon limit value of 80 mg/kg is intended to ensure that catalyst contamination would

be no higher on average than would have been implied by the limit of 30 mg/kg, previously proposed for aluminium only. The aluminium plus silicon requirement of 80 mg/kg maximum is therefore to be used in place of, not in combination with, a 30 mg/kg aluminium only limit. This limit is now generally accepted in the industry. Centrifuging a fuel containing the maximum permitted level of aluminium plus silicon should ideally reduce the concentration to below 15 mg/kg, which experience has shown to give little or no increase in abrasive wear.

Quite apart from the concentration present, the particle size of the catalyst fines has an important influence on wear. The larger particles would be expected to increase wear in the fuel injection system and the smaller particles (below about 5 microns in diameter) to pass through the clearances in the injection system without damage. There is evidence, however, that even such very small particles can promote piston ring and liner wear when they are trapped between these components and subjected to the high gas pressures behind the piston rings.

## 2.2.8 Other Elements

### Vanadium (V)

With sodium at 3:1 V/Na - high temperature corrosion after combustion, especially exhaust valves. Derives from crude oil and not removable by onboard treatment.

### Sodium (Na)

Corrosion (for example of fuel pumps & injectors) if present from seawater.

High temperature corrosion at 3:1 V/Na ratio. Can contribute significantly to ash deposits. NB: Sodium chloride (seawater, salt) is non-soluble in fuel. Removing water normally removes Na significantly.

### Iron (Fe)

Rust & scale may be somewhat abrasive, but if so, should be removable by centrifuge.

### Nickel (Ni)

Derives from the crude oil and not removable by inboard treatment.

### Calcium (Ca)

May be indicator of waste lubricants, but also inherent in a few crude oils.

Frequently used as additive to lubricants for the purpose of neutralising acidic components from the combustion process (sulphuric acids)

### Magnesium (Mg)

Main source is from sea water contamination

### Lead (Pb)

Used as an additive in petrol and hence when found in fuels may indicate the presence of waste automotive lubricants.

### Zinc (Zn)

Typical antiwear additive used in lubricants and hence indicates the presence of waste lubricants.

### Seawater

Seawater is detected when the Na/Mg ratio is approximately 8:1

## 2.2.9 Cleanliness/Total Sediment

Significance:

- Indication of dirt and sludge in the fuel.
- Wet sludge if water also high.

A fuel oil should ideally be composed of 100 per cent liquid hydrocarbon material. In practice, however, this is not possible. Inorganic matters (grit, clay, sand), naturally occurring in crude oil, remain in the residues after distillation and cracking processes, and thus carry through to the residual fuels. Every effort is made to remove such impurities in the refinery, but inevitably some will remain. Certain thermal conversion processes used in some refineries can cause the asphaltenes in a fuel to agglomerate, and can also lead to the introduction of coke into the residue. The fuel may pick up non-hydrocarbon material during its manufacture, transportation from the refinery to the final user or even on the vessel itself.

### Test methods:

Total Sediment Existent (TSE):

ISO 10307-1/93, modified

(IP 375/94, modified).

Total Sediment Potential (TSP):

ISO 10307-2/93, modified

(IP 390/94, modified).

Total Sediment Accelerated (TSA)

ISO 10307 Part 2, procedure A& B,  
Modified

Sediment or sludge occurs as a function of three different fuel properties. They are:

### Cleanliness

Cleanliness of a fuel is defined as the amount of sediment or sludge at the moment of measurement by the filtration test method ISO 10307-1/93. Some of this sludge may be due to the onset of an instability effect.

### Stability

With unstable fuels the amount of sediment or sludge increases significantly with time, or as a result of heating in storage or during transport.

There are two ageing procedures available in the form of the ISO 10307-2/93 method. They determine the potential increase in sediment after

- a) 24 h. heating at 100°C (Thermal Ageing)
- b) 1hrs heating at 100°C after addition of cetane (Chemical Ageing)

Either may be applied but the method should be stated. The property "Total Sediment after Ageing" is obtained by measuring the cleanliness after applying either of the above ageing procedures. The revision of ISO 8217 publicised Spring 1996 specify method a) referred to above: Total Sediment Potential (TSP).

### Compatibility

Fuels are incompatible if a mixture of two or more fuels produces a blend with an increased amount of sludge. Since compatibility is not a property of the delivered fuel alone, it can not be included in these requirements.

An indication of the compatibility of two fuels can be obtained by means of any cleanliness test, applied to a mixture of the fuels in the intended ratio.

For use on board, the ASTM D 4740 spot-test can give a quick answer for this purpose. Experience, however, has indicated that compatible fuels occasionally fail to pass this test due to deficiencies in the test procedure. A general problem with compatibility assessment is that samples of both fuels are normally not available in advance. The risk of incompatibility problems should therefore be avoided as much as possible by appropriate design and operation of the fuel storage and treatment installation. Refer to Section 11 – "Commingling of fuels" on some practical guidelines in order to avoid compatibility problems.

### 2.2.10 Flash Point

Significance:

- Statutory Safety Requirement

This is the temperature at which the fuel produces sufficient vapour to ignite (flash) when a test flame is applied under standardised conditions. The vessel's engineer must be sure that the fuel can be safely handled without undue fire hazard. A flash point determination provides the information he requires ensuring, for example, that the fuel is not contaminated by very light fractions.

Minimum flash point temperatures to meet insurance and statutory requirements are quoted in the various fuel specifications. If a fuel is heated during storage, some classification societies and authorities require that its temperature should not exceed a value 10°C below the actual flash point. For more detailed information on existing statutory rules with regard to flash points, see Section 14 – "Guidelines for the handling of fuel oil with flash point below 60°C".

### 2.2.11 Low-temperature properties (Pour Point)

Significance:

- Wax formation impeding fluidity

If the fuel is allowed to fall below a certain critical level, wax begins to separate out, tending to block filters and restrict the fuel flow. Fuels of lower viscosity may have to be heated to prevent wax formation. The

more viscous fuel oils are normally heated anyway to reduce viscosity to a level at which they can easily be pumped; the degree of heating required is usually more than adequate to prevent any wax separation.

With heavy fuels, in particular, pour point is the usual criterion of low-temperature properties. The pour point is 3°C above the temperature at which the fuel will just not flow under its own weight when tested by certain standard methods. For the heavier grades of fuel, it may be as high as 30°C, in some areas of the world even above 30°C.

With distillate fuels, i.e. gas oil, the Cloud Point (CP) or the Cold Filter Plugging Point (CFPP) more commonly judges low-temperature performance. The cloud point is the temperature at which, in a standard test, wax crystals first become visible and start to turn the fuel opaque. It may be up to 10°C above the pour point.

Nowadays, especially for distillate fuels for inland use, the CFPP is often used in preference to the cloud point, since it is considered to give a more reliable indication of blocking of fuel filters in service. The CFPP is the temperature at which wax crystals plug a standard filter mesh under controlled conditions.

In the main specifications for marine fuels ISO 8217 and ASTM D 975-81, however, cloud point is still retained for defining low-temperature properties. In the BS 2869: 1983 Specification for non-marine fuels, limits are laid down for the CFPP and not for the cloud point. For additional information on waxy fuels, see Section 3 – “Stability and Compatibility”.

### 2.2.12 Specific Energy (Calorific Value)

Since the object of burning a fuel oil is to liberate heat, it might be thought that one of the most important tests would be that of specific energy. On the contrary, this determination can normally be dispensed with altogether, as specific energy can be calculated sufficiently accurate for most practical purposes from one of the recognised formulae. The most relevant formula is that contained in the International Standard ISO 8217 -

Petroleum Products - Fuels (Class F) - Specifications of Marine Fuels.

Gross specific energy MJ/kg =

$$(52.190 - 8.802d^2 \cdot 10^{-6})(1 - 0.01(x + y + s)) + 9.420(0.01s)$$

Net specific energy MJ/kg =

$$(46.704 - 8.802d^2 \cdot 10^{-6} + 3.167d \cdot 10^{-3})(1 - 0.01(x + y + s)) + 0.01(9.420s - 2.449x)$$

Where

d is density at 15°C, kg/m<sup>3</sup>

x is the water content in %, m/m

y is the ash content in %, m/m

s is the sulphur content in %, m/m

These formulae give the specific energy in megajoules per kilogram (MJ/kg).

To convert to British thermal units/lb. multiply MJ/kg by 429.9.

To convert to calories/gram (cal/g) multiply MJ/kg by 238.8.

### 2.2.13 Distillation Range

The distillation characteristics of distillate fuels are assessed by certain ASTM or IP laboratory methods. The two best known (ASTM D86 or IP 123) are carried out in standard laboratory apparatus, in which a 100 ml sample is distilled at a prescribed rate and volumes of condensate are measured against boiling temperature. With fuels boiling above 350°C, there is a tendency for thermal decomposition to occur. It is usual with such fuels to record not the final boiling point, but either the per cent distilled at a particular temperature, say 350°C, or the temperature at which a certain proportion, say 90 per cent, distils.

Residual fuels decompose (crack) before heavy ends are boiled off, and their full distillation range cannot therefore be determined.

### 2.2.14 Ignition Quality

Ignition quality is a fuel property of major importance in diesel engines, affecting the time between injection and the start of combustion. If ignition, or combustion, is delayed too long, too large a quantity of

fuel will have been injected and these will all fire at once, producing a rapid pressure rise and the characteristic “diesel knock”. On the other hand, if the ignition delay is short, combustion will start when relatively little fuel has been injected and the remaining fuel will burn in a controlled manner as it enters, producing a smooth pressure rise. See also Section 6 – “Ignition and Combustion”.

### 2.2.15 Ignition Quality of Distillate Fuels

The methods described below for evaluating ignition quality - cetane number, diesel index and calculated cetane index - apply only to distillate fuels, and are not meaningful for residuals.

#### Cetane Number.

The only reliable way to determine the ignition quality of a diesel fuel is to compare it with suitable reference fuels in an engine test. The result is expressed in terms of cetane number on a scale defined by pure cetane as the high reference fuel (cetane number 100) and (alpha)-methyl naphthalene as the low reference fuel (cetane number 0). The cetane number of the test fuel is the percentage in volume of cetane in a blend of cetane and (alpha)-methyl naphthalene with the same ignition quality when tested in the same engine under the same conditions.

Because the determination of cetane number requires a special engine rig, which is both fairly large and expensive, alternative means have been sought to ascertain the ignition quality of distillate fuels; these use the traditional apparatus commonly found in laboratories.

#### Diesel Index.

For many years diesel index was used to estimate cetane number. This method relied upon established knowledge of the ignition quality of the standard distillate streams traditionally used to manufacture gas oils, that is the high quality of n-paraffins and the low quality of aromatic and naphthenic compounds. The aniline point of the fuels was used, together with the API gravity, in the following formula:

Diesel index =  
 aniline point (°F) x API gravity/100.

The aniline point is the lowest temperature at which equal volumes of fuel and aniline become just miscible. The test depended on the fact that aromatic hydrocarbons mix completely with aniline at comparatively low temperatures, whereas paraffins require considerably higher temperatures before they are completely miscible. Thus, a high aniline point indicated a highly paraffinic fuel and, therefore, one of good ignition quality. Similarly, a high API gravity denoted low specific gravity and high paraffinicity, and again good ignition quality.

Owing to the wider use of hydrocarbons with high aniline points but poor ignition quality, however, diesel index frequently overestimated the cetane number and thus has become inappropriate in today's environment. As a consequence this method has been withdrawn, though reference to it will still be found in older textbooks and engine manuals.

#### Calculated Cetane Index (CCI).

The empirical formula (quoted below), when applied to gas oils manufactured from traditional straight-run components, gave numbers corresponding quite closely with the cetane number:

$$CCI = 244.4 - (321.3 * A) + (0.291 * B)$$

where

A = API gravity

B = 50 per cent recovery temperature in °F

But, unfortunately, this formula is unreliable when applied to fuels with large proportions of isoparaffins and/or thermally cracked components. Because of the wide usage of such components in modern gas oils, therefore, the method has been withdrawn and replaced by the “Calculated Cetane Index by Four Variable Equation”.

Calculated Cetane Index by Four Variable Equation.

This method enables the ASTM cetane number of distillate fuels to be estimated from density and distillation measurements. It is applicable to straight-

run and cracked components and blends of the two. It may also be used on fuels containing non-petroleum derivatives from tar, sands and oil shale.

$$CCI = [45.2 + (0.0892 * T_{10N})] + [(0.131 + (0.901 * B)) * T_{50N}] + [(0.0523 - (0.42 * B)) * T_{90N}] + [(0.00049 * (T_{10N}^2 - T_{90N}^2))] + (107 * B) + (60 * B^2)$$

Where

CCI = Calculated Cetane Index by Four Variable Equation

D = Density at 15°C, kg/m<sup>3</sup> (ISO 12185)

$$D_N = (D - 850)$$

$$B = (\exp(-0.0035 * D_N)) - 1$$

T<sub>10</sub> = 10% Distillation recovery temperature, °C (ISO 3405)

$$T_{10N} = (T_{10} - 215)$$

T<sub>50</sub> = 50% Distillation recovery temperature, °C (ISO 3405)

$$T_{50N} = (T_{50} - 260)$$

T<sub>90</sub> = 90% Distillation recovery temperature, °C (ISO 3405)

$$T_{90N} = (T_{90} - 310)$$

<sup>x</sup>) Corrected to standard barometric pressure.

### 2.2.16 Ignition Quality of Residual Fuels

The ignition quality of most residual fuels used in low-speed or medium-speed diesel engines is satisfactory, since there is normally ample time for ignition and complete combustion. Because of the trend towards residual fuels in place of distillate fuels in many engines running at relatively high speeds, however, the ignition quality of residual fuels has become of greater importance than formerly. Furthermore, certain residual fuels derived from conversion (cracking) processes have poor ignition characteristics and have sometimes caused problems. Engine designs and operating conditions have the greatest influence upon ignition delay. Relatively small variations in operating conditions, increased charge air temperature for example, can give a considerable improvement in ignition delay. Nevertheless it is desirable to have

information on the ignition properties of the fuel concerned.

Because residual fuels are blends of many different components, there has so far been no standard test method for evaluating their ignition quality, and no such test is laid down in the various specifications for them. Published work, however, has shown an empirical relationship between the density, the viscosity and the ignition performance of a fuel. The background of this phenomenon stems from the examination of the fundamental aspects of the ignition process. This led to the conclusion that ignition quality should be related to fuel aromaticity, which for this purpose was defined as of the percentage fuel's carbon atoms that are located in aromatic structures.

Aromatic molecules increase ignition delay for two reasons: They have a relatively high thermal stability and do not oxidise readily during the ignition process, and they also retard the oxidation of more reactive species. A longer ignition delay gives a greater risk of ignition trouble, although this also depends on the magnitude and the rate of pressure rise after ignition.

However, aromaticity is not a straightforward parameter to measure. Fortunately, further work established a correlation between carbon-aromaticity and the density and viscosity of the fuel. This is apparent in the experience that fuels causing ignition trouble often (not always) have a higher density than normally found at the occurring viscosity.

Two formulas have been presented to obtain an indication for ignition delay. That for CCAI, developed by Shell, is a measure for carbon-aromaticity, the relation with ignition delay being empirically confirmed. That for CII (Cetane Index Indicated), developed by BP, has an empirical basis. They are:

$$CCAI = D - 81 - 141 \log[\log(V + 0.85)] - 483 \log[(T + 273) / 323]$$

$$CII = [270.795 + (0.1038 * T)] - (0.254565 * D) + 23.708 \log[\log(V + 0.7)]$$

where

D is the density in kg/m<sup>3</sup> at 15°C

V is the kinematic viscosity in mm<sup>2</sup>/s

T is the temperature, in degrees Celsius, at which the kinematic viscosity is determined.

These values can also be obtained by drawing a straight line through the actual viscosity and density values of a fuel in the nomogram shown in Section 7 – “CCAI/CII Nomogram” and extending the line to the CCAI or CII scale.

Several engine manufacturers have published their experiences with ignition quality, mostly by referring to the CCAI of the fuels. It appears that the value above which ignition problems can occur is in the range of 850 - 890, with an increased probability for a large group of engines in the range of 870 - 890. For lighter grades, however, (up to about 25 mm<sup>2</sup>/s at 100°C - 200 mm<sup>2</sup>/s at 50°C) the value can spread between 840 and 860 so it is preferable to be below a CCAI of 840. Based on such experiences, some manufacturers specify CCAI limits for their engines, depending on engine type and application. Ref. Section 7.

It has now become clear that the density-viscosity relation does not allow a completely accurate prediction of ignition quality. As a consequence, limiting the calculated carbon aromaticity by means of

maximum density and minimum viscosity limits in a specification could be misleading as such limits do not guarantee a certain ignition quality but only increase its probability.

Therefore, in the CIMAC standards only the lighter fuel grades A, B and C 10 and D 15 have a reduced density and only two grades have a limit on minimum viscosity. These grades are presented here with the resulting maximum CCAI values:

The viscosity may be lower than the minimum value specified if the density is sufficiently low so as to ensure that the specified maximum CCAI value is not exceeded.

For all other grades the probability of reasonable ignition quality can only be increased by specified requirements in order to limit the maximum possible CCAI value.

The CCAI value required for a certain engine type and application may be specified by the engine manufacturer or may be obtained by experience. The graph in Section 7 enables the user to plot the CCAI values and fuels that give, or do not give, ignition difficulties and thus derive the statistically allowable CCAI value.

**Table 3**

<b>GRADE</b>	<b>A 10</b>	<b>E 25</b>
Density max (kg/m <sup>3</sup> )	950	991
Viscosity min (mm <sup>2</sup> /s)	6	15
CCAI max	850	869

**2.2.17 Fuel Ignition and Combustion Analyser**

Heavy knocking, sticking exhaust valves, erratic revolutions and starting difficulties are but some of the observations that may

be an indicator of poor fuel ignition and combustion properties.

CCAI (Calculated Carbon Aromaticity Index) is a calculated formula being used to indicate the ignition properties of a residual fuel oil. While slow speed, large

bore engines are supposed to be operating satisfactorily at fairly high CCAI, medium and high speed engines and engines of older design may experience ignition difficulties at much lower CCAI values. However, while some low CCAI fuels may perform poorly, some high CCAI fuels may perform well, confirming this calculated index is not always sufficient to predict the ignition quality of residual fuels, and the impact on the various engines types and models.

Recently a new international test method has been developed to determine the ignition and combustion properties of residual fuels. The test method which is the IP541/06 was approved in January 2006. The FIA-100 FCA test instrument (Fuel Ignition and Combustion Analyser) has been developed to operate according to new this test method. The ignition and combustion properties obtained by the instrument are based on the prevailing condition for the FIA instrument; combustion chamber preheated to 500 deg C and pre pressurized to 45 bar. However, the impact of the measured values will vary greatly for the various engine types and models.

Work is now in process within CIMAC (The International Council on Combustion Engines) to develop a recommendation and

adequate guidance in this important field of fuel quality. As a rule of thumb high and medium speed engines and engines of older design are more sensitive what these properties regard, compared with slow speed engines and engines of more recent design. It is the task of the CIMAC working group to create an ignition and combustion quality standards for the various engine types, based on the reported results and the experience feedback from ships and power stations. DNVPS are carrying out tests according to IP541/06 by the means of the FIA-100 FCA instrument, as well as by means of the older design FIA-100/3 instrument, which refers to a proprietary test method. While the latter was originally designed for the determination of the ignition quality of residual fuels, the former has been further developed to include the combustion characteristics as well.

#### **2.2.18 Health Aspects**

There are certain health aspects related to the exposure to petroleum fuels and their vapours, which have been studied in a recent project "Possible health problems by the use of fuel oil on board ships". See Section 8.



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**3**

**MARINE FUEL  
SPECIFICATION**

### 3.1 Introduction

Prior to 1982 there were no national or international fuel specifications catering for the special needs of the marine industry. The major oil companies formulated a unified classification for marine fuel grades during 1974-75 but it referred only to the maximum viscosity of each grade and was in no way a specification. Shell companies manufactured marine fuels to their own "International Bunker" specifications but these applied only to fuels supplied from Shell installations. The same applied to other major suppliers.

Up to 1982 the standards partly used by ship owners were British Standard BS 2869 and ASTM D975 and D396.

Following the oil crises in 1973 and 1979, and the subsequent changes in residual fuel characteristics caused by radical changes in refinery operations, ship owners suffered an increasing number of fuel-related operational problems. The shipping industry's call for international fuel specifications was consequently intensified.

#### 3.1.1 British Standard BS MA 100: 1982 and 1989

BS MA 100: 1982 – "Petroleum Fuels for Marine Oil Engines and Boilers" was published by the British Standards Institution (BSI) as a interim measure pending the issue and qualification by the International Organisation for Standardisation (ISO) of an international standard specification for Marine Fuels - ISO 8217 "Petroleum Products - Fuels (Class F) - Specifications of Marine Fuels". Details of the revised BS MA 100: 1989, which is identical to the ISO 8217, are obtainable through British Standards Institution. The ISO Standards can be ordered through the National Standardisation Organisations in the individual countries.

#### 3.1.2 ISO 8217 - Petroleum Products

ISO 8217 - Fuel (Class F) – Specifications of marine fuels was issued in 1987. It covered 19 different categories of fuel -

four distillates, ten residual fuels with a density limit of 991 kg/m<sup>3</sup> and five residual fuels with no density limit.

ISO 8217: 1996 was the first revision of ISO 8217: 1987. This standard contains requirements on sediment and abrasive particulates (catalytic fines).

The second revision of ISO 8217 was published in December 2005 and a copy of this ISO 8217 has been included in this ring binder. See section 16.

This edition introduces several important changes. Some of them are: reduction of the number of residual grades from 13 to 10; change of temperature for viscosity measurement from 100 °C to 50 °C with a subsequent revision of grade nominations; incorporation of lower global limits for sulphur, reduction of maximum water content to 0.5 % V/V and a prohibition on the inclusion of used lubricating oil in marine fuel.

#### 3.1.3 CIMAC Fuel Recommendation

The International Council on Combustion Engines (CIMAC), supported by engine manufacturers, marine fuel treatment plant manufacturers, fuel and lubricating oil suppliers, additive suppliers, ship owners, research institutes, technical universities and fuel testing services, in the early 80's set up a working group to provide recommendations for the quality of fuels to be used in marine and stationary diesel engines.

The outcome of their studies was the "CIMAC Recommendation Regarding Requirements for Heavy Fuels for Diesel Engines", published in 1986.

The first revision was published in 1990, while the second revision was published in 2003 as number 21/2003.

Although the CIMAC and ISO 8217 fuel standards are similar, CIMAC emphasizes that their specification has a different perspective from that of the ISO standards. Although in general the fuel requirements in table 2 are more or less identical, for the lowest CIMAC grade (A30) a minimum viscosity has been included to avoid fuels with poor ignition properties.

In addition the annexes in the CIMAC Recommendation contains more comprehensive information regarding various fuel parameters, including a reference to the development of test methods to determine the ignition and combustion properties of residual fuels.

While due to the formal procedures revision of the ISO standards inhibits flexibility CIMAC may react quicker to any changing circumstances in the bunker industry. As for future revisions, rather than revising the whole document or recommendation these recommendations are now available only in electronic format and may be downloaded from the Intranet by CIMAC members. Hence any changes may include without issuing a completely new revision.

## **3.2 MARINE FUELS – STORAGE AND HEATING**

### **3.2.1 Requirements**

The storage requirements for diesel fuel oil vary with local conditions and the grade of fuel oil being used but, in general, the storage tank should be maintained at a temperature that allows the fuel to be pumped or moved by gravity, without undue difficulty.

A temperature that keeps the viscosity at about 120 mm<sup>2</sup>/s ensures good flow and pumping conditions and represents an ideal situation. An IF 180 grade (180 mm<sup>2</sup>/s at 50°C), however, requires the tank to be held at about 57°C, which causes high heat losses, especially in bunker tanks where the vessel's shell plating forms part of the tank side. The convenience of handling rarely justifies the high cost of maintaining so high a temperature.

