Hydrocarbon management

HM 40

Guidelines for the crude oil washing of ships' tanks and the heating of crude oil being transported by sea

4th edition

energy institute

HM 40 GUIDELINES FOR THE CRUDE OIL WASHING OF SHIPS' TANKS AND THE HEATING OF CRUDE OIL BEING TRANSPORTED BY SEA

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FOREWORD

The Energy Institute (EI) Hydrocarbon Management Committee is responsible for the production and maintenance of standards and guidelines covering various aspects of static and dynamic measurement of petroleum. The Hydrocarbon Management subcommittee 4 (HMC-4 Oil Transportation Measurement Committee) deals primarily with the measurement of crude oil and hydrocarbon products, focusing in particular on transport in the marine environment.

HMC-4 is made up of experts from the oil industry, cargo inspectors, ship owners and representatives from marine terminals. It is an international panel with representatives from most Western European countries, the Middle East, Far East and North and South America. Equipment manufacturers and experts with specific knowledge of measurement techniques are regularly invited to present papers to the committee.

The EI liaises with parallel working groups of the American Petroleum Institute (API)'s Committee on Petroleum Measurement, and with organisations concerned with quantitative measurement in other countries and in other industries.

The EI Hydrocarbon Management guidelines (formerly Petroleum Measurement Manual and Petroleum Measurement Papers) are widely used by the petroleum industry and have received recognition in many countries by consumers and the authorities. In order to promote international good practice the EI works via the British Standards Institute to develop standards through the International Standards Organization (ISO)'s Technical Committee TC-28 *Petroleum Products and related products of synthetic or biological origin* and its subcommittee TC-28/SC2 *Measurement of petroleum and related products*.

A full list of Hydrocarbon Management guidelines is available from the EI.

The EI Hydrocarbon Management guidelines are recommended for general adoption, but should be read and interpreted in conjunction with safety, environmental, weights and measures, customs and excise and other regulations in force in each country in which they are to be applied. National regulatory requirements have precedence over corresponding clauses in the EI document except where the requirements of the latter are more rigorous, when its use is recommended. Users should also consider contractual constraints imposed by charterers, cargo owners, ship owners and other interested parties.

Although it is believed that adoption of the recommendations of this guideline will assist the user, the EI cannot accept any responsibility, of whatsoever kind, for damage or alleged damage arising or otherwise occurring on vessels or in or about premises where this document has been applied, as final responsibility for adequate preparation of the vessel to receive a cargo lies with the parties controlling this task.

Users of these guidelines are invited to send comments, suggestions, or details of relevant experience to:

Technical Department
Hydrocarbon Management
Energy Institute
61 New Cavendish Street
London
W1G 7AR

United Kingdom
http://www.energyinst.org

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1 SCOPE

This document provides guidelines for the carriage, heating and crude oil washing (COW) of many crude oils transported by sea.

As well as enhancing the current regulations regarding reducing marine pollution, the document provides guidance on the grades of crude oil that may give rise to an increase in volatile organic compounds (VOC) emissions (especially methane) if used excessively for COW. Also, in lieu of regulations on measures to reduce CO_2 emissions from Shipping, it provides guidance on optimising heating of cargoes.

The document also highlights a number of crude oils that are known to be potentially harmful due to concentration of hydrogen sulfide (H_2S).

2 INTRODUCTION

MARPOL regulations regarding COW were introduced into the shipping industry in the late 1970s. The purpose of these regulations was to reduce the chances of marine pollution by reducing the need for water washing ships' tanks after discharge of cargo. Notwithstanding anything written hereunder, the current MARPOL regulations should be adhered to.

IMO resolutions regarding the specifications for design, operation and control of crude oil washing systems '...*recognize that further improvement may be required in the specifications, taking into account the development of technology in this field and in the light of experience gained*'.

This publication has been compiled with the aim of sharing the experiences of the oil companies represented on committee HMC-4 with other branches of the oil industry, and to provide guidance in relation to the carriage, heating and COW of different crude oils. Some of the companies on the committee also operate tanker fleets, thus enabling the data to be reviewed by the marine industry at large.

A table of crude oil properties can be found in Annex B. In previous editions the table was included within this standard. For this edition the table is available as a separate document which can be downloaded *here*. Having the table as a separate document will allow regular updates to the table. **The data should not be used without referencing all other sections of this publication.**

The crude oils have been listed in alphabetical order. Against each crude is a set of characteristics obtained from a number of differewnt assays. Many of the characteristics are given as a range, which reflects the differences found in the base data. No single value in this guide should be considered as absolute. The carriage and discharge temperatures were generally obtained from current oil company guidelines or from voyage data reported to the HMC-4A database committee.

Safe handling of crude oil is paramount in the industry. The committee has obtained some information on liquid concentration of H_2S content of some crude grades and this is reproduced in Annex B. Further explanation can be found in section 9, with toxicity issues discussed in section 8.

Performing a full COW on all occasions is not necessarily environmentally sound and can increase rather than reduce cargo losses. However, COW methodology should be dependent on the crude oil characteristics, type of vessel, available equipment, length of voyage and previous experience. This guideline collates information and experience from a large number of users and should enable selection of a COW regime which is appropriate to the cargo being carried and which will assist in reducing losses and emissions.

This 4th edition replaces the 3rd edition published in 2016, including updated crude oil data and guidance in Annex B recognising that most non-segregated ballast tankers have been replaced by segregated ballast tankers (SBTs).

3 SHIP TYPE

3.1 GENERAL

A few crude oil carriers still in operation either do not have segregated ballast tanks, or they do not have sufficient segregated ballast capacity. Therefore ballast water must be loaded into cargo tanks to meet trim and stress requirements for departure from the discharge port. MARPOL 73/78, Annex 1, requires that ballast water is only put into cargo tanks which have been crude oil washed. For this type of tanker, the extent to which COW can be reduced is limited and these few remaining vessels without segregated ballast are not considered in the washing recommendations given in Annex B.

MARPOL Annex 1 Regulation 33 requires that all crude oil tankers over 20 000 mt deadweight (DWT) (this includes product/crude carriers) are fitted with a cargo tank cleaning system using COW. It is also a requirement that every tanker operating with COW systems shall be provided with a COW Operations and Equipment Manual describing the system, the equipment and specifying operational procedures. Regulation 35 discusses COW operations, including the requirement for a COW manual and the requirement to COW any cargo tank that will be loaded with ballast.

