

**MARINE VESSEL FUEL COOLING APPARATUS, FUEL MIXING APPARATUS, ISO TANK
CONTAINER AND CORRESPONDING METHODS**

The invention relates to marine vessel fuel cooling apparatus. The invention also
5 relates to on-board marine vessel engine fuel mixing apparatus. The invention also
relates to an ISO tank container. The invention also relates to a method of cooling a
low-flashpoint fuel component in a container or a conduit. The invention also relates
to a method of operation of a marine vessel fuel cooling apparatus. The invention
also relates to a method of producing a marine vessel engine fuel mixture on-board a
10 marine vessel. The invention also relates to a method comprising installing on a
marine vessel an ISO tank container.

The invention has particular, but not exclusive, application in the preparation and
cooling of a fuel mixture comprising a low-flashpoint liquid fuel component having
15 an alcohol, such as methanol or ethanol. Additionally or alternatively, the invention
may also have particular, but not exclusive, application in the preparation of a
mixture comprising an ether component, such as dimethyl ether (DME) or diethyl
ether (DEE).

20 Numerous systems relating to marine vessel engines and their fuels have been
proposed. These include Korean Patent Publication No. KR20120004628 and
International Patent Publication No. WO2012/130407.

Environmental issues in marine transportation are becoming more and more of a
25 concern. There are certain schools of thought that consider over industrialisation to
have resulted in global warming and manifestation of pollution, such as smog,
particulate matters PM 2.5, SO_x NO_x and volatile organic matters, and carcinogenic
agents.

There are some concerns that burning of bunker oil (e.g. MGO, MDO and HFO, perhaps the most prevalent of these being HFO, Heavy Fuel Oil) in marine diesel engines is contributing to the problem, and new rules and regulations from governing bodies such as Marine Pollution ("Marpol"), the International Maritime Organisation ("IMO"), and the Energy Efficiency Design Index ("EEDI") have been (or are being) implemented. From 2015, the IMO has announced the enforcement of new environmental regulations setting a maximum level of sulphur of 0.1% in Environmental Control Areas (ECAs). The EEDI stipulates for newly-built ships a 10% reduction in CO₂ emissions by 2019, a 20% reduction by 2024 and a 30% reduction from 2025 onwards. Efforts to comply require heavy capital investment in getting rid of SO_x, NO_x, greenhouse gases etc.

Of course, the problem of pollution from burning of fossil fuels is not restricted to marine vessel engines, and extensive research has been conducted into the use of, for example, alcohols, as a cleaner alternative, particularly for land transport vehicles especially in Brazil and China. Alcohol is a clean burning fuel, with no or minimal SO_x, NO_x, smog or soot formed if burned properly. Instead, CO₂ & H₂O are formed.

The literature considering the use of an alcohol as a fuel includes United States Patent No. 4,422,412 and United States Patent No. 4,603,662. However, use of alcohols such as methanol (and ethanol etc), is not without its problems. For instance, these alcohols are grouped with other liquids as low-flashpoint liquids (LFLs), and for good reason. For instance, the flashpoint of methanol is reported as being around only 11°C. Therefore, use of methanol in bulk quantities, particularly in high-temperature environments – such as use in heated engine rooms and burning in internal combustion engines – requires great care. For these and other reasons, their use in bulk quantities as transportation fuel is thus far not widespread, and largely limited to chemical feedstock. Their use has have been approached with apprehension, preferring instead to use less volatile crude oil containing LFL fuel

such as benzene and toluene with a flashpoint of around 20°C, even though this has its own dangers, with the potential to cause major fires in engine rooms of ships.

For ease of reference, the use of the term low flashpoint liquid (LFL) fuels herein are referring to families of chemicals including: alcohol (methanol, ethanol etc.), acetyl (for example acetaldehyde, ketone (for example acetone etc.), ether family (dimethyl ether, diethyl ether etc.), gasoline, aromatics (for example benzene, toluene, xylene etc.), alkane (for example methane, butane, pentane, hexane, propane, heptane, octane, etc.), acetylene and butadiene.

10

The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

15

Implementation of the techniques disclosed herein may provide significant technical benefits, particularly in comparison with the prior art systems identified above.

20

Thus far, safety has been the biggest problem in utilising methanol fuel in marine diesel engines. Since on-board storage for ship use can require between, for example, 10 and 100 tons of capacity (and in large and ocean-going vessels the capacity requirement can exceed 100 tons, in sharp contrast to use in motor car vehicles which only carry, say, between 40 and 50 litres) this has hitherto made the risk of carrying methanol fuel in bulk on ship (especially in bilge) undesirable. The techniques disclosed herein may make use of methanol fuel in marine internal combustion engines, such as diesel engines, possible.

