

During any oil spill incident, the properties of the spilled oil must be known immediately. Unfortunately, the properties routinely measured by oil producers and refiners are not the ones that on-scene commanders need to know most urgently. Oil producers and refiners typically do not know to what extent or at what rate their oils will evaporate; the viscosity of the oil at ambient temperatures as it evaporates; if the oil is likely to sink or submerge; if dispersion can be enhanced with chemicals; if emulsions will form; the health hazard to on-site personnel from volatile organic compounds; or the toxicity to marine or aquatic organisms.

The Emergencies Science Division (ESD), also known as the Environmental Emergencies Technology Division (EETD) prior to 1990, of Environment Canada, (the Canadian counterpart of the U.S. Environmental Protection Agency), is an organization that has been dedicated to performing oil and chemical spill research since 1973. Since 1984, Environment Canada has been analyzing crude oils and oil products to determine not only basic physical properties, but also how oil behaves when spilled in the environment. A 'catalogue' of oil properties, containing both data produced in-house and data from other sources was first prepared by Environment Canada in 1984. The oil catalogue has been so popular that interagency committees have requested that data collection and updating of the catalogue be an ongoing operation, and between 1986 and 1996, six updates were produced. This work has been continuously co-funded by the U.S. Minerals Management Service since 1989. The oil properties database now contains information on over 400 oils, and the database can also be accessed via the internet at www.etcentre.org/spills.

For each oil in the database, the properties presented are those that determine its environmental behaviour and effects. Environment Canada is the largest single source of data in the oil properties database. Whenever possible, Environment Canada has used standard test methods, such as those of the American Society for Testing and Materials (ASTM). In addition, many oil analytical methods have been developed by ESD specifically for determining environmentally significant oil properties and behaviours. These include methods for determining evaporation equations for oils, emulsion formation and characterization, measuring chemical dispersibility, measuring volatile organic compounds, and determining acute aquatic toxicity. Because evaporative loss results in significant changes in the physical properties and chemical composition of spilled oils, ESD measures most properties not only for fresh oils, but also for evaporated oils prepared in the laboratory to represent various degrees of evaporation. Most of the oil analytical methods used by ESD are described in **Appendix 1**. Some ESD methods have been described in detail previously in the literature and the reader is referred to these sources to avoid unnecessary repetition.

Data from many other sources are also included in the catalogue. The reader should be aware of the following points when searching for information on a specific oil. Crude oils from the same region are often given the same name even though oils from different wells can have markedly different properties. Oils that are transported are often blends of different crude oils, and the relative proportions of component oils frequently change. Therefore, the physical and chemical properties will vary. Similarly, the properties of oil taken from an individual well can vary with the depth of the well and the year of production. Also, different authors may refer to the same crude oil by different names, or to different crude oils by the same name. Differences in reported values may be due to the variance of samples and inherent differences in measurement techniques. The reader who wishes to make use of such data should refer directly to the original source to obtain specific details on the techniques and parameters used.

The crude oils and oil products are arranged in alphabetical order. Oil products are listed according to their most commonly used names. The names used to identify the oils in this catalogue are those used by the authors of the original data or by the suppliers of the samples. Common synonyms are included where appropriate. All names and synonyms are cross referenced in the **Index**. In addition, a list of oils by geographic origin has been included in **Appendix 2**.

Description of Tests and Methods

API Gravity (See Density).

Equations(s) for Predicting Evaporation

Evaporation is a major process that contributes to the weathering of spilled oil. While pure compounds evaporate at constant rates, oils, which are composed of thousands of compounds, do not. Rapid initial loss of the more volatile fractions is followed by progressively slower loss of less volatile components. It is not uncommon for 25% of the total volume of an oil spill to evaporate within one day of the spill (Fingas 79).

Using a simple pan evaporation technique, evaporation rate equations have been developed for many different oils (Fingas 95a). For more details, see Appendix 1.