3.2 SEGREGATED BALLAST TANKERS (SBTS)

The large majority of crude oil tankers and crude/product tankers trading at the present time have segregated ballast. Any crude oil carrier over 20 000 mt DWT (this includes crude/ product carriers) delivered after 1 June 1982 has to have segregated ballast tanks, with enough capacity to operate safely on ballast voyages without having to use cargo tanks for ballast water, except for some circumstances described in paragraph 3 or 4 of MARPOL Annex 1 Regulation 18.

Most vessels are double hull vessels. All vessels delivered after 6 July 1996 are required to be double hull. COW washing on these vessels is done mainly to control sludge accumulation (except for the occasion when it may be necessary to put ballast water into a cargo tank as described in 3.1). The degree of control that can be exercised over COW on these vessels is much greater, but is still dependent upon whether the vessel is fitted with programmable COW machines.

On double hull vessels, it is important to assess the effect that ballast water temperatures may have on the cargo when planning the ballasting and COW of the vessel during discharge. Should the ballast water temperature be close to, or lower than, the wax point of the crude oil cargo, then a delayed ballasting may be adopted so as to minimise the cooling effect upon the crude in the tanks adjacent to the ballast tanks, being discharged and crude oil washed. Vessel stress and DWT requirements must continue to be met at all times.

4 CRITICAL CRUDE OIL PROPERTIES

There are two situations where a full COW may be counter-productive: when handling crude oils unsuitable for COW due to their viscous or waxy nature leading to high remaining on board (ROB); and with crude oils which are particularly volatile, where COW could result in excessive gas evolution.

4.1 HIGH VISCOSITY CRUDE OILS

For these crude oils, the problem is high viscosity and not necessarily sludge deposition, therefore these crudes may have a lower carriage temperature than discharge temperature.

The discharge temperature should be such that the viscosity of the crude is less than 250 mm^2/s for the bulk discharge.

They usually have a high aromatic content and may be known as 'aromatic crude oils'. A further complication arises with aromatic crude oils in that, if they are used to wash paraffinic crude oil or vice versa, chemical incompatibility can cause the precipitation of asphaltenes which increases sludge deposition. Further guidance on viscosity is given in 9.9.

4.2 WAXY PARAFFINIC CRUDE OILS

It is important for these crude oils to maintain, or increase, the load temperature to the recommended level from the commencement of loading, i.e. always above cloud point temperature, to prevent sludge deposition. Generally, there will be no difference between carriage and discharge temperature. Further guidance on wax content is given in 9.6.

4.3 VOLATILE CRUDE OILS

These crude oils are not officially classed or listed in the MARPOL regulations, but have a potentially serious impact on vessel safety and the environment if used as a COW medium. Guidance on volatility is given in 9.5.

5 CARGO HEATING

5.1 GENERAL

The optimum temperature to which the cargo should be heated is largely dependent upon the pour point, cloud point, total wax content and the viscosity of the cargo. The ambient weather and sea conditions also influence the heating requirements. Furthermore, it may be necessary to heat the cargo required for COW to a higher temperature than the bulk cargo.

Optimal heating can result in reduced fuel costs and CO_2 emissions during the voyage and potential reductions in vapour emissions during discharge without increasing ROB or the risk of wax deposition.

The data supplied in Annex B give guidelines on the minimum carriage and transfer temperatures. It is emphasised that the temperatures (and procedures) recommended in Annex B are guidelines and that actual conditions experienced either during the voyage or during discharge may call for different temperatures or procedures.

Ambient sea temperature has less effect on cargo temperature with double hull tankers, but can be an issue when introducing new ballast.

Information on global sea temperatures can be found via various websites including:

http://www.ospo.noaa.gov/Products/ocean/sst/contour/

5.2 HEATING EQUIPMENT

Where cargo temperature is maintained using heating coils, the heat energy is imparted on a continuous basis for the majority of the discharge.

Where deep-well pumps are used to circulate cargo via 'on-deck' heat exchangers, it is probable that heating cannot be continued during discharge. Vessels with this type of system may be unsuitable for carrying some heated crude oils.

6 CRUDE OIL WASHING

6.1 PRE-CHARTERING STAGE

Before a ship is chartered, the following issues should be considered in relation to the cargo to be carried:

- COW and inert gas (IG) systems should be fully operational according to the international/national regulations. These regulations also apply to the continuous monitoring and recording of IG pressure and oxygen content for the duration of the transfer operation. Failure of the monitors and recording instrumentation will preclude the carrying out of COW operations.
- Ship type, which will dictate the level of COW required.
- COW machines, whether programmable or non-programmable.
- Number of COW machines per tank.
- Type of heating system, either continuous (heating coils), or not (heat exchangers with deep-well pumps).
- Voyage heating plan for the voyage, upon arrival at the discharge port and during discharge

Note: With respect to volatile cargoes, i.e. those with high gas to C4 content, refer to 9.5. Performing a full COW with non-programmable machines may generate unacceptable levels of hydrocarbon gas evolution which may cause a higher than normal loss on outturn and may give rise to increased VOC emissions.

These guidelines do not preclude charterers from specifying their own COW and heating requirements in a charter party.

6.2 CHARTERER'S REPRESENTATIVE

A charterer's or cargo receiver's representative may be appointed to monitor the cargo discharge. If appointed, their duties are to liaise with both the ship and shore personnel with regard to the general discharge operation and COW. Charterers' representatives are fully conversant with the crude oil properties and will be able to advise the ship's staff on the effectiveness of their discharge and COW plan. They should be sufficiently knowledgeable about discharging operations to be able to suggest changes to the plan that may be required during discharge, to maximise the outturn whilst minimising environmental pollution.

6.3 PRE-DISCHARGE PLANNING

To help maximise outturns, it is recommended that the charterer or cargo owner's representative should liaise with the ship's Master/chief officer to determine, discuss and agree if COW needs to be performed and, if so, assess its effectiveness, even if the data suggest that COW is not required.

For example, North Sea crude oils (e.g. Brent) generally have a moderate wax content and on short voyages in summer, where the cargo retains its loaded temperature, COW need not be performed. However, if the voyage is long, wax may settle out of the cargo and a bottom wash will be required.

In most cases, tank dips will need to be obtained at a number of points in each cargo tank to assess the amount and location of wax/sediments remaining after initial draining and to determine if COW is necessary. Tank dips should be carried out through gauging positions with vapour control valve only.