25

Since methanol is toxic and highly flammable with a low flash point, safe utilisation of this fuel is considered a significant problem. In case of the OBATE fuel system by Haldor Topsoe exemplified in International Patent Publication No.

30

WO2012/130407 noted above, a large high pressure tank held at a pressure of between 3 and 5 bars, or even up to between 20 and 30 bars (depending on the

temperature) for containing the modified methanol fuel is required, and this methanol fuel contains a high proportion of gaseous DME and/or other LFL fuels (up to between 20% and 50%) which may be considered to make the mixed fuel increasingly dangerous, leading to regulation issues. Furthermore, in a catalytic converter reactor chamber, temperatures are expected to rise to between 180°C and 260°C and pressure of the fuel to be between 30 and 90 bar. United States Patent No. 4,422,412 teaches the formation of methanol and a DME mixture from methanol as a raw material in a heat exchanger converter with a catalyst, with both the converter and tank placed in the engine room. This means the LFL fuels are exposed to temperatures between 80°C and 400°C perhaps raising safety concerns. International Patent Publication No. WO2012/130407 teaches use of a catalyst converter. It is understood that at least some shipping companies have their doubts about the practicality of such systems. This is because safety precautions to be taken for using LFL fuels must be increased significantly and special care must be taken in the tank, engine room, piping designs and even in the ship fabrication method, and so on.

Use of a storage/buffer tanks on board a ship for a low-flashpoint fuel component and an ether component allows us to dispense with a methanol conversion system using catalysts – a complex and expensive device – used in prior art techniques for in situ on-board conversion of alcohol to ether, a technique understood to be used presently on Stena Line vessel auxiliary engines. Further, the use of the heat exchanger and the catalyst requires temperatures of between 80°C and 400°C, raising the pressure up to between 20 and 400 bar. These are highly undesirable operating conditions in an engine room. However, the use of a storage/buffer tank for these low-flashpoint fuel and ether components introduces its own set of problems in that transporting such liquid in the required quantities for long distance voyages is in itself problematic despite the fact it may be safer.

The disclosed techniques also overcome the problems of the prior art where a single mixing in a container of methanol and DME takes place, such as in US 4,603,662 mentioned above. For instance, these prior art techniques are considered not to provide complete mixing and to cause the DME/methanol mixture fuel tank pressure to increase since gaseous DME is added or formed in situ, perhaps significantly. Further, the mixing of an alcohol with an ether in one tank lowers the flashpoint in the methanol fuel tank even farther, thereby causing an extra safety risk.

The techniques disclosed herein seek to solve these problems, or at least to mitigate their effects.

Cooling of the low flashpoint liquid – e.g. methanol and DME – lowers, amongst other things, the vapour pressure and storage pressure, thus lowering the danger of storage of the liquid fuel.

Ship builders, ship owners, classification societies (certification bodies who rate safety measures of shipbuilding, bunkering practices, engine etc.), regulatory bodies and other parties in the maritime eco-system have yet to think about bringing together the various components as described herein because, hitherto, the requirements for such precautions have simply not been identified since the idea of using LFL fuel in a marine environment has only begun to take shape in recent years. Simply put: the development of the techniques as disclosed herein is completely counterintuitive given prevailing practice in the field. This prevailing practice is for marine fuels to have a flashpoint of at least 60°C, which is a stark contrast to relatively much lower flashpoint of methanol and other LFL fuels etc. In fact, DNV GL (formerly Det Norske Veritas), at the forefront of certification bodies in marine safety, has only recently begun to adapt the classification rules of LNG tankers/carriers to LFL light craft and the classification rules are not even finalised yet. And these classification rules are considered to be directed currently at smaller craft and ferries, and not long haul ocean-going vessels. The techniques disclosed

herein provide what is considered to be the most environmentally-friendly, practical, viable and cheapest method to cool LFL fuel tanks for its safe usage for long haul ships and in large volumes.

5 Other general benefits of the use of low flashpoint liquid, particularly methanol, in the techniques disclosed herein, particularly include:

- Alcohols including methanol are clean burning fuels with no, or at least reduced, issues relating to pollution. It is believed that it is the only fuel that is 100%
10 recyclable from carbon dioxide. Further, no SCR or additional equipment for SO_x, NO_x scrubbing is required in meeting the new regulatory requirements for the shippers.
- In the CRI Reykjavik Iceland methanol project, mass production of methanol produced from carbon dioxide commenced in April 2012, so it is becoming more
15 abundant. World-wide production capacity is believed to be over 100 million metric tons per year with 40% idle capacity, supply widely available. Abundant methane raw material is available. China is understood to have approximately 47 million tons of methanol production capacity, produced from coal, natural gas, biomass, and even carbon dioxide can be used as methanol raw material. The
20 price of methanol is not as volatile as oil, especially with the discovery of shale gas technology making the raw material price stable.
- Existing internal combustion engines on existing ships can be converted for use with LFL fuel mixtures at minimal cost, much less expensively than the investment required in SCR for reducing NO_x, SO_x, etc. For instance, and for a
25 spark ignition engine, the engine may be converted for as little as USD 300. Compression ignition engine (diesel engine) conversion costs may be higher, but still within acceptable ranges. Modification of methanol fuel is simple for burning in internal combustion engines, like diesel engines. If not converted, shippers are faced with the prospect of changing the entire engine to an expensive new
30 engine such as those manufactured by MAN SE or Wartsilla. In such cases, the

capital cost may be considered too high, especially for existing ships when converting to use with alcohol-based fuels.