Sulphur

The sulphur content of a crude oil is important for a number of reasons. Downstream processes such as catalytic cracking and refining will be adversely affected by high sulphur contents. During an oil spill, the sulphur content becomes a health and safety concern for cleanup personnel. In addition, if high sulphur oils are burning, they can produce dangerous levels of sulphur dioxide.

The total sulphur content of oil can be determined by a number of standard techniques. ASTM method D 129 - *Standard Test Method for Sulfur in Petroleum Products (General Bomb Method)* is applicable to petroleum products of low volatility and containing at least 0.1 mass percent sulphur (ASTM D 129). Sulphur contents from EETD and ESD were determined using a Horiba MESA 200 sulphur and chlorine analyzer, in accordance with ASTM method D 4294 - *Standard Test Method for Sulfur in Petroleum Products by Energy-Dispersive X-Ray Fluorescence Spectroscopy*. This method is applicable to both volatile and non-volatile petroleum products with sulphur concentrations ranging from 0.05 to 5 mass percent (ASTM D 4294).

Water Content

Some of the oil samples received by ESD contain substantial amounts of water. Because any process that would separate the oil and water would also change the composition of the oil, most properties were determined on the oils as received. Exceptions are noted in the individual data tables. Therefore, for those oils with significant water contents (>5%), many of the properties measured do not represent the properties of the 'dry' oil.

At ESD, water contents were determined by Karl Fischer titration using a Metrohm 701 KF Automatic Titrator. For more details, see Appendix 1.

Flash Point

The flash point of a fuel is the temperature to which the fuel must be heated to produce a vapour/air mixture above the liquid fuel that is ignitable when exposed to an open flame under specified test conditions. In North America, flash point is used as an index of fire hazard. As such, shipping regulations use flash point as a criterion to establish labelling requirements.

Flash point is an extremely important factor in relation to the safety of spill cleanup operations. Gasolines and other light fuels can be ignited under most ambient conditions and therefore pose a serious hazard when spilled. Many freshly spilled crude oils also have low flash points until the lighter components have evaporated or dispersed.

There are several ASTM methods for measuring flash points, using either closed cup or open cup testers. Open cup methods will generally produce results that are higher than those measured with closed testers, and should not be used with volatile substances. The flash points of lubricating oils can be determined by ASTM method D 92/IP 36 - *Standard Test Method for Flash and Fire Points by Cleveland Open Cup* (ASTM D 92).

For determining the flash points of other oils, methods D 93/IP 34 - *Standard Test Methods for Flash Point by Pensky-Martens Closed Tester* and D 56 - *Standard Test Method for Flash Point by Tag Closed Tester* are the most commonly used. The Pensky-Martens tester has an integral stirrer, but no cooling bath. The minimum flash

point that can be determined by method D93/IP34 is 10°C (ASTM D 93). The Tag closed tester has an integral cooling bath, but no stirring mechanism. Method D 56 is intended for liquids with a viscosity less than 9.5 cSt at 25°C (ASTM D 56).

Many fresh crude oils have flash points below 10°C and/or viscosities above 9.5 cSt at 25°C. For this reason, at ESD, a SUR BERLIN TAG 2 automatic flash point tester, which has been modified by adding a stirring mechanism, is used to determine flash points. The mechanism operates in a similar fashion to a Pensky-Martens tester, but is of a more efficient design. The stirrer aids in producing more uniform heat transfer to oils that exceed the design viscosity, and in no way interferes with the test mechanism. Flash points measured by this instrument are generally repeatable to $\pm 4^\circ\text{C}$. For more details, see Appendix 1.

In the data section, flash points taken from the literature, and determined by open cup methods are designated by a footnote. No designation is provided if the test method was closed cup or not specified.

Flammability Limits in Air

The percent concentration in air (by volume) is given for the lower and upper limit. These values give an indication of relative flammability. The limits are sometimes referred to as 'lower explosive limit' (LEL) and 'upper explosive limit' (UEL).