The IMO publication, *Crude Oil Washing Systems* (edition 2000) advises in 4.4.4 that '*suitable arrangements for hand dipping must be provided at the aftermost portion of a cargo tank and in three other suitable locations unless other approved means are fitted for efficiently ascertaining that the bottom of every cargo tank is dry*'. The main disadvantage of COW is the generation of hydrocarbon gas. This gas constitutes a loss, and should be considered in the formulation of any COW policy.

Note: – IMO publication, *Crude Oil Washing Systems* (edition 2000) resulted from the IMO resolution 446(XI) Revised specifications for the design, operation and control of crude oil washing systems (A.897(21)

Other issues to be considered are as follows:

6.3.1 Previous cargo

The cargo representative must ascertain the type of cargo carried and the washing performed for the previous voyage. This information will help determine the COW to be carried out on the present voyage. If the previous cargo gave rise to substantial quantities of ROB/on board quantity (OBQ) then, even for a current cargo of a quality noted in Annex A as requiring no COW, a bottom, or possibly a full COW, may be required to clean the ship to an acceptable standard. However, closed conditions should be maintained.

6.3.2 Trim

'To optimise stripping of the cargo tanks it is recommended that the ship maintains a maximum safe stern trim as possible during COW and the stripping of cargo tanks and lines'

Current COW operation manual requirements advise that '*…the trim conditions for crude oil washing given in the* Operations and equipment manual *shall be adhered to. In general, trim by the stern is only important during the final stages of tank discharge and shall be the maximum possible compatible with operational constraints…*' If the tank suctions are offset from the centre line of the tank, then the ship may also be listed so that the oil flows towards the tank suctions. Reference should be made to the vessel's COW operations manual and/or the vessel's stability guidelines.

Note: The requirement for trim during COW should not be mistaken for the MARPOL requirement of a vessel in ballast condition which limit the vessel's trim to 0,015 of the vessel's length. However, certain ports require this as the maximum trim to be attained to enable the vessel to be safely manoeuvred in an emergency.

6.3.3 Draining

During COW, a slight build-up of washing oil on the tank bottom is normal. To some extent this is desirable, since it carries the wax and sediments to the tank suctions. However, the degree of build-up should be controlled. If the depth of oil at the aft end of the tank exceeds 0,30 metres, then COW should be suspended and the tank drained.

6.3.4 Stripping

– Low viscosity crude oils:

Tanks should be left for as long as possible for 'run-down' to occur after COW and/ or stripping for the first time. On completion of run-down the tanks should be restripped. Even if time is short, it is suggested that the tanks should be stripped at least twice.

– High viscosity/high wax crude oils:

Tanks should be stripped immediately after COW and/or when first emptied. Restripping should take place shortly afterwards, whilst the tank is still warm. High viscosity low pour point oils flow slowly and take time to reach the tank suction. In these cases, it is better to wait for as long as possible before stripping the tanks for the final time. Attention should be paid to the ambient conditions, including sea and ballast temperatures which, if cool, may increase clingage during COW. To limit this effect it may be necessary to reduce the planned COW programme.

In order to monitor the stripping process the vessel should record interim dips during stripping, and, where possible, from multiple gauging points.

6.3.5 Slop tanks/COW feed tanks

Because of electrostatic hazards, COW must not be performed with oil, wet crude oil or with measurable free water present. Ship's officers should be instructed to discharge the slop tanks first and refill with dry oil from other cargo tanks.

Experience has shown that for the COW of high pour/waxy cargoes the slop tank/COW feed tank should be heated to at least 10 °C above the average cargo temperature. Crude oils requiring this extra heating are noted in Annex B.

6.4 PERMISSIONS

Prior to COW operations, three levels of agreement must be satisfied:

– receiver's permissions to permit COW;
– terminal's permissions to permit COW, and
– vessel meets pre-COW conditions.

6.4.1 Receiver's permissions to permit COW

Time for COW is normally allocated in the vessel's charter party. The time allocation is dependent on vessel type and the charter party.

The COW time is normally pro-rated against demurrage, dependent on the number of tanks to be cleaned against a full COW (100 %). It is then for the receiver to decide whether they accept the vessel's proposals for COW considering, amongst other things, the potential increase or decrease of outturn for the specific crude concerned.

6.4.2 Terminal's permissions to permit COW

As outlined in the IMO pre-arrival checks at discharge port, the terminal will be asked (either as part of the receiver's communications or directly) whether the vessel will be permitted to conduct COW at the terminal. Various considerations will be made by the terminal as to whether COW will be conducted, with the receiver being advised as to their decision.

6.4.3 Vessel meets pre-COW conditions

Permission to COW could be rescinded if a vessel:

– fails to satisfy the pre-discharge meeting agreed preconditions for COW;
– fails to meet pre-COW checklist conditions, and/or
– fails to comply with industry accepted COW good practice to the satisfaction of the terminal or their representative

6.5 NON-HYDROCARBON COMPONENTS OF CRUDE OIL

COW is a vigorous washing method which ensures that the ship will discharge more of the non-hydrocarbon components such as sand and shale etc. than would be the case **if** COW were not carried out. These contaminants form part of the cargo and it is the responsibility of the terminal to receive these and treat/dispose accordingly. However, they are abrasive and may have a detrimental effect on the internals of pipes, valves and fittings, accelerating wear and leading to increased maintenance costs around refineries and terminals. The performance of in-line samplers may also be affected. Sludge build-up in shore tanks is increased, which in turn increases cleaning and disposal costs. The accumulation of sludge affects shore tank measurement and water draining. Inadequate water draining of crude feed tanks can adversely affect refinery operations.

6.6 COW MEDIUM

6.6.1 Crude oil

Many COW operations manuals suggest that when performing COW, cargo tanks should be washed with 'fresh' crude oil and not with 'recycled' crude oil from the slop tanks. The term 'fresh' means crude oil that is essentially dry and has not previously been used for COW, 'recycled' being crude oil that has been previously used to wash the ship's tanks. This is particularly important when performing COW with waxy crude oils, as continued washing with the same crude oil can lead to wax saturation and complete loss of solvency. COW using the 'closed-cycle' recirculation method is not suited to routine COW as it causes delay, and increases the risk of passing sediment through the machines and of using oil which has lost much of its solvency. In order to maintain a consistent quality of oil discharged, tank washings should be commingled and discharged with the main cargo. The exceptions are waxy paraffinic cargoes where the slop tank contents are heated to a higher temperature than the rest of the cargo to assist in the removal of waxes. The crude oils that require this special treatment are noted in the 'Remarks' column of Annex B.