- Methanol fuel is considered safer than compressed natural gas (CNG) and liquid natural gas (LNG), and initial capital equipment investment is much lower.
- 5 Further, the fuel is more concentrated in liquid form than CNG which is – obviously – normally in gaseous form and stored in very high-pressure conditions over 100 bar. Many ship operators are understood to consider that large-scale storage of CNG and LNG is simply a time bomb. Setting up an LNG terminal at a port is also very expensive, thus rendering LNG fuel not easily accessible.
- 10 • Methanol can be easily and cheaply transported and stored in trucks, ships, bunkering vessels, etc., and transport cost is relatively low, unlike CNG/LNG which has a much higher transport cost.
- Methanol is biodegradable and soluble in water. Unlike with oil, bunker oil, heavy oil, diesel, leakage will not cost an ecological disaster.
- 15 • Methanol fires can be extinguished by water, unlike petroleum and gas fires. At lower concentrations of methanol – below 20% – burning will stop automatically.
- Methanol has a boiling point of 68°C and is a liquid at room temperature. No high cost pressure tank is needed for methanol storage and the operation of the methanol is considered to be safer and cheaper than CNG, LNG & dimethyl ether (DME) and diethyl ether (DEE).
- 20 • Methanol has very low vapour pressure when its temperature is low, in stark contrast to gasoline, CNG, LNG, etc. which are highly volatile.
- Methanol has a high octane number. The auto-ignition temp of methanol is high at around 433 ± 8 °C so engine knocking problems are reduced, thus improving
- 25 fuel economy.
- Use of methanol does not cause any corrosion problems for steel, stainless steel, neoprene, rubber, viton, Teflon, etc., which means no corrosion for diesel engine if the fuel is burned completely.
 - It may be possible to realise around 10% more power from the same diesel
- 30 engine, when using a LFL-fuel mix. For example a 200kw engine running at 2100

rpm for diesel oil fuel will give us 2300 rpm running on methanol diesel fuel. The engine power can increase 10% from 200kw to 220kw, thus needing less investment in the engine, and more efficient running conditions.

- Toxicity is lower than gasoline.
- 5 • The exhaust gas temperature of an engine running on an LFL-fuel mix is reduced by between 100°C and 300°C, lower than diesel exhaust gas temperature. Because methanol is a clean burning low temperature burning fuel, more power is converted to mechanical energy than waste heat energy, causing less damage to environment and less danger in operation. Further, the engine may run more smoothly.

10

The invention will now be described, by way of example only, and with reference to the accompanying drawings in which:

Figure 1 is a block schematic diagram illustrating fuel mixing and fuel cooling systems according to the techniques disclosed herein;

15

Figure 2 is a block schematic diagram illustrating in more detail the cooling apparatus of Figure 1;

Figure 3 is a piping schematic diagram illustrating a second fuel mixing apparatus; and

Figure 4 is a partial plan view of a marine vessel having disposed thereon an LFL tank container according to the techniques disclosed herein.

20

Turning first to Figure 1, there is disclosed a marine vessel fuel cooling apparatus 100 installed in or on a marine vessel. In the example of Figure 1, the marine vessel fuel cooling apparatus includes an absorption refrigeration cooler 102. Also illustrated is a marine vessel engine 104. In the example of Figure 1, the marine vessel engine 104 is a compression ignition engine (diesel engine) and is the or one of the main vessel engines, but other arrangements are contemplated, as will be described below.

25

In a significant feature of the apparatus of Figure 1, a marine vessel engine fuel mixture is obtained, comprising a low-flashpoint fuel component (as defined above) and an ether component. A first on-board container 106 contains a low-flashpoint liquid fuel component 108. A second on-board container 110 is provided for
5 containing an ether fuel component 112. Either or both of containers 106, 110 may be, for example, main fuel storage tanks or buffer tanks. Low-flashpoint liquid fuel component 108 is discharged from first on-board container 106 through conduit 114 to a mixer 116. The ether fuel component 112 is discharged from second on-board container 110 through conduit 118 to the mixer 116. The two fuel components 108,
10 112 are mixed in mixer 116 (which may be a static mixing type), producing a marine vessel engine fuel mixture. In one exemplary arrangement, mixer 116 is a pipe mixer (mixing pipes system) to provide thorough and effective mixing of the two fuel components.

