

The INSTITUTE of MARINE ENGINEERS

Transactions

1950, Vol. LXII, No. 10

Marine Gassing and Fire and Explosion Hazards*

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INTRODUCTION

Fires on board ship can be extremely disastrous both from the point of view of damage resultant and loss of life. Marine fires can be divided up into the four following types:—

- (a) Explosions and resultant fires
- (b) Oil or petrol fires
- (c) Dry dock fires
- (d) Passenger liner fires.

Figs. 1, 2 and 3, Plate 1, show the result of a petrol vapour explosion on board the *Pan Massachusetts*. Fig. 4, Plate 2, gives an impression of the fury of an oil fire and Fig. 5, Plate 2, illustrates vividly a petrol fire. A dry dock fire which started in a blacksmith's shop is seen from the air in Fig. 6, Plate 3. Fires on passenger liners are illustrated in Figs. 7 and 8, Plate 4.

These illustrations show very clearly how disastrous and costly such incidents can be, but it will be agreed that the most spectacular ones, as illustrated, are not necessarily the most frequent. However, almost every day somewhere an outbreak of fire occurs in the cargo or bunker coal in a ship. Examples of these have not been illustrated but they account to a large degree for marine loss.

FIRE LEGISLATION AND RECOMMENDATIONS

This section of the paper discusses the legislation and recommendations relating to:—

- (a) The ship, its condition and equipment; the cargo and the duties and liabilities of the ship owner as carrier to the cargo owner, and conversely of the cargo owner to the carrier.
- (b) The duties of the ship or carrier whilst in harbour when carrying:—
 - (i) Explosives.
 - (ii) Petroleum oil or calcium carbide.
 - (iii) Coal.
- (c) When part or whole of the cargo is dangerous goods the markings, stowage and type of container required for that cargo.
- (d) Regulations and requirements in connexion with the

repair of ships, especially those which have carried petroleum oil or a similar substance either as cargo or as bunkers.

The ship, its condition and equipment

Broadly speaking, under the Carriage of Goods Act, 1924, the carrier has

- (a) To make his vessel sea-worthy;
- (b) To man, equip and supply the ship properly;
- (c) To make the holds, refrigerating and cool chambers and all other parts of the ship in which goods are carried, fit and safe for their reception, carriage and preservation.

Furthermore, he has to see that his cargo is correctly identified, tallied or weighed and that it is preserved in good order and condition. Similarly, it is the duty of the person who owns or delivers the cargo to the ship to see that it is appropriately labelled or packed and that it has no dangerous vices. Alternatively, if the cargo is dangerous then this must be declared to the carrier who may act accordingly. It will be realized that certain types of cargo of particularly dangerous characteristics, explosives for instance, may be carried only in limited quantity in particular types of ships as indicated in S.R. and O. 1942, No. 1382, "Explosive Substances".

Table 1 indicates the quantity and type of fire fighting equipment with which various classes of ships should be provided.

The duties of the ship or carrier whilst in harbour

Given below are the duties of the ship or carrier whilst in harbour when carrying:—

(i) *Explosives*. S.R. and O. No. 1181 (1939) "The Government Explosives in Harbour Order, 1939" indicates that, irrespective of any previous restrictions the provisions of this order shall apply to the loading and unloading, stowage and conveyance within all harbours in the United Kingdom of ammunition and explosives held for the service of a Government Department, and that the representative of the Government Department shall give written notice to the harbour master of the group, number and quantity of such explosive and of the time and place where it is intended to carry out such storage, shipment,

* This paper, as published, is in a slightly altered form as read before the Cardiff Local Section on 21st November 1949.

Marine Gassing and Fire and Explosion Hazards

TABLE 1. QUANTITY AND TYPES OF FIRE FIGHTING

Class	Description	Hydrant points	Portable fluid extinguishers	Carbon-di-oxide or similar smothering gas
<i>Passenger ships</i>				
A	International and home trade as distinct from classes B and C.	(1) Passenger and crew accommodation (at least two for every water-tight compartment). (2) Cargo spaces (at least two for every cargo space). (3) Machinery and bunker spaces (at least two into any part of coal bunkers, boiler rooms and machinery spaces).	As per Board of Trade requirements in (1) Passenger and crew accommodation. (2) Boiler rooms and machinery spaces.	If ship 1,000 gross tons and over—CO ₂ or smothering gas can be released by means of permanent piping system into any compartment carrying cargo. Note: Steam can be used as a substitute in some cases.
B1	Short excursion to sea, 1st April to 31st October. Daylight and fine weather.	(1) Passenger and crew accommodation (at least one hydrant). (2) Store rooms, etc. (at least one hydrant). (3) (a) If coal fired, at least one hydrant into coal bunker, boiler room and machinery spaces. (b) If oil fired, at least two hydrants into boiler room and machinery spaces.	As per Board of Trade requirements in (1) Passenger and crew accommodation.	
B2	Plying in partially smooth water.	As for class B.1. but if not oil fired only one jet into coal bunker, boiler room and machinery spaces.	As for class B.1.	
B3	Plying in smooth water, estuaries, and lakes.	As for class B.2.	As for class B.1.	
B4	Plying in smooth water, rivers and canals.	As for class B.2.	As for class B.1.	
B5	Steam launches, motor boats plying short distance to sea.	As for class B.1. if oil fired.		
C1	Open motor ships plying on estuaries and lakes.	Nil.		
C2	Open motor ships plying on rivers and canals.	Nil.		
C3	Motor ships plying for short distances to sea.	Nil.		

Marine Gassing and Fire and Explosion Hazards

EQUIPMENT CARRIED ON VARIOUS TYPES OF SHIP

Sprinklers and sand or other dry extinguishers	Foam portable extinguishers	Static foam	Pumps	Water service pipes and hydrants	Fire hose	Smoke helmets and safety lamps
<p>If the ship is oil fired, sprinklers must be provided. Similarly at least 10 cu. ft. of sand or similar smothering dry material in each firing space.</p> <p>Note: Motor passenger ships shall be provided in each machinery space with at least one 10-gallon foam extinguisher and one 2-gallon foam extinguisher for every 1,000 b.h.p. of the engines. Not less than two and not more than six of these 2-gallon extinguishers shall be provided.</p> <p>Wherever a donkey boiler is situated in a machinery space, instead of a 10-gallon extinguisher a 30-gallon extinguisher with hose shall be installed.</p> <p>War time provision. Spraying arrangements to deal with incendiary bombs must be fitted.</p>	<p>If oil fired at least two portable extinguishers in each boiler and machinery space, acting as part of fuel installation.</p>	<p>If oil fired, sufficient to cover whole of each boiler room to a depth of 6 inch or any space containing fuel units or settling tanks.</p> <p>Note: 30-gallon foam extinguishers with hose for each boiler room.</p>	<p>Up to 4,000 tons: two fire pumps. Over 4,000 tons: three fire pumps, also one or two portable emergency fire pumps for engine and boiler rooms.</p>	<p>As per Board of Trade requirements.</p> <p>Note: War time provisions.</p> <p>(a) one portable electric drill for gaining access in an emergency through decks and bulkheads, etc.</p> <p>(b) one stirrup pump and two buckets for every 100 feet registered length.</p> <p>(c) sand container and long handled scoops as per requirements.</p>	<p>As per Board of Trade requirements.</p>	<p>At least two of each.</p>
<p>If oil fired, sprinklers must be provided for machinery and bunker spaces. Similarly, 10 cu. ft. of sand or other dry material for machinery and bunker spaces.</p>	<p>If oil fired, two portable foam extinguishers in each boiler room and machinery space forming part of oil fuel installations.</p>	<p>As for class "A," also at least two 10-gallon foam extinguishers with hose in boiler room and oil fuel units.</p> <p>Motor ships have additional Board of Trade foam extinguisher requirements.</p>	<p>At least one fire pump, but if oil fired or motor ship, two pumps.</p>	<p>As for class A.</p>	<p>As for class A.</p>	
<p>If oil fired, as for class B.1.</p>	<p>If oil fired, as for class B.1.</p>	<p>If oil fired, one 30-gallon foam extinguisher with hose for boiler room and oil fuel units.</p> <p>For motor ships see class B.1.</p>	<p>As for class B.1.</p>	<p>As for class A.</p>	<p>As for class A.</p>	
<p>If oil fired, as for class B.1.</p>	<p>If oil fired, as for class B.1.</p>		<p>As for class B.1.</p>	<p>As for class A.</p>	<p>As for class A.</p>	
<p>If oil fired, as for class B.1.</p>	<p>If oil fired, as for class B.1.</p>		<p>As for class B.1.</p>	<p>As for class A.</p>	<p>As for class A.</p>	
<p>If oil fired, as for class B.1.</p>	<p>If oil fired, as for class B.1.</p>	<p>As for class B.1.</p> <p>For motor ships see class B.1.</p>	<p>As for class B.1.</p>			
<p>Receptacle containing sand or other dry fire fighting material also buckets and boilers to Board of Trade requirements.</p>	<p>Open motor ships</p> <p>(a) Less than 30 feet long must carry two 1-gallon C.T.C. and one 1-gallon foam extinguisher.</p> <p>(b) Between 30 and 50 feet long must carry three 1-gallon C.T.C. and two 1-gallon foam extinguishers.</p> <p>(c) Over 70 feet long, as per Board of Trade Directions.</p>					
<p>As for class C.1.</p>	<p>Decked motor ships</p>	<p>One fire pump.</p> <p>One fluid fire extinguisher in each passenger compartment.</p>				
<p>As for class C.1.</p>						

Marine Gassing and Fire and Explosion Hazards

TABLE 1. (CONT.) QUANTITY AND TYPES OF FIRE FIGHTING

Class	Description	Hydrant points	Portable fluid extinguishers	Carbon-di-oxide or similar smothering gas
<i>Non-passenger ships—tramps, merchantmen, etc.</i>				
D1	Foreign going steamships and motor ships.	If over 2,000 tons—at least two hydrants for all compartments between bulkheads. If under 2,000 tons—one hydrant.	Officers and crew accommodation—one per cabin. In any case a minimum of three.	If 2,000 tons and over CO ₂ or similar smothering gas can be released by means of permanent piping system into any cargo hold. Alternatively steam may be used.
D2	Home trade steamships and motor ships of 1,000 tons gross and over.	As for class D.1.	As for class D.1.	
E	Home trade steamships and motor ships of less than 1,000 tons gross. Including auxiliary motor ships.		Three to cover officers and crew accommodation. 500-1,000 tons : three extinguishers.	As for class D.1.
<i>Special requirements at Dictation of Ministry of War Transport (Shipping).</i>				
F	Whale factory ships and special service ships requiring exceptional provisions.			
G	Small coasting steamers, steam fishing vessels and fishing carriers.†		Two portable chemical extinguishers.	
H	Foreign going sailing ships.		One chemical extinguisher in each accommodation space.	
I	Home trade sailing ships, sailing fishing vessels and fish carriers.			

Note. Definition as to what comprises accommodation between water-tight bulkheads, cargo spaces, machinery and bunker spaces, water service pipes, hoses, pumps, arrangements for injecting smothering gases or steams, fluid extinguishers, smoke helmets, safety lamps, etc. as indicated in "Instructions as to the Survey of Passenger Steamships" Vol. 1; also Circular 1697 on "Instructions as to the Survey of Passenger Ships engaged in special trades in the Far East".