Ignition Temperature

Sometimes called 'autoignition temperature', this is the minimum temperature at which the material will ignite without a spark or flame being present. The method of measurement is given in ASTM method E 659 - *Standard Test Method for Autoignition Temperature of Liquid Chemicals* (ASTM E 659).

Fire Point

Fire point is the lowest temperature, corrected to one atmosphere pressure (101.3 kPa), at which the application of a test flame to the oil sample surface causes the vapour of the oil to ignite and burn for at least five seconds. For ordinary commercial lubricating oils, the fire point usually runs about 30°C above the flash point (Esso 90). The fire points of lubricating oils can be determined by ASTM method D 92/IP 36 - *Standard Test Method for Flash and Fire Points by Cleveland Open Cup* (ASTM D 92).

Reid Vapour Pressure

Vapour pressure is an important physical property of volatile liquids. It is the pressure that a vapour exerts on its surroundings. Its units are kilopascals, corrected to one atmosphere (101.3 kPa). For volatile petroleum products, vapour pressure is used as an indirect measure of evaporation rate. Vapour pressure can be measured by a variety of methods including Reid, dynamic, static, isoteniscopic, vapour pressure balance, and gas saturation. The most commonly used method for crude oils has been the Reid vapour pressure, as determined by ASTM method D 323 - *Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)* (ASTM D 323). This test method determines vapour pressure at 37.8°C (100°F) of petroleum products and crude oils with initial boiling point above 0°C (32°F). It is measured by saturating a known volume of oil in an air chamber of known volume and measuring the equilibrium pressure which is then corrected to one atmosphere (101.3 kPa).

Hydrogen Sulphide

Unlike other sulphur compounds in crude oils, which tend to accumulate in the distillation residue, hydrogen sulphide is evolved during distillation or other heating processes. During an oil spill, this makes it a safety concern, as hydrogen sulphide is a toxic gas with a time-weighted average (TWA) exposure limit of 10 ppm and a short-term exposure limit (STEL) of 15 ppm (ACGIH 99).

Description of Tests and Methods

Odour Threshold

This is the lowest concentration in air that most humans can detect by smell. The value cannot be relied on to prevent overexposure because human sensitivity to odours varies over wide limits, some chemicals cannot be smelled at toxic concentrations, odours can be masked by other odours, and some compounds rapidly deaden the sense of smell (CHRIS 91).

Density

Density is defined as the mass per unit volume of a substance. It is most often reported for oils in units of g/mL or g/cm³, and less often in units of kg/m³. Density is temperature-dependent. The table below gives the density of fresh and salt water at various temperatures. Oil will float on water if the density of the oil is less than that of the water. This will be true of all fresh crude oils, and most fuel oils, for both salt and fresh water. Bitumens and certain residual fuel oils may have densities greater than 1.0 g/mL and their buoyancy behaviour will vary depending on the salinity and temperature of the water. The density of spilled oil will also increase with time, as the more volatile (and less dense) components are lost. After considerable evaporation, the density of some crude oils may increase enough for the oils to submerge below the water surface.

Two density-related properties of oils are often used: specific gravity and American Petroleum Institute (API) gravity. Specific gravity (or relative density) is the ratio, at a specified temperature, of the oil density to the density of pure water. The API gravity scale arbitrarily assigns an API gravity of 10° to pure water. API gravity is calculated as:

$$API\ Gravity\ (^{\circ}) = \frac{141.5}{Specific\ Gravity\ (60/60\ ^{\circ}F)} - 131.5$$

Oils with low densities, and hence low specific gravities, have high API gravities. The price of a crude oil is usually based on its API gravity, with high gravity oils commanding higher prices. API gravity, density, and specific gravity at 15°C, can be interconverted using Petroleum Measurement Table 3 (API 82).

At ESD, density is measured using an Anton Parr DMA 48 digital density meter, and following ASTM method D 5002 - *Density and Relative Density of Crude Oils by Digital Density Analyzer* (ASTM D 5002). In this way, densities can be measured to 0.0001 g/mL with a repeatability of ±0.0005 g/mL. For more details, see Appendix 1.