In general, bunker tanks should be held at temperatures that allow reliable pumping while preventing build-up of wax in tank bottom.

Most bunker transfer pumps are designed to handle fuels with a kinematic viscosity of 600 mm<sup>2</sup>/s at the suction inlet. (Modern installations can handle much higher viscosities.) To maintain the fuel at 600 mm<sup>2</sup>/s an IF 180 grade should be stored at

a temperature of about 30°C and an IF 380 at about 43°C.

If transfer operations are infrequent, even lower storage temperatures may be contemplated. With high pour point waxy fuels, however, the bulk oil temperature should not be allowed to approach the pour point. Otherwise, when the fuel is reheated for pumping, there may be great difficulty in the re-melting the wax structures that have formed in the tank.

Since the removal of water, sediment and sludge becomes more difficult as fuel viscosities and densities increase, security against contamination assumes greater importance. Poor sitting and security of vent pipes, ullage pipes and caps, and filling connections are common causes of contamination from breaking seas, washing-down hoses, etc. Ingress of salt water through fractures, and corrosion in shell plating and tank tops, does occur occasionally, but is usually obvious from the volumes of water found. The use of double bottom tanks for fuel and water ballast has always been a lamentable practice as far as fuel quality is concerned, and the only safeguard can be maximum care in draining the ballast. Fortunately, separate ballast arrangements are now replacing this practice in new buildings. The potential rust and scale problems that can result from salt-water contamination are obvious.

Fresh water contamination is less likely, but can result from condensation, especially in slack tanks, which contain more air and moisture. The trend away from flanged joints and the use of better materials seem to have largely overcome steam and condensate leakage from heating coils but, even so, corroded steel coils have been encountered recently in vessel only a few years old.

Other contaminants are unlikely to find their way into storage tanks, except with incoming bunkers. Sediment and sludge deposition from successive bunkering slowly accumulate on tank bottoms, and tanks should be inspected at least every two to three years and cleaned when necessary.

Storage heating should be capable of raising the fuel temperature to 45°C, which

should be sufficient to make it pump able. If the fuel has been allowed to cool, however, extended heating time may be needed to dissolve all the wax in order to avoid filter blockage.

Heating coils should extend over all the tank area to ensure that wax can be dissolved. If heaters are situated at the outflow only, wax might build up elsewhere in the tanks.

### 3.2.2 Settling Tanks

From bulk storage, the fuel is pumped to the settling tank(s). Settling requirements depend upon the subsequent processes. In motor vessels, where fuel is centrifuged in hopefully adequately sized machines, settling may only be necessary as a safeguard against the possibility of gross water contamination, but also the level of Al+Si can be reduced during the settling. In steam-turbine vessels, on the other hand, settling is usually the principal means of removing water, sludge and sediment and is consequently more important.

As with so many aspects of vessel construction, settling tanks are often a compromise with space and other limitations. This results in many tank configurations that are not conducive to good settling and draining. Horizontal tank bottoms, especially where crossed by internal bulkheads, inhibit settling to drain points and can especially in heavy weather, cause water slugs to be drawn through tank suctions. Suitably constructed tanks have bottom surfaces inclined sufficiently to ensure good settling under all list and sea motion conditions. Since settling time is a function of oil depth as well as viscosity and density differentials, tank depths should be as small as practicable.

Suctions and drains are sometimes poorly sited. If they are too far apart suctions may be lower than drains when vessels are listed or rolling. Low suctions should always be high enough to clear adequately any normal sludge or water accumulations, with high suctions as an emergency safeguard. This latter feature appears to be omitted in some vessels nowadays. While small size drains are sufficient to remove water, sludge need a larger size, say 65 mm bore, and preferably a facility to draw by

pump while still maintaining a means to check the effluents visually.

Rebuilding tanks to better configurations in existing vessels is unlikely to be an acceptable way of improving fuel preparations, but an examination of drain and suction arrangements may reveal simpler ways of improvement - by relocating or adjusting the height of outlets.

Settling times and temperatures are more critical for higher fuel densities and viscosities. To adequately settle fuels with viscosities of 280 mm<sup>2</sup>/s at 50°C and higher, tanks should have the capacity to maintain their content at 60°C for four days. Maximum temperatures must, of course, be kept below the fuel flash point. If temperatures are too high, some of the more volatile fuel components may be evaporated and cause increases in fuel viscosity.

### 3.2.3 Purifying

Fuel from the settling tanks is normally pumped via a suction filter and a centrifuge (or centrifuges) to the treated-fuel tank. Before entering the centrifuge, the residual fuel is pre-heated to about 98°C, regardless of the initial viscosity.

### 3.2.4 Pipe Sizes and Heating

Since the section of the fuel system from the storage tank to the treated-fuel tank is used only intermittently (assuming batch centrifuging), the possibility of stagnant fuel cooling in the fuel lines must be borne in mind. In very cold climates it may be advisable to lag and heat all lines, but the system can generally be warmed by circulating fuel through the centrifuge to a point immediately before the treated-fuel tank and then back to the day tank. Since the fuel pressures are low in this part of the system, ample pipe sizes can be selected without the need for heavy wall thickness. Pipe lengths should be kept to a minimum.

Fuel heating can be carried out by steam, by electricity or by using the exhaust heat of the diesel engine. The last method has the advantage of economy, but is practicable only when provision is made for starting up from cold on a diesel fuel

that requires no pre-heating. Operation must continue on this fuel until the main supply is adequately heated. Where steam is available, it is the most adaptable medium for heating purposes. Electric heating, however, is frequently used; this necessitates care to select elements specially designed for fuel pre-heating, since local overheating may cause fuel cracking, with the production of hard carbon on the heater surfaces. Heater loadings should be limited to 1.5 watts/cm<sup>2</sup> (10 watts/in<sup>2</sup>) to avoid this trouble, and steam temperatures in steam heaters should not exceed 190°C.

### 3.2.5 Heating for Injection

Treated fuel is fed at a temperature of say 70 - 80°C to the booster pump. The pressurised fuel is then heated in the final heater to lower its viscosity to the value required for optimum performance of the engine injection equipment.

This viscosity should be specified by the engine manufacturer and normally lies in the range of 10 - 15 mm<sup>2</sup>/s. It is usual to feed the injector pumps from a ring-main system, the excess fuel being returned to the raiser tank to avoid vapour lock in the low-pressure pump. Modern installations have pressurised excess fuel system in order to eliminate vapours foaming. A thermostat located as close to an injector as possible normally controls the final heater. This allows for any temperature drop in the intervening fuel lines.

Ideally, the final heater should be controlled by a viscostat (viscosity controller), since supply of the fuel at constant temperature does not ensure constant viscosity; the characteristics of different deliveries of fuel oil may vary within the relevant specification. It is most important to check the calibration of the viscostat at regular intervals.

### 3.2.6 Diesel Fuel Supply

Alternatively, the low pressure-priming pump can be fed from an unheated diesel fuel day tank. Thus, before shutdown a change of fuel can be made, ensuring that the injection equipment and ring main contain low-viscosity fuel, which facilitates

start-up. Running on this fuel should continue until the fuel oil supply has been correctly heated. This is especially important if only engine exhaust is used for fuel heating.

### 3.2.7 On-Board Blending

Various types and blending equipment are now available for use on board vessel. This enables marine diesel fuel or gas oil to be blended with heavy fuel in the proportions required either to satisfy the recommendations of the engine builder or to allow the ship owner to economise in the use of expensive distillate fuel. Many of these blenders are quite sophisticated, having automatic viscosity control in conjunction with automatically regulated electric heaters. With some models, the proportion of distillate fuel is increased as the engine load is decreased, but at higher loads the proportion of heavy fuel is automatically increased to ensure maximum economy of operation.

There is a possible risk of incompatibility if two fuels from different sources are mixed together. In particular, the addition of a paraffinic-type distillate fuel to a heavy fuel could result in some of the asphaltenes coming out of solution and forming sludge, though usually oil suppliers ensure that the heavy fuel has sufficient "reserve" of stability to prevent this. The ship owner should, however, be aware of the problems that could arise with on-board blending of two different fuels, and where there is doubt the finished blend should be checked by a simple stability test such as the ASTM spot test. For additional information refer to Section 3.

References: Lubricants and Fuels in Ships

Shell International Trading Company,  
London 1989

# 4

# **DNV PETROLEUM SERVICES FUEL MANAGEMENT GUIDELINES**

## 4.1 INTRODUCTION

DNV Petroleum Services (DNVPS) is frequently asked to give advice on fuel purchasing standards, sampling, quantity determination and fuel treatment. Of course, individual ship-owning companies have their own style of management and standard procedures vary from company to company. Therefore, it may not be practicable for one company merely to adopt the policies of another.

These “Fuel Management Guidelines” have been compiled by DNVPS in order to assist companies develop their own procedures or review existing procedures. The subjects of sampling, quantity determination and specifications are covered in our videos and we suggest that this booklet be used in conjunction with the video programmes. Technical staff at any of the DNVPS regional offices will be pleased to provide more information or assist with any particular enquiries you may have.

Bunkering procedures should encompass all aspects of fuel management from selection of fuel grades through ordering, delivery and treatment on board. On occasions, vessel's staff may face a situation whereby they cannot follow a particular procedure, perhaps due to local regulations or working practices. The owners or managers should, therefore, add some guidance to vessel's staff regarding their contact with head office in such situations. Procedures and guidelines are usually compiled with a view to operating in the “ideal world” and as shipping does not enjoy such an environment, obstacles will be encountered and some minor revisions to policies or guidelines may be needed. However, the need for these changes should quickly be identified and solutions implemented or the risk of complete abandonment of the policies by all concerned becomes high.

## 4.2 FUEL SPECIFICATIONS

Background to Fuel Specifications, History and Current Status

Subsequent to 1970 marine fuel quality was fairly predictable and did not seem to be a major cause for concern. Firstly then,

let us consider the “quality demand” at that time.

Residual fuels were purchased for both boiler and slow speed diesel engine consumption, not only at sea but also on land, in power and co-generation plants where they were a viable alternative to solid fuels or gas. Residual fuels, at that time, were given many titles or “short” names such as “Burner Fuel”, “Heavy Oil”, “Boiler Oil”, “Bunker C” and “Class G”. Marine fuel purchasers probably became more familiar with the term “Bunker C” which can be related to “Class G” fuel listed in the British Standard BS 2869: 1970.

The original 1957 British Standard was given a great deal of attention in the first half of the 1970s with further revisions published in 1970, 1972 and 1974. The last revision introduced a split between fuels for burners and engines. However, engine class fuels were basically gas oils or diesel fuels and little attention was given to the growing need for grading of residual fuels being used in large diesel engines. To address this need a working group of the British Standard was set up and, after lengthy consultation with interested parties, produced a draft specification for marine fuels. Whilst this work was in progress the International Organisation of Standards (ISO) was kept informed of progress, as were the International Council on Combustion Engines (CIMAC). It was clear to all these parties that any developments in marine matters would have an impact on the international marine industry and therefore, an international marine fuel specification was needed. The draft British Standard was then given to a new working group within ISO (ISO/TC 28/SC 4/WG 6) which was to further develop the draft to an International Standard.

Development of any international agreement is, of course, a complex and slow process, and the working group recognised that it would be some years before the ISO Standard would be published. Probably realising that the ISO publication would be some time in the making, the British Standards committee

released their draft fuel specification early in 1981.

Subsequently, the official British Standard BSMA 100: 1982 was published and became the first standard to address marine fuel requirements. During the 1980s, BSMA 100: 1982 became a reference point for both fuel purchasers and sellers, and clauses in many charter parties referring to fuel qualities were updated to include reference to the British Standard.

The technical departments of shipping and management companies became more aware of fuel related engine problems and began to influence the fuel purchasers on their selection of fuels. Slowly the marine industry began to understand that the practice of ordering fuel by viscosity alone was insufficient if disputes and claims resulting from use of poor quality fuels were to be reduced.

In the late 1970s and early 1980s while the British Standards and ISO working groups were developing their fuel standards CIMAC was also active. CIMAC retained a permanent committee which as early as 1978 set targets to produce heavy fuel specifications for marine and land-based engines using these fuels. CIMAC's recommendations regarding requirements for residual fuels for diesel engines were published and introduced in their final version in 1986, although they had been released earlier in technical papers. The CIMAC recommendations only covered residual fuels and it is important to note that they were based on "fuels as delivered". In other words, it was assumed such fuels would be adequately treated before use, to reduce contaminant levels to those acceptable for use in the engine.

The main difference between the ISO/BS approach and the CIMAC perspective was that ISO/BS were concerned not only with setting quality standards for different grades of fuel, but also to ensure that such fuel standards were practicable and that suggested grades would be largely available to purchasers. CIMAC, predominantly representing engine manufacturers and users, concentrated on producing a series of fuel grades which would be suitable for both older and new engines. They took into consideration that older vessels may not be equipped with

fuel treatment plant that could adequately deal with some of the lower grade fuels.

The ISO working group completed all its draft document stages and the first International Standard for marine fuels was published in 1987: "International Standard ISO 8217 Petroleum Products - Fuels (class F) - Specifications of marine fuels". At this particular time a fuel purchaser wishing to refer to a fuel specification or standard may have been rather confused as there were three standards BSMA 100: 1982, ISO 8217 and CIMAC. In addition ISO standard 8216/1 a classification for marine fuels was also available. This classification described the fuel types and prescribed the symbols by which the different categories are designated in ISO 8217.

Eventually British Standards withdrew BSMA 100: 1982 and replaced it with BSMA 100: 1989 which was identical to the ISO 8217 Standard 1987, easing some of the confusion. In 1990, CIMAC published a third edition of its recommendations regarding fuel requirements for diesel engines.

#### **4.2.1 Current Situation**

In 1994 the ISO working group produced a committee draft of the first revision to ISO 8217 (ISO CD 8217: 1994). This draft included limits for Total Sediment and Aluminium + Silicon (catalyst fines). This was possible, as test methods had been approved by ISO. This committee draft document was then presented to ISO member countries for voting late in 1994 as a Draft International Standard (ISO/DIS 8217). No major objections to the draft standard were raised. The second edition of ISO 8217 was published in March 1996 with changes particularly in the aspects of methodology.

A third edition of ISO 8217, ISO 8217:2005, was published in November 2005.

This edition contains amendments to the ISO RM (Residual Fuel) and DM (Distillate Fuel) grades. It specifically incorporates the following changes for the ISO RM grades:



Residual viscosity grades are now based on measured viscosity @ 50°C. The most widely used grades, formerly RMG/H/K 35 and RME/F 25 have been encompassed by the RMG/H/K 380 and RME/F 180 grades.

The number of categories or grades has been reduced from 15 to 10, which implies that ships ordering IFO 40 cSt and IFO 500 cSt will have to stipulate RMA/B 30 or RMD 80 for IFO 40 cSt, and RMG/H/K 380 or RMH/K 700 for IFO 500 cSt respectively, with an additional note for maximum viscosity to be included.

Water for all RM grades has been reduced from 1% to 0.5% maximum.

Sulphur has been reduced from 5.0% to 4.50% maximum. This places the ISO maximum Sulfur content in line with IMO Annex VI world wide requirement.

Used lubricating oil (ULO) - The elemental specification has been expanded to include a maximum limit for three new elements, zinc (Zn), calcium (Ca) and phosphorous (P). A fuel oil shall be considered to be free of used lubricating oils if one or more of these elements are below or at the specified limits. All three elements shall exceed the same limits before a fuel oil shall be deemed to contain ULO's.

Density - For the RM grades 30 and 80 maximum densities have been reduced. The RMD 80 grade maximum density is 980 Kg/M<sup>3</sup>, RMB 30 maximum density is 975 Kg/M<sup>3</sup> and RMA 30 maximum density is 960 Kg/M<sup>3</sup>.

The new specification also contains the following changes for the ISO DM (Diesel, marine) grades:

Sediments - For the ISO DMB grade, formerly tested according to sediment by extraction, will now be tested according to the Total Sediment Existent (TSE) test procedure. The new limit is 0.10% maximum. This procedure will ensure that organic (oily sludge) as well as inorganic sediments are being determined,

The same ULO metals specification will apply to the ISO DMC grade.

In addition, several informative Annexes have been added to the revised standard, including interpretation of test results,

sodium and vanadium, used lubricants and acidity in marine fuels.

### Oil Company Fuel Specifications

Some of the major oil companies have produced their own fuel specifications. The marine fuel specifications issued by Shell are probably the most comprehensive and provide Shell customers with details of fuels which they should expect to receive when ordering distillate and residual fuels. In addition to providing general characteristics Shell also indicates where geographical variances may exist. Full details can be found in their booklet "Know your fuels". Other fuel suppliers also produce fuel specifications for internal quality control and for information to customers. Fuel buyers are advised to ask their fuel supplier for these specifications, however, they should always be read in conjunction with the "terms and conditions of sale" of the supplier.

#### 4.2.2 Selection of a fuel grade

##### Residual fuels

Marine fuels should never be ordered on the basis of viscosity alone. This can lead to prolonged and costly disputes and claims. Therefore, carefully evaluate the requirements of the vessel and refer to the current International Standards. The starting point should be a careful study of the heating capacities of the vessel regarding storage tanks and fuel system heaters. This should provide limits for viscosity and pour point.

A maximum limit for density can be established by firstly checking the design criteria of the purifier and then any limitations the Engine Builders may have regarding CCAI (Calculated Carbon Aromaticity Index). Fixing a density maximum and/or a viscosity minimum may control CCAI. However, due to modern refining- and blending routines the CCAI value can by some modern and high technology refineries be manipulated. So the highly used and popular ignition quality index (CCAI) do not in all cases give an correct ignition quality of the fuel.

Most engine manufactures will provide some detail on the quality of fuel needed for optimum combustion. The Ship owner should be able to establish the maker's

ranges or limits for at least the following parameters: - water, ash, sulphur, carbon and vanadium. Sometimes the makers' may also refer to sodium/vanadium ratios.

Often 180 mm<sup>2</sup>/s fuels are no "better" than 380 mm<sup>2</sup>/s fuels with the latter being cheaper and a general policy should be to use the highest viscosity possible with respect to the heating capability of the total fuel system. High viscosity fuels tend to have lower levels of catalyst fines than low viscosity grades and they tend to be more stable. Low viscosity fuels can be problematical with respect to ignition quality, stability and pour point.

Once the above review has been carried out, the ship owner or manager has to decide if he wishes to present individual fuel specifications for each vessel to fuel purchasers or as clauses in a charter party.

The main problem in issuing a long fuel specification to a supplier is that he will probably reply that his fuel will be to British or ISO standards and that is all he will guarantee. Some suppliers will not even guarantee as much. In reality, the supplier probably does not have a detailed analysis report on the fuel that he has for sale and the buyer will act as the quality assurance advisor. (If he is using a fuel analysis service.)

A very long and detailed fuel specification in a charter party may not be desirable as this may deter potential charters who may select a similar vessel with less rigid fuel requirement. However, this point is debatable and tight fuel specifications in a charter party are imperative should a dispute arise. With all the above in mind, it is suggested that the International Fuel Standard ISO 8217:2005 (and subsequent revisions) should be used as a basis for all ordering and chartering statements on fuel quality. The British Standard BSMA100: 1982 should no longer be used as this was replaced by BSMA100: 1989 which is in fact identical to the ISO: 8217:1987. We expect that BSMA100: 1989 will be updated to comply with the 1<sup>st</sup> revision of ISO 8217:1996. Though as mentioned it is highly recommended to use the most recent revision on the available fuel standard, which is at this date ISO 8217:2005.

Using all the data collected from the review of the quality requirements for the engine storage and fuel treatment plant, the owner should then study the ISO standard and select a grade, which gives parameters nearest to the vessel requirements.

As an example, an Owner may have decided that ISO RME180 would suit a particular vessel, but also wishes to expressly state a limit for CCAI, which is not covered in the Standard. The following clause would then be suitable in the Charter Party:

"Fuel for main engine to meet ISO 8217: 2005, (and subsequent revisions) RME180. Additionally CCAI not to exceed 860."

### **Selecting fuels for auxiliary engines**

Some vessels auxiliary engines are designed to use the same residual fuel as the main engine. In which case the Ship owners should ensure that the fuel buyer makes purchases with reference to the correct ISO 8217 (and subsequent revisions) fuel grade as discussed above.

Although these engines may have been designed to operate on residual fuels, care should be taken to avoid long periods of low load operation. This could lead to fuel ignition problems resulting in additional engine fouling and consequential higher maintenance costs.

Fuel blenders have been fitted to some auxiliary engine fuel systems, which allow the operator to blend residual and distillate fuels. As the quality of the residual and distillate blend components will vary on each delivery, the optimum blend ratio needs to be frequently calculated and adjusted. To assist their customers who use blenders DNV Petroleum Services offer a "Blend Optimisation Programme". After analysis of both the residual and distillate fuels the auxiliary engine fuel specification limits are referenced in order to calculate the minimum amount of distillate required in the blend. Significant savings in distillate consumption have been made by Ship owners using this service. In addition they will be assured that the correct fuel quality limits for the engine are being maintained.

### **Distillate Fuels**

The majority of marine auxiliary engines operate on marine diesel oil. Although distillate fuels are more expensive than

residuals, they require less treatment and heating is not necessary. They may however, contain a small residual component, in some cases up to 15% (DMC).

ISO 8217: 2005 provides four distillate fuel grades, DMX, DMA, DMB and DMC:

- DMX is a pure distillate fuel and due to its lower flash point may only be stored and used outside the vessel's main machinery space. It is usually purchased for use in emergency engines.
- DMA is also a pure distillate and should be a bright and clear product. This fuel may be referred to as marine gasoil
- DMB is similar to DMA but may have a very small (trace) residual component and therefore can be black in appearance.
- DMC has a larger residual component than DMB, which is reflected in the higher carbon level and the inclusion of a total sediment, aluminium + silicon and vanadium limits. The inclusion of used lubricating oil is controlled by limits on levels of zinc, phosphorus and calcium.

DNVPS suggests that DMX is ordered for emergency equipment. If the owner wishes to operate auxiliaries on marine gasoil this should be ordered on the basis of DMA. The choice between DMB and DMC can be made after checking the recommendations of the engine builder.

Some fuel purchasers do not use the ISO grades but merely state that they wish to purchase marine diesel oil. In which case the supplier would most likely assume this to be ISO DMC.

#### 4.2.3 Fuel ordering

##### Energy content

Unfortunately, the majority of buyers base their selection of supplier on price per ton with little regard for fuel quality or indeed energy content.

It may be noted from the DNVPS bunker supplier comparison (monthly fax report on

suppliers in major bunkering ports worldwide, see Section 18) that energy content can vary by as much as 10% between worst and best in a port for the same grade. At USD 250 per ton this obviously equates to a variation in price of 37 USD per ton. DNVPS recommends that more thought is given to ordering energy rather than apparent price per ton. Some purchasers are asking suppliers to quote the energy value of the fuel and seek compensation if the analysis shows the fuel to have a lower value. If an continuously and up to date supplier comparison is wanted, FUELWISE which is an online application by DNVPS is recommended.

##### Supplier Performance Records

By using the Bunker Supplier Comparison, ref. Section 15, and the Fuel Quality Statistics both produced by DNVPS, the buyer can also be wary when seeking prices from suppliers with a bad record on quality.

Some suppliers persistently overstate the density on the fuel delivery note, which results in the buyer paying for fuel he did not receive. In addition, high level of water will result in commercial loss perhaps in addition to engine problems.

The fuel purchaser must use the fuel specifications for each vessel when seeking quotations. If suppliers are not able to provide the quality required it might be necessary to accept an alternative grade (second choice).

The purchase and technical department should discuss these points and agree on a line of communication if the buyer is in any doubt regarding fuel quality. However, the technical department will also need to acknowledge that at certain times, the buyer will need to negotiate on price and quality depending upon availability.

Total rigidity to a specification may be technically desirable, but may not always be commercially feasible.

##### Terms and Conditions of Sale

The fuel purchaser should request a copy of the standard terms and conditions from all his fuel suppliers. These should be carefully examined and discussed with the supplier.