For high wax crudes, it is found that greater control of the washing programme can make a significant difference. The class approved COW manual should be followed but, typically, instead of a full cycle, and to ensure increased coverage in the tank in order to remove potential 'clingage' without once more painting the tank sides with crude once the downward arc has been performed, a COW programme of 40 degrees to zero followed by the machines being reprogrammed manually for COW from 40 degrees to zero once more, may improve the outturn and prevent further build-up on tank sides. This allows for COW in a downwards movement only and prevents reapplication of 'clingage'.

6.6.2 Cutter stock

On occasions where large amounts of ROB are detected, it may be financially advantageous to backload a suitable cutter stock, if available, to be used for COW. If the cutter stock, which is usually a middle distillate oil, is heated, further improvements in the reduction of ROB may be obtained. Alternatively, a suitable crude oil having similar properties to cutter stock could be used. Only a few crude oils, as noted in Annex B, require washing with cutter stock.

The residues from a high pour point crude oil with a high wax content can be successfully removed with heated cutter stock.

A typical procedure is to discharge all cargo tanks to a depth of one metre and leave with the heating on. Each tank is then successively stripped, washed with cutter stock, and finally stripped again. To clear the draining holes of wax the COW machines may be programmed to bottom wash first and then follow with a full-cycle wash.

Before backloading cutter stock, careful consideration must be given to the following points:

- If the cutter stock is an on-specification product, the cost of reprocessing may be high in relation to the quantity and quality of the cargo residues recovered from the ship's tanks.
- The quality of ROB. There would be no point in performing this operation just to clean the cargo tanks of non-hydrocarbons.
- Discharge time available. This may be considerably increased if backloading of the cutter stock cannot take place until the majority of the cargo has been discharged.
- The availability of suitable cutter stock.

It is recommended that this operation is not performed unless the economics of the situation have been carefully assessed.

Cargoes of waxy paraffinic or high viscosity crude oil which cannot be suitably conditioned to enable COW, or where cutter stock or a suitable crude oil is not available for washing, should be treated in the same way as fuel oil.

6.7 LONG TERM FLOATING STORAGE

This section discusses the long-term storage of crude oil on crude oil tankers. It does not include storage of crude oil on floating production storage offloading (FPSO) vessels.

With time, crude oil will settle and lighter ends may evaporate as the vapour space 'breathes'.

This may result in the crude losing some of its effectiveness when used for COW.

The crude oil will also become non-homogeneous as the crude settles, with water dropping out and the beginning of a density gradient forming, the density towards the bottom of the crude being higher than the crude layers above it. If the temperature falls, waxes may start to form; again, these will settle towards the bottom of the tank along with any sediments.

The ship's staff and the cargo owner will need to develop a strategy for maintaining the crude oil quality as best as possible.

By daily dipping of the cargo tanks, the formation of wax may be detected by feeling the 'sponginess' of the crude immediately above the tank bottom. The data in Annex B may determine the ease with which wax will precipitate from solution. Also see 9.6.

The crude may require circulation to prevent stratification. Depending on the storage time, the crude may require heating to reduce or prevent wax build-up.

Circulation may need an empty or slack cargo tank such that the crude can be pumped from one tank to another. This activity should not be carried out with the ship sailing but could be monitored safely with the vessel at anchor or drifting. If the vessel is equipped with deepwell pumps, each tank can be circulated within itself.

Circulation may slow wax build-up but heating is what is really required. If long-term storage is many days or weeks, heating will be uneconomical to do for the full storage period. However, heat must be applied along with circulation to remove the wax prior to arriving at discharge port. It takes more energy to melt the wax back into solution than it takes to maintain wax in solution. The cargo may have to be heated to between 5 °C and 10 °C above the wax appearance temperature.

Some vessels, particularly very large crude carriers (VLCCs), will not have heating equipment so it is unlikely that wax formation can be stopped or reversed. Other means will be required to reduce ROB after discharge which may include the use of a cutter stock either backloaded or supplied by barge.

If the storage vessel is classified for ice areas, it may be possible to heat double bottom ballast tanks. This may be a method of reducing wax build-up should the cargo spaces have no heating capability.

7 VENTING OF VAPOURS

7.1 IN TRANSIT

During the voyage, the vapour/IG pressure above the cargo may rise to a level considered as unsafe by ship's staff. Normal operations would involve releasing this pressure to the atmosphere by manual opening of the mast riser valves. The vapour/IG is released until the pressure falls to some arbitrary low level. However, if this low pressure is below the total vapour pressure (TVP) of the cargo at the observed temperature, the vapour/liquid equilibrium will be upset and more vapour will be evolved from the cargo. The eventual release of this vapour will increase environmental pollution and cargo loss.

Controlled venting at sea can reduce overall emissions and potential cargo loss. Traditionally, regular venting to a low pressure (200–300 mm water gauge) was thought to be the most effective method of tank pressure control. Studies have indicated that reducing to such low pressures can simply result in rapid evolution of more vapour and an accelerated pressure increase. Controlled venting to a higher pressure in the region of 800 to 1 000 mm water gauge could significantly reduce total emissions.

7.2 DURING CRUDE OIL WASHING

Any gas generated by COW should remain within the ullage spaces and will be mixed with the IG. Gas which is vented, especially during COW, results in loss of light ends to the atmosphere, increasing environmental pollution. It is recommended that charterers instruct, and Masters of ships ensure, that the IG system is operated such that excessive pressures are not generated and no vapour is vented to atmosphere during discharge. Except in an emergency, the mast riser and/or other vents should be kept closed. For dipping of tanks during COW operations, only gauging positions fitted with vapour control valves should be used.

8 TOXICITY HAZARDS

8.1 GENERAL

In addition to risks associated with flammability, all persons involved in the handling of petroleum cargoes should be aware of the information on toxicity hazards contained in the International Safety Guide for Tankers and Terminals (ISGOTT).