Pour Point

The pour point of an oil is the lowest temperature at which the oil will just flow, under standard test conditions. The failure to flow at the pour point is usually attributed to the separation of waxes from the oil, but can also be due to the effect of viscosity in the case of very viscous oils. Also, particularly in the case of residual fuel oils, pour points may be influenced by the thermal history of the sample, that is, the degree and duration of heating and cooling to which the sample has been exposed.

From a spill response point of view, it must be emphasized that the tendency of the oil to flow will be influenced by the size and shape of the container, the head of the oil, and the physical structure of the solidified oil. The pour point of the oils is therefore an indication, and not an exact measure, of the temperature at which flow ceases (Dyloff 93).

ESD's pour point method is based on ASTM method D 97 - *Standard Test Method for Pour Point of Petroleum Oils* (ASTM D 97). For more details, see Appendix 1.

Viscosity

Dynamic Viscosity

Viscosity is a measure of a fluid's resistance to flow; the lower the viscosity of a fluid, the more easily it flows. Like density, viscosity is affected by temperature. As temperature decreases, viscosity increases. The SI unit of dynamic viscosity is the millipascal-second (mPa·s). This is equivalent to the former unit of centipoise (cP).

$$\text{Dynamic Viscosity} = \frac{\text{shear stress}}{\text{shear rate}}$$

Viscosity is a very important property of oils because it affects the rate at which spilled oil will spread, the degree to which it will penetrate shoreline substrates, and the selection of mechanical spill countermeasures equipment.

Viscosity measurements may be absolute or relative (sometimes called 'apparent'). Absolute viscosities are those measured by a standard method, with the results traceable to fundamental units. "Absolute viscosities are distinguished from relative measurements made with instruments that measure viscous drag in a fluid, without known and/or uniform applied shear rates." (Schramm 92). An important benefit of absolute viscometry is that the test results are independent of the particular type or make of viscometer used. Absolute viscosity data can be compared easily between laboratories worldwide.

Modern rotational viscometers are capable of making absolute viscosity measurements for both newtonian and non-newtonian fluids at a variety of well controlled, known, and/or uniform shear rates. Unfortunately, no ASTM standard method exists that makes use of these viscometers. Nonetheless, these instruments are in widespread use in many industries.

Prior to 1989, the dynamic viscosity results reported by EETD were measured using a Brookfield LVT viscometer. For non-newtonian oils, the viscosity measurements were usually performed at shear rates of 1/s and 10/s. Dynamic viscosity data produced by EETD in 1989 or by ESD, were determined using a HAAKE RV20 Rotovisco with the M5 measuring system, and HAAKE RC20 Rheocontroller. The Rheocontroller, which is connected to a personal computer, allows the shear rates to be controlled with great accuracy and precision. A dedicated software package performs automatic dynamic viscosity measurements and outputs the stored data in table and graphical formats. For non-newtonian oils, measurements are made at multiple shear rates which are also reported. In general, the viscosity values obtained using this system will be repeatable to $\pm 5\%$ of the mean. For more details, see Appendix 1.

In the dynamic viscosity data tables, NM indicates that the viscosity was 'not measurable' as it exceeded the measurement range of the instrument.

Kinematic Viscosity

There are several ASTM Standard Methods for measuring the viscosity of oils. Of these, only methods D 445 - *Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)* (ASTM D 445) and D 4486 - *Standard Test Method for Kinematic Viscosity of Volatile and Reactive Liquids*, will yield absolute viscosity measurements (ASTM D 4486). Both of these methods make use of glass capillary kinematic viscometers and will produce absolute measurements in units of centistokes (cSt) only for oils that exhibit newtonian flow behaviour (viscosity independent of the rate of shear). Kinematic viscosity can also be calculated from dynamic viscosity and density data determined at the same temperature.

$$\text{Kinematic Viscosity} = \frac{\text{dynamic viscosity}}{\text{density}}$$

Description of Tests and Methods

Saybolt Viscosity

Although now obsolete, at one time the petroleum industry relied on measuring kinematic viscosity with the Saybolt viscometer and expressing kinematic viscosity in Saybolt Universal Seconds (SUS) or Saybolt Furol Seconds (SFS). Occasionally, Saybolt viscosities are still reported in the literature. ASTM practice D 2161 - *Standard Practice for Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity* establishes the official equations relating SUS and SFS to the SI kinematic viscosity units, mm²/s (ASTM D 2161).