Unreasonable terms should be brought to the attention of the supplier. In particular the buyer should check that clauses on sampling, quantity determination and claim periods are fair and acceptable. If any changes to the standard terms of the supplier are agreed upon these must be fully documented before the sale quotation is accepted.

A prudent company would, therefore, compile a statement with respect to their procedure for fuel ordering making sure the purchasing and technical departments fully understand and agree on the policy statement. This information should also be made available to vessel's staff.

The "Fuelcon" issued by Bimcom in 1995 is a well worth document which considers both seller and buyer of a marine fuel purchase. The use of "Fuelcon" is encouraged by DNVPS.

#### Order confirmation

Once the sale has been agreed the buyer should send an order confirmation to the supplier. This should contain, at least, the following information:

Vessel's name, Port of delivery, berth or anchorage, expected time of vessel arrival, desired bunkering date and time, type of fuel (HFO/MDO) including ISO grades and any special quality requirements, quantities of each fuel grade, agents, details of surveyors attending, agreements on sampling and quantity determination.

Copies of the confirmation should be sent to all involved parties (suppliers, agent, survey company and the vessel).

### 4.2.4 Fuel delivery

#### General

The Master, in consultation with the Chief Engineer, should ensure that the bunker fuel(s) offered to the vessel at each port is in accordance with the fuel specification relating to the particular vessel's engines and auxiliary machinery and as described in the vessel's Charter Party and in the fuel order confirmation. In particular, the bunker note should be examined prior to delivery to ensure that the viscosity and density stated are suitable for the vessels heating and fuel treatment equipment. The

vessel could be considered "not seaworthy" if this simple check had not been made and the fuel was found to be unsuitable later.

#### Pre-delivery arrangements

The Chief Engineer is to properly plan for the receipt of fuels as below:

- Identify which tanks are to be used and ensure that these are as empty as practically possible. (Note! Mixing of fuels from different deliveries should be avoided wherever possible).
- Advise the supplier that DNV Petroleum Services will be analysing a representative sample and invite the supplier to take part in joint sampling.
- In the case where the bunkering port is Singapore it is recommended to inform the supplier in the case where DNVPS will perform a BQS (Bunker Quantity Survey).
- Complete the DNVPS form "Request to witness sampling" and request the signature of supplier's representative. It is important that the name of the representative is legible. Also make sure of his identity (who is he representing)?
- If the suppliers' representative refuses to witness sampling, enter this fact into the engine room logbook. A letter of protest may also be issued.
- Prepare DNVPS bottles and labels (but do not sign in advance) and also make the sample box ready for dispatch (as vessel may be leaving shortly after completion of bunkering).
- Prepare the DNVPS Report Form, which is to be sent with the fuel sample.

If on board test kits are available, they may be used to check viscosity and density of a barge or tank sample before delivery commences. If repeated tests indicate that the fuel is not as stated on the bunker delivery note, contact the vessel owners

**DO NOT ACCEPT THE FUEL IF IT CANNOT BE TREATED OR USED ON THE VESSEL.**

## Bunker Spillage Prevention

Agreed quantities and an agreed pumping rate for bunker transfer to the vessel for each grade should be confirmed with supplier in writing and an established means of communication for stoppage agreed to eliminate spillage. All deck scuppers should be plugged/sealed as appropriate and relevant preventive measures taken to avoid spillage.

## Safety precautions during bunkering

The Chief Engineer is responsible for the bunkering operation and should observe at all times the safety procedures during bunkering activities and should read and apply the appropriate National Safety Regulations and Codes of Practice.

- Regulations regarding the entry and equipment used in hazardous areas should be strictly observed.
- Smoking and naked lights should be prohibited in the vicinity of the bunkering operations, including sounding and air vent pipe openings.
- Lamps and torches used at bunkering positions shall be of an approved safety type.
- Protective equipment to be worn by personnel involved in the sampling and bunkering.
- H<sub>2</sub>S detection should be carried out periodically.
- Spill prevention procedures should be adhered to.
- Spill containment equipment should be available at the bunker manifold.

## Bunker Delivery Note (BDN)

It is usual for the supplier or his representative to provide the Chief Engineer with a BDN. Though in the case the country where the bunkering is being performed or the ship's flag state have ratified the Annex of MARPOL 73/78, it is mandatory to be provided with a BDN with the following details:

Name and IMO number of receiving ship

Bunkering Port

Date of commencement of bunkering

Name, address and telephone number of marine fuel oil supplier

Product name (grade)

Quantity (metric tons)

Density at 15 °C (kg/m<sup>3</sup>)

Sulphur content (%m/m)

If the bunkering has been commenced in Singapore, it is required that the samples seal numbers are stated in the BDN. This to comply with the CP 60 (Code of Practice).

A declaration signed and certified by the fuel supplier's representative that the fuel oil supplied conforms to regulations 14 and 18 i.e. that the fuel supplied has a sulphur level as specified in the BDN and that the fuel is free from inorganic acid, does not include any added substance or chemical waste which either jeopardises the safety of ships, adversely affects the performance of the machinery, is harmful to personnel, or contributes overall to additional air pollution.

If this statement is not forthcoming by the supplier, the Chief Engineer should advise the Company and Charter's Agent immediately and issue a "Letter of Protest".

Before signing the BDN, it should be stamped with the vessels "NO LIEN" stamps. A copy of the bunker note should be retained on board and a copy sent to Head Office. The BDN should be signed with the following statement "**Signed for volume at observed temperature only. Determination of quantity will be made upon receipt of fuel analysis results**". A copy of the BDN should also be enclosed with the fuel sample sent to DNV Petroleum Services.

For chartered vessels, the Chief Engineer should sign the bunker delivery note "**Received on behalf of Charters**".

## Blending

For certain deliveries when large quantities of blended bunkers are supplied, barges will deliver bunkers by the following methods.

- From one or more tanks in which the fuel is fully blended.
- From different tanks on board the barge and blending occurs during transfer through their metering or

blending equipment (in line blending). If this process is used, vessel's staff should carefully monitor the situation to ensure proper blending is conducted. Though this might be performed from time to time it clearly stated in ISO 8217 section 5: "The fuels shall be homogenous blends of hydrocarbons derived from petroleum refining".

- Vessel receives calculated quantities of different grades held segregated in barge tanks and blending occurs in the vessel's bunker tanks. **THIS METHOD IS NOT ACCEPTABLE** and the Chief Engineer should check with the barge before loading bunkers that a correct blending method is to be used.
- Some purchasers state that all fuel deliveries are to be of homogeneous blend prior to barge or terminal discharge. This is considered good practice.

### Quantity Control

The bunker supply source metres or tank soundings must be sighted and readings taken before and after bunkers are taken. A barge outruns calculation on a volumetric basis can then be made. Any deviation from the volume discharged and a "Letter of Protest" must follow that recorded on the BDN up to the suppliers.

As protests on quantity should be made soon after delivery, an instruction to the vessel staffs to report discrepancies to the office by telex or fax would be prudent. The terms and conditions of most suppliers with respect to delivered quantity state that shore tank, shore metres or barge measurements will be the official reference in case of dispute.

It must be stressed that all barge tank soundings and temperatures must be made before delivery starts and the vessel's staff and the supplier agree these figures. Claims at a later date if this has not been done are usually pointless.

### Bunker Fuel Sampling Procedures

The main objective of sampling should be to obtain a representative sample, which will be an agreed point of reference to all

parties concerned with the bunkering. The following points should then be established between buyer and seller before the delivery.

- At which location a representative sample shall be taken?
- What volume of sample shall be collected and by what method?
- Who shall attend the sampling?
- How many samples shall be produced from the representative sample?
- How such samples shall be labelled, signed and sealed and by whom?
- Who shall take custody of the samples?
- Which individual sample shall be the agreed reference point in case of dispute?

#### A. Location

There should be only one location for taking a reference sample. This is at the point of custody transfer. The sample taken should be a representative sample taken by continuous drip method throughout the whole period of the bunkering and this should be the initial sample used as the reference sample in case of a dispute.

It has been found that both automatic or manual sampling gives comparable results. The correlation from test results of over 800,000 samples in the DNVPS database confirms that manual sampling equipment gives results which are consistently accurate. Statistical information made available from DNVPS also indicates that automatic sampling equipment does not provide any noticeable improvement in accuracy, while being substantially more expensive to purchase and maintain.

The point of custody transfer (the location where the risk and responsibility is transferred from the seller to the buyer) varies with the sales conditions. By for the majority of bunker deliveries is on a fob basis and as with the point of custody transfer is at the ships fuel manifold. This location also corresponds with international accepted terms, Incoterms 2000.

The port of Singapore, by far the largest bunkering port in the world, introduced in the early 1990 ties the Singapore Bunkering procedure and which has now

made into a Code of Practice which must be adhered to when bunkering from a barge (bunker tanker) in Singapore.

In January 2002, The Authorities (MPA) decided to include in CP 60, a requirement that sampling shall take place at the receiving vessels manifold jointly by seller and buyer using a sampler acceptable to CP 60. If the vessel does not have an acceptable sampler, the barge must provide one to be fitted by at the receiving vessels end of the bunker delivery hose.

DNVPS recommends that the buyer ensures that CP 60 is followed by both parties, as it provides for proper sampling and documentation. If the procedures are followed and a dispute arises it is then necessary to follow the dispute procedure described in the SBP.

An initiative was taken, based on the Singapore Bunkering Procedure, the forerunner to CP 60, to establish an international bunkering procedure. An ISO working group was set up with representatives from interested parties within the bunker industry from a number of countries. The working group, ISO TC 28/SC6/WG8 produced in 1996 a technical report called "ISO/TR 13739 Petroleum products - Method for specifying practical procedures for the transfer of bunker fuels to ships". A copy of the Technical Report is found in Section 18.

The reader will notice that on page 9 under 10.4 - Sampling location is stated: "Generally for bunker deliveries there is no single perfect location for obtaining a representative sample. However, the optimal location for obtaining an automatic or continuous drip representative sample is at either end of the bunker delivery hose. For practical reasons, the preferred sampling location is at the bunker tankers end of the delivery hose. However, it is recognised that other sampling locations such as the vessel's end of the delivery hose may apply, if mutually agreed between the parties".

DNVPS maintain that there is a "defined point" where the reference sample should be taken, a point corresponding to international rules for fob deliveries as well as to the great majorities of fuel suppliers terms of sale (or general conditions) name

the point where the responsibility of the product is transferred from the seller to the buyer, the point of custody transfer.

DNVPS have made a considerable effort to influence an amendment of 10.4 - Sampling location, before ISO/TR 13739 becomes an ISO standard.

## **B. Volume of sample and method**

At least 5 litres should be collected during the entire delivery period. Automatic or continuous drip method should be arranged. Remember to sample all fuel deliveries "Residual and Diesels". If fuel is delivered by more than one barge conduct separate sampling of each barge delivery.

## **C. Attendance at sampling**

An authorised representative of the supplier and receiver must attend to:

- Approval of the sampling device
- Adjustment and sealing of the sampling device
- Witness and approve the pouring out, labelling and sealing of the samples made from the representative sample.

If the receiving vessel is unable to provide an authorised person a surveyor should be appointed. The surveyor would need to attend during the entire bunkering.

## **D. Number of samples**

From the representative sample four samples should be made of one litre each whereof one sample should be for MARPOL purpose. Care must be taken to ensure the representative sample is thoroughly mixed prior to pouring out. Fill the bottles a little at a time to ensure the representative sample is evenly distributed.

## **E. Seals, labels and distribution**

All samples should preferably be double sealed, with a seal from both the supplier and receiver. Alternatively ensure the supplier agrees to a single seal provided by the vessel. The seals must have unique numbers and be tamper proof. All samples must be labelled giving at least the following:

- Vessel name

- Barge or installation name
- Type of fuel e.g. HFO, MDO
- Date of sampling
- Signature of supplier and receiver who witnessed the sampling and sealing
- Sampling method
- Seal number
- One sample should be retained on board the vessel.
- One sample should be retained by the supplier.
- One sample may be used for analysis purposes.
- One sample should be labelled with DNVPS blue MARPOL label and stored onboard in a safe location for minimum 12 months or until the fuel bunkered has been substantially consumed. This sample should only be handed over to a port or flag state authority.

A list of samples with seal numbers together with agreed distribution should be signed and issued to all concerned parties.

#### **F. Fuel Supplier's Sample**

Regretfully, the practice of both seller and buyer taking their own samples at different locations still prevail, causing serious problems whenever a quality dispute arises.

The fuel supplier may offer the Chief Engineer an additional sample of fuel, which allegedly represents the delivery. If the supplier has agreed, witnessed and received a sample taken as described above an additional supplier's sample should not be necessary.

However, the Chief Engineer should not refuse to accept the supplier's sample, but should sign for "receipt only". If he is not sure of the source or reliability of the sample taking he should add "for receipt only source unknown".

In case the supplier has taken a representative MARPOL sample according to the specified procedures i.e. at the receiving vessel's manifold using a continuous drip sampler and with a label containing the required details, then the supplier's sample is considered the official MARPOL sample. In such a case, the DNVPS MARPOL sample should not be used for statutory purposes.

#### **4.2.5 Fuel Management on Board**

##### **Fuel Storage**

- Wherever possible do not use bunkers until analysis data has been received. Allowances should be made for voyages to carry enough known quality fuel on board, while awaiting analysis results, which could be up to 5 days.
- Do not allow parcels of bunkers to be stored on board for long periods (for example for trim purposes), as there may be a stability problem.

##### **Heating of Storage Tanks**

When in colder sea temperatures heating coils should be used to avoid formation of wax crystals and allow ease of transfer to settling tanks (additionally heating in storage will promote settlement of water and sediments). DNVPS will advise correct storage and transfer temperatures in their analysis reports.

##### **Bunker Fuel Treatment**

The ship owner or manager may provide fuel treatment by chemical additives to alleviate handling or combustion problems.

A record should be kept of chemicals used on any batch of fuel in event of outcharge to Charters, if the additive was used to help consume a problematic fuel provided by the Charterers.

Before burning in the engines all bunkers must pass through the purification, separation and filtration plant on board the vessel. Careful attention must be paid in keeping this plant at peak operating conditions, for example correct preheating, flow rates and proper fitting of centrifuge gravity discs. Routine or selective sampling within the fuel treatment plant will provide useful indication of the performance of the fuel treatment plant. DNV Petroleum Services provides a special programme and sampling kit for this purpose (Fuel System Check).

Settling and service tanks should be checked for water by operation of drain valves on a watch basis (or 3 times per day). Should any excessive water be present the Chief Engineer must be made aware of it immediately and corrective action taken to resolve the problem.



Fuel oil must be preheated to the temperature recommended by DNVPS or the engine builder to ensure the correct viscosity at the fuel injectors. Preferably automatic fuel viscosity controllers should be fitted on all vessels and maintained in good working order.

Fuel filters in the supply lines to the engines should be carefully monitored and when cleaning is required the Chief Engineer should ensure that the filter elements are intact. Should the vessel experience any problems related to fuel, such as excessive sludging, engine performance deterioration or damage it must be reported to the responsible person in the organisation, without any delay.

### **Documentation**

Engine room logbook entries are to be made with respect to all fuel deliveries, recording times, barge names, suppliers and quantity loaded. Any letters of protest must be filed for further reference. Daily records of fuel transfer and quantities held in each fuel tank at noon are to be maintained.

In case of main or auxiliary engine damage which is considered to be fuel related it is essential that detailed written accounts of the incident are made. Additional fuel samples taken from the fuel system should be correctly labelled with dates, times, locations and signed by the Chief Engineer. Any engine components, which have been removed from service due to damage, are to be retained on board and correctly labelled for future reference. Photographs of damaged or defective parts taken with a camera which record date and time would be useful.

It is important that Charters and fuel suppliers are advised immediately of any potential claim with respect to fuel quality. If the DNVPS analysis shows the fuel to be out of specification Charterers and Fuel Suppliers should be immediately advised. Refer to suppliers' terms and conditions of sale regarding time limitation for claims.

### **4.2.6 Disputes and Claims**

The purpose of developing and using fuel management policies and procedures is to reduce risk. The aim should be to minimise

commercial loss. By following good procedures, an Owner or Charter should be in a position to quickly identify a problem and take appropriate action to mitigate the situation.

If a fuel Buyer, Ship owner or Manager wishes to peruse a claim for shortage or poor quality it is essential that good reliable evidence is provided. If the procedures outlined above are followed such evidence will be available and dispute resolution should be greatly facilitated.

We suggest that if quality or quantity problems are experienced attempts should be made to resolve the problem by discussions between all the parties involved.

All those concerned should have an interest in minimising cost associated with the problem.

If this fails mediation is recommended before high costs of arbitration and court proceedings are incurred.

DNV Petroleum Services, of course, will support their customers by providing expert testimony and advice regarding disputes and claims. Our aims are to safeguard life, property and the environment by providing risk management services, which are of benefit to our customers.

# 5

## STABILITY

## AND

## COMPATIBILITY

## 5.1 THEORY OF STABILITY

A residual fuel oil is a complex mixture of many hundreds of compounds of varying chemical and physical properties. In order to simplify the explanation of fuel oil stability it is convenient to consider the fuel as consisting of a mixture of two types of material.

When a fuel oil is diluted with a low molecular weight paraffinic solvent, such as n-heptane, a brown or black precipitate is produced. This precipitate is defined as asphaltenes. In fact, the precipitate will also contain materials such as grit and dust and it is only the part of the precipitate, which is soluble in benzene, which comprises asphaltenes.

Asphaltenes are complex, high molecular weight compounds (5,000 to 40,000) with a very high carbon to hydrogen ratio containing also small amounts of sulphur oxygen and nitrogen compounds.

The remainder of the fuel oil, that is that part which is soluble in n-heptane, is known as the maltene phase.

Asphaltenes are thought to exist in the fuel as a structure called a micelle which can be envisaged as an asphaltene nucleus held in a colloidal dispersion by the aromatic compounds in the continuous maltene phase.

When the equilibrium of this system is disturbed, some of the asphaltenes will agglomerate and will be precipitated from the fuel as SLUDGE.

The sludge that separates from residual fuel in storage may also be derived from wax in the fuel, from water, and other contaminants in the fuel for example scale, rust, fibrous waste, packing materials etc. Sludge formed from wax etc., are discussed later.

The ability to "hold the asphaltene in suspension" is determined by the aromaticity of the maltene phase. Adding more aromatic compounds increases the solvency and stability reserve.

At higher temperatures, the adsorptive forces between the asphaltenes and maltenes are reduced thus making sludge

precipitation more likely, that is reducing the stability reserve.

After prolonged storage sludge will precipitate from all residual fuels but the rate and amount of sludge precipitation is influenced by the stability reserve.

As a result of the wider use of "secondary conversion", process in the refineries (that is cracking) the use of thermally cracked residues in marine fuel blends has increased significantly. The cracking process changes the nature of the asphaltenes so that they require more aromaticity in the oily medium (the maltene phase) in order to remain in suspension. The obvious solution would appear to depend simply on using a more aromatic diluent (cutter stock) such as cycle oils from a catalytic cracking process. However, some refineries equipped with a thermal cracking process for residual components may not be equipped with a catalytic cracker. There are also limitations on the amount of cycle oils which might be used. For example, because of the high aromaticity, cycle oils have poor ignition qualities in a diesel engine, and cycle oils also have high density, which may also limit their use in blends.

Some refiners employ in-house test methods to judge fuel stability but these are not precise or widely accepted. In marine fuel specifications, filtration tests (see later) which may employ a thermal ageing step are used as a guide to the propensity of a fuel to precipitate sludge.

### 5.1.1 Compatibility

As explained above, in order for a residual fuel oil blend to remain stable, it is necessary that the "aromaticity demand" of the asphaltene phase is at least balanced by the "available aromaticity" of the maltene phase.

This relationship of aromaticity demand and available aromaticity will vary between different fuel oil blends depending upon the type and amounts of asphaltene components present in each blend.

When two fuels are mixed, the available aromaticity of the maltene phase in the blend is a linear relationship to that of the original fuels. This is not the case with the

aromaticity demand of the asphaltene phase.

It is, therefore, possible, and quite often the case, that when two stable fuel oils are mixed, the aromaticity demands exceed the available aromaticity and an unstable blend is formed, which immediately starts to precipitate sludge. Alternatively, the stability reserve may have been reduced such that precipitation of sludge takes place after a short period of time.

It is because of this phenomenon that marine fuel bunkers should always be loaded into empty bunker tank, and should not be added to fuel on board. When circumstances are such that the mixing of fuels is unavoidable then it is advisable to check their compatibility beforehand.

### **5.1.2 Sludge resulting from Wax Separation**

Most fuel oils contain wax, the type and amount of which varies with the crude source and the fuel viscosity. Normally, the wax will be present in the residual components, but some cutter stocks may also be waxy.

There are many different types of wax present in fuel oil. The waxes will be solid at room temperature, but will have different melting point depending upon the weight of the wax. When wax is cooled to temperatures close to and below the melting point of the wax, crystals are formed. The size of the wax crystal depends upon rate of cooling and upon the molecular weight (i.e. type) of wax. The lower the temperature of the fuel oil, the greater is the amount of wax that separates out. Reheating the oil may re-dissolve some of the wax, but a fine-grained sludge is thrown down. This may result in an increase in the pour point of the fuel.

When wax crystals have been formed, they tend to act as “catalysts” or “seeding sites” for further wax separation. Eventually, the fine wax crystals will agglomerate and lead to filter blocking.

Temperature cycles should therefore, be avoided and storage tanks should be examined frequently; any sludge should be “run off” and the tanks should be cleaned to reduce further problems.

### **5.1.3 Water shredding**

A subject that is related to stability and which will be briefly reviewed for completeness is water shredding. In general, water can be removed from fuel oil by settling and centrifuging without any great difficulty, but occasionally problems are experienced owing to the formation of very stable water/fuel oil emulsions; these can choke centrifuges in particular and cause a rapid decline in separation efficiency. Their formation is favoured by the presence of very fine water droplets in the fuel oil; one instance where this can occur is when a leak develops in a storage tank’s steam heating coil.

However, the composition of the fuel oil also plays a role. Polar compounds, particularly asphaltenes, will tend to concentrate at fuel oil/water interfaces and thereby maintain the water droplets in suspension; it has been found that there is some correlation between water shredding and asphaltene content. At the same time, fuel oil instability or low stability reserve can result in poor water shredding performance.

Manufacturing fuel oils with a stability reserve helps guard against water shredding occurring in practise.

### **5.1.4 Fuel blending**

The components for blending and the restraint imposed by specifications etc. have already been discussed.

The physical process to produce homogenous blends requires:

- The viscosity of viscous components to be sufficiently reduced by heating.
- Accurate apportioning of the components.
- Adequate energy/turbulence/circulation to ensure homogeneity.

In practice blending is commonly by means of an “In-line” blender, although tank blending is often used alternatively.

“In-line” blending involves bringing two streams together at a common point, with

sufficient energy to ensure the turbulence that will give good admixture as the blend progresses to storage or delivery. "In-line" blenders can appear relatively unsophisticated, but nevertheless produce satisfactory results with intelligent operation by experienced staff.

Tank blending involves pumping the correct proportions of each component into a tank. These are then mixed by such means as:

- Circulation by pumping.
- Blowing air into the bottom of the tank to induce circulation within.
- The use of a side paddle - a paddle device within the tank turns to circulate and mix the contents, trusting to luck that sufficient mixing will take place when the contents are drawn off for onward transportation or delivery. This is clearly a suspect practise that is nevertheless used at times.

The potential drawbacks of tank blending are rather obvious from the above descriptions of how mixing may be carried out.

Possible problems with "In-line" blending can be such as:

The pump for one of the components inadvertently stopping or perhaps running too slowly.

- The viscous component being too cold.
- Control valves not correctly set or sticking in one position.
- Controller improperly set or faulty.

A term commonly used is that of "Barge blending". Apart from indicating that blending has been made aboard a barge, the term can have no other meaning. Where appropriate clarification should be sought as to whether "In-line" or "Tank" blending was used. It may also be prudent to establish just how any "Tank" blending has been carried out.