15 Thus it will be appreciated that Figure 1 illustrates an on-board marine vessel fuel mixing apparatus 100, the fuel comprising a low-flashpoint fuel component 108 and an ether component 112. The apparatus is arranged to receive the low-flashpoint fuel component 108 from a first on-board container 106 and to receive the ether component 112 from a second on-board container 110. The apparatus comprises a
20 mixer 116 for mixing the low flashpoint fuel component 108 and the ether component 112 to produce a marine vessel engine fuel mixture.

Further, it will be appreciated there has been described a method of producing a marine vessel engine fuel mixture on-board a marine vessel, the fuel comprising a
25 low flashpoint fuel component 108 and an ether component 112. The method comprises receiving, at a mixer 116, the low flashpoint fuel component 108 from a first on-board container 106. The ether component 112 is received, at the mixer 116, from a second on-board container 110. The method comprises mixing, at the mixer 116, the low-flashpoint fuel component 108 and the ether component 112 to obtain
30 the marine vessel engine fuel mixture.

In one preferred implementation, the fuel mixture comprises methanol, dimethyl ether (a cetane improver) and lubricant such as castor oil. The DME facilitates use of methanol as a fuel, as otherwise the cetane level of methanol is too low for burning
5 in a compression ignition engine. Lubricant is introduced to allow use of the fuel mixture in existing ship engines, typically diesel engines. And conversion of the ship's engines for use with the fuel mixture is a relatively straightforward matter. One particularly beneficial recipe for the fuel mixture comprises around 94% methanol, 5% dimethyl ether and 1% lubricant. Such a mixture may be safer and less expensive to
10 use than, say, the OBATE fuel mixture offered by HaldorTopsoe, having typically around 20% to 30% DME content. The cost of DME is typically multiples of the cost of methanol, and more dangerous to use. Thus, use of the fuel mixture of where the DME content is much lower is an attractive prospect.

15 The proportions of the fuel components may also be varied depending on operating characteristics. For instance, in cold conditions, DME can be provided in a higher proportion to facilitate engine starting from cold conditions.

A colouring may also be provided in the fuel mixture so that, in case of fire, the fire
20 will be coloured, as otherwise methanol flames are colourless.

As noted above, the vessel engine 104 may be a marine vessel main engine (the main driving engine of the vessel) so the mixing apparatus is sized to produce sufficient marine vessel engine fuel mixture for an engine of this capacity, typically of
25 a minimum order of 75 m³. Thus, the apparatus is sufficient to produce marine vessel engine fuel mixture from a few tons to 100 tons or more.

Fuel mixture is discharged from mixer 116 through delivery system 120. Delivery system 120 comprises at least conduit 122 for conveying fuel mixture to the inlet 124
30 of marine vessel engine 104. That is, the on-board marine vessel engine fuel mixing

apparatus comprises a delivery system 120 for delivering the marine vessel engine fuel mixture to a fuel injector 150 of a marine vessel engine 104.

A significant feature of the apparatus of Figure 1 is that it provides cooling for at least the low-flashpoint liquid fuel component 108 below its flashpoint temperature. In this respect, first on-board container 106 is provided with a (first) cooling jacket 126. A nitrogen blanket 128 is also provided as a (further) safety measure. Second on-board container 110 may also be provided with a cooling jacket. In at least one implementation, second on-board container 110 is also provided with a nitrogen blanket 130.

In the example of Figure 1, conduit 114 is provided with a second cooling jacket 132. Conduit 122 is provided with a third cooling jacket 134.

Thus, at least the low-flashpoint fuel component 108 may be cooled, and to below its flashpoint. Where the low-flashpoint fuel component 108 is or comprises, say, methanol, this may be cooled to below 11°C, preferably to less than or equal to 9°C, more preferably to less than or equal to 7°C and even more preferably to less than or equal to 5°C.

In the example of Figure 1, conduit 136 is provided from the discharge of the marine vessel fuel cooling apparatus 100, and splitting off into: first distribution line 138 to the first cooling jacket 126; second distribution line 140 into second cooling jacket 132; and for a distribution line (not shown) into third cooling jacket 134. Thus, cooling medium 144, for example, chilled water, may be provided to the respective cooling jackets 126, 132, 134 to cool the low-flashpoint fuel component 108, whether or not it has been mixed with the ether component. It will also be appreciated that cooling medium may also be provided to any cooling jackets which have been installed around one or both of second on-board container 110 and its associated conduit 118.