Emulsion Formation

A water-in-oil emulsion is a stable dispersion of small droplets of water in oil. When formed from crude oils spilled at sea, these emulsions can have very different characteristics from their parent crude oils. This has important implications for the fate and behaviour of the oil and its subsequent cleanup. It is desirable, therefore, to determine if an oil is likely to form an emulsion, and if so, whether that emulsion is stable, and what its physical characteristics are.

In 1994, a method was developed for the formation of water-in-oil emulsions using a commercially available apparatus with the same end-over-end type of rotation described by Mackay and Zagorski (Mackay 82a). Studies to optimize the parameters of the test found the water-to-oil ratio, fill volume, and orientation of the vessels to be important (Fingas 94). Analysis of the water content, viscosity, and visco-elastic properties of the emulsion were found to be useful in characterizing the emulsions produced. A stability assessment is also reported, assigning each emulsion to one of four emulsion classes: stable, meso-stable, entrained water, and unstable. A description of each class and corresponding properties is provided in the literature (Fingas 98). See Appendix 1 for more details on the emulsion formation method and the measurement of properties.

Chemical Dispersibility

In some oil spill situations and under appropriate conditions, dispersants may be an effective countermeasure for minimizing contamination of shorelines, birds, and mammals.

The swirling flask test (SFT) was first developed in the late 1980s by Environment Canada and the U.S. Minerals Management Service with the objective of generating repeatable results for evaluating the effectiveness of chemical dispersants. Dispersibility testing by the SFT method is intended to provide only relative rankings of dispersant-oil combinations under controlled laboratory conditions. It is not intended to quantify the percentage of oil that would disperse on the open water.

The factors affecting dispersion include application rate (dosage), temperature, mixing energy (wave action), chemical composition of the oil, water salinity, and weathering of the oil, including emulsification and evaporation. The test method is designed to focus on the action of the dispersant on the oil. For this reason, the test uses low energy mixing (causing only a 'swirl'), and water column samples are not taken until after a period of settling to allow larger, less stable dispersed droplets to rise to the surface. In the SFT procedure, test parameters are fixed, including pre-mixing the dispersant-oil combination at a controlled ratio to limit variation in application and allow comparison between dispersant/oil combinations. Studies to confirm the optimization of the test parameters are provided in the literature (Fingas 97).

A dynamic system, such as dispersant application to open water, would in general yield higher dispersion values than those generated by the SFT method under similar conditions, as a result of counting large volume oil droplets forced into the water column.

Quantitation of the dispersed oil has been by gas chromatograph with flame ionization detector (GC/FID) since 1995. Prior to 1995, a colourimetric method was employed, using absorbance readings at 340, 370, and 400 nm (Fingas 87). See Appendix 1 for more details on the GC/FID method.

In the chemical dispersibility data tables, a 'visual' notation indicates that a visual assessment of the SFT dispersion was made. That is, if the solvent extract of the sample was colourless, the effectiveness was assigned

a zero value, and the test ended. An 'inferred' notation indicates that the oil was not tested, but was assigned a zero effectiveness value on the basis that a less evaporated sample of the same oil was not dispersed.

Hydrocarbon Groups

The behaviour of crude oils at sea is dominated by their chemistry. The main constituents of crude oils can be grouped into several broad classes of compounds: saturates (including waxes), aromatics, resins, and asphaltenes.

Saturates are alkanes with structures of C_nH_{2n+2} (aliphatics) or C_nH_{2n} in the case of cyclic saturates (alicyclics). Small saturates ($<C_{18}$) are the most dispersible components of oils. Large saturates (waxes) can produce anomalous evaporation, dispersion, emulsification, and flow behaviours.