## 5.2 STABILITY AND COMPATIBILITY

The sludge that separates out from residual fuel in storage consists of anything that is

insoluble in the fuel under the particular storage conditions. In practice, its possible components are:

- Derived from the fuel:
  - (i) Carbonaceous material
  - (ii) Wax
- Derived from contamination:
  - (i) Water
  - (ii) Inorganic contaminants (for example tank scale, rust, etc.)
  - (iii) Organic contaminants (for example fibrous matter, cotton waste, packing materials, etc.)

In this chapter the factors influencing the formation of carbonaceous sludge are described and the mechanism considered by which wax separates and contributes to sludge production that is sometimes wrongly attributed to fuel instability.

### 5.2.1 Sludge resulting from fuel instability or incompatibility

Only if the term "sludge" is limited to "carbonaceous material", can sludge formation be properly attributed to fuel instability or incompatibility. With this fact in mind the stability of a fuel oil can be defined as its resistance to the formation of non-waxy carbonaceous sludge - either during storage (storage stability) or as a result of heat (thermal stability). Similarly, two or more fuels can be defined as compatible when they can be blended without producing sludge.

Before considering the underlying causes of instability it is necessary to discuss the physical structure of fuel oils.

### 5.2.2 Physical structure of fuel oils

A fuel oil may be regarded as a dispersion of asphaltenes in an oily medium (the continuous phase) known as the "maltenes". When a fuel oil is diluted with a low molecular weight paraffinic solvent (that is low carbon/hydrogen ratio) such as n-heptane, a brown or black precipitate is produced. The portion of this precipitate soluble in benzene is defined as asphaltenes; the remainder being non-carbonaceous material such as grit or rust.

The part of the fuel soluble in n-heptane is defined as the maltenes. The asphaltenes and maltenes comprise the fuel oil, the proportion of each depending of the nature of the oil.

Asphaltenes are complex, high-molecular-weight compounds of very high C/H (carbon/hydrogen) ratios, but containing, in addition, small amounts (also dependent on the nature of the fuel) of sulphur, oxygen and nitrogen. They are aromatic in their molecular composition, the carbon being combined with the hydrogen mostly in ring structures.

The asphaltene is believed to exist in the fuel oil in a structure called "micelle". This can be envisaged as an asphaltene nucleus to which is adsorbed a surrounding zone of high-molecular-weight aromatic hydrocarbons from the maltenes, of a slightly lower C/H ratio than the asphaltene itself. In turn, this zone has a similar zone – of slightly lower C/H ratio – adsorbed to its surface, and so on, until, in the outermost zone of the micelle, the C/H ratio approaches that of the continuous phase (the maltenes).

### 5.2.3 Causes and mechanisms of instability

In a stable fuel, the asphaltenes are said to be "peptised" (that is colloiddally dispersed), but if the equilibrium is disturbed part of the asphaltenes will agglomerate and be precipitated as "sludge". Such a disturbance of the equilibrium between the asphaltene micelles and the maltenes is caused by a reduction in the C/H ratio of the maltenes. This gives rise to a disparity between the maltenes' C/H ratio and that of the outermost adsorbed hydrocarbon zone of the asphaltene micelles. This occurs if a highly paraffinic solvent such as pentane or heptane is added to the fuel oil, or if in practice the fuel is diluted with highly paraffinic gas oil. A similar condition may be brought about by heat, which alters the adsorptive forces between the maltenes and the asphaltene micelles, leading to agglomeration and precipitation of the asphaltenes as "sludge" in the manner described above.

Increasing the paraffinicity of the maltenes phase lowers its solvent power for asphaltenes; conversely, increasing its aromaticity improves solvency. Compounds of aromatic molecular structure (that is high C/H ratio) are produced during catalytic cracking. The addition of cracked components to a fuel oil consequently improves its ability to disperse asphaltenes and so remain stable. Cracked components are of rather high density, and this limits the concentration that may be used in a fuel that is subjected to density restrictions.

It follows that, in a stable fuel oil, all the asphaltene micelles are completely dispersed and in equilibrium with the maltene phase. If this equilibrium is disturbed parts of the asphaltenes agglomerates and is precipitated as "sludge". With stable fuels, there is what can be termed a "reserve of stability", due to the nature of the asphaltene micelle/maltene system, which allows some latitude in dilution or heat treatment without any sludge precipitation. With some other fuel oils the equilibrium may be so delicately balanced that the slightest change in external conditions causes instability. The latter types, though stable immediately after manufacture, will probably begin to throw down sludge as a result of instability developed during storage.

Hence, every effort is made by the refinery to blend fuels with sufficient "reserve of stability". Since asphaltenes present in various types of residual components differ in their capacity to be dispersed, a distillate stock suitable for blending with one residue may not be equally suitable for blending with another. To ensure that a given fuel oil will be stable, therefore, it is necessary for the refinery to know the asphaltenes' dispersibility in the residual component and the dispersing power of the diluent or cutter stock to be used.

Two stable fuel oils might prove incompatible and give rise to carbonaceous sludge if they are mixed during storage. This could happen, for example, with fuels from different sources or suppliers. In practice sludge formation caused by mixing fuels in this way appears to be rare.

### 5.2.4 Manufacturing considerations

As a result of the wider use of secondary conversion (cracking) processes to increase the yield of distillate materials from a given crude oil, today's fuel oils often contain higher concentrations of cracked components than in the past. With thermally cracked residues there are possible problems with instability, because the cracking process changes the character of the asphaltenes so that they require more aromaticity in the oily medium (the maltenes) in order to remain in suspension. The natural balance of the colloidal system can therefore sometimes be affected to the extent that part of the asphaltenes separates out as sludge.

Dilution of a thermally cracked residue with too high a concentration of a paraffinic diluent ("cutter-stock") such as gas oil could therefore result in an unstable fuel. It is consequently necessary to ensure that the aromaticity of any diluent is high enough to keep the asphaltenes dispersed. The addition of catalytically cracked cycle oils is one way of doing this, and so providing an adequate stability reserve.

Apart from selecting appropriate distillates as cutter stocks, the refinery must be satisfied that the residual material itself keeps them fully dispersed. This consideration, as mentioned above, is especially important when thermally cracked residues are used. In addition, it is necessary, for maximum stability, to blend the components in the correct order.

### 5.2.5 Storage stability and thermal stability

There is thought to be little fundamental difference between storage stability and thermal stability, the action of heat merely accelerating the process of sludge precipitation in an unstable fuel. The viscosity of the fuel oil is reduced with increased temperature and any flocculated asphaltenes originally present or formed during heating agglomerate and settles out more rapidly.

If cracking temperatures are reached (approximately 300/350°C), fresh asphaltenes, more difficult to disperse, may be produced, and a shift in the equilibrium is

then likely to cause flocculation. Such conditions are not normally encountered, except possibly where electric heaters are used at high skin temperatures.

### 5.2.6 Nature of waxes

Wax is that part of a homologous series of normal or isoparaffinic hydrocarbons that is solid at room temperature, and a whole range of these hydrocarbons, differing in melting point, may be present in a fuel oil. Generally speaking, as the molecular weight of the wax increases, so does its melting point and, in the high molecular weight range, its crystal size tends to be reduced.

Provided that a fuel oil is kept suitably heated, the wax remains dissolved but, as the wax's solubility decreases with temperature, it will begin to separate out in solid form as the fuel oil is cooled. The temperature at which the wax begins to separate out depends on the molecular weight of the fuel oil, and on the amount of wax present and its melting point. The greater the wax content and the higher its melting point, the higher the temperature at which it starts to come out of solution. The lower the temperature, to which the fuel oil is exposed, the greater is the amount of wax that separates out.

The size of the wax crystals deposited depends not only on the rate of cooling but on the nature of the waxes, and the difficulties arising from wax separation depend not so much on the total wax present in the fuel as on the amount and crystalline form of that part of the wax which comes out of solution in storage. Some wax fractions have melting points up to and above 93°C (200°F), and different crystalline structures can be obtained depending upon the types of wax present and the thermal history of the fuel.

### 5.2.7 Effect of temperature cycles

When the fuel oil is cooled, after being heated to a temperature at which the bulk of the low-melting-point wax is dissolved, re-crystallisation of this wax is influenced by undissolved micro-crystals of higher melting point wax, and a fine-grained sludge is thrown down. Hence, to limit the

formation of such sludge from wax deposition in storage, temperature cycles are to be avoided. The same mechanism accounts for the deterioration of a fuel's flow properties and the increasing pour point, which sometime occur in storage. To take account of such changes, lower pour points are specified than may be strictly necessary for the ambient temperatures to which the fuel is exposed.

### 5.2.8 Wax deposition in storage

Deposition of wax during storage occurs mainly with low-viscosity fuel oils, which are normally kept unheated, and is caused initially by the separation of micro-crystals of higher melting point wax. Since the viscosity of the fuel affects the rate of separation, it is governed to some extent by the prevailing atmospheric temperature. Under certain conditions of storage these small crystals tend to agglomerate into relatively large clusters.

Filter blocking - which, generally speaking, is the first outward sign of this type of wax separation - obviously depends on the size of the filter mesh and the size and number of the wax crystals. Usually the micro-crystals, or even their smaller agglomerates - are not large enough to block commercially used filters, but blockage will occur if enough small crystals are present. When the small crystals agglomerate into clusters they are, of course, much more likely to block filters.

Although the mechanism by which waxy sludge is deposited at ambient temperatures is still not completely understood, these difficulties are considerably reduced if the refiner pays proper attention to the choice of suitable blending stocks.

Temperature cycles, as already indicated, are most undesirable, and it is far better not to heat the fuel at all than to heat it spasmodically or heat part of the system and allow the fuel to cool off in another section. Ideally, of course, the fuel should be heated in storage and the whole fuel system (including the filter) kept at the same temperature.

It is also most important to examine storage tanks regularly for sludge separation and, if this is excessive, to run

off the sludge and clean the tank. If a satisfactory fuel is transferred into a tank containing sludge, waxy sludge may be thrown down from it as a result of a "seeding" action by the micro-crystals already present.

References: Lubricants and Fuels in Ships

Shell International Trading Company, London, 1989



**6**

**DENSITY -**

**VOLUME / WEIGHT**

In order for the Chief Engineer to determine the weight of bunkers loaded or consumed, he will necessarily have to use the volume correction co-efficient from the appropriate ASTM Petroleum Measurement Tables. However, before he can make his calculations he will first have to assess the “density” information supplied to him on the bunker note. The units in which the vessel's tank calibration tables are stated - usually either litres, cubic metres, barrels or sometimes, gallons - and also the units of temperature measurement, either °F or °C. Depending upon which particular petroleum tables are available, it may be necessary to convert some or all of the information into the appropriate units.

Three different ASTM volume correction tables, i.e. tables Nos. 54B, 24B and 6B are suitable for use with generalised products including bunker fuels. These tables should be entered respectively with density at 15°C, relative density at 60/60°F and API gravity at 60°F. Table 54B requires temperature measurements to be made in degrees Celsius whilst the other two require temperatures in degree Fahrenheit. Using the following can make temperature conversion from Centigrade to Fahrenheit and vice versa:

Centigrade to Fahrenheit:

$$^{\circ}\text{C} = \frac{(^{\circ}\text{F} - 32)}{1.8}$$

Fahrenheit to Centigrade:

$$^{\circ}\text{F} = (^{\circ}\text{C} \times 1.8) + 32$$

Provided the “density” information supplied on the bunker note is in the form either: density at 15°C, specific gravity (relative density) at 60/60°F or API gravity, no confusion should arise, as each of these terms can be inter-converted simply using ASTM tables Nos. 3, 21 or 51. Table No. 3 is entered using API gravity at

60°F and gives conversions to relative density at 60/60°F and density at 15°C. Table 21 is entered using relative density at 60°F and gives conversion to density at 15°C and API gravity at 60°F, and Table 51 is entered using density at 15°C, and gives conversion to relative density at 60/60°F and API gravity at 60°F.

Errors in calculations are often made either because of lack of understanding of the information supplied or the inadequacy of the information supplied. Common mistakes include mistaking relative density at 60/60°F for density at 15°C and using this directly for entry into Volume Correction Table No. 54B. Also, a variety of confusing information is not uncommonly found on bunker note including expressions such as: specific gravity at 20/4 or density at 15°C (in air). In order to assist the reader, a brief simplified explanation of the term's “density”, “specific gravity” and “relative density” is supplied below:

**DENSITY** is the mass of a substance divided by its volume. This value changes with temperature depending on the coefficient of expansion of the substance and, therefore, the appropriate units in which it was determined, together with the temperature at which it was determined or converted should accompany any stated density. The units of density most commonly associated with the petroleum industry are kg/l, kg/m<sup>3</sup> or g/ml. The standard reference temperature used in international trade for calculation of petroleum and its products using density, is 15°C.

The **SPECIFIC GRAVITY** of a substance is defined as the ratio of the mass of a given volume of substance at a certain temperature to the mass of an equal volume of water at the same temperature. Hence the expressions SG at 60/60°F or SG at 15/15°C. The previously mentioned expression SG at 20/4°C is, therefore, incorrect by definition and should more correctly be called a relative density, which is defined as the ratio of the mass of a given volume of the substance at a temperature t1, to the mass of an equal volume of pure water at a temperature t2. Because specific gravity and relative densities are ratios, they have no units, but

should always be quoted together with the appropriate reference temperature. The standard reference temperature for specific gravity is generally accepted as 60°F. Further since 1 ml of pure water at 4°C weighs 1 gram, the density of a substance at t1°C is equivalent to the relative density at t1/4°C.

Since the terms **“DENSITY IN VACUUM”** or **“DENSITY IN AIR”**, which are sometimes found on bunker note and which have been known to cause confusion, they will be explained in detail. Density is the ratio of the mass of a substance to its volume; not its weight to volume ratio and, therefore, density by definition is in vacuum. The term “density in air” although often used incorrect, and should be referred to as a "weight factor". This result due to the fact that a substance weighed in air is supported to a small extent by the buoyancy of the air acting on it. The weight of a liquid in air therefore being slightly less than weight in vacuum. In most countries the weights of petroleum products including bunker fuels are calculated in air, although there are some notable exceptions which calculate weight in vacuum. Standard hydrometers, e.g. ASTM, IP and BS used in density and specific gravity determinations are calibrated to read density/specific gravity in vacuum. Densities and specific gravities thus obtained are used directly in the volume correction tables to determine volume correction co-efficient, which can be subsequently used to calculate the volumes at standard temperatures (i.e. standard volume), usually either at 15°C where volume is in litres or cubic metres, or at 60°F where volume is in barrels. From the standard volume the apparent weight in vacuum can be found by multiplying by the density at standard temperature. To find the weight in air the density must be converted to the corresponding “weight factor” before

multiplying by the standard volume. The relationship between density and the corresponding weight factor (wrongly called “density in air”) is not strictly a simple one. However, for the density range of bunker fuels usually between 0.80 - 1.00 g/ml, the conversion calculation approximates to the difference of 0.0011 g/ml, that is to convert density at 15°C to the “weight factor” at 15°C, 0.0011 g/ml should be deducted.

Summarising, the calculation of bunker quantities either by standard volume or by weight can only be conducted accurately and simply provided that correct use is made of the information and tables available. Temperatures can be converted from Fahrenheit to Celsius and vice versa. Volumes in cubic metres, litres, barrels or gallons can be inter-converted by use of ASTM - IP Table 1.

Also, as stated previously, density at 15°C, relative density at 60/60°F and API gravity can be inter-converted using either ASTM Tables 3, 21 or 51. Therefore, the overriding factor limiting the ability of the ship's engineer to calculate bunker quantities is the availability of suitable volume correction tables, the tables which should be made available being ASTM Table 54B, 6B or 24B. The engineer must then check which table he has and converts the “density” or SG, volume and temperature to the correct units. The table, next page, shows the correct temperature and density/SG requirements for use with each table:

The standard and internationally accepted units of volume for petroleum products are cubic metres or litres at 15°C and barrels at 60°F.

It should be noted that the weight of bunker fuel can only be calculated by use of density and not directly with specific gravity or relative density.

**Table 4**

TABLE 54B	TABLE 6B	TABLE 24B
(°C)	(°F)	(°F)
Density at 15 <sup>0</sup>	SG at 60/60 <sup>0</sup>	Relative density at 60/60 <sup>0</sup>

**7**

**IGNITION**

**AND**

**COMBUSTION**

## 7.1 DISTILLATE FUELS

There are three main stages of combustion:

- The delay period, during which part of the fuel has been injected and the “pre-flame” reaction takes place. During this period the fuel must become thoroughly mixed with the air.
- The period of uncontrolled combustion following ignition, during which the fuel injected in the delay period is burned. This is the most violent period of combustion.
- The period of controlled combustion, during which the fuel particles burn almost as they are injected into the burning gases in the cylinder.

During the period of uncontrolled combustion the pressure in the cylinder rises rapidly and considerable stresses are imposed on the piston as it approaches top dead centre; it is therefore desirable to keep the rate of pressure rise as low as possible, thus reducing both engine stresses and combustion noise. The initial delay period requires the following conditions in the combustion chamber:

- Rapid mixing of the air and fuel by vigorous movement and good spray distribution throughout the air. (Since fuel viscosity influences the spray characteristics, limits are placed on this property.)
- High air temperature and the pressure to evaporate the fuel droplets and rapidly oxidise them so that the mixture “self ignites”.

The ignition quality of the fuel, as measured by its cetane number has a profound effect on the delay period. The lower the cetane number the longer the ignition delay, and consequently the greater the rate of pressure rises when combustion occurs. The ignition delay should therefore be short, but sufficient for the fuel and air to become thoroughly mixed. If the delay is too short combustion will be incomplete and result in a smoky exhaust.

The period of controlled combustion is more or less dependent on the rate of injection, and if the engine is to operate

efficiently must not be unduly prolonged. By the end of the uncontrolled combustion period the piston is already past its top dead centre. The fuel must therefore be burned quickly once the piston is moving downwards; otherwise the gases cannot expand down to the low pressure and temperature necessary before the exhaust period commences. If any fuel is injected too late, or burns slowly during the expansion stroke, the engine loses power, excessive heat is developed and carbon is formed. The duration of controlled combustion is determined by the size of the injection pump plunger and the shape of the cam, together with the various dimensions of the injection equipment used.

The spray penetration (the distance any fuel particle can travel across the combustion chamber with a given air density) is a function of the engine design, but is very much influenced by spray atomisation and fuel volatility. For this reason, limits are generally specified for the distillation characteristics of distillate diesel fuel. Some fuel particles may strike the walls or piston crown while still in the liquid phase and either “flash off” as vapour from the hot surfaces, or burn from the metal surface itself. In either case carbon may be deposited.

The carbon value of distillate fuels is very low, and deposits in the engine are consequently kept to a minimum. Any deposits that do form are likely to be due to poor atomisation at the nozzle, or to a “dribbling” injector that allows fuel to enter too late for proper combustion. The injector should therefore be kept free from dribble, since any carbon that forms in the chamber will be deposited on the piston, rings and cylinder walls, causing abrasive wear and interfering with the lubrication of these vital parts.

## 7.2 RESIDUAL FUELS

The same three stages of combustion apply to residual fuels, but the relative importance of the factors influencing combustion is different.

### 7.2.1 Fuel viscosity and droplet size

To give correct atomisation and spray pattern when it is injected into the combustion chamber the fuel must be pre-heated to produce the correct viscosity at the injector. All viscosities should be measured in absolute units (mm square per second), as the true kinematic viscosity is the most reliable guide to the hydraulics of the fuel injection equipment.

The effect of viscosity on spray particle size, when fuel is injected into air at atmospheric pressure, is appreciable, but decreases markedly at the high pressures in the engine cylinder. The spray cone angle or dispersion is greatly influenced by fuel viscosity. Any large increase in fuel viscosity tends to overload the injection pump driving shaft, gears and cam faces.

The joint effect of increased particle size and reduced spray dispersion increases the penetration of the spray. This is because more compact spray suffers less retardation from the dense air, and deceleration of the larger particles is less. Not only is the air-fuel mixing hindered by high viscosity, but there is also increased danger of fuel impingement on the piston crown and cylinder wall.

Highly viscous fuels of high asphaltene content tend to burn more slowly. The size of the injected fuel droplets is, therefore, critical in ensuring satisfactory combustion. Larger droplets require a longer period for heating, evaporation and combustion, and it is now generally accepted that, in most engines "difficult" fuels require a maximum droplet size of around 20 microns to ensure good combustion. To provide such small fuel particles during injection, injection pressures have to be very high.

### 7.2.2 Ignition delay

In general the ignition delay with a residual fuel is longer than with a distillate fuel, resulting in a longer first stage of combustion. It does not necessarily follow that the second stage burning times of the residual components promote a slower rate of combustion than with a distillate fuel. Supercharged engines have less ignition

delay, because of the increased cylinder temperature and pressure.

With a distillate fuel, the ignition delay can be defined by the traditional parameters of cetane number, calculated cetane index, or diesel index. None of these, however, can be satisfactorily applied to residual fuels, and some other means of assessing ignition performance must be used.

One method is to determine the ignition performance of the distillate component of a blended fuel, and to regard this as an indication of the finished blend's ignition quality. Experience has shown, however, that this technique is not generally reliable, because the ignition quality of the residual component itself influences the final result.

It is widely agreed that ignition quality needs to be more closely defined than at present, especially for fuels containing cracked components that tend to give rather a long ignition delay. So far, there is no generally accepted test method for defining the ignition performance of residual fuels, and no such test is featured in current fuel oil specifications. Work in the Shell research laboratories at Amsterdam, however, has evolved a technique for assessing ignition performance based on the chemical nature of the fuel. This work has confirmed that there is a relationship between the ignition delay and the carbon-aromaticity of the fuel.

Since aromaticity as such can be determined only in certain specialised laboratories, it would clearly be of more practical value if this property could be linked to the physical properties of the fuel. There is a relationship between aromaticity and a function of two critical properties, density and viscosity. These properties can be combined to provide what is called the Calculated Carbon Aromaticity Index (CCAI), which did correlate closely with the measured ignition delay of a number of different fuels at the time it was derived.

### 7.2.3 Methods of Shortening Ignition Delay

It has long been known that the ignition delay with distillate fuels can be shortened by certain fuel additives, especially relatively unstable compounds such as

nitrate, - for example cyclohexyl nitrate. Such additives are not widely used, however, largely because of their cost, and there is little information available on their performance in residual fuels.

A means recommended by some engine manufacturers for shortening the ignition delay period is to increase the charge air temperature. This technique is especially useful at low loads and during starting, when there may be difficulties with certain fuels of poor ignition performance. At higher loads, pre-heating the air in this way may not be necessary once the initial starting problems have been overcome.

In some designs, for example in Allen engines, the charge air temperature is regulated by the engine load, the temperature being high (around 56°C at low loads and lower (around 43°C) at high loads. Not all engine manufacturers agree that charge air pre-heating is beneficial, and MAN, for example, recommends its use only in exceptional cases, such as idling at ambient temperatures below 0°C.

Combustion can sometimes be improved by advancing injection by reducing the length of the injector nozzle holes, thus increasing the spray dispersion and the rate of air/fuel mixing. The manufacturer's advice should be sought on these points, and any modifications to the injector orifices carried out only by makers of the nozzles. Some engine manufacturers supply special fuel nozzles to improve combustion when the engine is operating at low loads. Though this makes the ship non-compliant with the new MARPOL ANNEX VI Regulation 13- Nitrogen Oxides. In reg 13 it is stated to keep the initial certifications "no major conversion can be made to the engine". Major conversion is for example change of camshaft, fuel injection system or any other NOX-related settings or components.

Advancing the fuel injection timing, within limits, can sometimes reduce the harmful effects of a long ignition delay by making the engine run more smoothly and with less combustion knock. But it is more important not to advance injection too far, since the fuel will then be injected into relatively cool air in the combustion chamber and ignition delayed rather than shortened.