The risk of exposure to toxic vapours on deck is not to be disregarded. Reliable testing of gas concentrations on deck is difficult and the dilution of high concentrations of cargo vapour into the atmosphere depends on turbulence and diffusion. For this reason, care is needed during loading, ballasting and gas freeing tanks, and when measuring or sampling the cargo. Precautions on measuring and sampling are given in ISGOTT and should be complied with.

In addition, any person involved in the measurement and sampling of petroleum cargoes should always ask the terminals and Masters if cargoes have any abnormal concentrations of toxic components and/or whether special precautions should be applied.

8.2 HYDROGEN SULFIDE (H_2S)

All personnel handling hydrocarbon cargoes should be fully aware of potential H_2S hazards as outlined in HM 69 *Procedures for determining H_2S concentrations in cargo head spaces* and of the precautions detailed in ISGOTT. It is strongly recommended that ships' staff (deck), cargo inspectors and jetty/offsite operators should wear H_2S monitors during all crude oil gauging and sampling operations.

8.3 MERCAPTANS

Mercaptans are organic sulfur compounds present in some crude oils, natural gasolines and feedstocks. Concentrations of over 500 ppm mass can occur in pentanes and up to 150 ppm in naphthas.

It should be noted that the threshold limit value (TLV) for mercaptan is 0,5 ppm so the toxicity hazards, and the precautions necessary, are very similar to those which apply to H_2S.

9 KEY TO CRUDE OIL DATA SHEETS (ANNEX B)

9.1 CRUDE OIL TYPE

The crude oils have been arranged in alphabetical order.

Note: The absence of a value for a particular parameter indicates that there are currently no data available; it does not indicate a nil result

9.2 ASSAY DATE

The assay date is the date of the most recent assay which has been consulted. However, an assay may not contain all of the data for the crude oil under consideration presented in Annex B. Therefore, some data may not be as recent as the assay date implies.

The data are generally displayed as a range except in the case of viscosity. One of the shortcomings of this collection method is that possible trends in crude quality cannot be tracked.

Crude oil characteristics of an oil field change over time; thus, additional caution is required for older assay data.

9.3 API GRAVITY

Crude oils are traded mainly in barrels and API gravities and the data in Annex B follow this system.

9.4 REID VAPOUR PRESSURE (RVP)

RVP is the most common vapour pressure data available. However, the sampling conditions are generally not known and as a result the values have a large uncertainty. Also, it is likely that RVP is not directly related to vapour release from crude oil being carried in a ship's tank. However a high RVP value does indicate a potential for vapour loss during COW.

9.5 GAS TO C_4

As for RVP, the results given in this column are highly dependent upon the conditions under which the samples were drawn. Figures are taken from the assay of each crude oil, considering the boiling fractions from methane to butane.

If the gas to C_4 is a high value, generally in excess of about 2,5 % m/m, high gas losses may be experienced during transportation and particularly during COW operations.

9.6 TOTAL WAX

The total wax, expressed as a percentage weight, is the sum of the wax found in various boiling fractions of the crude oil assay.

Total wax gives an indication of likely deposition as follows:

Wax content (% m/m)	Sludge deposition
< 3	Minimal
3–6	Some deposition under cooler climatic conditions
> 6	Some cargo conditioning may be required i.e. heating

9.7 POUR POINT

In the past, pour point has been considered as the primary indicator as to whether or not a crude oil should be heated. It was considered adequate to heat cargoes to a temperature of 10 °C above the pour point. However, more recent research has indicated that this may not be such a useful criterion as once thought. Even at a suitable temperature above the pour point significant sludge deposition can still occur. It is now felt that cloud point is a more suitable temperature indicator. However, pour point is included in Annex B and a correlation between pour point and cloud point is given in Annex A.

9.8 CLOUD POINT (CALC)

Cloud point is the temperature at which phase separation occurs. One of the considerations in this section has been terminology. Other publications use the terms 'wax appearance point', 'wax appearance temperature', or 'cloud point'. All of these involve some form of experimental determination.

The temperatures quoted in Annex B are based on the two calculation methods shown in Annex A.2. The first correlation is based on a weighted wax content of individual boiling fractions. The second correlation is based on a blending indices method. In order to differentiate between the experimental and calculation methods the term 'cloud point (calc)' will indicate that it has been calculated.

As the determination of the temperature at which the first wax crystal precipitates out of solution is not so important in the marine industry, the equations used in this publication are of sufficient accuracy. However, cloud points calculated in this publication may not be sufficiently accurate for pipeline operations. Experimental techniques such as microscopy should be used.

9.9 KINEMATIC VISCOSITY

Where possible, two kinematic viscosities, at two temperatures, are given. In all cases, both viscosities have been obtained from the same assay data. Using the formulae in Annex A.1 it is possible to calculate the kinematic viscosity at any temperature.

The viscosity at ambient temperature is important because it affects the efficiency of both the cargo and stripping pumps. To maintain optimum efficiency for cargo pumps, reference should be made to the vessel's COW manual for manufacturer's minimum viscosity requirements where listed.

For centrifugal cargo pumps, the cargo viscosity should not typically exceed 250 mm^2/s. During stripping operations, the viscosity of the cargo should not typically exceed 600 mm^2/s.

9.10 RECOMMENDED CARRIAGE AND DISCHARGE TEMPERATURES

This information was collated from data supplied by the companies represented on committee HMC-4. Where data are unavailable, carriage and discharge temperatures have been included, where possible, which are based on the carriage and discharge conditions of other crude oils having similar properties. Generally, for paraffinic crude oils there will be no differentiation between carriage and discharge temperature. However, for aromatic crude oils the discharge temperature may need to be increased above the carriage temperature to reduce the viscosity during pumping operations.

The data indicate the minimum temperature in all cases and have been arrived at by experience. However, ambient conditions throughout the voyage should also be given due consideration, as minimum temperatures may need to be increased.

9.11 RECOMMENDED COW CODES

Wash codes are given for summer and winter. As a general guide, the following summer/winter dates apply:

- Northern Hemisphere (north of the Tropic of Cancer). Summer: 1 April to 30 September. Winter: 1 October to 31 March.
- Southern Hemisphere (south of the Tropic of Capricorn). Summer: 1 October to 31 March. Winter: 1 April to 30 September.
- The summer code should normally be used for the Tropical zone. However, winter codes may be used if the crude or the conditions are of particular concern.