Marine Gassing and Fire and Explosion Hazards

EQUIPMENT CARRIED ON VARIOUS TYPES OF SHIP

Sprinklers and sand or other dry extinguishers	Foam portable extinguishers	Static foam	Pumps	Water service pipes and hydrants	Fire hose	Smoke helmets and safety lamps
If oil fired, at least 10 cu. ft. of sand or other dry material in each firing space; also fire hose with sprinkler attachment for spraying water on oil in boiler and machinery spaces. If mixture of coal and oil is afire—as above.	If oil fired, 2 portable foam extinguishers at each firing space. Suitable quantity of foam extinguishers in each firing space and need not exceed 10 gallons. If mixture of coal and oil fired—as above. One or more portable 30-gallon foam extinguishers to be provided in boiler and machinery spaces as well as steam points. Motor ships must also have one or more with a maximum of six 2-gallon foam extinguishers provided in machinery spaces.	Sufficient to cover whole area of boiler room to a depth of 6 inch. Note: Steam or other smothering gas may be used as alternative.	If over 2,000 tons: two power pumps with hoses. If under 2,000 tons: one power pump. Spray nozzles for dealing with incendiary bombs in each case. If over 4,000 tons: two portable power pumps. If under 4,000 tons: one portable power pump.	One stirrup pump and two buckets for every 100 feet registered length, also sand containers and scoops to requirements.		1 approved breathing apparatus, safety lamp and hatchet, portable electrical drilling machine, one smoke helmet, twelve fire buckets.
As for class D.1.	As for class D.1.	As for class D.1.	As for class D.1.	As for class D.1.		As for class D.1.
If oil fired, as for class D.1.	If oil fired as for class D.1., if only 500-1,000 tons. Motor ships 150-500 tons require two portable extinguishers also sand as above. Less than 150 tons: one hydrant, one pump with hose, two fire buckets and hatchet, two portable foam extinguishers, also sand, etc.	As for class D.1.	500-1,000 tons: one power pump and hose to cover every part of ship. 150-500 tons: one power pump. Less than 150 tons: one power pump.	500-1,000 tons: two stirrup pumps, four buckets and sand container with scoop. 150-500 tons: two stirrup pumps, four buckets and container.		500-1,000 tons: safety lamp and hatchet; 150-500: four fire buckets and hatchet; 150 and under: three buckets and hatchet.
	If oil fired, two foam extinguishers, sand and scoop.		One power pump and hose.			Four fire buckets.
			Hand pump and fire hose.			One smoke helmet, six fire buckets.
			If over 100 tons gross: one pump with suction delivery, hose and fittings.			Four fire buckets.

Main references

Merchant Shipping (fire appliances) SR + 0 1932 No. 1055
 Merchant Shipping (fire appliances) SR + 0 1940 No. 2170
 Board of Trade Notice No. M.140. Notice to shipowners, shipbuilders and masters.

*See Board of Trade Notice No. M.146 notice to shipowners, shipbuilders and masters.
 †Notice to owners and skippers of fishing boats and other small vessels fitted with internal combustion engines.

Marine Gassing and Fire and Explosion Hazards

loading and unloading, etc., and that the master of every vessel containing or conveying explosives as cargo on loading or unloading explosives in any harbour shall display by day a red flag and by night a red light at the masthead or if the vessel has not a mast, on a staff. This light is in addition to any navigation lights which may be carried.

Hose shall be rigged and all other available ship and shore fire fighting appliances shall be kept ready during the operation of loading and unloading explosives, etc.

(ii) *Petroleum Oil or Calcium Carbide.* S.R. and O. No. 1180 "The Petroleum Spirit in Harbour Order, 1939" qualifies the conditions relating to a vessel carrying petroleum spirit in much the same way as the carriage of explosives has already been qualified. Written notice shall be served on the harbour master and such ships shall display by day a red flag with a white circular centre and by night a red light at the mast-head or where it can best be seen but in any case at a height of 20 feet above deck.

This latter order includes a provision to the effect that pipes, joints, flexible hoses and other appliances used in the loading and unloading of petroleum spirit in bulk shall be adequately earthed to prevent accumulation of a dangerous static charge of electricity.

A further provision is that iron or steel tools or other equipment capable of causing a spark shall not be used for the purpose of opening or closing hatches, tank lids, etc., of a petroleum ship.

All ships and shore fire fighting appliances capable of extinguishing a petroleum fire shall be kept ready during the operating of loading and unloading petroleum spirit.

(iii) *Coal.* Ministry of War Transport Circulars Nos. 1641 and 1655 are of interest in connexion with ships which load coal as cargo in that they refer to the fact that when loaded, coal by virtue of breakage which it experiences may release a gas, methane, within the containing hold where the gas may accumulate under the deck above to such an extent that if ignited an explosion may take place. The circulars therefore call for ventilation of the holds whilst the vessel remains in harbour and indeed at periodic intervals after it has put to sea.

When part or whole of the cargo is dangerous goods

"Dangerous goods" are, of course, substances which have inherent vices that may lead to disaster if not especially catered for. Probably the primary reference to the law on such goods lays in the Carriage of Goods Act, 1924, where it is indicated that goods of an inflammable, explosive or dangerous nature, to the shipment of which the carrier has not consented with knowledge of their character, may at any time before discharge be landed at any place or rendered innocuous by the carrier without compensation and the shipper of such goods will be liable for all damages and expenses directly or indirectly arising from such shipment.

If any such goods are shipped with knowledge and consent, and become a danger to the ship or cargo they may in like manner be destroyed or rendered innocuous by the carrier without liability on the part of the carrier except to general average, if any.

Nevertheless, in spite of the above, a carrier may make an agreement in which responsibility and liability of the carrier for such goods can be shared or apportioned providing it is not contrary to public interest and policy and where the type of goods is such as to justify especial agreement and so on.

Probably the best understanding of the nature and type of goods which are to be regarded as dangerous goods is indicated in the Board of Trade publication "Carriage of Dangerous Goods and Explosives in Ships". Figs. 9 and 10, Plate 5, give some idea of how the containers for such goods shall be labelled, while given below is a summary of the groups of dangerous goods and their properties. The names of the individual substances or goods falling within the various groups may be obtained by referring to the actual memorandum or other appropriate authority.

Classification of hazardous chemicals

(1) Explosives may be:—

- (a) Detonants exploded by shock, heat or friction.
- (b) High explosive exploded by detonants or by heat (in bulk).
- (c) Propellants exploded by heat when confined, otherwise incendiary.
- (d) Pyrotechnics, war gases, etc.

(2) Compressed, dissolved, permanent and liquified gases may be:—

- (a) Inflammable. The most hazardous have low spontaneous ignition temperatures.
- (b) Supporters of combustion. These increase the degree of inflammability of combustible substances.
- (c) Toxic. Anaesthetics, asphyxiants, poisons, etc.
- (d) Inert (to fire).

All types of gases present danger of explosion by expansion when confined in cylinders and subjected to heat.

It is important to know whether a specific gas is heavier or lighter than air in order to determine the probable location of danger in partially confined spaces.

(3) Substances reacting dangerously with air and/or water may evolve:—

- (a) Inflammable vapours (which may ignite spontaneously).
- (b) Toxic vapours.
- (c) Corrosive vapours or residues.

(4) Substances evolving inflammable vapours which may be:—

- (a) Highly inflammable if of flash point less than 73 deg. F.
- (b) Inflammable if of flash point 73/150 deg. F.
- (c) Combustible if of flash point above 150 deg. F.

It is important to know whether specific inflammable liquids are miscible with, or alternatively, heavier or lighter than water, since this may determine the effectiveness of water as a fire extinguishing medium.

(5) Corrosive substances which may be acids, caustics, etc.

Note: Acids + metals = hydrogen + etc.

(6) Poisonous substances

Assume any substance to be poisonous unless the contrary is known.

(7) Substances of specific fire hazards, which may be:—

- (a) Oxidizing agents or strong supporters of combustion.
- (b) Liable to spontaneous combustion.
- (c) Readily combustible substances.

Note: Solids may be correlated with liquids thus:—

Solid	Hazard	Liquid
Tinder (high surface area to bulk)	Highly inflammable	Flash point below 73 deg. F.
Kindling (medium surface area to bulk)	Inflammable	Flash point 73/150 deg. F.
Bulk fuel (low surface area to bulk)	Combustible	Flash point above 150 deg. F.

Regulations and requirements in connexion with the repair of ships, especially those which have carried petroleum oil or the like either as cargo or as bunkers

Broadly speaking, a ship when under repair is a factory and so the duty of the repairer is, first of all, to comply with the Factory Act of 1937. With regard to toxic and inflammable hazards it should be noted that Section 4 stipulates that the factory owner shall provide adequate ventilation in each work-room and shall take all practical steps to remove fumes and dust which may be injurious to life.

Section 27, which relates to confined spaces, stipulates that unless it has been ascertained by a suitable test that the space is free from dangerous fumes, then the person entering shall wear breathing apparatus and a safety belt, etc.

Section 28 requires that all means of igniting inflammable vapours and dusts shall be eliminated or properly enclosed,

whilst it also provides that plant, tanks or vessels on which repairs involving hot work are required shall not be the subject of hot work until they have been cleaned and gas-freed or the contents otherwise rendered non-inflammable.

Ships which have carried oil or spirit, either as cargo or as bunkers, are likely to present inflammable vapour hazards. The regulations governing repair work on such ships should therefore be exacting. This actually is the case, as in the Shipbuilding Regulations, 1931, Regulation 27 states that only properly approved electric lamps and no sources of naked lights or sparks shall be taken into any oil tank until a "Certificate of Test" has been obtained.

An oil tank is defined as any tank, compartment or space which contains, or has contained, any oil or any sludge, deposit or residue therefrom so that, presumably, a passage-way in which has been stored drums of oil becomes an oil tank within the meaning of the Regulations. In practice it is not always appreciated that a "Certificate of Test" is a positive document, i.e., it should only indicate the absence of inflammable vapours, it should not be issued to indicate their presence. This means that, especially when taken in conjunction with Regulation 28, a "Certificate of Test" cannot be issued in respect of any oil tank in which there remains any inflammable vapour, any sludge or deposit therefrom. Such an interpretation carries a wide significance as it would appear that, even if a tank contains only the most minute trace of inflammable vapour (a concentration, say, which is well below the lower limit of inflammability of that vapour) or the smallest patch of oil or sludge, then, since a "Certificate of Test" should not be issued for that space, no hot work can be done there.

Regulation 29 is even more interesting, since it states that even after a "Certificate of Test" has been obtained for a particular oil tank, no lamps other than suitably enclosed safety lamps or electric lamps shall be used, and no rivet or other fires, and no naked lights shall be taken into the tank unless these prohibitions can be dispensed with on the written authority of a competent analyst who is the only person allowed to issue the "Certificate of Test". The implication here is that no hot work of any kind shall be permitted in, or on, an oil tank which has been gas-freed and cleaned until a competent analyst has satisfied himself that there are no nearby dangers in adjacent tanks or spaces. It has been found that these regulations work well in practice once they have been understood, but that there is often a confusion as to their meaning, and it is suggested that the compilers of factory acts and other regulations would do well to standardize their use of definitions which apply to "safety lights and torches". Such official expressions as "properly enclosed electric lamp" and "suitably enclosed safety lamps or electric lamps" are not as precise as they might be.