#### 7.2.4 Influence of Water in the Fuel

One of the prime requirements of fuel treatment, for example by means of purifiers, is to remove accidental water contamination, since the water is not usually emulsified with the fuel and is present as discrete droplets that can spoil combustion and result in rough running of the engine. There is also evidence that, in some circumstances, the water could increase cylinder and piston temperatures, possibly because its presence in heavy fuel delays combustion of the asphaltenes, which in themselves are already slow burning. The asphaltenes are then still burning when they strike the combustion chamber surfaces. Hence temperatures in these regions rise above normal levels and, if the surfaces become hot enough to burn off the lubricating oil film, might lead to engine failure.

These problems occur when water is present in the fuel in relatively large droplets. If the water is fully emulsified with the fuel, the effect can be beneficial rather than harmful. Much experimental work with water emulsified with distillate fuel has shown that, because the peak temperatures of combustion are reduced, the presence of harmful nitrogen oxides ( $\text{NO}_x$ ) in the exhaust is greatly reduced. Smoke in the exhaust is also reduced, because evaporation of the water during combustion is believed to result in "micro-explosions", which improve the mixing of the fuel droplets with the available air. Furthermore, the improved efficiency in combustion results in an improved fuel consumption.

Similar work has been carried out with water emulsified in heavy fuel, and comparable benefits have been recorded. Trials in test-bed engines, and subsequently in service, have shown significant improvements in fuel consumption. But engine manufacturers are generally rather sceptical of these claims, and have not been able to confirm them. The general belief appears to be that a well tuned engine, operating at a high thermal efficiency of around 50 per cent, is unlikely to achieve any further worthwhile savings in fuel consumption if emulsified water is added to the fuel.

It is not disputed that addition of water does reduce NO<sub>x</sub> emissions, and this advantage, is very important in a stationary engine operating under regulations that strictly control exhaust emissions. Some stationary engines are now designed to run continuously with about 20 to 25 per cent water in the fuel to reduce NO<sub>x</sub> emissions to levels that meet local regulations for air pollution.

As a rule of thumb by adding x% water the NO<sub>x</sub> production is reduced equally.

To ensure that the water added to the fuel is thoroughly emulsified, and that droplets do not exceed about 2 microns in diameter, it is necessary to adopt a closed pressurised fuel system incorporating some form of emulsifier. A homogeniser installed after centrifuge(s) is an effective emulsifier, and some engine manufacturers suggest that where this is used the centrifuge need be operated only as a clarifier. This practice removes any risk of the centrifuge being faulty adjusted if it is employed as a purifier.

### **7.2.5 Carbon Residue and Distillation Characteristics**

Owing to the presence of residual components, the fuel oil is not vaporised completely when injected into the combustion chamber; consequently only a part of the fuel spray vaporises and burn from the vapour phase. Thermal cracking of the residual components occurs, yielding additional smaller molecules that can burn in the vapour phase, but there is inevitable a “carbonaceous” residue, which burns from the liquid phase at a much lower rate than the vapours already mentioned.

Although fuel injection at the correct viscosity ensures the designed pattern of spray, combustion may not be complete. From previous comments it is evident that the complete combustion of a fuel oil droplet takes appreciably longer than that of a distillate droplet injected under similar conditions. Thus, there is a possibility of incomplete combustion causing either smoke or the impingement of incompletely burned fuel on the cylinder or piston, where it forms hard carbon deposits. The carbon build-up corresponding to each hole of a multi-hole injector is often clearly

visible when pistons are removed. If this hard carbon breaks away, it can cause accelerated wear of the cylinder liner and piston rings.

As with ash deposits, any carbon that becomes trapped between an exhaust valve and its seat causes valve pitting, and eventually burning, due to the leakage of high-temperature gases. Apart from the factors already mentioned the formation of such carbonaceous deposits depends on:

- the engine speed and cylinder bore, since these affects the time and travel available to a fuel particle in the combustion chamber,
- the length of the injection period, since the third stage of combustion will extend appreciably beyond the normal end of injection,
- the engine load, since high temperature is more conducive to rapid combustion.

It is common practice nowadays for vessels to operate under slow-steaming conditions in order to improve fuel economy, so the engines run for prolonged periods at relatively light loads. Special measures are needed to ensure that the engines run satisfactorily under these conditions. One method is to fit fuel nozzles specifically designed to operate at loads between, say, 20 per cent and 75 per cent fuel load, the fuel being injected under conditions that promote a spray of suitable pattern and droplet size for providing satisfactory combustion.

### **7.2.6 Combustion period**

The combustion of a residual fuel may differ from that of a distillate fuel during the period of controlled combustion. The asphaltenes in a residual fuel tend in general to burn more slowly than distillate fuel or than the other components of the residual fuel itself, though in low-speed and medium-speed engines there is usually sufficient time to ensure complete combustion even of the relatively slow-burning components. With cracked fuels of high asphaltene content (perhaps around 10 per cent) there is some evidence that the asphaltenes do not always burn completely



and could give rise to heavy carbon deposits in the combustion area. This problem would probably be more severe under low-load, low-temperature conditions, when it is essential that the fuel injection gives the optimum combustion characteristics. This can be achieved, for example, by fitting the specially designed fuel nozzle referred to above.

The period of burning is an aspect of combustion quality not necessarily related to ignition delay, but it is recognised that some measure of burning should be made available and possibly eventually included in fuel specifications. There is so far no generally accepted test for this purpose.

# 8

# POSSIBLE HEALTH PROBLEMS

## 8.1 Introduction

Report summary from a research project arranged by the Norwegian Ship owners Association.

The knowledge of health problems related to fuel oil handling ashore and on board ships has increased the last years.

On the other hand possible health effects caused by the introduction of improved methods in refining technology, has not yet been fully investigated. In addition chemical analysis of certain fuel oils has revealed presence of odd components unlikely to be present in the fuel oil as derived from refinery, thus indicating that mixing of the fuel oil with other chemical products does take place.

On this background and the result of a pre-study which was published in January 1985, the Norwegian Ship owners Association initiated a project with the aim to investigate closer the blending of fuels with compounds that may represent health risks to operators handling such fuel products on board ships.

## 8.2 The objectives of this project were:

- to produce a record of components that may be present in marine fuel oils, and which represent a potential health hazard. The record contains both components present in the oil itself as well as components from other sources such as fuel additives and/or chemicals, which could have been dumped into the fuel.
- to develop analysis procedures that makes possible the determination of potentially hazardous compounds.
- to determine the amount and investigate the origin of such components in fuel oils.
- to perform environmental studies in engine rooms by means of stationary and personal exposure measurements.

- to correlate the work environment studies with the results from fuel oil analyses to form a basis for more consistent assessments of the health risk connected to the handling of fuel oils.

By the collection of information about chemical components that may represent a health risk, a list consisting of 58 compounds was established. The list is supposed to cover a number of compounds that are present as part of a normal fuel oil composition and compounds that may occur as contaminants in cases where chemicals have been added to the fuel at some stage after the delivery from the refinery.

In order to identify the above compounds, as well as other odd components, an automated analysis procedure was developed for combined gas chromatography/mass spectrometry (GC/MS).

This method will be useful in the control analysis of fuel oil samples suspected to be contaminated by chemical waste.

The same procedure was utilised for the examination of air. The samples drawn from the working environment on board four (4) vessels. The samples were collected in different positions in the engine room by adsorption on solid adsorbents. The total amount of hydrocarbons in the working atmosphere was recorded by means of a flame ionisation detector (FID).

Included in the fuel analyses were samples collected from different sources:

- Nineteen (19) samples were suspected to contain some sort of chemical contamination. They had either caused acute physical symptoms by handling on board ships or had been picked out during analysis in laboratories due to unusual odour.
- Four (4) samples of heavy fuel oil had been drawn directly from refineries to represent typical fuels as delivered in the marine fuel market.

- Seven (7) refinery samples were drawn to represent main processes that normally contribute to a fuel blend, such as catalytic cracking products.

As reference samples, one pyrolysis oil and 4 synthetic oils (shale/coke) were analysed.

The remaining samples to be analysed were randomly selected fuels drawn during bunkering from major suppliers in main ports in Europe, USA, and Asia.

The analysis results show that 13 out of the 19 samples suspected to be contaminated did contain chemical components that must have been added to the fuel after having left the refinery. The concentration of contaminants in the samples varies from 0.5% up to 20%.

Five out of the contaminated fuels contained different organic compounds: In three samples were found a mixture of organic acids, esters and aldehydes, some of them (butyrates) providing a nuisance, stitching smell that had caused physical problems for operators being in contact with the product, especially at high temperatures. Two samples contained acetophenins/ benzylalcohols and phenols respectively.

In eight of the contaminated samples, pyrolysis oil was detected. Pyrolysis oil is a by-product deriving from certain industrial processes, for instance the polymer industry. It is a highly aromatic product with strong, unpleasant odour, being characterised as irritative and carcinogenic.

These results clearly show that chemical waste products do occur in marine fuel oils. None of the 40 randomly selected bunkering samples did, however, contain components that indicate contamination by chemicals. The selection of samples is therefore too small for conclusions with respect to how frequent blending of chemicals into fuels does occur.

### **8.3 Studies of the working atmosphere on board**

Air samples were drawn from the engine room on board four (4) vessels; two tankers, one car ferry and one cruise ship. The total amount of hydrocarbons as

determined in the working atmosphere, was during normal operational conditions at a level far below the upper limits recommended by the Norwegian Occupational Health Authorities. Typical values recorded in the engine rooms did vary between 2 and 40 mg/m<sup>3</sup> air. The limit as given for white spirit, which is most relevant compound to compare with, is 120 mg/m<sup>3</sup>.

The results also show that volatile compounds do represent the main contributing factor to the hydrocarbon level in the working atmosphere. Potentially carcinogenic aromatic hydrocarbons were not recorded in the air samples drawn on board. The results do, however, indicate that solvents for cleaning of engine parts etc., may contribute significantly to the concentration of hydrocarbons in the working atmosphere.

### **8.4 Conclusions**

Based on the results from the above test programme, the following conclusions have been drawn:

- Heavy fuel oils do normally contain a large number of compounds that may represent a health risk to engineers by exposure. The concentrations as recorded in each fuel oil sample and air samples drawn in the engine rooms are, however, low, and indicate that the health risk by normal operation is most probably also low.
- Due to the complex composition of the fuel oils and the varying toxicity of each compound, the overall health risk assessment is complicated. The degree of exposure is also likely to vary to a large extent, depending on the working operations to be carried out. The total amount of hydrocarbons recorded during certain maintenance operations was more than 20 times higher than the level recorded at normal operation. Other operations may provide even higher degrees of exposure.
- Compounds deriving from chemical waste products have been found in some of the examined fuel oils. Chemical waste products may arise from a vast number of different

sources, and represent a variety of compounds of unknown toxicity. This fact makes the health risk assessment even more complicated.

- Since the contamination of the working atmosphere seems to be moderate, long term health effects are most likely to be caused by direct, skin contact with the fuel products.
- The importance of using precaution on board should therefore be emphasised, in order to protect engine crew and other people on board against both daily contacts with the fuel oils/solvents and against excessive exposure during maintenance work

# 9

# QUALITY DISPUTES

# AND

# CLAIMS

## 9.1 Introduction

Fuel quality disputes are notorious for their complexity, what at first seems to be a simple matter of a substandard fuel delivery often develops into a lengthy investigation, disproportional associated costs and unsatisfactory conclusions.

Bunker disputes fall broadly into two categories.

### 1. Quantity

- Quantity received different to quantity ordered.
- Quantity received different to that recorded on bunker delivery note.
- Dry oil quantity received below that on delivery note due to high water content.

### 2. Quality Disputes

- Rejection of fuel at time of delivery.
- Claim over quality following analysis of sample taken at time of delivery.
- Claim for engine damage as a result of using a poor quality fuel.

The following text highlights some of the problems frequently encountered by those involved with such disputes.

#### 9.1.1 Quantity

Marine fuels, unlike the majority of land traded petroleum products, are sold by weight not volume. In order to determine weight it is necessary to know the density of the product.

At the time of fuel delivery it is likely that the only available information on density is that provided by the fuel supplier, which he usually records on the Bunker delivery note (BDN).

On completion of bunkering, the fuel supplier requests the Chief Engineer, to sign for receipt of quantity, which includes volume and weight.

It would seem to be unreasonable for the supplier to insist on a signature concerning weight of fuel delivered as the Chief Engineer usually has no means to verify the advised density.

In addition to this, in most cases, the Chief Engineer has no knowledge of the quantity of water delivered with the fuel.

To compound the problem ships bunker tanks are not in shape and calibration tables used to determine tank contents are frequently found to be inaccurate. It is therefore unlikely that the measurement of fuel received into ship's tanks will correspond with shore or barge measurement.

### Case study\*

A ship owner ordered 1000 MT of IF380. The fuel was delivered by barge and according to the bunker delivery note the volume discharged by the barge was 1010 cubic metres and density 0.9900. The BDN therefore recorded the weight of fuel delivered as 1010 x 0.9900 or 1000 MT.

The Chief Engineer concluded by measurements of his own tanks that he had only received 900 cubic metres and using the supplier's density calculated a receipt weight of 891 metric tons.

Agreement on volume transferred could not be reached between supplier and the Chief Engineer and letters of protest were exchanged. However, the Chief Engineer acknowledged that at worst he had only received only 891 MT and advised his owner accordingly.

Being prudent the Chief Engineer had taken a sample during loading of the fuel and forwarded this to DNVPS for analysis. DNVPS determined the following:

- Density @ 15°C.(kg/m<sup>3</sup>) :960.0
- Water content (% V/V) :5.0

Applying this knowledge to the delivery the owner reached the following conclusion:

- Mass received by Ch. Eng.: 900 MT
- Less 5% water : (45 MT)
- Total mass: 855\*0.9600 : 820 MT

The fuel suppliers invoiced as below:

\* This case study is based on ISO 8217-1996, though there is always recommended to use the newest edition of the ISO 8217, which at the time is 8217-2005

1000 MT\*290 USD/MT = 290 000 USD

The owner calculated their bill to be:

820 MT\*290 USD/MT = 237 800 USD

and therefore withheld payment of:

52 200 USD

The foregoing case is of particular interest as it raises many issues and highlights the everyday problem connected with bunker deliveries.

#### WHAT WAS THE TRUE VOLUME DELIVERED?

In this particular case, without any further documentation regarding barge loading figures, ship on board quantities before receipt, etc. it is unlikely that anybody could resolve this issue, of course the problem is that the supplier had no interest in ship received volume and the receivers had taken no interest in measurement of barge tanks prior to and after delivery.

Unfortunately many purchasers see the cost of an independent inspector at the time of delivery as unjustified. However, the cost of such a service should be put into perspective.

- Approx. cost of inspector/surveyor:  
1000 USD
- Cost of 1000 MT fuel purchase:  
290 000 USD
- Premium on 1000 MT:  
1 USD/MT

It is not uncommon to find that the price variation across several suppliers in the same port for a similar product is as much as 5-10 USD/MT. If such a service is not used then the Chief Engineer should be instructed to attend the barge and witness sounding before and after delivery. Deliveries should be based upon accurate barge outturn rather than ship received quantity.

The fuel buyer should carefully study the conditions of sale provided by the supplier. In the majority of cases it is likely that the supplier will state that the volume delivered will be based only upon

measurement of shore tanks or barges. Pursuing a claim on Ships figures under such an agreement would seem to be pointless.

#### Density and water content

From Attachment 1 it can be seen that the odds of the true density being in the favour of the receiver are not good. In some ports high water contents are frequently determined by DNVPS. (Attachment 2). However, this matter raises one of the key issues involved with Bunker disputes.

#### Representative Sampling

On completion of most fuel deliveries the fuel supplier or his representative, which is usually the Barge Master will hand the Chief Engineer a can of oil which is alleged to be representative of the fuel delivered.

In the majority of cases the receiver would not have been invited to witness the taking of this sample and consequently would have no knowledge of its origin.

The Ship staff may also go about the business of collecting a sample during the delivery but all too frequently without the knowledge or attendance of the supplier. In addition the supplier may not be offered a proportion of such a sample.

If a dispute does arise over the quantity of the fuel delivered, due to density and water content, the argument centres on whose sample was representative of the fuel delivery. It could well be that the supplier in such case could demonstrate that the density on the BDN was correct by asking the receiver to analysis the sample given to the Chief Engineer at the time of delivery. It may also be found by analysis of this sample that the water content was only a trace.

If the Chief Engineer signed for receipt of the supplier's sample the case for the Ship owner then starts to become fairly weak. In one case in which DNVPS were involved the fuel supplier had agreed a clause in a contract of sale, which stated that the sample, which would be refereed to in case of dispute, was, that provided.



**9.1.2 Quality**

It is more likely that a fuel dispute which comes to the attention of solicitors, P & I CLUBS and underwriters will be centred on quality parameters rather than quantity as the associated costs are likely to be higher.

**Case study**

A ship owner chartered a vessel out and the Charter party Clause, which referred to fuel quality, stated:

“Fuel quality IF180”

On the first voyage of the Charter the vessel called into Los Angeles and loaded 1500 MT of IF180. Some days after leaving port the exhaust temperatures on the main engine began to rise significantly and the speed was reduced.

The Charterers were advised that something was wrong and after a further 12

hours the Chief Engineer decided to stop the engine to investigate the problem. He discovered that two of the main engine cylinder liners were badly worn, piston rings broken and the fuel pumps had suffered severe wear.

Spare parts were fitted and the voyage continued but the next day the Chief was forced to stop again to investigate similar problems on other units. He found damaged components in more cylinders and was concerned that he had only limited spares. The voyage was continued to Panama where more spares were delivered and a fuel sample was taken from the ship's service tank and landed for analysis.

Whilst the vessel underwent repairs the fuel sample was analysed and the following results obtained:

**Table 5**

<b>PARAMETER</b>	<b>UNITS</b>	<b>RESULTS</b>
Density	kg/m <sup>3</sup> at 15°C	995
Viscosity	mm <sup>2</sup> /s at 50°C	185
Carbon (MCR)	% m/m	16.0
Water	% V/V	2.0
Sulphur	% m/m	3.5
Ash	% m/m	0.25
Vanadium (V)	mg/kg	225
Sodium (Na)	mg/kg	300
Aluminium	mg/kg	180
Silicon	mg/kg	300
Flash Point (FP)	°C	70

The ship owner protested to the Charterers claiming that analysis had shown the fuel purchased by them to be of poor quality. They highlighted:

- Density 995.0 above the industry maximum of 991.0
- High % of water above the industry maximum of 1.0% (ISO 8217-1996)
- Sodium levels indicated water to be saline.
- Aluminium plus silicon above recommended maximum of 80 mg/kg.

- Ash level well above 0.15% maximum.

The Charterers asked the Ship owner to submit the sample given to the Chief Engineer by the fuel suppliers in Los Angeles for independent analysis. The Charterers advised the fuel suppliers that this would be done.

Analysis conducted on the sample provided the following results:

**Table 6**

PARAMETER	UNITS	RESULTS
Density	kg/m <sup>3</sup> at 15°C	989
Viscosity	mm <sup>2</sup> /s at 50°C	180
Carbon (MCR)	% m/m	14.0
Water	% V/V	0.3
Sulphur	% m/m	2.5
Ash	% m/m	0.02
Vanadium (V)	mg/kg	220
Sodium (Na)	mg/kg	20
Aluminium	mg/kg	2
Silicon	mg/kg	4
Flash Point (FP)	°C	90

With this information both the fuel suppliers and Charterers rejected any claims made by the ship owner. However, it was agreed to supply the vessel with new fuel and to segregate this from the alleged poor quality fuel in order that the vessel could continue on its voyage. The ship completed the voyage but many days late and claim/counter claims regarding engine

damages, poor performance and breach of agreement ensued.

Subsequently the following facts were established:

- The engine suffered damages.
- The fuel retained on the vessel segregated from new supplies was of high density, had a high salt-water content and high levels of aluminium and silicon.

Appointed experts concluded that the engine damages were consistent with using a fuel of this quality.

**The following points were less clear:**

- What was the origin of the poor quality fuel? Was it on the vessel before the Charter voyage commenced? Was it delivered in Los Angeles?
- Was the Supplier's sample fuel, which was found to be of good quality representative of the delivery in Los Angeles?
- Could it be demonstrated by reference to the ship's logbook that the ship had operated well before the voyage and that it only had a very small amount of fuel prior to the Charter voyage?
- Could it be shown from the logbook that the problems only started when the Los Angeles fuel was used?
- If it could be shown that the engine damage was probably a result of using the Los Angeles fuel, had the Charterers complied with the Charter party Clause regarding fuel quality?
- Had the fuel suppliers delivered fuel in accordance with the Charterers request?
- Who should pay for the damage and delays?

Experts later concluded that it was highly probable that the fuel, which was delivered in Los Angeles, contained high levels of water, aluminium and silicon, and was of high density. It was then a matter of deciding who was responsible.

The Charterers has, as agreed in the Charter Party, ordered IF180 and both they and the fuel suppliers maintained that they fulfilled their obligations as all viscosity results were close to 180 mm<sup>2</sup>/s.

This dispute then entered around fuel standards, specifications, grades and "merchantable quality".

Firstly let us consider ordering fuel by viscosity alone.

Viscosity is a measurement of a fluid's resistance to flow. The higher the viscosity the greater its resistance to flow.

For many years when fuels were basically of reasonable quality, the only principle difference between grades of fuel was viscosity. Residual fuels as supplied to ships are a blend of the heavy components left over after refining and light distillates. The lighter distillates are more expensive therefore the higher the percentage of distillates in the fuel the greater the price. The lower viscosity fuels have a higher proportion of distillate and therefore command a premium over more viscous fuels.

As far as the ship operator is concerned the only limitation on viscosity is the capability of the heating plant. The higher viscosity fuels require more heating for pumping and injection to the engine.

The DNVPS database convincingly shows that ordering 180 mm<sup>2</sup>/s fuels is no guarantee of quality. In fact, it can be shown quite conclusively that in many major ports the quality of IF380 is better for the diesel engine. IF380 is cheaper than IF180, but requires, of course, additional heating.

Early refinery techniques tended to produce a residual fuel oil of uniform quality and for many years viscosity orderings made sense but today refiners are principally concerned with maximising the production of high quality distillates. These processes have resulted in the deterioration and unpredictable quality of residual fuels.

Refinery techniques, blending and fuel distribution are outside the scope of this paper, however, the following brief notes serve to identify the reasons behind variation in quality (table 7).

Table 7

QUALITY PARAMETER	PROBLEM	SOURCE OF PROBLEM
Density	High	Refinery / blending techniques / too much of high density components.
Viscosity	Too high / low	Refinery / blending techniques / too much of high viscosity components.
Carbon	High levels	Refinery techniques.
Water	Above 1.0 % V/V	Poor refinery / storage / transport housekeeping or perhaps foul play.
Sulphur	High levels	Crude source / refinery techniques.
Sediment	Too high	Refinery / blending technique fuel stability cleanliness. Use of wrong components.
Ash	Too high	Crude source / refinery techniques / contamination (spent lubes).
Vanadium	High levels	Crude source / refinery techniques
Sodium	High levels	Usually combined with high water content – seawater. Possibility crude sweetening
Aluminium + Silicon	High levels	Refinery techniques / poor control / house keeping.

### Fuel standards

When considering what was “probably” inferred by ordering IF180 we could refer to the published fuel standards, which are listed below:

- ISO 8217:1996 \*
- BSMA 100:1989
- CIMAC.

Some of the differences between the standards can be noted from Table 8 (next page)

It can be seen that a viscosity of 180 mm<sup>2</sup>/s at 50°C would be equivalent to a viscosity of approximately 25 mm<sup>2</sup>/s at 100°C. In which case it should be argued that the ship owner wished to interfere that by ordering 180 mm<sup>2</sup>/s fuel it should have been reasonable quality normally associated with the fuel grade. However, we would then have to decide which standard should be used to compare analysis results against.

In our case study, assuming that it had been agreed that the fuel analysis results on the tank samples were correct, they may then be set alongside the available standards below (Table 8).