Ambient conditions, for example cold sea water, can greatly affect the crude oil temperature, especially layers close to the hull or adjacent to the ballast tanks. Localised cooling to temperatures below the cloud point leads to precipitation of wax, which in turn aggravates clingage and ROB on discharge. On the other hand, high oil temperatures caused by high air and sea temperatures may lead to the evolution of hydrocarbon gas. Global air and sea temperature data can be found through various on-line sources. At the time of publication, sea temperatures were available from:

https://www.seatemperature.org/

http://www.ospo.noaa.gov/Products/ocean/sst/contour/

with air temperatures at:

https://www.bbc.co.uk/weather/map

http://www.eldoradocountyweather.com/forecast/world-forecasts/world-temperatures.html

References are frequently made under 'Remarks' to heating the contents of the slop tanks supplying the COW system to a temperature of at least 10 °C above the average cargo temperature. The value of 10 °C is arbitrary but is based upon experience. A temperature difference of less than 10 °C does not give rise to an appreciable change in crude oil quality (usually viscosity) which will improve COW. Temperature differences greater than 10 °C may be required with some crude oils.

9.12 HYDROGEN SULFIDE (H_2S) IN LIQUID PHASE

Concentrations of H_2S (ppm mass) in the liquid phase of various crude oils are also supplied. There is no correlation between the concentration of H_2S in the liquid phase (ppm mass) with the concentration of H_2S in the vapour phase (ppm volume), (refer to HM 69 *Procedures for determining H_2S concentrations in cargo head spaces* and ISGOTT). At all times, crude oil should be treated with caution as advised in HM 69 and ISGOTT, as referenced in 8.2 of this document.

9.13 REMARKS

In the tables of Annex B the committee has tried to pull together as much added information as possible.

Some crude oils listed as 'subject to wax laydown in cold conditions' are those having a relatively high wax content that could result in larger than usual sludge deposition under certain conditions. A good example of this is Brent Blend which is transported unheated all the year round on short voyages across the North Sea, but requires some heating when being transported across the Labrador Current to the East Coast of the USA in winter.

Another note that has been used is 'COW with this crude may result in high tank pressures'. This is a reflection of the relatively high gas to C_4 content of the crude oil. Due to their solvent properties these crude oils are generally considered good as a COW medium for removing the residues from past cargo. However, they generate high vapour volumes which increase cargo loss, cause tank pressures to rise, and may lead to air pollution as pressure is relieved to the atmosphere. With some of these types of crude oil the need to COW is questionable. An example of this is Saharan Blend which has a high gas to C_4 content, low wax content and low cloud point temperature.

Past versions of COW manuals listed a number of crude oils which were considered to be unsuitable for COW due to their high pour point or viscosity. However, nearly all of these crude oils have been successfully used for COW by suitable conditioning beforehand. Conditioning generally means heating the oil but the addition of a detergent may be a possibility. It is for these reasons that most of the unsuitable crude oils listed in the COW manual have been given COW codes in Annex B.

ANNEX A
CALCULATION PROCEDURES

A.1 VISCOSITY

The viscosities given in Annex B are taken directly from assay data. Where it is considered necessary to calculate a viscosity at a particular temperature, other than those quoted, a Refutas type equation can be used:

$$\log_{10}\log_{10}\left(V_x + 0{,}8\right) = \log_{10}\log_{10}\log_{10}\left(V_2 + 0{,}8\right) + B\left[\log_{10}\left(\frac{T_2}{T_x}\right)\right] \quad \text{(Equation 1)}$$

where:

V_x is the unknown viscosity at temperature T_x

V_2 is the known viscosity at temperature T_2

B is the temperature/viscosity slope and is a constant for each crude type

Note: The unit of kinematic viscosity is mm²/s. The unit of temperature is the Kelvin (K).

where: K = °C + 273 (Equation 2)

Although Equation 1 is using $\mathrm{Log}_{10}\mathrm{Log}_{10}$ (logs to the base 10) throughout, natural logs (lnln) could also be used. It is essential to use a constant log base.

The *B* factor for a particular crude oil may be determined by substituting the two viscosity/temperature pairs into Equation 1. This factor can then be used with one of the two known viscosity/temperature pairs to determine the viscosity at a third temperature, T_x. Where available the tabulated data include viscosities at two temperatures.

If only one viscosity/temperature pair is known from assay data an average *B* factor of 3,50 can be used.

A.1.1 Example 1 – Calculation of a viscosity B factor

Using the data for Maya crude oil given in Annex B, the following viscosity/temperature pairs are obtained:

T_1 = 40,0 °C; V_1 = 84,30 mm²/s

T_2 = 60,0 °C; V_2 = 40,35 mm²/s

The two temperatures must first be converted from Celsius to Kelvin:

T_1 = 40 + 273 = 313 K

T_2 = 60 + 273 = 333 K

Using Equation 1 let $T_x = T_1$ = 313 K, let $V_x = V_1$

= 84,30 mm²/s, let T_2 = 333 K, and let V_2

= 40,35 mm²/s.

$$\log_{10}\log_{10}(84,3+0,8)=\log_{10}\log_{10}(40,35+0,8) + B\left[\log_{10}\left(\frac{333}{313}\right)\right]$$

0,2855 = 0,2080 + (*B* x 0,0269)

B = (0,2855 − 0,2080)/0,0269

B = 2,88

A.1.2 Example 2 – Calculation of viscosity of a typical crude oil at an arrival temperature of 35 °C

In this example the *B* factor is 2,88 as calculated in example 1.

T_x = 35 + 273 = 308 K

From the two viscosity/temperature pairs given in Annex B choose the pair whose temperature is closest to T_x. That is 84,3 mm²/s at 40 °C.

Using Equation 1 the viscosity V_x is calculated as follows:

$$\log_{10}\log_{10}(V_x+0,8)=\log_{10}\log_{10}(84,3+0,8) + 2,88\left[\log_{10}\left(\frac{313}{308}\right)\right]$$

$\log_{10}\log_{10}(V_x + 0,8) = 0,2855 + 0,0201$

$$V_x = \left(\left(\log_{10}^{-1}\log_{10}^{-1}(0,2855+0,0201)\right)\right)-0,8$$

V_x = 104,19 mm²/s

Viscosity at 35 °C is 104,19 mm²/s.

A.2 CLOUD POINT (CALC)

Two methods were used to calculate the cloud points in Annex B. These methods assume different wax concentration curves and neither method has been proven to be more reliable than the other. The cloud points for both methods are given as a temperature range.