Aromatics are compounds that have at least one benzene ring as part of their chemical structure. The small aromatics (one and two rings) are fairly soluble in water, but also evaporate rapidly from spilled crude oil. Larger aromatics show neither of these behaviours to any extent.

Resins and asphaltenes are similar in many ways. Asphaltenes can be thought of as large resins. Both groups are thought to be composed of condensed aromatic nuclei which may carry alkyl and alicyclic systems containing heteroatoms such as nitrogen, sulphur, and oxygen. Metals such as nickel, vanadium, and iron are also associated with asphaltenes. Both groups do not appreciably evaporate, disperse, or degrade, and both groups stabilize water-in-oil emulsions when they are present in quantities greater than 3% (Fingas 94).

Waxes are predominantly straight-chain saturates with melting points above 20°C. The preceding definitions may be overly simplistic given the complex chemical composition of petroleum. A greater appreciation of oil chemistry and of how petroleum can be chemically fractionated can be obtained from more detailed texts such as the one by Speight (Speight 91).

Saturate, aromatic, and polar contents can be determined using various techniques such as open column chromatography, high pressure liquid chromatography (HPLC), or thin layer chromatography with flame ionization detection (TLC/FID; also known by the trade name latroscan). TLC/FID is usually restricted to determinations on weathered oils, as significant losses of low boiling component are likely with fresh oils. It should be noted that each technique will likely yield different results.

At ESD, hydrocarbon groups in fresh and evaporated crude oils have been determined by using a combination of old and new methods. Asphaltenes are precipitated from n-pentane. To separate saturates, aromatics, and resins, deasphalted oil (maltenes) is placed on an open silica column, and eluted sequentially with solvents of increasing polarity. Waxes can be precipitated from the maltenes with a mixture of methyl ethyl ketone and dichloromethane at -32°C. Alternatively, waxes can be determined by using gas chromatography with flame ionization detection (GC/FID) to analyze the saturate fraction. This method is especially useful with very waxy and/or viscous oils (Jokuty 97) and was used to produce most of the wax data for this catalogue. For more details of both methods, see Appendix 1.

If the oil used has an initial boiling point (IBP) above 250°C (determined by simulated distillation), a good mass balance can be obtained (>95%). However, most fresh crude oils will have an IBP well below 250°C, and the loss of light ends during solvent recovery results in a poor mass balance. Fortunately, by making the reasonable assumptions that a) resin and asphaltene contents are not affected by evaporative losses, and b) the aromatic portion of the lost light ends can be equated to the total volatile organic compounds (see **Volatile Organic Compounds**), it is possible to calculate the distribution of hydrocarbon groups.

Adhesion

It has long been recognized that different oils tend to adhere to surfaces to a greater or lesser degree. A test was developed, using a standard surface, that gives a semi-quantitative measure of this adhesive property.

Description of Tests and Methods

For the purposes of this test, oil adhesion is defined as the mass of oil per unit area that will remain on a standard test surface, after 'dipping and draining' for 30 minutes, under prescribed conditions. For more details, see Appendix 1. The standard procedure was developed using both fresh and evaporated oils with a wide range of viscosities. Test parameters that were evaluated included temperature, oil viscosity, time, and test-surface area. A recent study has also determined that the relative adhesiveness of different oils is independent of the type of surface material used (Jokuty 96).

Volatile Organic Compounds (VOCs)

Benzene, toluene, ethylbenzene, and xylenes (BTEX), and substituted benzenes are the most common aromatic compounds in petroleum, making up to a few percent of the total mass of some crude oils. They are the most soluble and mobile fraction of crude oil and many petroleum products, and as such, frequently enter soil, sediments, and ground water because of accidental spills, leakage of petroleum fuels from storage tanks and pipelines, and improper oil waste disposal practices. BTEX are hazardous carcinogenic and neurotoxic compounds and are classified as priority pollutants regulated by Environment Canada and the US Environmental Protection Agency.