\*It is always advised to use the most updated ISO specification, (ISO is 8217-2005, or the latest revision)

Table 8

PARAMETER***	RESUL TS	RME25 BSMA 100: 1989	RME25 ISO 8217: 1996	RMF25 ISO 8217: 1996	E25 CIMA C 1995	F25 CIMA C 1995
Density, 15°C at kg/m <sup>3</sup> (max)	995.0	991.0	991.0	991.0	991.0	991.0
Viscosity, mm <sup>2</sup> /s 100°C (max)		25.0	25.0	25.0	25.0	25.0
Viscosity, mm <sup>2</sup> /s 50°C (max) (calculated)	185	180	220	220	180	180
Flash Point, °C (min)	70	60	60	60	60	60
Pour Point, °C (max)		30	30	30	30	30
Carbon, % m/m	16.0	20.0	15.0	20.0	15.0	20.0
Ash, % m/m	0.25	0.15	0.10	0.15	0.10	0.15
Water, % V/V	2.0	1.0	1.0	1.0	1.0	1.0
Vanadium, mg/kg	255	500	200	500	200	500
Aluminium + Silicon, mg/kg	480		80	80	30*	30*
Sediment (TSP), % m/m			0.10	0.10	**	**

Additional comments for CIMAC specification only

\* limit is based on the content of Aluminium only

\*\* no limit, but fuel should not cause excessive sludge during normal fuel treatment

\*\*\* In this case study the old ISO specifications (8217 -1996) have been used, but now there is a new ISO specification available.

It is always recommended to use the most recent ISO 8217 edition available for bunker purchase.

It is apparent that the density determined in the laboratory is well above all the standards.

The viscosity measured to be 185 mm<sup>2</sup>/s is close enough to the required 180 mm<sup>2</sup>/s maximum taking into account the precision of the test.

Flash Point, Pour Point, Sulphur and Carbon would seem to be acceptable and were not points of issue between Owner and Charterer. However, the ash level of 0.25 exceeds the maximum of all standards.

The water content is twice the maximum in most cases and if compared to the newest ISO 8217 2005, it is 4 times the maximum limit.

However, the real problem is that of aluminium and silicon indicating the presence of “catfines” from catalytic cracking, far exceeding the accepted max. value of the standards.

In arbitration the Ship owner would probably argue that he could not remove the water due to the high density of the fuel and that even if he could have relied upon removing 50% of the aluminium and silicon (reasonable cleaning performance) these contaminants would still have been many times the 15 mg/kg maximum recommended entering the engine.

If the arbitrators accepted this argument they would still have to decide whether the Ship owner should have expected to receive fuel with less than 30 mg/(kg aluminium when he had merely ordered 180 mm<sup>2</sup>/s material. If the Ship owner had ordered fuel against CIMAC E25, F25, ISO RME25, RMF25 the case would have been simple. Sampling

Unless all parties interested in the quality of fuel delivered to vessel can agree on one set of representative fuel samples, confusion and additional costs will be inevitable when a quality dispute begins.

Unfortunately many fuel suppliers will refuse to refer to analysis of any sample except that produced by them at the time of delivery. In many cases this included in their terms and conditions of sale which the buyer rarely reads.

The Ship owner may well take samples at the time of delivery but if he does not inform the supplier of his intentions, invite him to witness his sampling, and offer such a sample to the supplier the credibility of this sample will be challenged.

DNV Petroleum Services recognised this problem and now provide Ship owners with “Request to Witness Sampling” forms.

## 9.2 Sampling methods

Representative samples may be taken from barge tanks before delivery, however, this is time consuming and requires some degree of skill and proper sampling equipment if representative composite samples are to be obtained.

The most satisfactory method and that recommended by DNVPS, is by continuous drip from bunker manifold of the receiving vessel throughout the entire loading period. A sketch of a simple device for such sampling forms Attachment 3.

Some solutions

- Ship owners/Charterers (fuel buyers) should carefully examine clauses in the fuel suppliers’ terms and conditions particularly with reference to quantity/quality disputes and sampling.
- Ship owners should work together with technical departments to produce a fuel specification for each vessel that will reflect the type of main engine and cleaning plant.
- This fuel specification should then be compared against International Standards and a grade selected which covers all the key parameters.
- If certain quality parameters are considered important and they are not included in the fuel standards, these should be highlighted.

- Charter Party clauses on fuel quality should be updated to include an International fuel standard plus any special requirements.
- Refer to published information on supplier performance. Section 18 details the DNVPS Bunker Supplier Comparison that gives an overall analysis of recent supplier's performance in the 25 major bunkering ports around the world.
- Standard sampling procedures should be used for each delivery and every attempt made to obtain joint witnessed samples at the point of custody transfer.
- Independent fast analysis of samples from each delivery should be conducted and quantity/quality problems brought to the attention of all parties immediately the problem is identified.
- Ship's staff or independent surveyors should be used to accurately determine delivered quantities.
- Bunker note should be signed on a "volume only" basis.
- Whenever possible, new fuel deliveries should be segregated from stocks held on board.
- New fuel should not be used until analysis results have been received. Precise records of fuel deliveries, transfers and consumption should be maintained, as these may be required at a later date to support a claim.

### 9.3 QUALITY DISPUTES, SUPPLIERS POINT OF VIEW

Sample integrity is seldom an issue. This should not be meant to construe that good practice in sealing samples with tamper evident seals should be ignored. The vessel staff must regard proper sampling as an important job. A tamper evident seal is consistent with this.

"Representativeness" of clients' complaint sample is always the first item challenged by the supplier. This, not the sample integrity, is the issue on which a complaint is "won or lost". The reverse is also true, i.e. sample integrity of suppliers retains is seldom an issue. The representativeness, however, always is.

Reputable suppliers have a "paper trail" on the history and quality of most fuel and fuel components in their terminals. If their analyses confirm problem cited by client, they will generally seek to arrive at an equitable settlement. Clients are advised to be "reasonable" in financial claims, for example padding of bills can alienate the supplier will reject a claim because it is large. The suppliers technical expert will critically evaluate, the claim. Reasonableness not \$ magnitude is the key consideration. There are many examples of large claims in excess of \$100,000, which were successfully settled.

More often than not the issue is less clear cut, that is the clients' sample indicates a problem; the suppliers' sample does not. In these cases the following items are generally important:

- Details of the exact origin of samples
- Prompt notification
- A history of fuel quality supplied to the vessel
- Marpol compliant bunker delivery note (BDN)
- Samples seal number in the BDN (mandatory when bunkering in Singapore to comply with CP 60)
- Marpol compliant sample which is taken at the receiving vessel bunker manifold.

Since the key issue almost always comes down to which sample is most truly representative, complaint/claims are seldom settled on the basis of one analysis. The additional analyses when combined

with the original analysis should ideally corroborate the complaint/claim. Indeed, the facts that a number of samples “tell the same story” speak to the credibility of the original sample and claim.

The supplier knows for example some or all of the following: Suppliers have information on their fuel quality (other than analyses) which they normally do not disclose. Other operators supplied with the same fuel and incidence of complaints from them, other operators supplied from the same barge and associated complaint incidence, detailed knowledge of blending component quality etc., etc. If their data make them doubt that they were responsible for complaint, they can be formidable adversaries.

Third part laboratories; such as DNVPS also has information, which they do not disclose, specifically sample to other vessels, from the same supplier during the same time period. Under certain circumstances this may be waived.

The remedies for certain complaint/claims are relatively straightforward. Once a set of data is agreed, settlement is easy. These include:

Density differential (assuming it is in spec) which translates to short delivery.

Higher viscosity grade delivered than ordered resulting in a lower price (if ship can handle delivered viscosity).

Moderate water in fuel, which results in overpaying on invoice.

Large customers of large suppliers have the best success rate in settling these types of complaints. Remedies for certain other complaints are anything but straight forward. These include among others, high catalyst, density, sediment/sludge content. These are particularly tricky if consequential damages are claimed.

In the last analysis, operators that (1) keep good records, (2) are cognisant of fuel quality and monitor it carefully as in a quality test program, (3) document claims without padding, (4) provide supporting evidence stand the best chance of arriving at an equitable settlement.

Any claim, which is not documented with competent and reliable analytical results, is almost certainly doomed to failure. A complete analysis does not guarantee success, but it does insure a serious hearing from all reputable suppliers



**10**

**GUIDELINES**

**FOR**

**FLASH POINT**

**BELOW 60°C**

## 10.1 Introduction

The objective of these guidelines is to highlight some of the practical and safety aspects associated with handling fuel oil with flash point below 60°C.

From time to time we are receiving requests regarding the use of fuel oil with flash point below 60°C. In this connection it is desirable to have a set of guidance which may hopefully ensure uniform internal handling of such cases.

## 10.2 SOLAS

According to 1974 SOLAS II-2 Regulation 15, no fuel oil with flash point of less than 60°C shall be used. Following exemptions are listed:

- In emergency generators fuel oil with flash point of not less than 43°C may be used.
- Subject to such additional precautions as it may consider necessary and on condition that the ambient temperature of the space in which such fuel oil is stored or used shall not be allowed to rise within 10°C below the flash point of the fuel oil, the Administration may permit the general use of fuel oil having a flash point of less than 60°C but not less than 43°C.
- In cargo ships the use of fuel having a lower flash point than otherwise specified in this paragraph, for example crude oil, may be permitted provided that such fuel is not stored on any machinery space and subject to approval by the Administration of the complete installation.

The flash point of oils shall be determined by an approved closed cup method (ASTM D93 or ISO 2719).

## 10.3 DNV Rules for Ships Pt.4 Ch.1 Sec.5 D100 Flash Point of fuel oil

Fuel oils with a flash point of less than 60°C (closed cup) are not permitted, except for the following:

Ships certified for restricted service within areas having climate ensuring that ambient temperatures of spaces where such fuel oil is stored will not rise to temperatures within 10°C below the flash point of the fuel, may use fuel oil with flash point below 60°C but not less than 43°C.

- Installation specially approved for the use of crude oil as fuel.

**102** Fuel oil storage tank shall not be heated to temperatures within 10°C below the flash point of the fuel except for the following:

Fuel oil in service tanks, settling tanks and any other tanks in the supply system may be heated above this limit, provided:

The length of the vent pipes from such tanks and/or a cooling device is sufficient for cooling the vapours to at least 10°C below the flash point of the fuel oil.

A temperature sensor is fitted in the vent pipe and adjusted to give alarm if the temperature should exceed a limit set at 10°C below the flash point of the fuel.

The vent pipes are fitted with flame screens meeting the requirements of IMO's "Standards for devices for preventing passage of flames into cargo tanks".

There are no openings from the vapour space of the fuel tanks into the machinery spaces.

Enclosed spaces shall not be located directly above such fuel tanks, except for well-ventilated cofferdams.

Electrical equipment shall not be fitted in the vapour space of the tanks, unless it is certified to be of intrinsically safe.

**103** Liquids for specific purposes and whose flash point is lower than 43°C are preferably to be stored outside the machinery space. If tanks for such liquids

are installed in the engine room, installation drawings are to be submitted for approval in each case.

IACS Requirements F35 Items 2.3.1 and 2.3.2 contain the same requirements as the DNV Rules D 101 and 102.

#### 10.4 Guidelines

Guidelines for the handling of fuel oil with flash point below 60°C.

Requests for the use of fuel oil with flash point below 60°C will in general be rejected, with reference to DNV Rules and 1974 SOLAS Convention.

However if the vessel documents that it meets the requirements of the Exemption of 1974 SOLAS II-2 Regulation 15, the vessel may use the fuel.

If the vessel is at sea when the analysis result of the fuel oil is received, the vessel may proceed to the next scheduled port where the fuel oil shall be re-tested or removed.

Safety precautions and operational procedures as outlined below should as far as possible be adopted during the sea voyage to minimise the rate of generation of flammable vapours and to minimise the risks associated with such vapours.

##### 10.4.1 General Safety Precautions

- Reduce and maintain fuel oil tank temperatures at a minimum practical temperature. It is recommended that fuel oil tanks shall not be heated to temperatures within 10°C below the flash point of the fuel.
- The splashing and agitation of the fuel oil in the fuel oil tanks, particularly during transfer, should be kept to a minimum.
- No-smoking or hot work in areas where a potential build up of flammable gases from fuel oil tanks, vent lines, or around fuel oil equipment, may occur.
- When filling empty or near empty tanks, it should be conducted such as to take due care to avoid the hazards associated

with static electrical charges. These precautions would, for example, include that metallic sampling and ullaging equipment is properly earthed or bounded to the tank structure.

- The flammability of the headspace of fuel oil tanks should if possible be monitored regularly. Should a measured value in excess of 50% LEL be detected, action should be taken to reduce the vapour concentration by purging the head space with low-pressure air. Gases should be vented to a safe area with no ignition sources in the vicinity of the outlet. On completion of venting, gas concentrations within the tank should continue to be monitored and further venting undertaken if necessary.
- Once the tank has been purged with air, consideration may be given to inerting the headspace should it be practical to do so.
- Conventional portable detectors (explosimeters) can be used to give an indication of the flammability of the head space, although they are not primarily designed for this purpose and, therefore, do not necessarily give an accurate measurement.
- The gas detector should be calibrated on regular basis and used by trained staff who should follow the equipment manufacturer's recommendations.
- The machinery space should be attended at all times.

DNV, Flag and Port State Administrations  
The Master/Owner should notify DNV, Flag and Port State Administrations.

#### Re-test of Flash Point

Upon arrival in the next scheduled port, the fuel oil should be removed from the vessel or be re-tested.

When fuel oil has been stored for some time, it is likely that the flash point will increase due to vaporisation of the most volatile components of the fuel oil. If the flash point now meets the requirement the fuel oil is then deemed suitable for use.

#### References:

1974 SOLAS II-2 Regulation 15

DNV Rules for Ships Pt.4 Ch.1 Sec.5 D

IACS F35 Items 2.3.1 and 2.3.2

OCIMF “The flammability hazards associated with the handling, storage and carriage of residual fuel oils”.

IMO Resolution A.565(14)

SHELL “Practical guidelines for the handling of marine residual fuel oil particularly with respect to bunker tank vapour space flammability”

ISO Petroleum products – Fuels (class F) – Specifications of marine fuels. Draft international standard. ISO/DIS 8217

**11**

**COMMINGLING**

**OF**

**FUELS**

## 11.1 USEFUL RULES OF THUMBS

- TRY NOT TO MIX FUELS OF DISSIMILAR DENSITIES
- IF YOU MUST MIX, AVOID EQUAL PROPORTIONS
- TWO FUELS OF ESSENTIALLY THE SAME VISCOSITY, WHICH ALSO HAVE ESSENTIALLY THE SAME DENSITY, CAN BE COMMINGLED WITH A MINIMUM RISK OF INCOMPATIBILITY
- WHERE DISSIMILAR FUELS MUST BE COMMINGLED IN A TANK, THE CHANCES AND INCOMPATIBILITY CAN BE MINIMISED BY REDUCING THE AMOUNT OF ONE FUEL TO A MINIMUM BEFORE ADDING THE OTHER FUELS TO THE TANK

**12**

**FUEL IGNITION**

**ANALYSIS**

## 12.1 FUEL IGNITION AND COMBUSTION QUALITY

Fuel ignition quality is an increasingly important parameter for the purchase and use of marine bunkers. Due to the different fuel fractions used in bunker production, marine fuels in the market can vary greatly in ignition and combustion properties. Experience shows that in order to increase safety and to reduce engine damages, controlling the ignition and combustion quality of marine fuels is becoming more important.

Why is Fuel Ignition and Combustion Quality Important?

Delayed fuel ignition and incomplete combustion can lead to:

Undesirable peak pressures

Unstable operation

Varying revolutions which are in turn highly undesirable for auxiliary engines operation

Formation of carbon deposits on the engine pistons, which can cause serious damage to the internal machinery

In the worst case scenario, ignition and combustion irregularities can render the engine inoperative and affect the safe operation of the ship.

Increased catalytic cracking activities in refineries not only contribute abrasive elements in the bunkers, but are also producing fuel of higher density and poorer ignition quality. Ship operators should therefore be aware of the overall fuel quality, including the ignition and combustion quality of bunkers delivered to their vessels.

Medium speed engines are generally less tolerant of poor fuel ignition quality, compared to slow speed engines. Studies have identified instances where a fuel can cause little or no problem at all for the main (slow speed) engine but severe damage to the auxiliary (medium speed) engines. As more ships begin to use a single fuel for both engines, ignition quality is poised to take on more importance as a fuel quality parameter.

### 12.1.1 How is Fuel Ignition and Combustion Quality Determined?

Previously, fuel ignition and combustion quality has neither been determined through traditional fuel analysis.

Instead, ignition quality was estimated from a mathematical formula called the Calculated Carbon Aromaticity Index. Known commonly as CCAI, this calculation only takes into account density and viscosity and therefore fails to reflect the effects of all other variables on the ignition and combustion processes. Although it is long recognised as an imperfect tool, CCAI has nonetheless enjoyed widespread use for want of a more accurate and reliable measure.

Lab-based measurement of fuel ignition and combustion quality is now possible and also with a recent approved IP test method.

By the use of constant volume combustion technology it is possible to examine the ignition and combustion characteristics of the fuel. It is mainly two types that is used for this testing. The Fuel Ignition Analyser (FIA) which has been on the market for quite some years and the new FCA (Fuel Combustion Analyser) which is approved in the new IP test method. Both of them are a 'constant volume combustion rig' which methodology is to effectively simulate the combustion chamber of a ship engine on low load.



## How the FIA/ FCA works

A sample of the fuel to be investigated is first injected into a combustion chamber containing pressurised and heated air. As the fuel spray self-ignites and burns, its ignition delay is established as a measure for ignition property and expressed in terms of an FIA Cetane number. In addition, the combustion quality is evaluated from a qualitative judgement of the combustion pressure diagram and a “rate of heat release” diagram.

The higher the FIA Cetane number, the better the ignition quality of the fuel analysed.

The entire FIA/ FCA testing procedure, including instrument control, compilation of test data and presentation of test results, is computer controlled for greater accuracy.

Although the FIA/FCA provides a reliable means for testing fuel ignition and combustion quality, the analysis and interpretation of test data require experience and extensive background knowledge of this fuel parameter.

**13**

**CCAI / CII**

**NOMOGRAM**

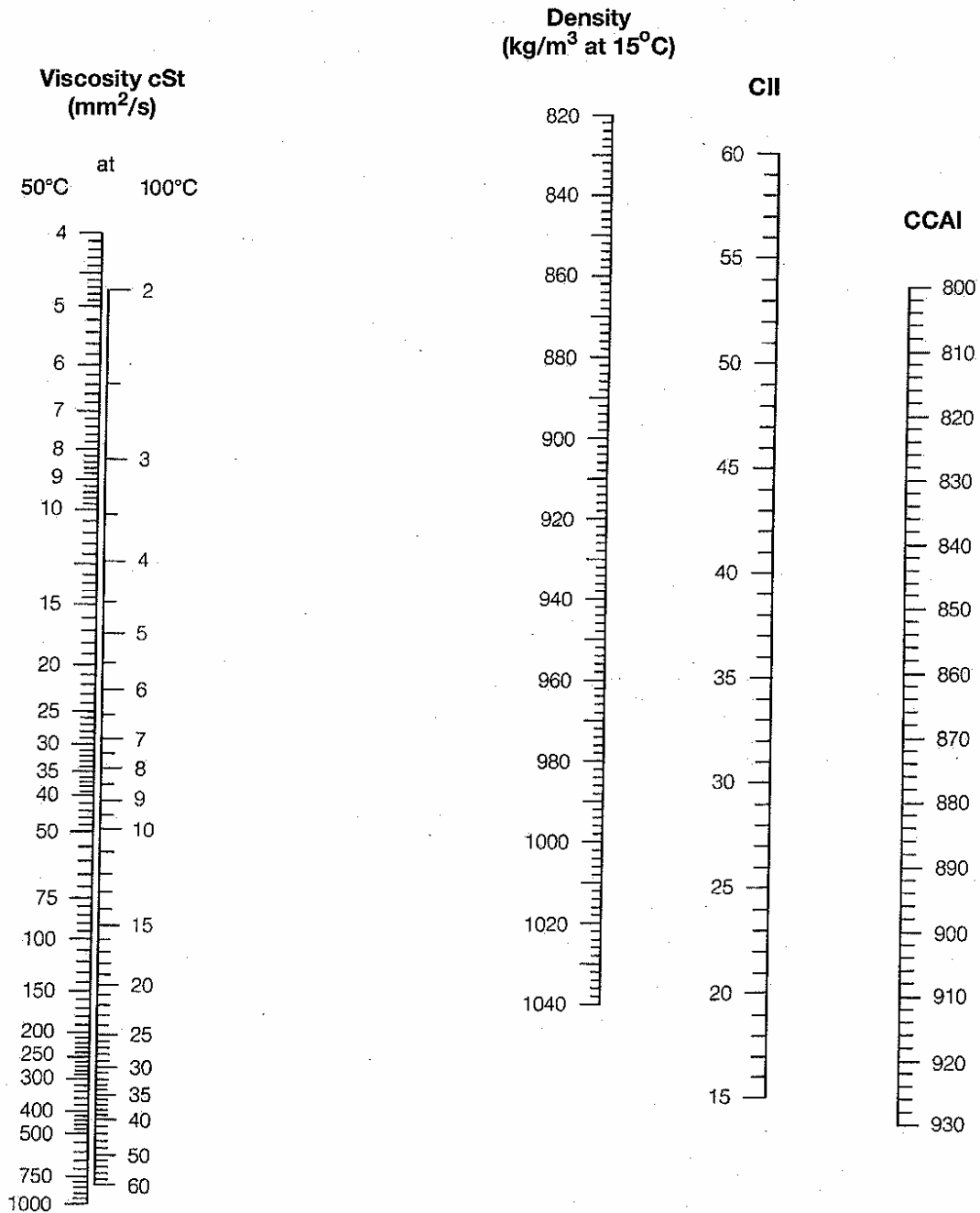


Figure 1

### NOMOGRAM FOR DERIVING CCAI

$$CCAI = D^{-81} - 141 \log \log (V_k + 0,85)$$

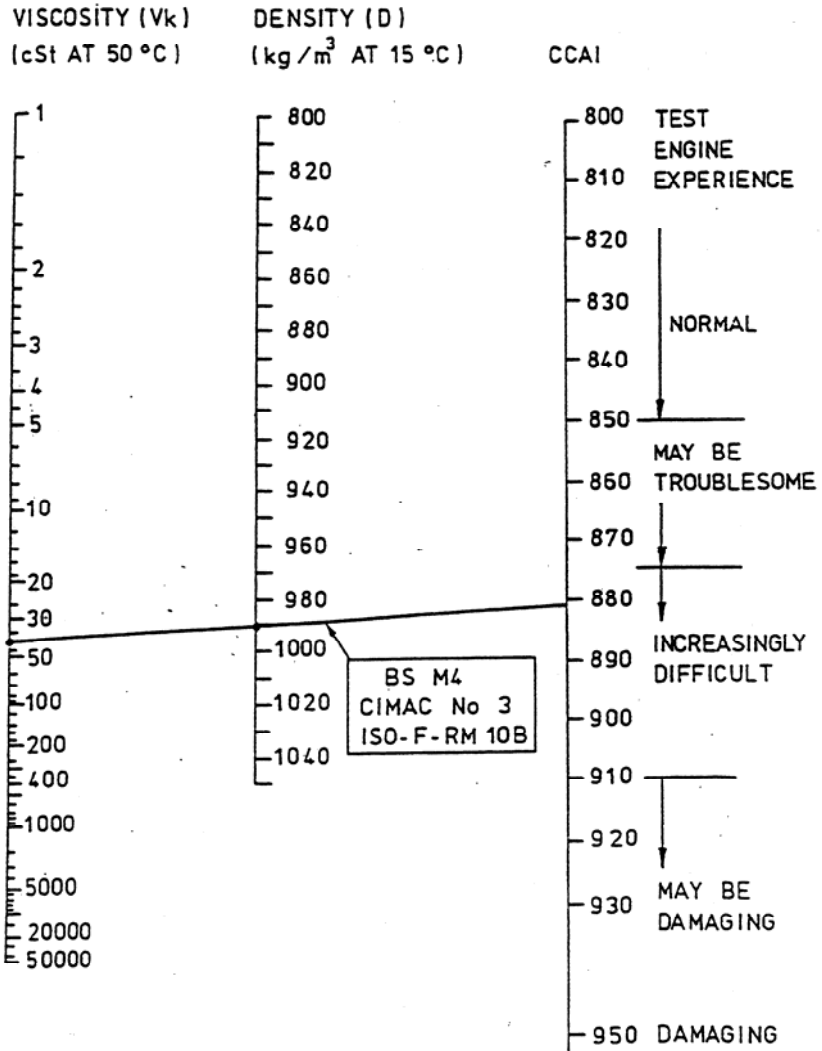
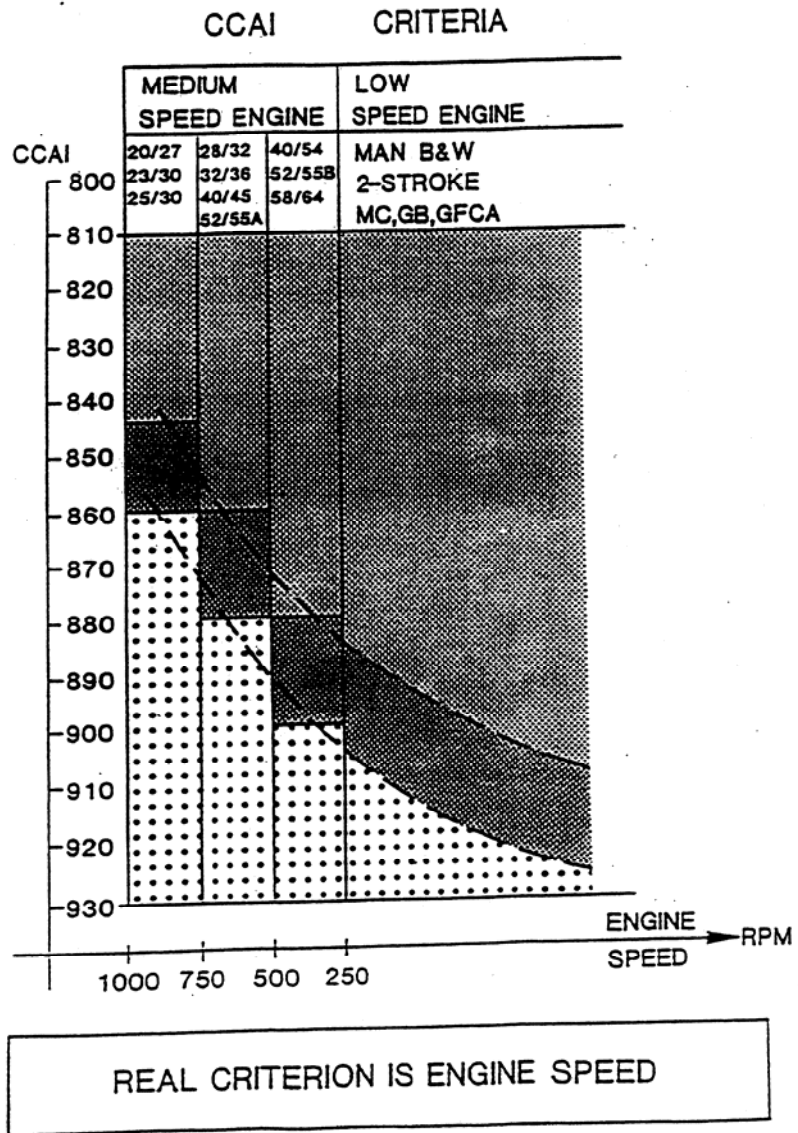