A.2.1 Method 1

This method is based on an early equation developed by Dr T.J. Gunner:

Cloud Point (°C) = 104,26 (loglogF – 1,55) (Equation 3)

where: $F = \dfrac{\alpha + \beta + \gamma}{2T}$

and $\alpha = 4(W_{550} \times M_{550} \times C_{550})$

$\beta = 2(W_{509} \times M_{509} \times C_{509})$

$\gamma = (W_{369} \times M_{369} \times C_{369})$

$T = EC_{149}, C_{232}, C_{342}, C_{509}, C_{550}$

and W_x is the wax content (% weight) of the relevant C_x 'cut'.
M_x is the melting point (°C) of the wax content W_x.
C is the % weight of the given distillation 'cut'.

Note: The subscript numbers have been used to indicate the distillation fraction (boiling range) on a crude oil assay such that:

149 means the cut between C_5 and 149 °C
232 means the cut between 149 °C and 232 °C
342 means the cut between 232 °C and 342 °C
369 means the cut between 342 °C and 369 °C
509 means the cut between 369 °C and 509 °C
550 means the cut between 509 °C and 550 °C

Generally, the assay cut points are company-dependent and will not conform to those given in this section. However, there are software distillation packages available that will transform any series of 'cut' points to conform to those shown here.

Many crude oil assays do not report the melting points of the wax contents of the various fractions. A survey of the data available from 150 crude oils revealed the mean values and standard deviation from the mean of the three relevant fractions to be:

Crude 'cut' (°C)	Mean melting point (°C)	Standard deviation (°C)
550	65	4
509	53	3
369	39	1

It is recommended that if wax melting points are not available then these values are used.

A.2.2 Method 2

This utilises the blending indices of the various distillation 'cuts'. The blending index is calculated using the following equation:

$\log_{10} I = 0{,}02916$ (Cloud Point (°C) + 73,33) (Equation 4)

where I is the blending index of the fraction under consideration. However, it is usual to add a subscript to indicate the particular fraction.

For fractions distilling below 149 °C, the index is assumed to be zero. For the fraction boiling between 149 °C and 232 °C, denoted by I_{149}, the index is 4,8. For the middle distillate fractions in the higher boiling ranges, the blending index has to be calculated from cloud points given in the crude oil assay. To do this, the cloud point for each fraction is substituted into Equation 4. For residues where only the pour point is reported, the cloud point is assumed to be 2 °C above the pour point and the index calculated.

The blending indices for each cut are now combined on a weight basis, according to the percentage weight of each fraction in the crude oil, to derive what may be termed the cloud point index of the blend, CPI_B. That is, the cloud point index for the crude oil in question:

$$CPI_B = \left(\frac{(W_{149} \times 4{,}8) + (W_{232} \times I_{232}) + (W_{342} \times I_{342}) + (W_{369} \times I_{369})}{100} \right) \quad \text{(Equation 5)}$$

where:
W_{149} is the percent weight of the fraction boiling between 149 °C and 232 °C
W_{232} is the percent weight of the fraction boiling between 232 °C and 342 °C
W_{342} is the percent weight of the fraction boiling between 342 °C and 369 °C
W_{369} is the percent weight of the fraction boiling greater than 369 °C

I_{232}, I_{342} and I_{369} are the cloud point indices calculated for these fractions.

Once the CPI_B has been derived it can be entered into Equation 6 to calculate the required cloud point of the crude oil:

$$\text{Log}_{10} CPI_B = 0{,}02916(\text{Cloud Point}(°\text{C}) + 73{,}33) \quad \text{(Equation 6)}$$

Where the assay data do not include boiling data at the temperatures prescribed here, other boiling points can be used along with their corresponding cloud points.

A.2.3 Simplified procedure

Another equation is available to readers having no assay data. This is especially true for marine staff who may only have a load port Certificate of Quality. It is based upon the crude oil pour point and may be subject to very high uncertainty.

$$\text{Cloud Point}(°\text{C}) = (20{,}2 \times 10^{(0{,}00708y - 0{,}1157714)}) + 8 \quad \text{(Equation 7)}$$

where: y is the crude oil pour point (°C).

A.2.4 Example 3 – Calculation of cloud point using Equation 7

Consider a cargo of Brent Blend crude oil where the Certificate of Quality advises that the pour point is 3 °C.

First calculate the exponential term in Equation 7:

Exponential term = (0,00708 x pour point) – 0,1157714

Exponential term = (0,00708 x 3) – 0,1157714

Exponential term = –0,0945314

Cloud Point = $(20{,}2 \times 10^{-0.0945314}) + 8$

Cloud Point = 24 ºC

The cloud points calculated from methods 1 and 2, and given in Annex B, give the range 20 ºC to 26 ºC. For this crude oil the simplified method appears reasonable.

Further information can be found in IMO *Crude oil washing systems*.

ANNEX B
CRUDE OIL DATA

Explanations for the assay categories can be found in section 9. The following codes should be referred to in conjunction with the data sheets that are available in a separate document *here*.

http://publishing.energyinst.org/__data/assets/excel_doc/0014/1021334/HM40-COW-and-Heating-Annex-B-4th-Ed-Dec2022.xlsx

The committee has made every attempt to ensure that the data are correct. However, differences may be experienced from those described in this section since the quality of crude oil can change rapidly in a short time, especially if it is blended from a number of small fields.

The data should not be used without referencing all other sections of this publication.

B.1 COW CODES

Code Washing requirement

1. No COW. Maximum possible safe trim for stripping tanks and lines. Strip all tanks at least twice, three times if time permits.
2. Bottom wash only required.
3. Full cycle wash of all cargo tanks.
4. Full cycle wash for cargo wing tanks and a bottom wash for cargo centre tanks.
5. No COW, except with a suitable crude oil or cutter stock such as heated gas oil. Otherwise treat as heavy fuel oil with maximum possible safe trim for stripping.
6. Cargoes are small, normally carried in heavy fuel oil tankers, and treated in the same way as heavy fuel oil.
7. Bottom wash all cargo tanks, using the contents of the slop tanks. Oil in the slop tanks should be heated to at least 10 °C above the average cargo temperature.
8. Full cycle wash of all cargo tanks, using the contents of the slop tanks for COW. The COW medium should be heated to at least 10 °C above the average cargo temperature.

Note 1: Heavy weather ballast tanks are subject to MARPOL COW requirements.