A rapid, reliable, and effective method for direct determination of BTEX plus C₃-substituted benzenes has been developed using gas chromatography with mass spectrometric detection (GC/MS). Details of the method are given in a paper by Wang *et al.* (Wang 95). In the data tables, 'Total VOCs' is used instead of the more accurate but cumbersome 'Total BTEX plus C₃-substituted benzenes'.

Surface Tension and Interfacial Tension

Interfacial tension is the force of attraction between the molecules at the interface of two fluids. At the air/liquid interface, this force is often referred to as surface tension. The SI units for interfacial tension are millinewtons per metre (mN/m). These are equivalent to the former units of dynes per centimetre (dyne/cm). The surface tension of an oil, together with its viscosity, affects the rate at which an oil spill spreads. Air/oil and oil/water interfacial tensions can be used to calculate a spreading coefficient which gives an indication of the tendency for the oil to spread. It is defined as:

$$\text{Spreading Coefficient} = S_{WA} - S_{OA} - S_{WO}$$

where S_{WA} is water/air interfacial tension, S_{OA} is oil/air interfacial tension, and S_{WO} is water/oil interfacial tension. Spreading to a thin slick is likely if the spreading coefficient of an oil is greater than zero, and the higher the spreading coefficient, the faster the spreading will occur (Twardus 80).

Unlike density and viscosity, which show systematic variations with temperature and degree of evaporation, interfacial tensions of crude oils and oil products show no such correlations. Nor is there any correlation to viscosity (Jokuty 95).

A single ASTM method, D 971 - *Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method* (ASTM D 971), is applicable to the measurement of oil/water interfacial tensions. At EETD, measurements were taken using a Fisher Surface Tensiometer Model 21. Prior to 1993, ESD made interfacial and surface tension measurements with a CSC Du Nouy Tensiometer #70545. Since 1993, these measurements have been made using a Kruss Digital Tensiometer K10ST. This instrument uses the Du Nouy principle for measuring interfacial tension, as recommended in the ASTM method. Unlike manually operated ring tensiometers, the maximum deformation of the lamella is detected electronically, and occurs before the ring pulls completely through the interface. This results in interfacial tensions that are slightly lower than those measured manually. Repeatability is $\pm 2\%$ of the mean. For more details, see Appendix 1.

The following abbreviations are used in the surface and interfacial tension tables: NM (not measurable), and DNF (did not flow).

Boiling Point Distribution

In the oil refining industry, boiling range distribution data are used to evaluate new crude oils, to confirm crude quality before purchase, to monitor crude quality during transportation, and to provide information for the optimization of refinery processes. From the point of view of oil analysis for environmental purposes, boiling range distributions provide an indication of volatility and component distribution. In addition, this data can be used as input to some oil spill modelling programs. Boiling range distribution data may also prove to be useful in the development of equations for predicting evaporative loss.

Traditionally, boiling range distributions have been determined by distillation. However, atmospheric and vacuum distillation techniques have largely been replaced by 'simulated' distillation methods. These methods use low resolution gas chromatography and correlate retention times to hydrocarbon boiling points. ASTM methods D 2887 - *Standard Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography* (ASTM D 2887) and D 3710 - *Standard Test Method for Boiling Range Distribution of Gasoline and Gasoline Fractions by Gas Chromatography* (ASTM D 3710) use external standards composed of n-alkanes. ASTM method D 5307 - *Standard Test Method for Determination of Boiling Range Distribution of Crude Petroleum by Gas Chromatography* is very similar to D 2887, but requires two runs to be made with each sample, one of which uses an internal standard. The amount of material boiling above 538°C (reported as residue) is calculated from the differences between the two runs (ASTM D 5307).

At ESD, boiling point distributions are determined by simulated distillation with an AC Analytical Controls SIMDIS analyzer, comprised of a Hewlett Packard 5290 Series II gas chromatograph with an Analytical Controls Programmable Temperature Vaporizer (PTV) injector. The system uses a special high-temperature column and is capable of determining boiling point distributions between 35°C and 750°C. For more details, see Appendix 1.