Figure 2



Source: MAN B&W

**Figure 3**

**14**

**BUNKER  
SUPPLIER  
COMPARISON**

# DET NORSKE VERITAS

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## BUNKER SUPPLIER COMPARISON

Issue Date 12/09/2007

### General

These comparisons are based on the latest samples as received and analyzed by DNV Petroleum Services at its own laboratories. The samples were taken by participating shipowners during bunkering operation and dispatched to DNVPS together with the bunker receipt and other appropriate sample papers. DNVPS' standard instructions are that the supplier's representative is given a duplicate sample for his own analysis.

For each port the comparison is divided into two sections, 180 cSt fuels and 380 cSt fuels. These are based on the most recent five samples received, which the accompanying papers show can be attributed to the relevant supplier. The number of samples received in the last month and the last six months is shown against each supplier.

Where DNVPS has received less than five samples for a supplier in each grade over the preceding six months, that supplier is not rated but merely listed under the relevant port.

### Ratings

Four characteristics of the fuel are separately rated against defined parameters. These parameters are, density difference (D), viscosity difference (V), water content (W) and abrasives content (A). The rating range is 0 to 5, and the figure for any characteristic is the number of "adverse events" for the last five samples.

It is suggested that users should treat an "0" or "1" rating as similar. As the difference is only one event this may have been caused by a temporary housekeeping problem.

## Density difference (D)

The rating for density is based on the variation, if any, between that analyzed and the value quoted on the bunker delivery receipt note. As marine fuel is sold by weight but delivered by volume an accurate measurement of density is essential to determine the weight supplied. If the density difference is greater than 5 kg/cu.m in the supplier's favour this is considered an "adverse event".

## Viscosity difference (V)

Most suppliers deliver fuel to within 10% of the viscosity stated on the bunker receipt note. If the actual viscosity is greater than that stated this is considered an "adverse event". The parameter used for a 180 cSt fuel is 200 cSt, and for a 380 cSt fuel is 420 cSt.

## Water content (W)

The presence of water in marine fuel reduces the available specific energy. An "adverse event" with respect to water content is considered to have taken place if the water content is greater than 0.5% V/V.

## Abrasive content (A)

Most suppliers deliver fuel with a low or negligible level of abrasive content. If the abrasive content is greater than suggested by 20 mg/kg (ppm) aluminium, or a combined aluminium and silicon content of greater than 55 mg/kg (ppm), this is considered an "adverse event".

It should be noted that the combined aluminium and silicon value is less than that included in the international specification ISO 8217.

## Averages

Average values for the last five samples are shown for density (kg/cu.m at 15° C), viscosity (cSt 50°C), water content (% V/V) and calculated net specific energy (MJ/kg). The energy content is included since often an apparent keenly negotiated price for a stem is negated by the ship receiving fuel of a lower energy content.

Each supplier's average net specific energy is compared with the port's overall average, and the percentage difference is shown.



## Premium

A bunker price of 100 US\$/tonne has been assumed in calculating the cost premium to take account of density difference and variation in specific energy.

The difference in density between the bunker delivery receipt and measured density is calculated for each of the last five deliveries. These differences are averaged and, assuming a fuel price of 100 US\$/tonne, the premium of this element is calculated. It is possible for this figure to be negative which means the average density difference is in the buyer's favour, whilst a positive value means that this element is in the supplier's favour.

The average energy for the last five samples for each rated supplier is calculated and compared against the average port energy for all suppliers over the past six months. For this calculation data from samples delivered by both rated and non-rated suppliers is used. The premium with respect to energy is calculated assuming a fuel price of 100 US\$/tonne. A positive figure indicates an energy content higher than the port average, whilst a negative figure shows an energy content below the port average.

The premium shown takes account of both the density and the energy elements. In cases where the total is less than 20 cents/tonne (0.2 US\$/tonne), the premium for that supplier appears blank.

Practical application of the premium is illustrated in the example below.

Assume comparison of three suppliers A, B and C, who quote prices of 101, 100 and 99 US\$/tonne. For these suppliers the bunker supplier comparison premium is shown to be +1.5, -0.5 and 3.0 US\$/tonne. Hence the comparison price can be determined.

Supplier	Quoted Price	Premium US\$/Tonne	Comparison Price
A	101	1.5	102.5
B	100	-0.5	99.5
C	99	3.0	102

Based on the data from the last five deliveries, and considering only the commercial aspects of density difference and energy, supplier "B" would be the best purchasing option.

In the example shown the average quoted price is 100 US\$/tonne and, as the premium is calculated on this assumption, clearly the premium has to be adjusted to take account of the total quoted price. This is achieved by multiplying the premium by average quoted price [US\$/tonne]/100.

The premiums presented by DNVPS show the suppliers' performance over the last five samples analyzed by DNVPS. Trends in suppliers performance may be established by review of monthly Bunker Supplier Comparison reports.

Certain of the fuels included in this Bunker Supplier Comparison report may have been specifically ordered as high density fuels. Such high density fuels may therefore result in a high average density for certain suppliers. This may give the impression that some suppliers offer , on average, 'off-spec' fuels which is an incorrect deduction.

#### Disclaimer

While every care is taken to ensure that the fuel analysis data featured in Bunker Supplier Comparison Report are accurate, DNVPS makes no claims, promises or guarantees about the accuracy, completeness, or adequacy of the data and expressly disclaims liability for errors and omissions in the contents of the data in Bunker Supplier Comparison Report and/or the consequences of applying such data.

## BUNKER SUPPLIER COMPARISON

	Rating for the last 5 samples D V W A	Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$) ----- Total
		6-m	1-m	Dens	Visc	H2O	Energy		
<b>ANTWERP</b>		<b>180 FUELS</b>							
Port Average Energy :		40.63 MJ/Kg							
Ranging 40.11 - 41.22 MJ/Kg		(2.79 % )							
O.W.BUNKER	1-1-0-0	10	2	982.8	175.3	0.1	40.67	0.10	0.08
VERBEKE	0-0-0-4	99	13	981.4	170.4	0.1	40.93	0.75	-0.61
WILJO	0-0-0-0	27	5	984.3	168.1	0.2	40.52	-0.26	0.17
Not Rated : ATLANTIC,BP,CHEVRON,EXXONMOBIL,FRISOL,OIL CHART,VAN STAPPEN									

<b>ANTWERP</b>		<b>380 FUELS</b>							
Port Average Energy :		40.54 MJ/Kg							
Ranging 38.36 - 41.17 MJ/Kg		(7.33 % )							
ABC BUNKEROI	0-0-0-2	9	0	990.2	370.2	0.1	40.52	-0.05	0.05
ATLAS	0-0-0-0	7	2	986.8	336.7	0.1	40.54	0.01	0.14
BP	0-0-0-2	84	14	986.9	247.5	0.0	40.54	0.01	0.00
CHEVRON	1-0-0-0	5	0	986.8	358.9	0.0	40.51	-0.06	0.14
EXXONMOBIL	0-0-0-0	113	20	985.2	394.6	0.0	40.69	0.37	-0.31
FRISOL	0-0-0-1	36	3	989.2	240.6	0.1	40.48	-0.15	0.20
O.W.BUNKER	0-0-1-2	191	28	989.6	327.7	0.3	40.43	-0.25	0.34
OIL CHART	0-0-0-0	110	18	987.9	241.1	0.1	40.33	-0.51	0.56
SHELL	0-0-0-0	6	1	979.9	374.4	0.0	40.92	0.94	-0.99
TOTAL	1-0-0-2	6	0	989.3	355.8	0.0	40.50	-0.10	0.22
VERBEKE	1-0-0-0	376	76	984.1	285.5	0.1	40.34	-0.49	0.82
WILJO	1-0-0-0	259	63	980.1	325.7	0.1	40.38	-0.39	0.78
Not Rated : ATLANTIC,CHEM OIL,JADACO									

<b>AUGUSTA</b>		<b>180 FUELS</b>							
Port Average Energy :		40.68 MJ/Kg							
Ranging 40.03 - 41.20 MJ/Kg		(2.93 % )							
MAXCOM	2-0-0-0	36	6	973.0	160.1	0.2	40.78	0.24	0.00
Not Rated : ALPHA T,EXXONMOBIL									

<b>AUGUSTA</b>		<b>380 FUELS</b>							
Port Average Energy :		40.45 MJ/Kg							
Ranging 39.86 - 41.03 MJ/Kg		(2.93 % )							
EXXONMOBIL	0-0-0-0	54	9	988.6	350.7	0.2	40.14	-0.76	0.82
MAXCOM	1-0-0-1	75	9	979.3	350.4	0.2	40.30	-0.37	0.85
Not Rated : ALPHA T,ENI									

	Rating for the last 5 samples D V W A	Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$) ----- Total
		6-m	1-m	Dens	Visc	H2O	Energy		
<b>FUJAIRAH 180 FUELS</b>									
Port Average Energy : 40.37 MJ/Kg									
Ranging 38.67 - 41.09 MJ/Kg (6.26 %)									
AEGEAN	1-1-0-2	9	0	966.1	185.6	0.3	40.48	0.27	0.26
FAL	0-0-1-0	29	3	963.7	177.2	0.4	40.68	0.78	-0.88
IMPERIAL MAR	5-0-2-0	5	0	945.0	86.4	0.6	40.47	0.25	3.82
INTER.SUP.	1-3-0-1	7	1	969.7	216.2	0.2	40.30	-0.17	0.01
OMTI	4-0-0-0	37	4	972.0	203.6	0.2	40.07	-0.75	2.14
Not Rated : ASEAN INT.,FNB									
<b>FUJAIRAH 380 FUELS</b>									
Port Average Energy : 40.22 MJ/Kg									
Ranging 39.66 - 41.16 MJ/Kg (3.78 %)									
AEGEAN	0-0-0-0	86	22	987.5	361.3	0.2	40.15	-0.17	0.11
AKRON	1-1-0-1	170	25	979.8	348.6	0.1	40.22	0.00	0.42
ENOC	1-1-0-1	225	32	980.5	344.7	0.1	40.28	0.14	0.29
FAL	0-1-0-1	572	85	984.4	338.6	0.1	40.24	0.05	0.04
FNB	0-1-0-1	10	0	987.6	336.5	0.1	40.32	0.25	-0.19
INTER.SUP.	0-0-0-0	48	9	980.9	331.6	0.0	40.13	-0.22	0.19
OMTI	3-0-0-0	53	5	978.5	297.4	0.2	40.16	-0.16	0.97
Not Rated : ADNOC									
<b>GENOA 180 FUELS</b>									
Port Average Energy : 40.79 MJ/Kg									
Ranging 40.14 - 41.41 MJ/Kg (3.16 %)									
EXXONMOBIL	0-2-0-3	9	4	979.3	245.1	0.1	40.38	-1.00	0.48
GETOIL	2-2-0-0	13	1	962.6	201.9	0.1	41.09	0.73	-0.48
Not Rated : MAXCOM,PETROLMAR									
<b>GENOA 380 FUELS</b>									
Port Average Energy : 40.44 MJ/Kg									
Ranging 39.83 - 40.96 MJ/Kg (2.84 %)									
ALPHA T	1-0-0-2	5	1	980.0	343.6	0.1	40.41	-0.07	0.26
ENI	0-0-0-2	6	1	987.2	335.8	0.2	40.31	-0.32	0.12
EXXONMOBIL	0-0-0-2	55	12	983.7	357.1	0.1	40.32	-0.30	0.24
GETOIL	1-1-0-0	19	3	976.5	366.6	0.2	40.76	0.80	-0.52
Not Rated : MAXCOM,PETROLMAR,PISANO									
<b>GIBRALTAR 180 FUELS</b>									
Port Average Energy : 40.43 MJ/Kg									
Ranging 39.91 - 41.11 MJ/Kg (3.00 %)									
AEGEAN	0-2-0-0	13	1	970.1	193.1	0.0	40.74	0.76	-0.86
CMF	0-1-0-0	17	0	983.9	186.1	0.0	40.43	0.01	0.07
VEMA OIL	1-0-0-1	34	10	986.5	164.5	0.3	40.35	-0.19	0.49
Not Rated : BOMINFLOT,PENINSULA,MACOIL									

	Rating for the last 5 samples				Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$) Total
	D	V	W	A	6-m	1-m	Dens	Visc	H2O	Energy		
<b>HAMBURG 180 FUELS</b>												
Port Average Energy : 41.01 MJ/Kg												
Ranging 40.40 - 41.67 MJ/Kg (3.15 %)												
BOMINFLOT	1-0-0-1				7	1	973.1	188.1	0.0	40.82	-0.48	0.58
O.W.BUNKER	1-1-0-0				7	0	982.0	166.7	0.0	40.76	-0.63	0.85
SHELL	2-0-0-0				25	2	977.1	146.7	0.0	40.85	-0.40	0.72
WRIST	0-2-0-2				5	3	969.2	195.3	0.0	41.04	0.06	-0.32
Not Rated : BMT,RINCK,TOTAL												

<b>HAMBURG 380 FUELS</b>												
Port Average Energy : 40.82 MJ/Kg												
Ranging 40.25 - 41.59 MJ/Kg (3.35 %)												
BOMINFLOT	0-0-0-0				68	12	978.5	317.2	0.0	40.71	-0.26	0.24
O.W.BUNKER	0-0-0-0				37	0	973.3	296.0	0.0	40.79	-0.08	0.12
RINCK	0-0-0-0				49	11	969.5	314.1	0.0	40.90	0.19	-0.06
SHELL	0-0-0-0				69	13	964.4	303.2	0.0	41.05	0.57	-0.48
TOTAL	1-0-0-0				70	12	956.1	265.6	0.0	41.27	1.11	-0.51
WRIST	0-0-0-3				16	10	976.8	369.7	0.0	40.91	0.23	-0.86
Not Rated : BMT,OIL CHART												

<b>HOUSTON 180 FUELS</b>												
Port Average Energy : 40.17 MJ/Kg												
Ranging 39.70 - 40.59 MJ/Kg (2.24 %)												
BOMINFLOT	1-0-0-1				28	2	980.4	221.1	0.1	40.35	0.44	-0.02
BP	0-2-0-0				31	10	990.0	232.2	0.1	39.98	-0.46	0.54
CHEM OIL	0-3-0-2				12	2	993.3	191.7	0.1	40.18	0.02	-0.05
EXXONMOBIL	0-0-0-0				14	3	987.8	152.4	0.0	40.25	0.21	-0.14
HMS	0-0-0-0				16	5	988.6	175.1	0.0	40.09	-0.20	0.16
MATRIX	0-0-0-0				22	3	983.6	121.2	0.1	40.10	-0.16	0.09
Not Rated : CHEVRON,FAMM,JAM,SHELL												

<b>HOUSTON 380 FUELS</b>												
Port Average Energy : 40.09 MJ/Kg												
Ranging 39.23 - 40.68 MJ/Kg (3.71 %)												
BOMINFLOT	0-0-0-0				64	7	989.3	343.6	0.1	40.04	-0.13	0.23
BP	0-0-0-0				105	22	989.8	317.0	0.1	40.08	-0.04	0.10
CHEM OIL	0-0-0-3				85	15	990.1	294.7	0.1	40.14	0.11	-0.10
CHEVRON	0-0-0-1				49	12	989.4	340.9	0.0	40.07	-0.04	0.11
EXXONMOBIL	0-0-0-0				57	5	988.4	368.4	0.0	40.12	0.07	-0.03
FAMM	0-0-0-1				70	11	989.3	349.0	0.0	40.09	-0.02	0.08
HMS	0-0-0-0				30	12	988.7	350.4	0.0	40.25	0.38	-0.44
MATRIX	0-0-0-0				111	21	990.4	299.0	0.2	39.80	-0.74	0.67
SHELL	0-0-0-0				14	1	990.2	359.5	0.1	39.96	-0.32	0.33
Not Rated : MGL,MIDSTREAM,TOTAL												

	Rating for the last 5 samples				Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$)
	D	V	W	A	6-m	1-m	Dens	Visc	H2O	Energy		
<b>ISTANBUL 180 FUELS</b>												
Port Average Energy : 40.80 MJ/Kg												
Ranging 39.95 - 41.37 MJ/Kg (3.55 %)												
ANADOLU	1-1-1-0				34	9	959.3	183.5	0.3	40.63	-0.41	0.44
CYE	0-2-2-0				10	3	957.6	187.9	0.5	40.80	-0.01	-0.50
ENERGY PET.	0-4-0-0				18	1	959.1	237.1	0.0	40.86	0.15	-0.68
PETROL OFISI	0-0-0-0				13	1	957.8	153.6	0.1	40.88	0.18	-0.15
TBS PETROL	1-0-0-0				16	2	954.4	146.7	0.0	40.93	0.32	-0.54
Not Rated : BAYTUR,LUKOIL												
<b>ISTANBUL 380 FUELS</b>												
Port Average Energy : 40.66 MJ/Kg												
Ranging 39.84 - 41.00 MJ/Kg (2.90 %)												
ANADOLU	0-0-0-0				90	13	967.3	283.1	0.1	40.64	-0.04	0.11
CYE	0-0-1-0				21	3	968.5	368.0	0.5	40.62	-0.09	-0.28
ENERGY PET.	0-0-0-0				20	4	963.6	346.9	0.0	40.77	0.27	-0.66
PETROL OFISI	0-0-0-0				141	13	965.9	359.9	0.0	40.74	0.20	-0.20
TBS PETROL	1-2-0-0				34	5	964.7	400.2	0.0	40.76	0.27	-0.46
Not Rated : BAYTUR,LUKOIL,OPET,TUPRAS												
<b>LEGHORN 380 FUELS</b>												
Port Average Energy : 40.06 MJ/Kg												
Ranging 39.66 - 40.80 MJ/Kg (2.87 %)												
DALMARE	0-0-0-1				7	0	986.2	366.1	0.1	39.99	-0.17	0.28
Not Rated : ALPHA T,EBOMAR,ENI												
<b>LOS ANGELES 180 FUELS</b>												
Port Average Energy : 40.52 MJ/Kg												
Ranging 40.02 - 41.19 MJ/Kg (2.91 %)												
CHEM OIL	0-5-0-5				27	4	989.9	233.7	0.2	40.60	0.19	-0.25
CHEVRON	0-5-0-0				13	2	990.1	240.5	0.1	40.36	-0.40	0.35
DOLPHIN	0-0-0-0				8	0	979.0	175.2	0.1	40.72	0.49	-0.53
FAMM	0-5-0-0				35	2	989.9	219.8	0.1	40.37	-0.37	0.33
P-D	0-1-0-0				7	1	969.0	186.6	0.1	41.08	1.38	-1.45
Not Rated : CONOCOPHIL,WESTPORT												
<b>LOS ANGELES 380 FUELS</b>												
Port Average Energy : 40.53 MJ/Kg												
Ranging 40.04 - 41.08 MJ/Kg (2.59 %)												
CHEM OIL	0-0-0-5				157	27	990.3	256.4	0.1	40.57	0.09	-0.42
CHEVRON	0-0-0-0				31	8	990.3	329.9	0.1	40.44	-0.24	0.19
CONOCOPHIL	0-0-1-0				32	6	982.7	321.2	0.3	40.35	-0.45	0.43
FAMM	0-0-0-0				59	17	988.5	332.8	0.1	40.50	-0.07	-0.04
P-D	0-0-0-0				52	8	978.7	366.7	0.1	40.93	0.98	-1.06
WESTPORT	0-0-0-0				7	0	977.4	327.3	0.2	40.71	0.42	-0.53
Not Rated : GP RESOURCE												