ANNEX C
GLOSSARY OF TERMS

The general definitions (HM 0) regarding Cargo Inspection Procedures are available free of charge as a downloadable PDF document from the EI website https://www.publishing.energyinst.org

aromatic crude oil — See *high viscosity crude oil*.

asphaltenes — Wax-free material, insoluble in heptane but soluble in hot benzene.

ballast — Water taken on board when a vessel is empty or partially loaded/discharged to increase draught so that the propeller is fully immersed, stability and trim are maintained, and stresses minimised.

bottom wash — Crude oil washing operations restricted to the lower parts of the tank bulkheads, internal structures and bottom of tanks. This can only be carried out by vessels equipped with programmable tank-washing machines.

clingage — Material which adheres to the surfaces of tank walls and structures, both horizontal and vertical, within empty and part empty tanks, other than bottom surfaces.

cloud point — For the purposes of this document, a calculated temperature (°C) as defined in 9.8.

crude oil — For the purposes of these guidelines, crude oil types have been subdivided as follows (see *ballast)*.

crude oil washing (COW) — The use of a high-pressure stream of crude oil cargo to dislodge or dissolve clingage and sediments from the bulkheads, bottom and internal tank structures of a vessel during the discharge operation.

cutter stock — Diluent material used for tank washing, acting as a solvent or viscosity reducer to enable better recovery of ROB. It may be heated.

full cycle washing — Crude oil washing operation in which the complete cargo tank is washed.

FPSO — Floating production storage offloading

gas to C_4 — An abbreviation for the percent mass of hydrocarbon gases at normal temperature and pressure from C_1 to C_4 inclusive, present in crude oil.

heavy weather ballast — Additional ballast loaded into cargo tanks to enable the vessel to maintain a safe seagoing condition under extreme weather conditions.

high viscosity crude oil	A crude oil which due to its viscosity alone requires heating during transportation, COW or discharge. These types of crude oil generally have a high aromatic content and may have the designation *aromatic crude oil*.
inert gas (IG)	A gas or gas mixture used to render the vapour space above the cargo non-flammable.
IMO	International Maritime Organization
ISO	International Organization for Standardization
ISGOTT	International Safety Guide for Oil Tankers and Terminals
MARPOL	The Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1973, amended 1992.
on board quantity (OBQ)	Sum of measured liquid volume, including free water and measured non-liquid volume but excluding any vapours, in cargo tanks prior to loading.
pour point	The lowest temperature (ºC) at which an oil will continue to flow when it is cooled under specified standard conditions.
reid vapour pressure (RVP)	Absolute pressure exerted by the gas produced by evaporation from the liquid, as measured by Reid apparatus under the specific conditions of test temperature, vapour/liquid ratio and air saturation.
remaining on board (ROB)	Sum of measured liquid volume, including free water, and measured non-liquid volume but excluding vapours, in cargo tanks on completion of discharge.
segregated ballast	Ballast that is contained in dedicated ballast tanks serviced by dedicated ballast pumps and lines with no permanent connection to the cargo system.
segregated ballast tankers (SBTs)	Vessels having sufficient dedicated ballast tanks to enable safe seagoing operations under normal weather conditions. See also *heavy weather ballast*.
slop tank(s)	For the purposes of these guidelines, tank(s) utilised as a reservoir for COW medium and receipt of tank washings.
stripping	The removal of the final contents of a cargo tank using equipment additional to the main cargo pumps.

threshold limit value (TLV)	The time-weighted average concentration of a substance to which workers may be repeatedly exposed, for a normal eight-hour workday or 40-hour workweek, day after day without adverse effect.
trim	The difference between the fore and aft draught of the vessel. When the aft draught is greater than the forward draught, the vessel is said to be trimmed 'by the stern'. When the aft draught is less than the forward draught, the vessel is said to be trimmed 'by the head'.
true vapour pressure (TVP)	The absolute pressure exerted by the gas produced by evaporation from a liquid, when the gas and liquid are in equilibrium at the prevailing temperature.
viscosity	A measurement of a fluid's resistance to flow at a prescribed temperature. In this document, the unit of viscosity is mm^2/s.
VLCC	Very large crude carrier
volatile crude oil	Crude oil, having a high concentration of components boiling below ambient temperature (gas to C_4), which results in excessive gas evolution if used as a COW medium.
volatile organic compounds (VOCs)	A large family of carbon-containing compounds which are emitted or evaporate into the atmosphere and can take part in photochemical reactions in the air.
wax	A mixture of long chain hydrocarbons that crystallise at different temperatures as the overall fluid temperature falls.
wax/sediment = sludge	That element of the material in a ship's cargo tank which is essentially not free-flowing. It consists of hydrocarbon waxes and may contain water/oil emulsions and sediments.
waxy paraffinic crude oil	A crude oil which, by function of its total wax content, requires heating to prevent sludge deposition during transportation and discharge.

ANNEX D
REFERENCES AND BIBLIOGRAPHY

The following standards and papers have been used in the preparation of this document. The latest editions should be referred to in all cases.

ASTM (https://www.astm.org/)

ASTM *Annual book of standards, Section: 5, Petroleum products, lubricants, and fossil fuels*

EI (https://www.energyinst.org)

The IP Standard methods for analysis and testing of petroleum and related products, and British Standard 2000 Parts

EI HM 69 *Procedures for determining H_2S concentrations in cargo head spaces*

IMO (http://www.imo.org/EN/Pages/Default.aspx)

Articles, protocol, annexes and unified interpretations of the international convention for the prevention of pollution from ships, 1973 as modified by the 1978 and 1997 Protocols. (MARPOL)

Crude oil washing systems

International Convention for the Control and Management of Ships' Ballast Water and Sediments

Revised specifications for the design, operation and control of crude oil washing systems, IMO resolution A.446 (XI) as amended A.496 (XII)

Intertanko (https://www.intertanko.com/)

Cloud point and crude oil washing, T.J. Gunner, October 1995, published by INTERTANKO.

Witherby Seamanship International (http://www.witherbyseamanship.com/) *International safety guide for oil tankers and terminals*

Other

API/ASTM/IP *Petroleum Measurement Tables*

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Energy Institute
61 New Cavendish Street
London W1G 7AR, UK

t: +44 (0) 20 7467 7100
f: +44 (0) 20 7255 1472
e: pubs@energyinst.org
www.energyinst.org

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