Yield on Crude

Yield on crude data are still widely reported in the oil assay literature, providing information on the yield of specific fractions obtained from a crude oil. Although by no means universal, the following is a commonly used set of petroleum fractions and their corresponding true boiling point (TBP) cut points:

Product	TBP Cut Points, °C	TBP Cut Points, °F
Light straight-run gasoline	C5-70	C5-158
Light naphtha	70-100	158-212
Medium naphtha	100-150	212-302
Heavy naphtha	150-190	302-374
Light kerosene	190-235	374-455
Heavy kerosene	235-265	455-536
Atmospheric gas oil	265-343	536-650
Vacuum gas oil	343-565	650-1049
Atmospheric residue	>343	>650
Vacuum residue	>565	>1049

Metals

Metal content in crude oils can provide valuable information about the origin of those oils, potentially aiding in identifying the source of oil spills. Crude oil assays often include nickel and vanadium contents due to the detrimental effects of these metals on catalysts used in cracking and desulphurization processes. In lubricating oils, metal contents can provide information on both the types of additives used in the oil and on the wear history of the equipment being lubricated. ASTM method D 5185 - *Standard Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)*, (ASTM D 5185) can be used to determine over 20 different metals in a variety of petroleum products.

Description of Tests and Methods

To overcome problems inherent in the direct analysis of xylene solutions by ICP/AES, a method was developed at ESD using microwave digestion of oils with nitric acid (Cao 92; Fingas 95b).

Aqueous Solubility

The solubility of oil in water can be determined by bringing to equilibrium a volume of oil and water, and then analyzing the water phase. This analysis can be done by purging and trapping the dissolved hydrocarbons or, alternatively, directly analyzing the headspace above the water. Since oil is a complex mixture of components and each component has a different solubility in water, an oil's aqueous solubility is expressed as the cumulative concentration of the individually dissolved components. The composition and concentration of the solubilized mixture will depend upon conditions used during equilibration. The term 'solubility' as applied to oils is being replaced by the technically more precise term 'water-soluble fraction'. The values reported in this catalogue were taken from those studies where an excess of oil was used (oil-to-water volume ratios of at least 1:20) and where the processes of evaporation and oil-in-water emulsification were prevented. Results reported by ESD were obtained as described in Appendix 1.

Toxicity

Toxicity values in this catalogue may be reported as:

LC₅₀: *Median lethal concentration* is the estimated concentration of a compound that will cause death to 50 percent of the test population in a specified time after exposure. In most instances, LC₅₀ is statistically derived by analysis of mortalities in various test concentrations after a fixed period of exposure.

EC₅₀: *Median effective concentration* is used when an effect other than death is the observed endpoint. EC₅₀ is the estimated concentration of the compound in water that will have a specific effect on 50 percent of the test population in a specified time after exposure. As with LC₅₀, the EC₅₀ is generally derived statistically.

TLm: *Median tolerance limit*; a term sometimes used instead of EC₅₀.

Biological Oxygen Demand (BOD)

Also called 'biochemical oxygen demand', this is the standard way of describing how much oxygen, dissolved in water, is consumed by biological oxidation of the chemical during the stated period of time. The unit lb/lb indicates the pounds of oxygen consumed by each pound of chemical during the time stated. When given in percent, the values indicate the pounds of oxygen consumed by each 100 pounds of chemical during the time stated (CHRIS 91).

Threshold Limit Values (TLV)

The following excerpts are taken from ACGIH 99:

Threshold Limit Values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects.

Threshold Limit Value – Time-Weighted Average (TLV-TWA)

the time-weighted average concentration for a conventional 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect

Threshold Limit Value – Short-Term Exposure Limit (TLV-STEL)

a 15-minute TWA exposure which should not be exceeded at any time during a workday even if the 8-hour TWA is within the TLV-TWA