	Rating for the last 5 samples				Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$)
	D	V	W	A	6-m	1-m	Dens	Visc	H2O	Energy		
<b>MARSEILLES 380 FUELS</b>												
Port Average Energy : 40.63 MJ/Kg												
Ranging 40.34 - 41.11 MJ/Kg (1.91 %)												
BP	0-0-0-0				67	6	989.1	354.6	0.0	40.61	-0.04	0.10
EXXONMOBIL	0-0-0-0				38	6	987.1	359.2	0.0	40.75	0.30	-0.32
SHELL	0-0-0-3				15	5	987.4	345.0	0.0	40.54	-0.20	0.26
TOTAL	0-0-0-0				27	5	989.7	353.6	0.0	40.42	-0.52	0.42
Not Rated : OCEAN ENERGY												
<b>MIAMI 380 FUELS</b>												
Port Average Energy : 40.41 MJ/Kg												
Ranging 40.02 - 40.78 MJ/Kg (1.92 %)												
COASTAL	0-0-0-0				44	7	989.0	324.5	0.3	40.40	-0.03	0.06
TRANSMONT	0-0-0-0				246	29	987.2	319.6	0.2	40.50	0.21	-0.10
Not Rated : CHEM OIL,TROPIC OIL												
<b>NAPLES 180 FUELS</b>												
Port Average Energy : 40.69 MJ/Kg												
Ranging 40.54 - 40.90 MJ/Kg (0.90 %)												
KPC	0-0-0-3				12	1	969.8	182.7	0.1	40.70	0.02	-0.14
Not Rated : PETROLMAR												
<b>NAPLES 380 FUELS</b>												
Port Average Energy : 40.62 MJ/Kg												
Ranging 38.77 - 40.94 MJ/Kg (5.60 %)												
KPC	1-0-1-2				86	16	979.7	347.3	0.2	40.62	0.02	0.21
Not Rated : SARDAS												
<b>NEW ORLEANS 180 FUELS</b>												
Port Average Energy : 40.35 MJ/Kg												
Ranging 39.89 - 41.49 MJ/Kg (4.01 %)												
BOMINFLOT	0-0-0-0				8	1	990.2	178.7	0.0	40.15	-0.49	0.47
FAMM	0-4-0-0				8	0	988.4	227.0	0.1	40.20	-0.38	0.48
STONE	0-0-0-0				30	10	976.3	175.4	0.1	40.92	1.43	-1.57
Not Rated : CHEVRON												
<b>NEW ORLEANS 380 FUELS</b>												
Port Average Energy : 40.19 MJ/Kg												
Ranging 39.65 - 40.57 MJ/Kg (2.32 %)												
BOMINFLOT	0-0-0-1				19	3	990.3	335.9	0.0	40.18	-0.04	0.01
CHEVRON	0-0-0-0				24	2	989.6	370.6	0.0	40.12	-0.19	0.19
FAMM	0-0-0-0				18	1	989.7	376.2	0.1	40.17	-0.07	0.06
SHELL	0-0-0-3				34	6	991.0	334.4	0.3	39.93	-0.65	0.51
STONE	0-0-0-0				106	17	990.6	298.5	0.2	40.11	-0.20	0.15
WESTPORT	0-0-0-0				7	1	991.0	313.4	0.0	40.36	0.43	-0.57
Not Rated : EXXONMOBIL												

	Rating for the last 5 samples				Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$) Total
	D	V	W	A	6-m	1-m	Dens	Visc	H2O	Energy		

**NEW YORK**                      **180 FUELS**  
Port Average Energy :      **40.57 MJ/Kg**  
Ranging **40.13 - 40.99 MJ/Kg (2.16 %)**

**Not Rated : BP,CHEM OIL,CHEVRON, CONOCOPHIL ,FAMM,HESS,WESTPORT**

**PANAMA CANAL**                      **180 FUELS**  
Port Average Energy :      **40.37 MJ/Kg**  
Ranging **39.72 - 41.29 MJ/Kg (3.94 %)**

CEPSA	<b>0-4-0-4</b>	19	0	987.5	211.9	0.0	40.40	0.07	-0.03
CHEM OIL	<b>1-2-0-0</b>	74	7	976.2	174.7	0.2	40.71	0.85	-0.27
CHEVRON	<b>0-1-0-0</b>	9	0	987.1	188.5	0.1	40.26	-0.27	0.26
CMF	<b>1-1-0-0</b>	34	2	977.1	175.9	0.3	40.49	0.28	-0.04
FAMM	<b>1-2-0-0</b>	25	2	975.0	181.6	0.1	40.52	0.38	-0.23
SHELL	<b>1-0-0-0</b>	16	0	987.3	158.0	0.1	40.11	-0.65	0.88

**Not Rated : EXXONMOBIL,QUINN OIL,UNIVERSALOIL**

**PANAMA CANAL**                      **380 FUELS**  
Port Average Energy :      **40.30 MJ/Kg**  
Ranging **37.89 - 40.99 MJ/Kg (8.16 %)**

CEPSA	<b>0-0-0-2</b>	14	0	989.3	286.8	0.1	40.26	-0.11	0.16
CHEM OIL	<b>0-0-0-0</b>	163	31	987.2	340.6	0.2	40.47	0.42	-0.48
CHEVRON	<b>0-0-0-0</b>	48	17	990.3	352.0	0.1	40.09	-0.54	0.53
EXXONMOBIL	<b>0-0-1-1</b>	40	2	989.0	319.3	0.3	40.33	0.06	-0.41
FAMM	<b>0-0-0-0</b>	84	17	990.5	354.0	0.1	40.04	-0.66	0.63
QUINN OIL	<b>1-0-1-1</b>	7	1	986.9	284.6	0.5	40.26	-0.12	0.04
SHELL	<b>0-0-1-1</b>	53	6	989.8	351.7	1.1	39.84	-1.15	1.02
UNIVERSALOIL	<b>0-0-1-0</b>	15	1	987.4	344.5	0.3	40.26	-0.12	0.13
CMF	<b>0-0-0-0</b>	117	31	989.9	308.9	0.3	40.15	-0.37	0.34

**Not Rated : BP,CHIMBUSCO,PENINSULA,TRITON,TRITON ENERGY**

**PHILADELPHIA**                      **380 FUELS**  
Port Average Energy :      **40.37 MJ/Kg**  
Ranging **39.41 - 40.87 MJ/Kg (3.70 %)**

BOMINFLOT	<b>1-0-1-4</b>	30	2	988.5	319.7	0.5	40.20	-0.41	0.53
BP	<b>1-0-0-0</b>	16	1	983.2	308.8	0.2	40.31	-0.14	0.42
CHEVRON	<b>0-0-0-0</b>	20	7	984.2	374.0	0.0	39.98	-0.95	0.91
FAMM	<b>0-0-0-0</b>	18	3	988.0	359.5	0.1	40.21	-0.40	0.36
HESS	<b>0-0-0-4</b>	58	14	985.3	374.1	0.0	40.59	0.54	-0.51
VANE	<b>0-0-0-1</b>	5	2	986.7	346.2	0.0	40.58	0.52	-0.48

**Not Rated : DELPHI**



	Rating for the last 5 samples D V W A	Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$) ----- Total
		6-m	1-m	Dens	Visc	H2O	Energy		
<b>ROTTERDAM</b>									
<b>180 FUELS</b>									
Port Average Energy : <b>40.64 MJ/Kg</b>									
Ranging <b>39.82 - 41.32 MJ/Kg (3.76 %)</b>									
ARGOS	<b>1-1-0-2</b>	147	28	982.9	183.5	0.1	40.85	0.51	-0.30
BP	<b>0-0-0-1</b>	8	0	966.7	172.0	0.0	41.12	1.19	-1.24
FRISOL	<b>0-0-0-0</b>	45	9	990.3	186.6	0.0	40.72	0.20	-0.24
LUKOIL	<b>2-0-0-3</b>	24	3	983.5	178.0	0.2	40.59	-0.12	0.63
Not Rated : ATLANTIC,O.W.BUNKER,WILJO									

<b>ROTTERDAM</b>									
<b>380 FUELS</b>									
Port Average Energy : <b>40.50 MJ/Kg</b>									
Ranging <b>39.27 - 41.20 MJ/Kg (4.91 %)</b>									
ABC BUNKEROI	<b>0-0-0-3</b>	34	6	989.3	360.6	0.2	40.40	-0.25	0.26
ARGOS	<b>0-0-0-2</b>	337	64	987.8	360.0	0.1	40.67	0.43	-0.29
BP	<b>0-0-0-3</b>	189	36	986.4	340.5	0.1	40.64	0.34	-0.38
CHEM OIL	<b>0-0-0-0</b>	163	35	980.1	366.6	0.1	40.85	0.87	-0.71
CHEVRON	<b>0-0-0-1</b>	15	7	989.3	367.5	0.2	40.41	-0.22	0.22
EXXONMOBIL	<b>0-0-0-0</b>	20	3	984.6	372.0	0.0	40.71	0.52	-0.56
FRISOL	<b>0-0-0-0</b>	420	95	990.0	365.4	0.1	40.56	0.14	-0.15
LUKOIL	<b>0-0-0-1</b>	181	30	988.8	368.1	0.0	40.42	-0.20	0.27
NIOCO	<b>0-0-0-2</b>	55	11	989.6	372.7	0.0	40.25	-0.61	0.66
O.W.BUNKER	<b>0-0-0-1</b>	145	34	985.9	356.9	0.2	40.54	0.09	-0.03
PETROVAL	<b>0-1-0-2</b>	8	3	990.4	377.4	0.2	40.30	-0.48	0.43
SHELL	<b>0-0-0-0</b>	62	14	985.4	373.2	0.1	40.79	0.73	-0.75
VERBEKE	<b>0-0-0-2</b>	46	15	988.8	373.1	0.2	40.46	-0.08	0.08
WILJO	<b>0-0-0-2</b>	7	0	982.6	337.1	0.1	40.62	0.30	-0.31
Not Rated : ATLAS,DE BOER,FAMM,NSP,OCEAN ENERGY,POSTOILS									

<b>SAN FRANCISCO</b>									
<b>180 FUELS</b>									
Port Average Energy : <b>40.43 MJ/Kg</b>									
Ranging <b>40.27 - 40.81 MJ/Kg (1.33 %)</b>									
CHEVRON	<b>0-5-0-0</b>	13	6	989.2	221.2	0.1	40.37	-0.14	0.20
FAMM	<b>0-5-0-0</b>	59	10	989.0	214.9	0.1	40.39	-0.10	0.21
Not Rated : CONOCOPHIL									

<b>SEATTLE</b>									
<b>380 FUELS</b>									
Port Average Energy : <b>40.62 MJ/Kg</b>									
Ranging <b>40.29 - 40.83 MJ/Kg (1.34 %)</b>									
CONOCOPHIL	<b>0-0-0-4</b>	69	13	984.8	358.3	0.0	40.67	0.11	-0.15
TESORO	<b>0-0-0-0</b>	162	29	987.8	333.1	0.1	40.66	0.09	-0.12
US OIL	<b>0-0-0-0</b>	32	5	985.0	367.8	0.0	40.54	-0.19	0.19
Not Rated : CHEM OIL									

	Rating for the last 5 samples				Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$) Total
	D	V	W	A	6-m	1-m	Dens	Visc	H2O	Energy		
<b>SINGAPORE</b>												
<b>180 FUELS</b>												
Port Average Energy : <b>40.34 MJ/Kg</b>												
Ranging <b>39.79 - 41.06 MJ/Kg (3.19 %)</b>												
ALLIANCE	<b>1-2-0-1</b>				7	2	985.2	214.3	0.2	40.25	-0.20	0.47
BARREL OIL	<b>1-0-1-0</b>				10	2	984.4	133.3	0.3	40.34	0.00	0.30
BOMIN	<b>1-0-1-2</b>				5	3	982.9	118.8	0.3	40.52	0.45	-0.27
BP	<b>0-1-0-1</b>				19	3	984.0	181.3	0.2	40.32	-0.05	0.09
EQUATORIAL	<b>0-0-0-3</b>				100	16	985.6	129.4	0.1	40.43	0.24	-0.10
FABER	<b>5-4-1-1</b>				8	1	977.4	203.9	0.4	40.40	0.16	0.97
GAS TRADE	<b>3-0-0-0</b>				5	0	977.3	143.3	0.2	40.49	0.38	0.83
GLOBAL ENER	<b>0-2-0-3</b>				14	1	979.7	182.5	0.3	40.64	0.76	-0.71
GOLDEN	<b>5-0-0-1</b>				13	3	970.3	125.0	0.1	40.46	0.30	1.56
MARUBENI	<b>1-1-0-0</b>				11	1	985.6	170.8	0.2	40.25	-0.22	0.40
NORTHWEST	<b>1-0-0-1</b>				41	4	979.2	163.3	0.2	40.43	0.23	-0.01
O.W.BUNKER	<b>2-0-0-3</b>				10	1	984.9	161.8	0.2	40.33	-0.02	0.47
OCEAN BUNK	<b>1-0-0-0</b>				9	1	979.6	168.0	0.3	40.56	0.57	-0.49
SENTEK	<b>3-2-0-0</b>				29	6	978.3	189.4	0.2	40.28	-0.14	1.09
SEVEN SEAS	<b>3-0-1-1</b>				22	4	981.0	119.5	0.3	40.41	0.18	0.45
SHELL	<b>0-4-0-0</b>				48	12	988.3	230.9	0.0	39.95	-0.97	0.98
SKES	<b>0-0-1-2</b>				21	2	985.1	134.0	0.3	40.22	-0.28	0.53
TITAN	<b>2-0-0-1</b>				10	3	981.7	133.0	0.3	40.40	0.16	0.43
UNI	<b>4-0-0-0</b>				26	4	973.2	138.1	0.2	40.53	0.48	1.05
WIRED	<b>2-1-0-2</b>				7	1	983.5	177.0	0.3	40.26	-0.19	0.76

Not Rated : AEGEAN,CATHAY,CHEM OIL,CHEVRON,CONSORT,COSTANK,COTEAM,EXXONMOBIL,FRATELLI,G-FUEL, GOLDEN STAR,HIR HUAT,IGNITION,IMPEX,PANOIL PTE,SEARIGHTS,SINANJU,SINGAMAS,SPC,TRANSOCEAN

	Rating for the last 5 samples D V W A	Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$) ----- Total
		6-m	1-m	Dens	Visc	H2O	Energy		
<b>SINGAPORE</b>									
<b>380 FUELS</b>									
Port Average Energy : <b>40.19 MJ/Kg</b>									
Ranging <b>38.47 - 41.10 MJ/Kg (6.85 %)</b>									
AEGEAN	0-0-0-2	63	18	988.7	341.1	0.2	40.25	0.15	-0.01
ALLIANCE	0-0-0-1	87	16	989.2	355.6	0.3	40.23	0.10	0.01
BARREL OIL	0-0-0-0	44	9	988.3	358.2	0.3	40.08	-0.29	0.48
BOMIN	0-0-0-0	10	1	988.5	319.1	0.2	40.22	0.06	0.15
BP	0-0-0-2	471	77	989.4	355.6	0.1	40.15	-0.10	0.16
BUNKER H	0-0-0-2	134	28	988.5	348.1	0.3	40.13	-0.14	0.34
CATHAY	0-0-0-4	15	5	988.8	360.5	0.2	40.32	0.32	-0.16
CHEVRON	0-0-0-2	63	13	987.4	301.2	0.2	40.37	0.44	-0.34
COAST-CHAN	0-0-0-0	10	7	988.1	329.1	0.3	40.64	1.13	-1.05
COSTANK	0-0-1-1	8	1	984.2	359.8	0.6	40.22	0.07	0.12
EQUATORIAL	0-0-0-1	230	32	988.6	344.7	0.3	40.23	0.08	0.03
EXXONMOBIL	0-0-0-0	215	26	979.5	342.8	0.3	40.10	-0.24	0.22
FABER	1-0-2-1	11	1	985.9	349.8	0.4	40.28	0.22	0.08
FRATELLI	0-0-1-0	38	12	987.7	298.0	0.2	40.16	-0.08	0.25
GAS TRADE	0-0-0-1	111	14	987.8	332.0	0.2	40.05	-0.35	0.58
GLOBAL ENER	0-0-0-0	258	60	988.1	358.9	0.2	39.85	-0.85	0.92
GOLDEN	0-0-0-2	106	24	988.7	350.9	0.3	40.20	0.03	0.09
GRANDEUR	0-0-0-1	8	1	988.7	343.7	0.4	40.27	0.18	-0.14
HIR HUAT	0-0-0-0	25	7	988.3	372.0	0.2	40.14	-0.12	0.34
IGNITION	0-0-0-2	14	0	990.3	347.7	0.2	40.18	-0.03	-0.10
LUKOIL	2-0-0-0	67	3	985.4	341.9	0.2	40.13	-0.15	0.63
MARUBENI	0-0-0-3	30	7	990.0	365.8	0.2	40.21	0.05	-0.05
NORTHWEST	0-0-0-2	107	24	988.6	362.4	0.3	40.31	0.29	-0.15
O.W.BUNKER	0-0-1-1	124	17	989.1	354.8	0.4	40.16	-0.09	0.22
OCEAN BUNK	0-0-0-4	71	11	988.6	357.5	0.2	40.35	0.39	-0.23
PANOIL PTE	0-0-0-2	16	2	989.4	342.0	0.2	40.25	0.13	-0.05
PRESTIGE	0-0-0-2	15	0	988.9	371.8	0.3	40.23	0.09	0.07
PROSPERBIZ	0-0-0-1	5	0	988.2	329.8	0.3	40.16	-0.07	0.18
SEARIGHTS	0-0-0-2	154	27	988.5	327.0	0.2	40.13	-0.15	0.27
SENTEK	0-0-0-0	81	17	989.2	345.3	0.3	40.19	-0.01	0.14
SEVEN SEAS	0-0-0-1	46	10	987.9	344.5	0.3	40.26	0.18	0.06
SHELL	0-0-0-0	192	27	996.3	345.1	0.0	39.76	-1.06	1.05
SINANJU	0-0-0-0	7	1	986.1	368.6	0.2	40.00	-0.47	0.58
SINGAMAS	0-0-0-3	23	5	989.7	351.8	0.2	40.27	0.20	-0.14
SKES	0-0-0-1	171	27	989.2	330.8	0.3	40.10	-0.24	0.36
SPC	0-0-0-1	112	18	989.8	347.2	0.2	40.05	-0.34	0.37
TITAN	0-0-0-1	145	30	989.6	318.7	0.1	40.15	-0.10	0.16
TRANSOCEAN	0-0-0-1	8	2	989.6	345.6	0.1	40.13	-0.16	0.23
WIRED	0-0-1-1	23	3	989.1	336.5	0.3	40.13	-0.14	0.19

Not Rated : BRAVE,CHEM OIL,COCKETT,CONSORT, EXCIM OIL,FAMM,FEOSO,GMT,HAI SOON,HIN LEONG,PALMSTONE,  
STANDARD, TOTAL,TRITON BUNKERIN

	Rating for the last 5 samples D V W A	Sampling rates in the last		Average Values of				+/- Port Average Energy	Premiums (US\$) ----- Total
		6-m	1-m	Dens	Visc	H2O	Energy		
<b>TOKYO BAY</b>									
		<b>180 FUELS</b>							
		Port Average Energy : <b>40.61 MJ/Kg</b>							
		Ranging <b>40.36 - 41.02 MJ/Kg (1.65 %)</b>							
HANWA	<b>0-1-0-0</b>	6	1	965.1	201.0	0.0	40.84	0.56	-0.56
IDEMITSU	<b>0-2-0-0</b>	5	1	978.2	200.8	0.0	40.50	-0.28	0.29
KANEMATSU	<b>0-1-0-0</b>	7	2	983.1	180.5	0.0	40.52	-0.22	0.22
MARUBENI	<b>0-1-0-0</b>	12	2	977.2	186.1	0.0	40.57	-0.11	0.13
NYK TRADING	<b>0-0-0-0</b>	5	1	973.1	159.6	0.0	40.66	0.12	-0.13
SOJITZ	<b>0-2-0-0</b>	6	2	975.5	191.5	0.0	40.60	-0.04	0.01
SUMITOMO	<b>0-3-0-0</b>	7	1	982.0	219.1	0.0	40.48	-0.32	0.33
Not Rated : ASAHI,COSMO,DAITOH,JFE,MITSUI,NIPPON OIL,NIPPON STEEL,NISSAN,PANOCO,SINANEN,TOMEN,YUASA									

<b>TOKYO BAY</b>									
		<b>380 FUELS</b>							
		Port Average Energy : <b>40.43 MJ/Kg</b>							
		Ranging <b>40.13 - 40.78 MJ/Kg (1.62 %)</b>							
HANWA	<b>0-0-0-0</b>	12	2	971.6	361.2	0.0	40.50	0.18	-0.14
KANEMATSU	<b>0-0-0-0</b>	6	0	975.6	322.0	0.0	40.50	0.19	-0.18
MARUBENI	<b>0-0-0-0</b>	13	3	983.9	307.3	0.0	40.42	-0.03	0.03
MITSUI	<b>0-0-0-0</b>	19	0	971.6	382.4	0.0	40.52	0.24	-0.19
NIPPON OIL	<b>0-0-0-0</b>	14	2	971.4	332.2	0.0	40.33	-0.24	0.28
NYK TRADING	<b>0-0-0-0</b>	7	1	980.3	352.8	0.0	40.44	0.02	0.02
SINANEN	<b>0-0-0-0</b>	9	2	979.7	332.1	0.0	40.48	0.14	-0.10
SOJITZ	<b>0-0-0-0</b>	8	0	972.1	297.8	0.1	40.56	0.32	-0.23
SUMITOMO	<b>0-0-0-0</b>	11	1	976.5	288.3	0.1	40.53	0.26	-0.27
Not Rated : COSMO,DAITOH,IDEMITSU,ITOCHEU,JFE,NIPPON STEEL,NISSAN,P-D,PANOCO,SIGMA,TOMEN,TOYOTA									

<b>VANCOUVER (CA)</b>									
		<b>180 FUELS</b>							
		Port Average Energy : <b>40.82 MJ/Kg</b>							
		Ranging <b>40.67 - 40.96 MJ/Kg (0.71 %)</b>							
ICS	<b>0-0-0-4</b>	11	2	974.3	164.1	0.0	40.90	0.20	-0.32
MARINE PET	<b>2-1-0-2</b>	7	3	973.3	183.5	0.0	40.89	0.17	0.15
Not Rated : EXXONMOBIL,IMPERIAL									

<b>VENICE</b>									
		<b>380 FUELS</b>							
		Port Average Energy : <b>40.62 MJ/Kg</b>							
		Ranging <b>39.99 - 40.98 MJ/Kg (2.47 %)</b>							
ENI	<b>0-0-0-0</b>	7	1	981.6	351.1	0.0	40.45	-0.42	0.20
MAXCOM	<b>0-0-1-0</b>	11	0	973.1	375.6	0.2	40.87	0.62	-0.63
Not Rated : EXXONMOBIL,PETROMAR,PETROVEN									

**15**

**DNV**

**PETROLEUM  
SERVICES**

## 15.1 DNV Petroleum Services Total Fuel Management

To support Shipowners, Managers, Charterers and fuel purchasers, DNVPS has developed services, which provide an essential part in the Total Fuel Management onboard. Part of the services below is available as an integrated part of the DNVPS TOTAL FUEL MANAGEMENT (TFM):

- Seminars and lectures on all aspects of fuel management.
- Fuel oil quality testing of bunkering samples.
- DNV Petroleum Services Fuel Oil Quality Testing Programme (VFQT).
- Fuel Combustion Analyser (FCA) & Fuel Ignition Analyser (FIA). Fuel ignition quality is an increasingly important parameter for the purchase and use of marine bunkers. Due to the different fuel fractions used in bunker production, marine fuels in the market can vary greatly in ignition and combustion properties. Experience shows that in order to increase safety and to reduce engine damages, controlling the ignition and combustion quality of marine fuels is becoming more important.
- FCA is a further developed method which has been based on the FIA. The FCA is using the approved IP test method. It has a better repeatability and also gives improved results regarding the combustion and afterburning period of the tested fuel sample.
- Quarterly statistics on fuel qualities worldwide.
- Bunker Supplier Comparison (BSC) - A monthly fax providing information on recent performance of fuel suppliers in each port. Specific reference to energy content and price premiums.
- Fuel treatment plant performance monitoring using "Fuel System Check" (FSC) - a special analysis and technical reporting system designed to highlight poor performance of fuel treatment system.
- Bunker Quantity Surveys in major bunkering ports. Our surveyors attend the vessel throughout the entire bunkering period to determine quantity delivered and to take samples. Key ports around the world are presently covered.
- Technical assistance with fuel quality disputes and support in arbitration.
- DNVPS produces its own manual line-sampling device to assist with the collection of representative samples.
- Training instruction videos on sampling, quantity determination and fuel specifications, fuel purchasing.
- Fuelwise is DNVPS' on-line database which will assist fuel purchasers and ship operators in their bunker management operations. Fuelwise provides real-time updates of bunker quality from virtually any supplier in the world.

For more details on any of these services please check the attachments were the different service brochures are attached, or contact your local DNVPS office, see below.

## 15.2 DNV Petroleum Services (DNVPS) Worldwide Region Offices

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