An interesting provision of these regulations relates to inflammable liquids of flash points below 73 deg. F. Such liquids would, of course, include petrol and benzene. It is to the effect that where the oil last contained in an oil tank was of flash point below 73 deg. F. a fresh "Certificate of Test" shall be obtained daily before work is commenced and if, during the course of the work, any pipe or joint in (and, presumably, on) an oil tank is broken, or there is any other risk of oil or oil-vapour entering it, work therein shall be suspended until a fresh certificate has been obtained. In other words, in spite of the fact that an oil-tank may have been clean and gas-free for say, twenty days, if hot work is to be done on the twenty-first day, then a fresh certificate is required before that work commences. Such a requirement, although presumably too exacting in theory, has been found in practice to be quite justified, and indeed unions in many places have sought to improve on it by insisting that the flash point of the oil is immaterial, and even if it is as high as that of lubricating oil there is still the need for a fresh certificate daily.

The same regulations also have a somewhat insignificant requirement relating to the possible presence of toxic fumes in confined spaces in ships. In Regulation 18, it is stipulated that there shall be adequate ventilation so as to remove injurious

fumes from confined or enclosed spaces, especially where painting is being done (the hazard being related to the solvent thinner of the paint); or where high temperature work such as oxy-acetylene burning or electric welding is being conducted (the hazard being related to the production of nitrous fumes by the oxidation at high temperature of atmospheric nitrogen); or where rivet fires (which are a source of carbon monoxide) are used.

It is interesting to note that "Certificates of Exemption No. 14" which relates to the "Ship Building Regulations", indicates that external welding may be executed upon a tank which still contains oil provided an analyst's certificate is available which indicates that oil has a flash point of above 150 deg. F. and that the external welding shall be conducted at least 1 foot below the level of the oil inside.

It must be emphasized that the author does not claim that his interpretation and abstractions from the relevant laws and regulations are either complete or wholly accurate. He is merely attempting to reveal the pattern or plan which exists in what might be called marine protective and precautionary legislation.

METHODS OF DEALING WITH MARINE GASSING, FIRE AND EXPLOSION HAZARDS AND RELEVANT CONSIDERATIONS

This section of the paper is presented under the following headings:—

(a) Fire hazards:—

- (i) Considerations relating to fire extinguishers and their practical application;
- (ii) Types of fires including those involving spontaneous combustion, grain, fibre, textiles, oil fires, etc.;
- (iii) Fires involving dangerous goods;
- (iv) Passenger liner hazards.

(b) Explosion hazards.

(c) Gassing hazards.

(a) Fire hazards

A ship can be regarded as an island in an unfriendly element. If the island is set on fire the situation becomes grim in contrast to land fires, for the crew cannot readily withdraw from the danger zone as they could on land. On a ship, too, manoeuvring space is small and usually full of obstacles whilst the fire itself may be situated in some inaccessible space in a lower hold. Naturally, fire fighters on ships are never short of water with which to fight the fire, but this particular fire fighting medium may introduce its own complications and disadvantages. Its nature is such that it may cause considerable damage to cargo, whilst it can endanger the safety of the ship every bit as much as the fire with which it contends. This point will be discussed later.

(i) Considerations relating to fire extinguishers and their practical application

Fire Extinguishers. Since fire is a process of oxidation which is not initiated and sustained until the combustible has been heated to its ignition temperature, the main principles of fire extinction must be:—

To reduce the temperature of the combustible to below its ignition temperature.

To cut off the supply of oxygen to the combustible (sometimes known as "starving" or "asphyxiating").

To add an inert or incombustible material to the combustible until the latter is eventually rendered incombustible.

To add an "anti-oxidant" to the atmosphere surrounding the fire until combustion can no longer take place therein.

The most common agent for dealing with fire is water, although, as will be discussed later, it is not universally applicable. Water usually achieves its purpose by means of:

Reducing the temperature of the combustible to below ignition temperature due to its cooling ability.

Cutting off the supply of oxygen to the combustible since the heat of the fire serves to vaporize some of the water which

Marine Gassing and Fire and Explosion Hazards

then, as steam, reduces the oxygen content in the surrounding atmosphere until it will eventually no longer support combustion, and

By wetting the combustible, thus serving to dilute it to an incombustible state. So far it is not claimed that water has any effects as an anti-oxidant.

Extinguishers now used fairly widely are:

Water in liquid bulk.

Water as fog (i.e., in the form of a very fine mist or spray).

Water as steam.

Carbon dioxide (asphyxiant gas).

Sulphur dioxide (asphyxiant gas).

Carbon tetrachloride (asphyxiant gas).

Methyl bromide (asphyxiant gas).

Foam.

Miscellaneous powders and patent compositions including earth, ashes, graphite, etc.

It is convenient to treat combustibles as solids, liquids or gases.

Solid Combustibles. For solid combustibles, water in bulk is generally an efficient fire extinguisher, except in the case of such combustibles as metals (which have high burning temperatures), baled fibres, and chemicals such as calcium, sodium, potassium and barium. If water is discharged on to burning metals explosive effects take place, incandescent metal is hurled far and wide, so that the fire is spread instead of confined. Dry powders, especially graphite, are suitable for dealing with small metallic fires. In the case of baled fibres, unless a suitable wetting agent is previously added to the water (known as "wet water"), it fails to wet the fibres, and attempts to extinguish the fire are unsuccessful.

When water is used upon some chemicals, they either explode or are aggravated by its use, or alternatively, yield objectionable products of decomposition.

TABLE 2. SUITABILITY OF LIQUID CHEMICAL EXTINGUISHERS FOR ALL CLASSES OF FIRES.

	Class 1 Soda and acid Subdivisions A and B	Class 2 Compressed gas	Class 3 Foam	Class 4 Carbon Tetrachloride Subdivisions C and D	Class 5 Methyl bromide
Class A fires: wood, textiles, paper rubbish, general domestic risks.	Very suitable, inexpensive, and reliable if inspected regularly.	Very suitable, specially so where chemical action of the solutions might damage pictures, leather, tapestries, or other valuable and delicate articles. Valuable where there is any danger of freezing. Quickly and easily recharged. Somewhat expensive.	Not specially adapted for fires of this class.	Not adapted for fires of this class, and should not be installed to cover general domestic risks, as the toxic effects of gases given off, more particularly if the liquid comes in contact with heated surfaces, are dangerous, particularly in confined spaces.	Not very well adapted for fires of this class.
Class B fires: spirits, oils, varnishes, etc.	Not well adapted for this class of risk.	Not well adapted for this class of risk.	Best available for this class of fire, as even a 2-gallon appliance will cover a very large area with a complete blanket of dense foam. Used in conjunction with a mixture of bicarbonate of soda and sawdust to control flow of burning material; a very considerable fire can be dealt with.	Not very well adapted for this class of fire, but more efficient than class 1 or 2.	Efficient when used as a directed horizontal spray.
Class C fires: electrical machinery.	Not specially suitable.	Not specially suitable.	Not specially suitable.	Best available for this class of fire. Particularly suitable for use on high-tension current machines, as the liquid is a non-conductor. Will not damage delicate machinery, such as switchboard gear, motor or generator windings, as the liquid is very volatile and has no rusting properties.	Particularly suitable for use on high-tension current machines, as the liquid is a non-conductor. Will not damage delicate machinery, such as switchboard gear, motor or generator windings, as the liquid is very volatile and has no rusting properties.
Class D fires: motor-cars, lorries, and petrol engines.	Not specially suitable except for contents of lorries, etc., but subdivision B better than A owing to the risk of splashing over of acid in subdivision A.	Not specially suitable except for contents of lorries, etc. No danger of apparatus functioning through splashing over.	Very efficient, especially if whole engine becomes involved. Some danger of apparatus functioning owing to splashing.	Very efficient, especially for a carburettor fire or petrol or oil burning under or round an engine. Dangerous fumes are given off if the engine is hot, and there is some risk of these being driven back into body of car.	Very efficient, especially for a carburettor fire or petrol and oil burning around an engine.
Class E fires: chimney fires.	Efficient, especially if used both up chimney from room and down chimney from roof.	Not specially suitable, better from above than below.	Efficient if used both from above and below. Fire in grate can be smothered out with this type.	Efficient if used from above and below.	Efficient if used from above and below.