Therefore, it will be appreciated that Figure 1 illustrates a marine vessel fuel cooling apparatus 100, the fuel comprising a low-flashpoint fuel component 108 in a container 106 or conduit 114, apparatus 100 comprising an absorption refrigeration cooler 102 configured to supply chilled liquid 144 to a cooling jacket 126, 132 of the container 106 or the conduit 114 to cool the low-flashpoint fuel component 108 to a temperature below a flashpoint of the low-flashpoint fuel component.

That is, there has been described a method of cooling a low-flashpoint fuel component 108 in the container 106 or a conduit 114, the cooling being effected using a marine vessel fuel cooling apparatus 100 comprising an absorption refrigeration cooler 102, the method comprising supplying chilled liquid 144 from the absorption refrigeration cooler 102 to a cooling jacket 126, 132 of the container or the conduit to cool the low-flashpoint fuel component 108 to a temperature below a flashpoint of the low-flashpoint fuel component.

It will be understood that these statements may apply equally to cooling of the ether component 112, and its associated container 110 and conduit 118. Indeed, and as noted above, the term low-flashpoint liquid may also encompass ethers.

20

Cool water circulates back from the cooling jackets to the chiller 102 on lines 145 to input 149. Hot air is exhausted on outlet 160 from the chiller 102.

Marine vessel engine 104 has a series of engine cylinders 146, four engine cylinders 146 being illustrated in the example of Figure 1. Each of these engine cylinders has a piston 147 operable therein, as is well-known. Marine vessel engine 104 comprises a fuel injector fuel line 148 which receives fuel mixture at inlet 124 of the marine vessel engine 104 from the delivery system 120, particularly conduit 122. The fuel injector fuel line distributes fuel mixture to each fuel injector 150 of each cylinder

146. Exhaust gases are exhausted from cylinders 146 on the lineout 152, these gases being exhausted to the exhaust 154 of marine vessel engine 104.

Note that it is possible for at least part of the exhaust gas to be directly injected to the air inlet manifold of the engine and/or the cylinder to facilitate combustion of the LFL fuel mixture at higher temperatures. This may be particularly beneficial if the ambient temperature is low.

A significant feature of the apparatus of Figure 1 is that a line (conduit, ducting or the like) 156 is provided to convey waste heat in the form of exhaust gases 158 from exhaust 154 of marine vessel engine 104 to marine vessel fuel apparatus 100 thereby to power the chiller, which as mentioned is an absorption refrigeration chiller 102 in the example of Figure 1. That is, the absorption refrigeration cooler 102 is configured to be powered by waste heat 158 from marine vessel engine 104.

As noted, this is a significant feature of the apparatus of Figure 1 and may be provided independently. In which case, Figure 1 illustrates a marine vessel fuel cooling apparatus 100, the fuel comprising a low-flashpoint fuel component 108, the apparatus comprising an absorption refrigeration cooler 102 configured to be powered by waste heat 158 from a marine vessel engine 104. Further, a corresponding method has been described. A method of operation of a marine vessel fuel cooling apparatus 100 for cooling a low-flashpoint fuel component 108, the apparatus comprising an absorption refrigeration cooler 102, where the method comprises powering the absorption refrigeration cooler 102 by waste heat 158 from a marine vessel engine 104.

These techniques may be equally applicable whether the marine vessel engine 104 is a main marine vessel engine or an auxiliary marine vessel engine (although it will be appreciated that less waste heat is generated from the latter type of engine).

In one preferred implementation, the absorption refrigeration cooler 102 is a lithium bromide water chiller. This chiller may use waste heat with no additional utility cost such as electricity to cool the fuel.

- 5 In at least one implementation, the low-flashpoint fuel component 108 is an alcohol. The alcohol may be methanol or, perhaps, ethanol, or a combination of one or both of these whether combined with other liquids (e.g. additives) or not.

- 10 In at least one implementation, the ether component 112 comprises dimethyl ether, diethyl ether or a combination of one or both of these, whether combined with other liquids or not.

- 15 There may be instances where further cooling of the low-flashpoint fuel component 108 is required. One particularly suitable technique for providing further cooling is to provide a second stage cooler comprising a compression refrigeration cooler. Such coolers are suitable for cooling below a temperature of 0°C. The second stage cooler is powered by electricity.

- 20 It will be appreciated that, in the illustrated system, various pumps and control valves and the like will be provided to effect and control the flow of the liquids, but these are omitted from Figure 1 for the sake of clarity.

- 25 As mentioned above, in particular with reference to Figure 1, engine 104 is the or one of the main diesel engines of a marine vessel. However, other arrangements are contemplated. For instance, the techniques disclosed herein are equally applicable for spark ignition engines. Further, the techniques are equally applicable for marine vessel auxiliary engines.