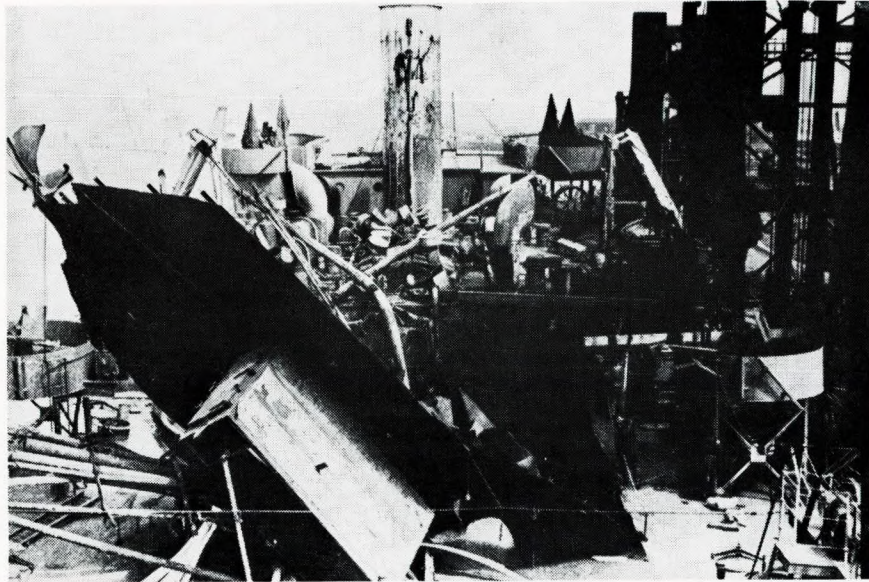


FIG. 1—View of vapour explosion on board Pan Massachusetts

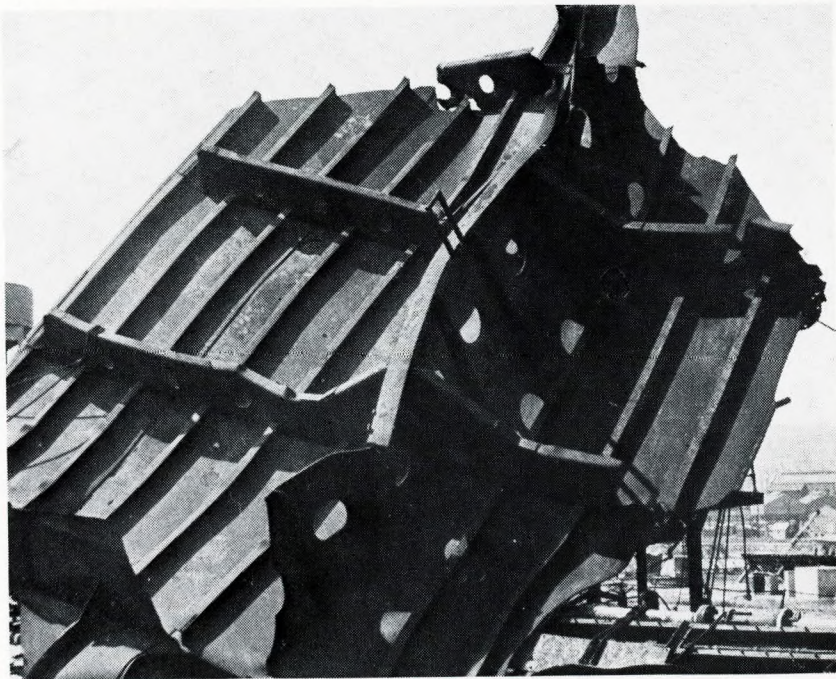


FIG. 2—View of vapour explosion on board Pan Massachusetts

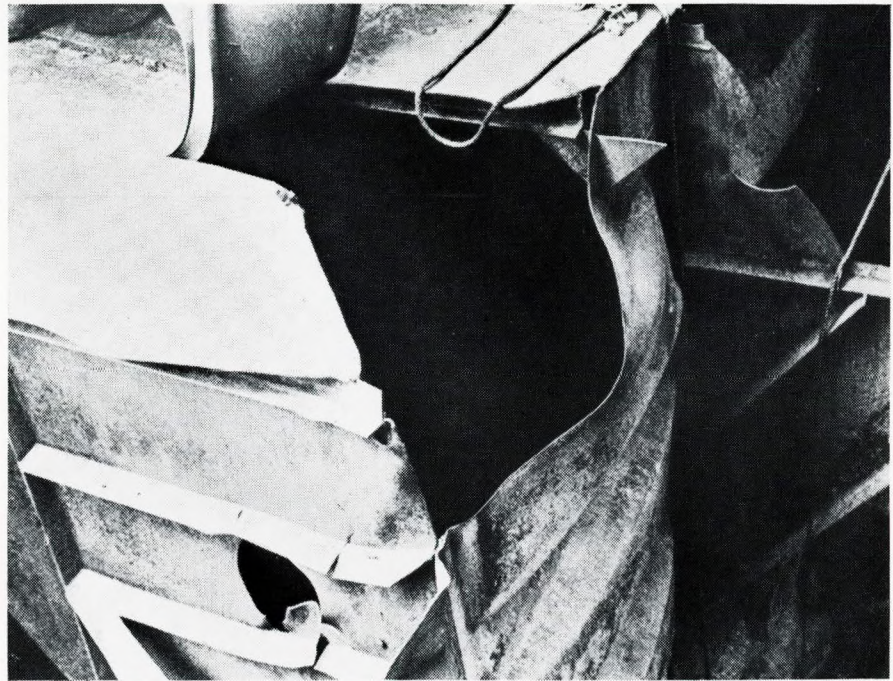


FIG. 3—View of vapour explosion on board Pan Massachusetts

Marine Gassing and Fire and Explosion Hazards

Plate 2

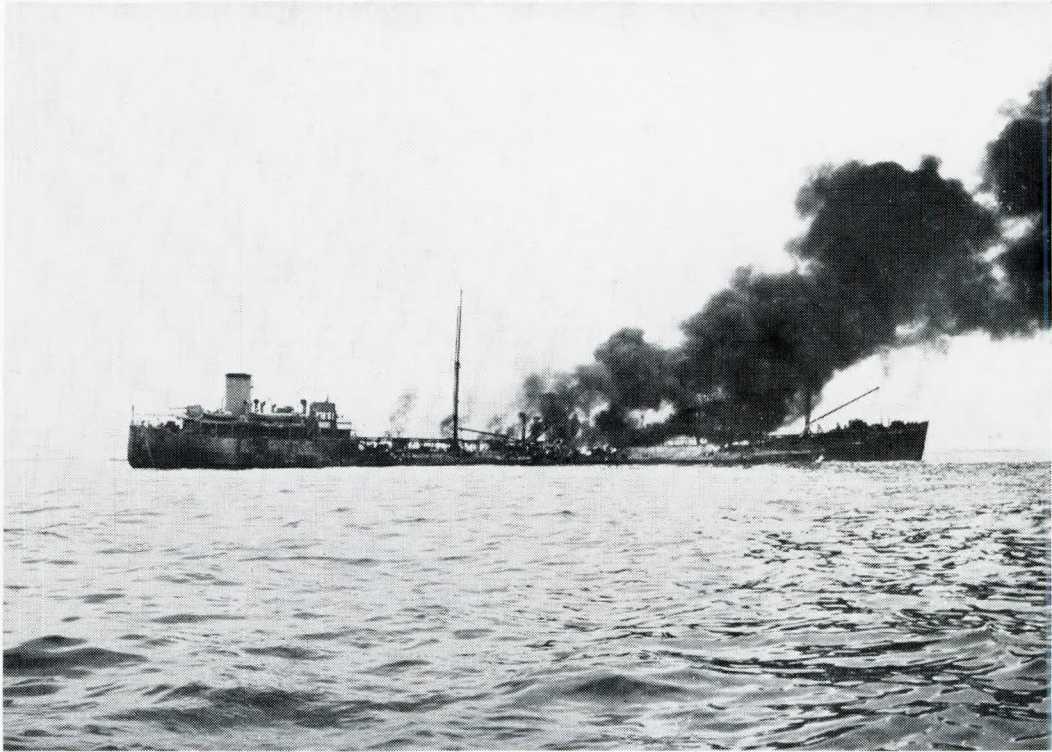


FIG. 4—*Oil fire*



FIG. 5—*Petrol fire*

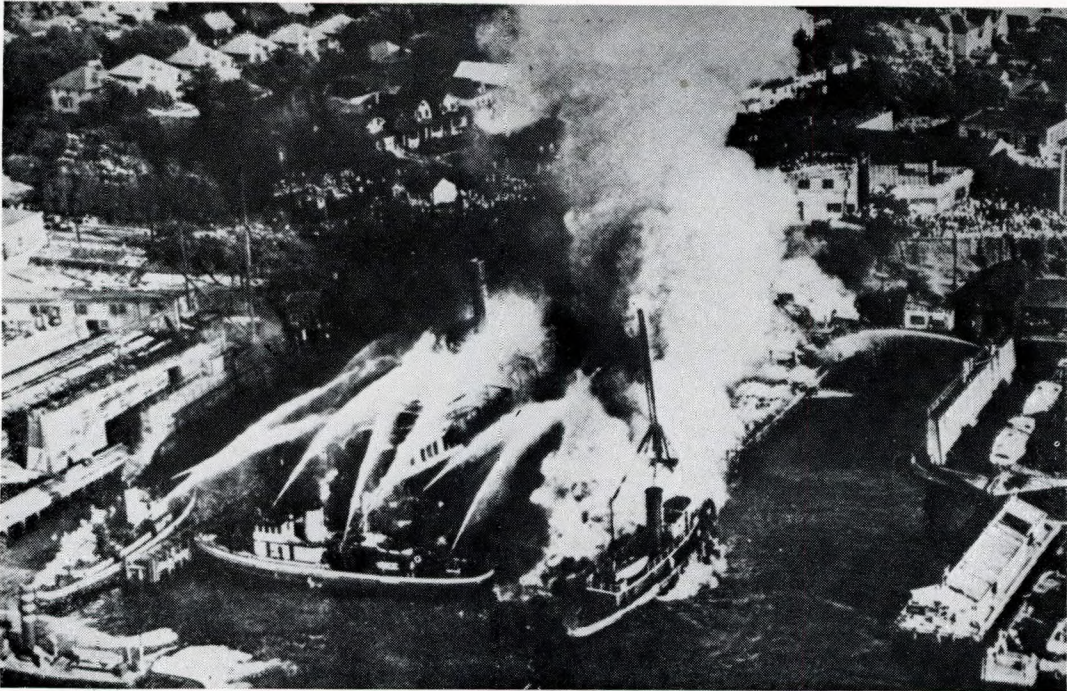


FIG. 6—*Fire in a dry dock*

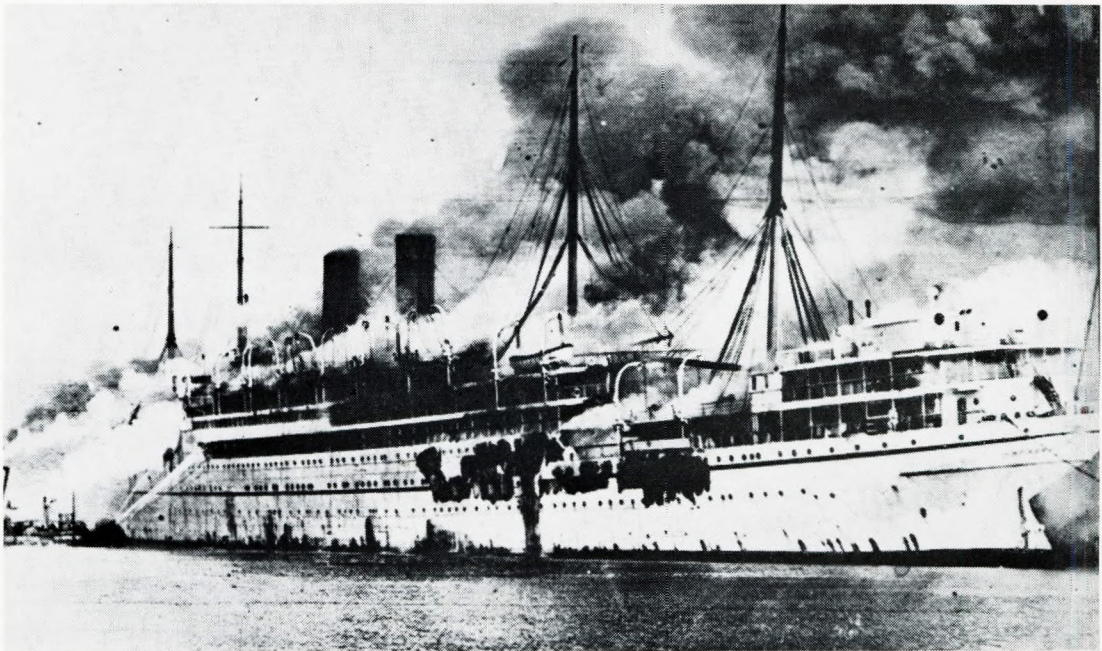


FIG. 7—*Passenger liner fire*



FIG. 8—*Passenger liner fire*



FIG. 9

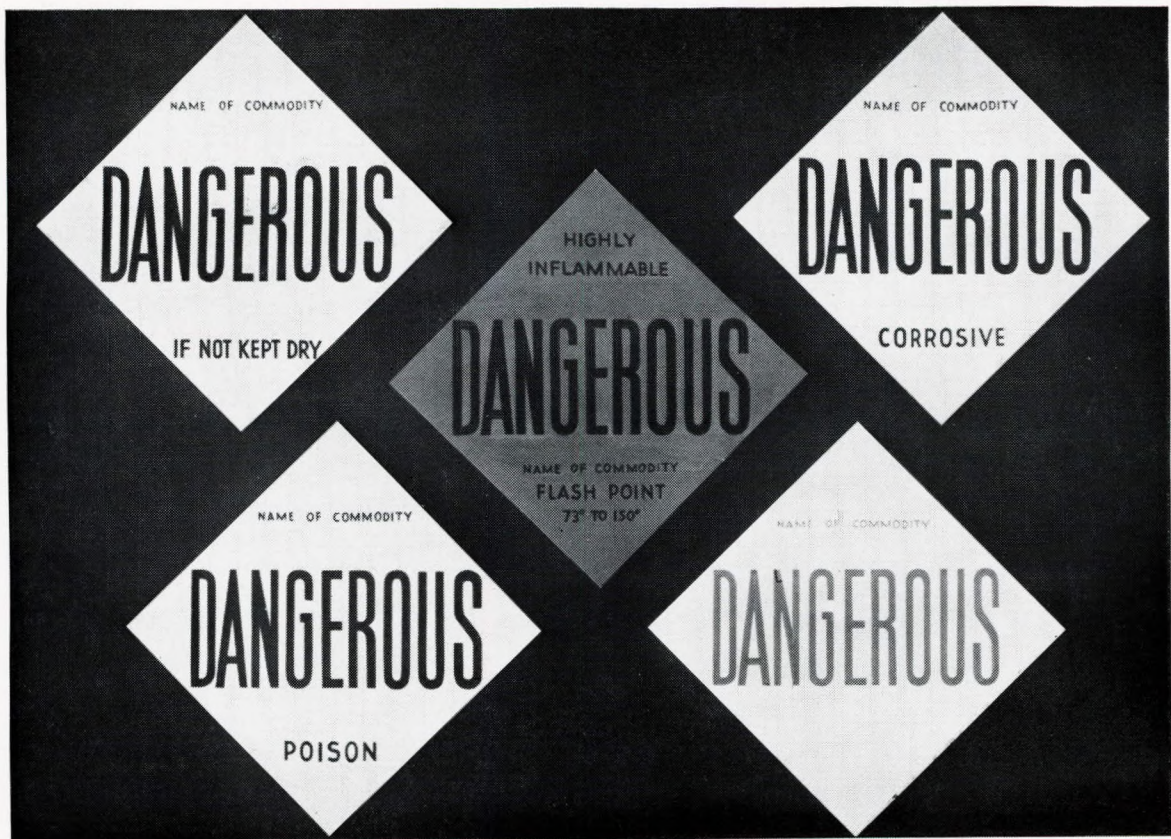


FIG. 10

Figs. 9 and 10 show types of markings for containers in which dangerous commodities are being carried



FIG. 11—*Oil explosion*



FIG. 12—*Exploding asphalt tank*



FIG. 13—*Result of use of water on a magnesium fire*



FIG. 14—*After effects of nitrate bath experiment*

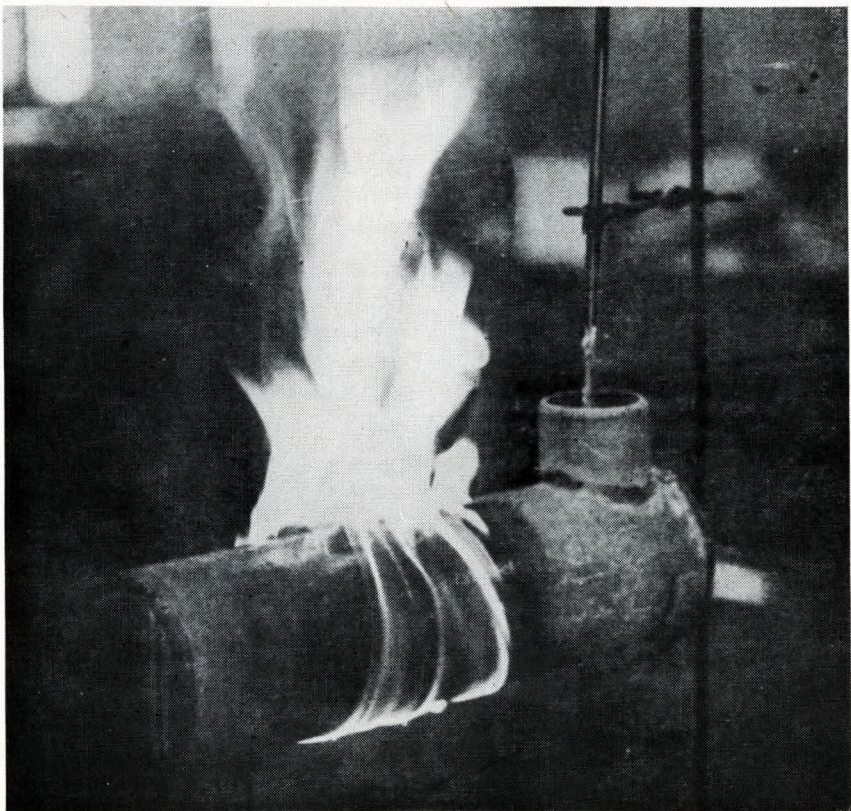


FIG. 15

Figs 15 and 16 illustrate the lowering of the ignition temperatures of heavy oil by cracking



FIG. 16

Steam and the asphyxiant gases are often efficient for fires in confined spaces.

Liquid Combustibles. With regard to liquid combustibles, it is necessary to take into account many of their characteristics, including specific gravities, miscibility with water, volatility, and reactivity with water, before deciding upon the most appropriate extingteur. Generally speaking, water in bulk form is unsuitable for all liquid fires, whereas water as a finely dispersed fog or mist has been found to be remarkably successful in the case of oil and solvent fires, in spite of the fact that the inflammable solvents concerned have been lighter than water. The water fog provides a blanket of "wet air", which will not support combustion, above the burning combustible. Water fog is a comparatively cheap agent, but foam, which provides a floating scum on the surface of the burning liquid, and which, in consequence, shuts off the supply of air, is in most common use for dealing with liquid fires. For small "spill" fires featuring inflammable liquids the asphyxiant gases, especially when derived from the small carbon tetrachloride or methyl bromide containers, have the advantages of speed, cleanliness, and ease of handling, although it is dangerous to employ such extingteurs in confined spaces as personnel may be affected by toxic fumes.

Gaseous Fires. Vapour or gaseous fires (as distinct from explosions, which are momentary and irrevocable effects) are generally most fierce to behold and yet most easy to overcome. One has merely to seal off the gas at the point of issue to effect extinction. Where coal-gas is on fire as it leaks from a puncture in a gas-holder, although the gas may be burning in the form of a long and terrifying flame, the fire is quickly extinguished by covering the puncture with a plate and plugging up with clay. In the comparatively remote case of gaseous fires burning within a confined space, the introduction of carbon dioxide into the space has been highly effective.

It would not be fitting to conclude this discussion on gaseous fires without referring to the dangers relating to acetylene in cylinders or other containers which have been involved in fires. There are records to the effect that such cylinders of acetylene have apparently been safe long after the fire, and then have suddenly exploded with consequent loss of life. Acetylene is a remarkable gas in that under the influence of heat it can decompose progressively over a long or short period of time until eventually its container or cylinder can no longer withstand the terrific internal pressure (which accompanies the decomposition) and bursts with explosive violence. If cylinders or other containers of acetylene have been affected by fire, do not disturb them in any way. Keep personnel away

from them and notify the police, fire service, or suppliers of the gas. They will know how to deal with the dangers.

Table 2, which has been published by permission of the Home Office, summarizes the efficiencies and suitability of various extingteurs, as supplied in portable forms, for different types of small fires.

(ii) *Types of fires including those involving spontaneous combustion, grain, fibre, textiles, oil fires, etc.*

Many types of commodities may experience spontaneous combustion. It is not proposed to give a lengthy explanation of this phenomenon, especially in view of the fact that the phenomenon is not clearly understood. It is sufficient to indicate that by spontaneous combustion is meant self-ignition which is the eventual outcome of self-heating in a commodity. However, rarely are the so-called self-heating and self-igniting processes completely independent of outside factors, and indeed the terms are misnomers to the extent that more often than not there are external factors such as the stowing of coal against hot steam pipes or the like. These external factors are termed contributory causes and it is interesting to note that Board of Trade Notice No. 106 suggests that many if not most of the outbreaks of fire in steamship bunker and cargo coal are due, at least partly, to avoidable causes. Some of these avoidable causes include on the coal side, the stowing together of coals of different ages (from the time of mining) and/or from different coal fields. In connexion with the ship, as distinct from the coal, there may be faulty ventilation which allows air currents to flow through the coal. Yet another avoidable cause which is termed "local heating" is the stowing of coal against a source of heat. Table 3, which has been abstracted from the D.S.I.R. Fuel Research Special Report No. 5 entitled "Fires in Steamship Bunkers and Cargo Coal", indicates the results of an investigation carried out by the Government, and indicates that of all the cases investigated only 12 per cent was due to true spontaneous heating, no less than 52 per cent being due to direct or local heating, i.e., the stowing of coal against an adjacent source of heat such as a steam pipe. It is also interesting to note that 40 per cent of the fires occurred in 'tween decks, 29.3 per cent in lower side bunkers and 17.6 per cent in cross-bunkers. As a direct conclusion from the above, it may be said that the way to avoid such fires is to eliminate the contributory causes.

An interesting but now very old survey of coal fires in ships revealed that out of a total of over 30,000 voyages, one-quarter per cent of all the voyages featured coal fires in either cargo or bunkers, one-eighth per cent were short voyages in

TABLE 3. POSITIONS OF OUTBREAKS OF FIRES IN SHIPS. FIRES CONCERNING COAL CARRIED AS CARGO OR BUNKERS

Cause	Position of fire					Total for each cause as percentage of cases investigated
	Cross bunker	Lower side bunkers	'Tween decks	Bridge spaces	Holds	
	Percentage	Percentage	Percentage	Percentage	Percentage	
Direct heating	2.1	17.8	28.2	3.1	0.8	52
Junction of new and old coals	5.9	7.0	3.1	0.8	0.2	17
Air leakage	4.3	3.8	4.6	0.3	1.0	14
Faulty ventilation	0.5	0.2	2.8	0.2	1.3	5
True spontaneous heating	4.8	0.5	1.3	0.8	4.6	12
Total for positions	17.6	29.3	40.0	5.2	7.9	100

OBSERVATIONS

- (a) 40 per cent of the fires investigated occurred in 'tweendecks, of which more than half (28.2 per cent) were due to direct heating from boilers, steam-pipes, etc.
- (b) Lower side bunkers contained the next greatest number of fires, and again, more than half of these (17.8 per cent.) were due to direct heating.
- (c) Very few of the fires occurred in holds, i.e., they were mostly bunker fires (92.1 per cent).
- (d) Direct heating was the cause of 52 per cent of these fires, 51.2 per cent occurring in bunkers.
- (e) Loading new coal (fresh wrought and probably of different origin) on top of old coal was responsible for 17 per cent of the fires investigated, and 16.8 per cent of these occurred in bunkers.

Marine Gassing and Fire and Explosion Hazards

temperate waters, and one-eighth per cent were long voyages through tropical waters. Concerning cargo as distinct from bunkers, the size of the hold appears to be an important factor since it was observed that of all the reported outbreaks of fire in holds of coal:—

- 1½ per cent were fires in holds containing less than 500 tons,
- 5½ per cent were fires in holds containing between 500 and 1,000 tons,
- 18 per cent were fires in holds containing between 1,000 and 1,500 tons,
- 25 per cent were fires in holds containing between 1,500 and 2,000 tons,
- 50 per cent were fires in holds containing over 2,000 tons.

Important considerations in connexion with coal fires in ships are given below. Once the temperature of coal has exceeded 150 deg. F. (with some coals it is as low as 90 deg. F.) self-heating must lead inevitably to fire unless the coal is quickly discharged and allowed to cool.