- 30 The system illustrated in Figure 1 comprises single tank containers 106, 110 for, respectively, the low-flashpoint liquid fuel component 108 and the ether fuel

- component 112. It will be appreciated that other arrangements are available. For example, multiple tanks may be provided for one or both of the low-flashpoint liquid fuel component 108 and the ether fuel component 112. These tanks may be arranged in arrays of multiple tanks , such as being laid up like ordinary ISO
- 5 containers on a container vessel, where each of the tanks is provided with cooling jackets and nitrogen blanket as described above. In such arrangements, a plurality of the tanks may be provided with chilled liquid from an on-board marine vessel fuel cooling apparatus.
- 10 The tanks may be fixed tanks or movable tanks. One particularly suitable form of tank is an ISO tank, especially when LFL fuel is not available as a bunker fuel at a port of call. Therefore, LFL fuel may be filled at a production plant and shipped to port, and then put on a ship. Movable tanks are connected into the chilled liquid distribution system using flexible pipes and couplings, preferably stainless steel and
- 15 neoprene rubber lined or other LFL resistant flexible piping.

It is generally preferable that the piping and tank fixtures and fittings used for implementation of the techniques disclosed herein are stainless steel, thermally insulated (thereby providing an additional safety factor to help to keep any low-

20 flashpoint liquids below their respective flashpoints). Thermally insulating materials which are particularly suitable include glass wool, rock wool, polyurethane foam , polystyrene foam etc. The piping and tank fixtures and fittings may also be electrically insulated.

- 25 It is not explicitly shown in Figure 1, but a diesel fuel tank (e.g. in bilge) may also be retained, so that diesel fuel may be used interchangeably with the LFL fuel mixture.

Referring now to Figure 2, the marine vessel fuel cooling apparatus is shown in more detail. As will be seen, absorption refrigeration chiller 102 comprises a driving heat

30 source coil 200. Also provided is a preheater (for example, an electric preheater) 202,

- and the heat exchanger 204. Heat exchanger 204 is arranged to receive waste heat 158 online 156 from the exhaust 154 of marine vessel engine 104. Preheater 202 is provided so that fresh air may be fed to the inlet 203 of the heat exchanger 204 in a cold condition, before sufficient waste heat energy is available from the marine
- 5 vessel engine at start-up. Once stable hot running conditions have been achieved, the preheater can be shut off. Heat exchanger 204 receives "fresh" cold air in 206, and discharges "fresh" hot air out 208 for the engine manifold. Typically, given the heat transfer taking place herein, temperature of the exhaust gases discharged from discharge 205 of the heat exchanger will be reduced somewhat in comparison to the
- 10 temperature of the gases at the heat exchanger inlet 203. For example, the temperature at inlet 203 of heat exchanger 204 may be expected to be in the region of around 400°C. The temperature of the exhaust gases at the discharge 205 of heat exchanger 204 may be expected to be in the region of around 300°C.
- 15 In an alternative arrangement, the preheater 202 may be installed after the heat exchanger and directly before the engine manifold.

A line (conduit, ducting or the like) 210 is provided to transport the exhaust gases 212 discharge from heat exchanger 204. These gases are conveyed to the absorption

20 refrigeration chiller 102, and circulated around hot air coil 200. It is expected that the principles of operation of the absorption refrigeration chiller 102 will be known, but in summary chiller 102 uses the heat from the exhaust gases 212 to provide the energy needed to drive the cooling process. Typically, the absorption cooling cycle can be described in three phases:

- 25
- Evaporation: A liquid refrigerant evaporates in a low partial pressure environment, thus extracting heat from its surroundings.
 - Absorption: The gaseous refrigerant is absorbed – dissolved into another liquid – reducing its partial pressure in the evaporator and allowing more liquid to evaporate.

- Regeneration: The refrigerant-laden liquid is heated, causing the refrigerant to evaporate out. It is then condensed through a heat exchanger to replenish the supply of liquid refrigerant in the evaporator.

5 Thus, the exhaust gases 212 are used to provide chilled water to be distributed on line 136 for cooling as described above with reference to Figure 1.

After circulating around hot air coil 200, the remaining exhaust gases 216, further cooled, are discharged 220 directly to atmosphere, say through the ship's chimney.

10 Alternatively, and to increase further operational efficiency, the gas can be first routed online 214 to another heat exchanger 218 prior to being finally exhausted 220 through the chimney of the marine vessel. Heat exchanger 218 can be provided for on-board heating, such as heating of water for general services such as bathing, cooking and central heating. That is, the absorption refrigeration cooler 102

15 comprises a hot air coil 200 for conveying exhaust gas from the marine vessel engine and wherein the absorption refrigeration cooler is configured to discharge the exhaust gas, after having passed through the absorption refrigeration cooler, for final exhausting through a chimney of the marine vessel.

20 Referring now to Figure 3, a second fuel mixing apparatus will be described. Apparatus 300 comprises a first on-board container 306 for containing a low-flashpoint fuel component. As before with reference to Figure 1, the low-flashpoint fuel component may be or comprise an alcohol such as methanol or ethanol. Apparatus 300 also comprises a second on-board container 310 for the ether fuel

25 component. Again, the ether fuel component may comprise, for example, DME or DEE. First and second on-board containers may be buffer or storage tanks.

Each of containers 306, 310 feed into mixer 316 (in this example, a mixing pipes system), where these fuel components are thoroughly mixed together for supply to

30 the fuel injector of a marine vessel engine 304. In this example, each of

the containers 306, 310 feed into mixer 316 through a series of piping fittings, including check valves 360, flow indicators 362, solenoid valves 364 and pumps 366. Check valve 368 is provided on the downstream side of mixer 316, and upstream of the marine vessel engine 304 fuel injector. The check valves ensure one way flow of the fuel (components) only.

With reference to Figure 4, positioning of an on-board fuel container will now be described. As illustrated in Figure 4, a marine vessel 400 comprises a navigational bridge 402. A blast resistant wall or partition 404 is provided aft of navigational bridge 402. In some arrangements, the blast resistant wall or partition may be an integral part – i.e. rear wall – of the navigational bridge itself. One or more ISO tank container is provided aft of the wall/partition 404, the tank container being configured to store a fuel component, such as the low-flashpoint liquid fuel component or the ether fuel component described above with reference to Figure 1. Thus, the or each ISO tank container 406 is adapted for installation, or intended to be installed, aft of the main navigational bridge 402, and optionally above the main engine room. Therefore, the aft wall of the navigational bridge and/or the bottom plate of the tank, and/or the deck of the ship where the LFL fuel tanks are placed upon and/or the roof of the engine room may be blast resistant. In one arrangement, the tank is provided around 1m to 1.2m from the wall/partition 404. The method of installation comprises installing the ISO tank container 406 such that the blast resistant wall 404 or partition is disposed between the ISO tank container 406 and the navigational bridge. The or another blast resistant wall or partition may be positioned between the ISO tank container and the engine room, so that in the event of there being an explosion, the navigational bridge, accommodation areas and engine rooms will not be damaged seriously. The ISO tank container is preferably cooled with chilled liquid generated, for example, in accordance with the principles described above with reference to Figure 1. The ISO tank container may also be insulated, and may have a jacket or a cooling coil in the tank for receiving chilled liquid.

Thus, Figure 4 illustrates an important aspect of the currently-disclosed techniques. An ISO tank container 406 configured as a marine vessel 400 fuel tank is configured to store a low-flashpoint liquid fuel component. Likewise, there is disclosed a
5 method comprising installing, on a marine vessel 400, an ISO tank container 406 configured to store a low-flashpoint liquid fuel component.

ISO tank container 406 can be installed in a number of arrangements, including being installed exposed to the environment, or installed in a ventilated space 408.

10 Ventilated space 408 may be, for example, an open enclosure, or a sealed or partially sealed enclosure having a ventilator 410. Ventilator 410 is provided for ventilation of low-flashpoint fuel vapour. If the low-flashpoint fuel vapour is heavier than air, then ideally ventilator 410 is installed at or near floor level of space 408. Space 408 may also be cooled, such as through standard air conditioning techniques or, for example,
15 using chilled water produced using the system of Figures 1 and 2.

Vapour detectors can be provided at the tank location, whether installed in an enclosed space or in the open air for detecting concentration levels of around 200 PPM. Fire detection and prevention equipment can also be provided, including for
20 example an automatic fire extinguishing foam injector arranged to inject foam into the fuel tank directly in abnormal or dangerous conditions. The fire suppression systems may be specifically designed depending on the precise fuel component being used. For instance, they may be specially designed to prevent methanol fire. Methanol fire can be extinguished by water once the methanol content falls below
25 20% in mixture with water, and since methanol is highly biodegradable, spillage/leakage will not cause ecological disasters. Alcohol resistant aqueous film foams may be used as an alternative to water.

The ISO tank container 406 may be insulated, having thermal insulation and/or
30 electrical insulation. The ISO tank container may preferably have a nitrogen blanket.

The ISO tank container may be a fixed tank or a movable tank. The container 406 may be adapted for installation, or intended to be installed, on or above deck of the marine vessel 400.

5

Multiple tanks may be provided, and arranged in arrays. Blast resistant walls may also be installed in between tanks.

The tanks may be provided with instrumentation including temperature reading,
10 level reading, and pressure reading instruments. Ruptured discs may also be installed. All electrical equipment may be suitably rated, such as explosion proof or intrinsically safe.