- (1) Especially at sea, it is rarely possible to extinguish a fire in a hold or bunker. The only sure way is to discharge the coal, killing the fire as and when necessary. At sea, the best that can be hoped for is that the fire can be held in check by reducing ventilation to a minimum which means closing the hatches loosely and putting the covers on the ventilators.
- (2) Steam is not considered to be helpful and indeed has led to explosions caused by the reaction between red hot coal and the steam.
- (3) The use of smothering gases such as carbon dioxide and sulphur dioxide which may be available on the ship, is not particularly helpful although they may hold the fire in check temporarily.
- (4) Water should be employed in a definite and determined manner rather than haphazardly. If played directly on to red hot coal it may cause serious explosions. It is better to adopt encircling tactics, i.e., endeavour to play water all round the zone of fire in ever narrowing circles. Once in port, the fire can be dealt with expeditiously by working out the cargo and it is most surprising but generally true, that when this has been done it is rarely the case that more than 100 tons of coal are actually charred by fire. Incidentally, it is generally risky to re-ship coal which has been involved in fire, since discharging has caused the coal to be freshly oxidized and it will now have an even greater tendency to spontaneous combustion.

Other types of commodities carried in ships as cargo which are liable to spontaneous combustion are esparto grass which, because of its extreme susceptibility in this capacity, is generally carried as deck cargo; cotton, of which there is considerable doubt as to whether it will self-heat except when contaminated with oil or grease; wool, especially when wet, damp or contaminated with oil, and possibly, jute. With fires involving such commodities, once again it is necessary to reduce ventilation to a minimum, but often in the early stages it is possible to "knock-out" such fires at source.

Grain. Fires featuring this material are very rare by virtue of the free flowing nature of the material. The fire would be suffocated by the flow of the grain as the ship rolled. However, grain, when wet, can evolve the inflammable gas methane which may then accumulate at the top of a hold and may result in a violent explosion if a naked light is brought near. The most important attribute to remember about grain in connexion with fire is the fact that should it be necessary to play water on a fire in a 'tween deck above grain, the water descending into the grain will cause it to swell badly with the consequent possibility that the ship's plating may be distorted and methane gas may be evolved.

Fibre. Fibre, including those of cotton and wool, deserve special mention in view of the fact that such commodities may be shipped as bales. If ignited, such bales may smoulder quietly and indiscernibly for weeks on end before suddenly bursting into open and fierce fire. It is known that there have been cases wherein workmen who have been loading baled fibres

into a ship have carelessly discarded lighted cigarettes which have ignited bales. They have smouldered undetected throughout the whole voyage but when discharged they have burst into fierce flames or else when touched have crumbled to dust since they have been burnt to hollow shells. In passing, it must be mentioned that it is exceedingly difficult to extinguish baled fibre fires with water. Fibres are hollow and contain enough air internally to support their combustion. The modern means of dealing with baled fibre fires is with "wet water" by which is meant water to which a detergent or wetting agent has been added. This agent causes the water to wet or penetrate the fibre more thoroughly and so makes extinguishment more certain. The detergent is unlikely to be available on a ship unless that ship customarily carries baled fibre cargoes and the owners have thought fit to take suitable precautions. However, the point is worth noting because wetting agents greatly reduce the quantity of water required to extinguish a given fire. There is thus far less water-damage.

It is advisable to recall the terrible war-time disaster at Bombay, when millions of pounds worth of damage were done to ships, the harbour and the port because of a fire which started in cotton in the lower holds of a particular ship. Water was pumped into the hold containing the burning cotton which then floated upon the water until eventually the burning cotton was floating underneath a 'tween deck in which were explosives. A violent explosion took place and this caused other explosions and fires to occur all over the port.

Textiles. Textiles packed in bales or wooden cases have characteristics much the same as baled fibres. Thus in a hold of a ship their fires are difficult to deal with. In common with baled fibres and many other commodities they evolve acrid fumes which make the wearing of breathing apparatus a necessity.

Oil. Oil fires justify far greater consideration than is possible here. It will be appreciated that the term "oil" covers a host of substances ranging from petrol (petroleum oil), gas oil, Diesel oil, fuel oil, lubricating oil, vegetable oil and so on. It is well known that there are two main hazards of importance with oil, viz., the risk of explosion if the oil is volatile under the conditions of stowage (i.e., has a flash point at or below the prevailing atmospheric temperature) and the other risk is that of actual fire. The subject of explosions is dealt with subsequently but in the meantime it is sufficient to remark that although an explosion may lead to fire in itself it is something which is ended instantaneously (see Figs. 11 and 12, Plate 6) whereas in the case of fire something can be done.

Fig. 12 illustrates an exploding 2,000-barrel asphalt tank at an oil refinery. This shows the result, in an explosion, where the top of a vertical tank is stronger than the bottom. If the top is relatively weak, it will let go and vent the pressure, usually without any disastrous consequences. Where the bottom fails, under pressure, there is the rocket effect shown in the picture. In this fire, fire fighters were showered with burning asphalt and four died.

It is encouraging to note that in general the more readily the oil takes fire the easier it is to extinguish. The lighter the oil the more readily it takes fire so that in order of readiness to take fire, oils can be placed thus:—petrol, benzene, Diesel, gas oil, and so on to lubricating oil. Readiness to take fire is a function of "flash point" which is a constant for each particular inflammable substance and marks the temperature at which it first evolves an inflammable concentration of vapour. Once an inflammable concentration of vapour is evolved only the application of a naked light is necessary to initiate fire. Fig. 5, Plate 2, indicates a fire in a cargo of petrol and although the tanker was abandoned by the crew, it is interesting to note that when once boarded by the fire service the fire was extinguished in about three hours and two-thirds of the entire cargo was saved. It was extinguished with foam. Foam is almost invariably available on tankers and is a most efficient means with which to extinguish oil fires. The lighter oils are extinguished very readily because they burn at low temperatures and are thus easily cooled down by the

TABLE 4. CONDITIONAL EFFECTS UPON DANGEROUS GOODS

Chemical group and class	Spontaneous ignition	Heat		Water		Air			Shock or friction
		No flame	Flame	Liquid	Vapour	Cold	Hot	Damp	
(1) <i>Explosives</i>									
(a) Detonants	Yes	Explode	Explode	Safe	Safe	Safe	Explode	Safe	Explode
(b) H.E.	No Some, if damp	Explode Ignite, damp	Explode Ignite, if confined	Safe	Safe	Safe	Unsafe	Safe	Unsafe
(c) Propellants				Safe	Safe	Safe	Unsafe	Safe	
(d) Pyrotechnics	Yes	Ignite	Ignite	Safe	Safe	most are Safe	most are Safe		Dangerous
(2) <i>Gases, compressed, permanent and (confined) liquified</i>									
(a) Inflammable	Some yes	Explode	Explode				Explode		May explode
(b) Supporters of combustion	No	Explode	Explode				Explode		May explode
(c) Toxic	No	Explode	Explode				Explode		May explode
(d) Inerts	No	Explode	Explode				Explode		May explode
(3) <i>Reacting with air or water since they may evolve :</i>									
(a) Inflammable vapours	Yes	Ignite May ignite May ignite	Ignite May ignite May ignite	Unsafe	Unsafe	Unsafe	Unsafe	Unsafe	
(b) Toxic vapours	Possible			Unsafe	Unsafe	Unsafe			
(c) Corrosive vapour or residues	Possibly			Unsafe	Unsafe	Unsafe			
(4) <i>Evolving inflammable vapours</i>									
(a) Flash point below 73 deg. F.	Safe	Unsafe	Unsafe						Sparks unsafe
(b) Flash point 73/150 deg. F.	Safe	Unsafe	Unsafe						Safe
(c) Flash point above 150 deg. F.	Safe	Unsafe	Unsafe	Unsafe when hot	Unsafe when hot				
(5) <i>Corrosive substances</i>									
Acids	No	Unsafe	Unsafe	Some unsafe	Some unsafe				
Caustics	No			Some unsafe	Some unsafe				
(6) <i>Poisonous Substances</i>									
(7) <i>Fire Hazardous</i>									
(a) Oxidizing agents	Unsafe with combustible matter	Unsafe with combustible matter	Unsafe with combustible matter	Unsafe with combustible matter					Unsafe with combustible matter
(b) Liable to spontaneous combustion	Unsafe	Unsafe	Unsafe	Unsafe			Unsafe	Unsafe	Unsafe
(c) Readily combustible									

Marine Gasping and Fire and Explosion Hazards

Marine Gassing and Fire and Explosion Hazards

foam whereas the heavier oils which have high burning temperatures have fires which can be readily dealt with by foam in the initial or incipient stages but which, if prolonged, may introduce hazards which are now becoming quite well-known as "slop-overs" and "boil-overs". Such phenomena result because the applied foam, which is a mixture of water and chemical substance, breaks down under the heat of the burning oil, in consequence of which water accumulates underneath the oil. Eventually, the temperature of the bulk of oil within the tank may attain and exceed the boiling point of water, i.e., 100 deg. C. The water is then evaporated and a rush of steam passes through the oil and causes it to froth or boil over. The consequences are dangerous to personnel who run the risk of being covered with heated or burning oil and to the ship because by this means fire may spread from one space to another. Nevertheless, it is emphasized that given adequate supplies of foam an oil fire may be dealt with successfully and efficiently.

(iii) Fires involving Dangerous Goods

The various classes of dangerous goods have been introduced earlier and unfortunately it is impossible to generalize about such a wide variety of substances except to the extent shown in Table 4. However, it is as well to point out that with such goods, more often than with any other type of commodity, prevention is better than cure. In view of their dangerous vices such goods must be carefully packed and stowed under conditions which will not incite their dangerous characteristics. They are rarely carried in bulk but it is fitting to mention that the recent Texas disaster featured an example of a bulk cargo of ammonium nitrate which exploded and almost destroyed the whole town. It is believed that this explosion took place because a form of spontaneous combustion was set up in the containing packages of the ammonium nitrate.

Fig. 13, Plate 7, indicates the danger of applying water to burning magnesium.

Fig. 14, Plate 7, shows the after effects of a nitrate bath explosion.

(iv) Passenger Liner Hazards

These deserve particular comment because they have characteristics peculiar to their construction. In the first place passenger cabins and accommodation, which virtually resemble a rabbit warren, present a series of flues or air ducts through which fire can travel with amazing rapidity. The only parallel example ashore lies in big hotels with lift shafts. It is well known that these lift shafts carry hot air and fire with tremendous rapidity to floors in the building well above the seat of the fire. So it is with passenger liner accommodation and matters are worsened by the fact that every effort is made to make this accommodation decorative and ornamental. In consequence of this, steel bulkheads are covered with wooden or other types of combustible facings whilst between the steel bulkhead and wooden facing there may be sound and heat insulation material of a combustible nature. Fire can spread between the facing and the steel bulkhead through the insulation with tremendous speed and it has been known for fire to burst into the open over a hundred yards away from where it started without apparent connexion in between. Above all, it would appear that passenger accommodation is particularly vulnerable to fire, hence the ever-growing tendency to provide such accommodation with automatic water sprinklers.

As an example of a disaster in a liner fire, one is reminded of the *Normandie* wherein the passenger accommodation was set on fire by a spark from a welding process igniting insulation.

(b) Marine Explosion Hazards

These are likely to fall into five categories:—

- (1) Those associated with petrol, benzene or similar petroleum derivative.
- (2) Those associated with high explosives.
- (3) Dust explosions.
- (4) Explosions due to the carriage of chemicals such as ammonium nitrate as with the Texas disaster.

- (5) Mechanical explosions as with the bursting of a steam boiler.

It is not proposed to discuss this latter aspect here neither it is proposed to discuss crankcase explosions, the causes of which are the subject of research and investigation at the present moment.

Explosions concerned with petroleum derivatives. The carriage of petrol in liquid bulk is quite commonplace, and in consequence petrol vapour explosions are unfortunately almost equally commonplace. For an explosion of inflammable vapour to take place, two conditions have to be fulfilled. They are:—

- (a) There must be an inflammable concentration of the vapour.
- (b) There must be a means of ignition.