And while Figure 4 illustrates tanks installed above the main deck of the marine
15 vessel 400, the or each tank can be situated in other ways. For example, they can be below deck such as in the tank room. In a preferred arrangement, the tanks are placed in the bulkhead (which in this context refers to compartments present in the whole of the ship, separated by vertical walls, and these may be blast proof). Cooling jackets may be installed around the tanks.

20

In another arrangement, the tanks are installed in the rear of the ship, above deck.

It will be appreciated by those skilled in the art that the invention has been described by way of example only, and that a variety of alternative approaches may
25 be adopted without departing from the scope of the invention, as defined by the appended claims.

It will be understood that the invention disclosed and defined in this specification extends to all alternative combinations of two or more of the individual features

mentioned or evident from the text or drawings; all of these different combinations constitute various alternative aspects of the invention.

Claims

1. A marine vessel fuel cooling apparatus, the fuel comprising a low-flashpoint fuel component in a container or a conduit, the apparatus comprising an absorption
5 refrigeration cooler configured to supply chilled liquid to a cooling jacket of the container or the conduit to cool the low-flashpoint fuel component to a temperature below a flashpoint of the low-flashpoint fuel component.
2. The apparatus of claim 1, wherein the absorption refrigeration cooler is
10 configured to be powered by waste heat from a marine vessel engine.
3. A marine vessel fuel cooling apparatus, the fuel comprising a low-flashpoint fuel component, the apparatus comprising an absorption refrigeration cooler configured to be powered by waste heat from a marine vessel engine.
15
4. The apparatus of any preceding claim, wherein the absorption refrigeration cooler is a lithium bromide water chiller.
5. The apparatus of claim 4, wherein the absorption refrigeration cooler
20 comprises a hot air coil for conveying exhaust gas from the marine vessel engine, and wherein the absorption refrigeration cooler is configured to discharge the exhaust gas, after having passed through the absorption refrigeration cooler, for final exhausting through a chimney of the marine vessel.
- 25 6. The apparatus of any of claims 1 to 3, wherein the absorption refrigeration cooler is configured to be powered by waste heat from a main marine vessel engine.
7. The apparatus of any of claims 1 to 3, wherein the absorption refrigeration cooler is configured to be powered by waste heat from an auxiliary marine vessel
30 engine.

8. The apparatus of any of claims 1 to 3 configured to supply chilled liquid at a temperature less than or equal to 11°C , preferably less than or equal to 9°C, more preferably less than or equal to 7°C, and even more preferably less than or equal to 5°C.
- 5
9. The apparatus of any of claims 1 to 3 configured to supply chilled liquid to cool a fuel comprising a low-flashpoint fuel component which is an alcohol.
10. The apparatus of any of claims 1 to 3 configured to supply chilled liquid to cool a fuel comprising dimethyl ether.
- 10
11. The apparatus of any of claims 1 to 3 further comprising a second stage cooler comprising a compression refrigeration cooler.
- 15
12. On-board marine vessel engine fuel mixing apparatus, the fuel comprising a low-flashpoint fuel component and an ether component, the apparatus being arranged to receive the low-flashpoint fuel component from a first on-board container and to receive the ether component from a second on-board container, the apparatus comprising a mixer for mixing the low flashpoint fuel component and the ether component to produce a marine vessel engine fuel mixture.
- 20
13. The apparatus of claim 12 , further comprising a delivery system for delivering the marine vessel engine fuel mixture to a fuel injector of a marine vessel engine.
- 25
14. An ISO tank container configured as a marine vessel main engine fuel tank, and configured to store a low-flashpoint liquid fuel component.

15. The ISO tank container of claim 14, wherein the ISO tank container comprises a cooler for receiving chilled liquid, and for cooling the low-flashpoint liquid fuel component.
- 5 16. The ISO tank container of claim 14 or claim 15, wherein the ISO tank container comprises a nitrogen blanket.
17. The ISO tank container of claim 14 or claim 15, wherein the ISO tank container is adapted for installation, or intended to be installed, aft of the main
10 navigational bridge.
18. The ISO tank container of claim 14 or claim 15, wherein the ISO tank container is a movable tank adapted for installation, or intended to be installed, on or above deck of a marine vessel.
- 15
19. A method of cooling a low-flashpoint fuel component in a container or a conduit, the cooling being effected using a marine vessel fuel cooling apparatus comprising an absorption refrigeration cooler, the method comprising supplying chilled liquid from the absorption refrigeration cooler to a cooling jacket of the
20 container or the conduit to cool the low-flashpoint fuel component to a temperature below a flashpoint of the low-flashpoint fuel component.
20. A method of operation of a marine vessel fuel cooling apparatus for cooling a low-flashpoint fuel component, the apparatus comprising an absorption
25 refrigeration cooler, the method comprising powering the absorption refrigeration cooler by waste heat from a marine vessel engine.