Concerning (a), it is important to note that not all concentrations of an inflammable vapour in air will support flame, i.e., will permit an explosion to take place. In the case of petrol vapour, for example, there must be at least 1 per cent and not more than 6 per cent mixed with air to present an inflammable concentration and concentrations below 1 per cent are too lean to propagate flame whereas concentrations above 6 per cent are too rich. Between 1 per cent and 6 per cent there is a peak concentration (2¼ per cent in the case of petrol) at which flame travels through the mixture so rapidly that violent shock waves or detonation result. Different inflammable vapours have different ranges of inflammability. It is a fortunate fact that the ullage spaces in oil tankers carrying petrol are usually too rich in petrol vapour to present inflammable concentrations. It is believed that such ullage spaces contain as much as 10 per cent of petrol vapour. It will be seen why the tanks are more dangerous when they have been emptied of cargo but have not been gas-freed than when they are full. In this case, the so-called empty tank contains residual petrol vapour and abundant quantities of air, in consequence of which, at some level within the tank there is bound to be a concentration of petrol vapour within the range of inflammability. Hence the necessity for gas-freeing before liberties may be taken with an oil tanker.

With regard to (b), means of ignition, whilst it has been recorded that different inflammable vapours have different ranges of inflammability so too have they different ignition temperatures. For example, carbon disulphide may be readily ignited by the heat of a hot steam pipe, whereas the gas, methane, which is liberated from coal, has an ignition temperature of 650 deg. C. It follows that the lower the temperature at which an inflammable liquid may be ignited, the more hazardous is the vapour. However, Figs. 15 and 16, Plate 8, show that the ignition temperatures of heavy oils may be lowered in effect by cracking, i.e., exposing the oil to the effects of heat.

It would not be fitting to conclude remarks concerning means of ignition without discussing the subject of what might be termed "surprise ignition". Although it is now quite well known that in the possible presence of inflammable vapour, tools capable of causing a spark are not to be employed, the use of spark-proof tools (those made of beryllium bronze and the like) is by no means a common custom. Another means of surprise ignition comes under the heading of static electricity, and the need to earth pipelines and other fittings through which inflammable liquids flow at considerable velocities is quite well-known. However, it is not so well known that there are cases on record wherein live steam was being passed through hose lines into tanks which had contained petrol, and which were required to be gas-free, the steam being passed with such velocity that the petrol vapour became ignited by sparks from the static electricity which was generated. There is in existence a Home Office circular which warns of this danger. A further example of surprise ignition may come about in connexion with the carriage of crude oil rich in sulphur. It is alleged that this sulphur may combine with the scale on the sides of an oil tank to form finely divided iron sulphide. This substance has been known to ignite spon-

Marine Gassing and Fire and Explosion Hazards

taneously when exposed to air in consequence of which it has ignited the residual vapour within a recently emptied tank.

Probably the least appreciated aspect of risk of explosions in connexion with liquids which evolve inflammable vapour, is concerned with the amount of such liquid that is necessary to cause a serious explosion. Three gallons of petrol when fully vapourized are capable of wrecking a fairly large tanker.

A very good maxim to apply to all spaces in ships which are in any way confined is "a confined space is dangerous until it has been proved by test to be innocent".

High Explosives. The reputation of recognized explosives is such that they are generally recorded all the respect they deserve. Thus, the only point worthy of interest here is that it is not sufficient to treat the explosives with unusual respect, unusual attention and respect must also be paid to the adjacent spaces or commodities stowed therein.

Dust Explosions. Dust explosions occur sufficiently often in ships to warrant comment here. During the war several cases of sulphur dust explosions were recorded in British shipping whilst explosions of coal dust during the loading or discharging of coal are not unknown. As with inflammable vapours, the dust concerned must be mixed with air in the right proportion for an explosion to take place, but if a cloud of combustible dust is created, then inevitably, as the dust settles, somewhere between its upper regions and the ground, an inflammable concentration will be created. It requires only a coincidence of a means of ignition existing within that zone of inflammable concentration for an explosion to occur, and the moral is that spark-proof tools and flame-proof lights should be employed within the vicinity of such dust concentrations.

Chemical Explosions. Several major catastrophes in the history of shipping due to the dangerous characteristics of certain chemicals have made the shipping world fully conscious of such dangers. However, as always, time softens the blow and a certain laxity creeps into the treatment accorded to such chemicals.

(c) Gassing Hazards

Marine gassing hazards may be surveyed under the following headings:—

- (1) In connexion with the carriage of inflammable liquids, the vapours of which generally have anæsthetic properties.
- (2) The hazard of asphyxiation which can be associated with carbon dioxide and oxygen deficiency.
- (3) Fumigation.
- (4) Refrigerating gases.
- (5) Carbon monoxide poisoning.
- (6) Nitrous fumes.
- (7) Miscellaneous.

In general it may be said that of all the gases and liquids employed in industry, air and water only are safe. All other gases and liquids are hazardous under certain conditions. Of the inflammable gases and vapours, it must be remembered that concentrations in air well below the limits of inflammability for those gases, may be toxic. Petrol, for example, has a lower limit of inflammability of 1 per cent, whereas 0.1 per cent stupifies a man by creating a condition of anæsthesia. It should be remembered that even moderate traces of gases, although insufficient in quantity to produce toxic fatality may nevertheless cause fatality indirectly by stupifying a man as he is climbing a ladder. In that condition he may fall from the ladder with serious consequences.

Thus a review of gassing hazards under the foregoing headings is:—

(1) All inflammable liquids evolve inflammable vapours which have toxic properties.

(2) A more indirect toxic hazard can arise in connexion with the presence of carbon dioxide or a deficiency of oxygen in atmosphere. In the case of carbon dioxide, this may accumulate in a part of a ship such as a fore or after peak tank or a double bottom tank which has not been opened for a con-

siderable time. There are many cases on record of men entering such tanks and losing their lives by carbon dioxide asphyxiation. 5 per cent or thereabouts of carbon dioxide in air will kill a man almost instantaneously whereas concentrations exceeding 2 per cent will upset him seriously when he exerts himself physically and may cause serious errors in his judgment. Carbon dioxide may also be found in a ship as an escape from a refrigerating or fire fighting installation or even as a gas which has been evolved from a cargo of grain or fruit. The so-called apple and orange gases familiar to dockers who discharge fruit cargoes are merely the essential oils of the particular fruit airborne in carbon dioxide. Men have lost their lives when discharging such fruit especially when the cargo has been worked out to near the bottom of the hold. Two further possible sources of carbon dioxide in ships arise in connexion with leakages of flue gases or as a product of the spontaneous combustion of coal. A most important characteristic of carbon dioxide is its heaviness when compared with air. It is so heavy that it will readily settle to the bottom of a hold and lie there in a compact layer. Thus one may have the experience of standing up on the bottom of a hold without experiencing any harm, yet when bending or lying down one may be asphyxiated.

Oxygen deficiency is an even more insidious hazard than carbon dioxide. Fortunately, it is a comparatively rare condition in a ship, but may arise in confined tanks, compartments, or spaces which have either been recently painted or have contained vegetable oils or substances such as steel or iron turnings which have a strong affinity for oxygen. In all cases, the paint, vegetable oil or iron turnings absorb and combine with the oxygen content of the atmosphere, in consequence of which it may be reduced to such an extent that that particular atmosphere can no longer support life. Less than 16 per cent of oxygen in air may be hazardous, whereas below 14 per cent will generally kill instantaneously.

Table 5 shows the properties of various gases including their toxic hazards.

(3) *Fumigation.* It is well known that substances such as hydrocyanic gas which are employed for fumigation purposes have toxic properties. There are several cases on record of such gases not dispersing as readily as was anticipated (probably due to the partially confined nature of the space of the ship concerned) in consequence of which lives have been lost.

(4) *Refrigerating gases.* Refrigerating gases may have toxic characteristics which vary with the individual gas. However, all of them are dangerous and only a few years ago an engineer lost his life in a ship in Cardiff Dock due to the fact that he entered a space in which was stowed cylinders of refrigerating gases, one of which was leaking. The gas was methyl chloride.

(5) *Carbon monoxide poisoning.* Carbon monoxide will undoubtedly continue to produce its annual crop of fatalities in ships and shipping circles. It is unlikely to be encountered in a vessel at sea except when fire has broken out (especially a coal fire) or perhaps as a flue gas leakage. However, with ships under repair, the risk is very real and arises in connexion with blacksmiths' fires which may be located inside or near the openings of a semi-confined tank. When such fires are near the openings of semi-confined tanks a suitable wind may carry their fumes, including carbon monoxide, into the tank or space, in consequence of which the lives of personnel are endangered.

(6) *Nitrous fumes.* Nitrous fumes in connexion with shipping are, in the main, a hazard related to high temperature burning or welding. Thus they should not be encountered in vessels at sea but more particularly in ships undergoing repair. It has been definitely established that the high temperature of the oxy-acetylene torch or electric arc welding process may cause atmospheric nitrogen to be oxidized, the product being nitrous fumes. Such fumes are every bit as toxic as the well-known war gas, phosgene, so that if men are burning or welding in confined spaces, the hazard is serious.

Marine Gassing and Fire and Explosion Hazards

TABLE 5. PROPERTIES

Name of substance	State at N.T.P.	Specific gravity at 15 deg. C. (water=1)	Vapour density at 15 deg. C (air=1)	Fire hazard	Physiological effects
Acetaldehyde	Liquid	0.783	1.52	Highly inflammable	Irritant and anæsthetic
Acetone	Liquid	0.791	2.01	Highly inflammable	Anæsthetic
Acetylene	Gas	0.61	0.91	Highly inflammable	Asphyxiant and anæsthetic
Acrolein	Liquid				Anæsthetic irritant
Ammonia	Gas	0.82	0.60	Low inflammability	Irritant
Amylene	Liquid	0.63	2.42	Highly inflammable	Asphyxiant and anæsthetic
Aniline	Oily liquid	1.022	3.22	Inflammable	Irritant
Arsine	Gas		2.7		Poison
Benzene (benzol-benzole)	Liquid	0.89	2.69	Highly inflammable	Toxic anæsthetic
Butane	Gas (liquifies at about 0 deg. C.)	0.60	2.07	Highly inflammable	Anæsthetic asphyxiant
Butyl acetate	Liquid	0.86-0.88	4.0	Highly inflammable	Irritant
Butylene	Gas	0.65	1.93	Highly inflammable	Asphyxiant and anæsthetic
Carbon dioxide	Gas	1.519	1.52	Non-combustible	Asphyxiant
Carbon disulphate	Liquid	1.263	2.63	Highly inflammable	Poison
Carbon monoxide	Gas		0.968	Highly inflammable	Asphyxiant
Carbon tetrachloride	Liquid	1.59	11.5	Non-combustible	Toxic anæsthetic
Chlorine	Gas		2.5		Irritant
Chloroform	Liquid	1.49	4.1	Non-inflammable	Toxic anæsthetic
Coal gas	Gas		0.35-0.45	Highly inflammable	Asphyxiant
Cresol	Liquid		3.72	Inflammable	Poison
Cyanogen	Gas	0.86	1.81	Combustible	Asphyxiant
Dichlorethylene	Liquid	1.26-1.29	3.35	Non-inflammable	Irritant and narcotic
Diethyl ether	Liquid	0.71	2.56	Highly inflammable	
Dimethyl ether	Liquid		1.60	Highly inflammable	
Ethane	Gas	0.55	1.05	Highly inflammable	Anæsthetic asphyxiant
Ethyl acetate	Liquid	0.90	3.04	Highly inflammable	Irritant
Ethyl alcohol	Liquid	0.794	1.59	Highly inflammable	Irritant

Marine Gassing and Fire and Explosion Hazards

OF VARIOUS GASES

Human reactions			Boiling point deg. C.	Flash point deg. F.	Spontaneous ignition point in air, deg. C.	Ignition point in air induced by pressure, deg. C.	Limits of inflammability at N.T.P.		Relative volatility (ether=1)
Safety tolerance for 1 hour	Dangerous 30 min. to 1 hour	Fatal 10 min. to 1 hour					lower limit	upper limit	
			21	-17	230	170	4	57	
3,000 (pts. per million)	10,000	75,000	56.5	-4	440	310	2.5	9	2.1
			-88.5		335		2.4	80.0	
—	5.5	10+	52.4				17.1	26.4	
500	2,500-4,500	5,000	-33.3		780		16	27	
30,000	50,000-70,000	100,000	36.5-37.0		500	270	1.6		
100	300	25,000	184	79	770				
20	50	100	-62						7.7-11.8
3,000	6,000	19,000	80.4	-8	550	500	1.4	7.5	3
50,000			-0.5	-76	480	280	1.9	8.5	
100			106-127	18-25	422		1.7	15	6.6-11.8
			-0.5		510	280	1.7	9	
30,000	50,000-70,000	100,000							
483-807	1,150	2,500	34.0-35.0	-20	120	81	1.0	50	1.8
400-500	1,500	10,000	-190		570	520	12.5	74	
6,000	24,000	50,000	76						3
4	10	50	-33.6						
5,000	14,000	25,000	61.2						2.5
2,000	15,000	50,000			650		5.3	31	
Not readily volatile			191	80	347				
20	100	2,000	-21.0				6.6	42.6	
			37.0	57	465		9.7	13.0	
2,000	3,000-10,000	35,000+	35.0	-49	180	175	1.7	48.0	1
>1	>20	>40	-24.0	-42	310	310	2.0	10.1	
50,000			-88.3		530	310	3.1	15.0	
140		10,000+	74.0-77.0	24	428		2.3	11.5	2.9
2,000			78.3	57	440	270	4	19	8.3

Marine Gassing and Fire and Explosion Hazards

TABLE 5. (Cont.) PROPERTIES

Name of substance	State at N.T.P.	Specific gravity at 15 deg. C. (water=1)	Vapour density at 15 deg. C. (air=1)	Fire hazard	Physiological effects
Ethylene	Gas	0.57	0.97	Highly inflammable	Asphyxiant and anaesthetic
Formaldehyde	Gas		1.03	Inflammable	Irritant
Heptane	Liquid	0.683	3.45	Highly inflammable	Anaesthetic and irritant
Hexane	Liquid	0.66	2.97	Highly inflammable	Anaesthetic and irritant
Hydrogen	Gas	0.071	0.07	Highly inflammable	Asphyxiant
Hydrogen chloride	Gas				Irritant
Hydrogen cyanide	Gas	0.70	0.94	Inflammable	Asphyxiant
Hydrogen sulphide	Gas	0.96	1.19	Highly inflammable	Irritant and poison
Methane	Gas	0.42	0.55	Highly inflammable	Asphyxiant
Methyl alcohol	Liquid	0.79	1.11	Highly inflammable	Irritant
Methyl bromide	Gas	1.732	3.27	Non-inflammable	Irritant
Methyl chloride	Gas	0.92	1.78	Non-inflammable	Irritant
Nitrobenzene	Liquid	1.2	4.25	Inflammable	Irritant
Nitrogen	Gas	0.81	0.97	Non-inflammable	Asphyxiant
Nitrous fumes	Gas		1.53		Asphyxiant
Octane	Liquid	0.706	3.86		Anaesthetic and irritant
Oxygen	Gas	1.14	1.11	Non-inflammable	Irritant at high pressure
Pentane	Liquid	0.60	2.49		Anaesthetic and irritant
Petrol (benzine-benzoline-gasoline-ligroin-naphtha)	Liquid	0.75	3.0-4.0	Highly inflammable	Anaesthetic
Phenol	Liquid	1.07	3.24	Inflammable	Poison
Phosphine	Gas			Highly inflammable	Poison
Propane	Gas	0.59	1.56	Highly inflammable	Asphyxiant
Propylene	Gas	0.61	1.45	Highly inflammable	Asphyxiant
Pyridine	Liquid	0.98	2.73	Inflammable	Irritant
Sulphur dioxide	Gas	1.49	2.26		Irritant
Toluene (toluol)	Liquid	0.86	3.18	Highly inflammable	Toxic anaesthetic
Trichlorethylene	Liquid	1.475	4.5	Non-inflammable	Narcotic
Xylene (xylol)	Liquid	0.87	3.66	Highly inflammable	Toxic anaesthetic

Marine Gassing and Fire and Explosion Hazards

OF VARIOUS GASES

Human reactions			Boiling point deg. C.	Flash point deg. F.	Spontaneous ignition point in air, deg. C.	Ignition point in air induced by pressure, deg. C.	Limits of inflammability at N.T.P.		Relative volatility (ether = 1)
Safety tolerance for 1 hour	Dangerous 30 min. to 1 hour	Fatal 10 min. to 1 hour					lower limit	upper limit	
Toxic hazard remote			-103.9		485	300	3.0	29.3	
20			-21.0	90	430	370			
500	5,000		98.4	25	255	245	1	6	
1,000			68.7	-15	275	255	1.3	6.9	
			-252.7		550	520	4	75	
100	1,000	1,350							
20	100	2,000	26.0		540		6	40	
100	200-500	1,000	-10.0		290		4.3	46	
30,000	50,000-70,000	100,000	-161.4		650	470	5	15.0	
500			64.7	6.5	480	420	5.5	21.0	6.3
50			4.6		530		13.5	14.5	
250-500			-23.7		630		8	19	
200	500-1,000	1,000+	210.9	190	480				
			-195.8						
20	50	150	-89.5						
			125.6	60	245	240	0.8	3.2	
			-183.0						
3,000			36.2	< -40	470	270	1.4	7.8	
4,500	11,000	24,500	38.0-205.0	-45	257		1.3	6.0	
Not readily volatile			188.2	175	715				
100-200	400-600	1,000			Below 15 deg. C.				
50,000			-42.7		500	300	2.4	9.5	
Toxic hazard remote			-47.0		530	290	2.0	11.1	
			115.3	68	482		1.8	12.5	
100	400	600	-60.0						
100	800	—	109.5-110.5	40	810		1.3	7.0	6.1
			85.0-87.0						3.8
200	1,000		137-139	23	500		1	5.3	13.5

Marine Gassing and Fire and Explosion Hazards

(7) *Miscellaneous fumes.* Miscellaneous fumes or gassing hazards which may be encountered in ships include paint fumes, the hazards of which will correspond with those of the vapours from the paint thinners, chlorine, ammonia, hydrogen sulphide, sulphur dioxide, etc. Chlorine is quite rare but has arisen as a product of a parcel of bleach powder, whereas ammonia and sulphur dioxide arise when such gases are the bases of the refrigeration equipment. Hydrogen sulphide is a comparative rarity but has been encountered as a product from crude oil. A unique example of sulphur dioxide arose when the fire tubes of a boiler system were being cleaned. Evidently at one time a coal rich in sulphur had been employed as a fuel and the soot surrounding the fire tubes was heavily laden with sulphur fumes which pervaded the atmosphere as sulphur dioxide when the soot was being removed.

It would not be fitting to conclude this section without mentioning carbon tetrachloride and trichlorethylene. One would have thought that by now everybody was aware of the danger of employing the carbon tetrachloride extinguisher for extinguishing a fire in a confined space. This extingteur will readily extinguish a small fire but in so doing the carbon tetrachloride vapour may be decomposed by the heat of the fire with the result that some phosgene is formed. In confined spaces a lethal concentration of phosgene can be set up. Trichlorethylene is quite frequently employed nowadays for degreasing double bottom tanks. It is indeed the universal degreaser. In confined spaces the fumes are dangerously anaesthetic and, as with carbon tetrachloride, there is great danger if men smoke in the presence of this gas. Both gases can be decomposed by the heat of burning tobacco with the result that some phosgene is formed and this, as previously stated, may approach lethal concentrations.

SUMMARY AND CONCLUSIONS

It would be difficult in a paper of this length to discuss every aspect of importance in connexion with its subject matter. As planned, the paper comprises three sections apart from the final summary and conclusions, and it will have been noted that the object of the first section has been to offer a cross-section of actual marine fires and explosions of many types so as to reveal the nature of the incidents concerned. The object of the second part has been to indicate the equipment and appliances which ships are expected to carry in order to deal with such incidents and, additionally, the laws and requirements with which ships should comply so as to avoid occurrence of those incidents. The third part is, therefore, a logical continuation in the sequence in that it attempts to indicate how marine gassing, fire and explosion incidents may be dealt with by discussing the most suitable application of the various types of extinguishers which are available, by presenting the characteristics of various types of commodities and goods and by indicating features of particular types of fires. In essence the section dwells upon the particular, so that a logical conclusion to the paper as a whole is some attempt at generalization. Often, to generalize is to reiterate the well known or commonplace, but in this case there is every justification for so doing because the available evidence seems to indicate that many major disasters in marine history feature incidents where the obvious or general is not catered for correctly, in consequence of which, major disaster has resulted. The *Normandie* fire, for instance, would appear to be an example of minor fire damage (although, nevertheless, involving great cost) giving place to major disaster in view of the fact that the vessel turned turtle.

Dealing with fires

Thus, the first point which has to be raised under the heading of generalization is in connexion with the use of water in ships. Fig. 18 illustrates how the longitudinal trim of a vessel may be affected when a great volume of water accumulates in it. It would be agreed that in this manner a vessel may go down by the bow or by the stern, in consequence of which, in shallow water, she can experience structural damage. Generally speaking, water which finds its way to the bottom

of a vessel does little or no harm to the vessel because comparatively large quantities of water can be taken in before appreciable submerging results.

It has been stated that 1,000 gallons of water uniformly distributed over the bottom of a 100-ton vessel will cause it to submerge 1 inch, therefore, 10,000 gallons of water will

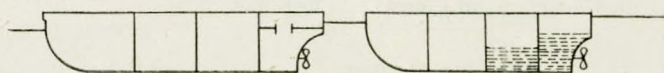


FIG. 17—Effect on longitudinal trim

submerge a 1,000 tonner 1 inch, whilst 1,000,000 gallons of water will submerge a 10,000 tonner 10 inch. These figures are, of course, only approximations, but may be generalized by stating that by multiplying the gross tonnage of a vessel by 10, the number of gallons of water necessary to cause 1-inch submersion is obtained. There is, of course, a fallacy since in view of bulkheads, etc., it is unlikely that the water will be uniformly distributed and, accordingly, this generalization can be accepted only as a rough guide and as a prelude to the more serious aspect relating to water and its effect on stability. Fig. 19 illustrates how seriously water which accumulates above sea level (as in a 'tween deck) can affect the vessel's latitudinal trim and it is this aspect which in particular has caused such serious consequences in passenger liner fires. When fighting

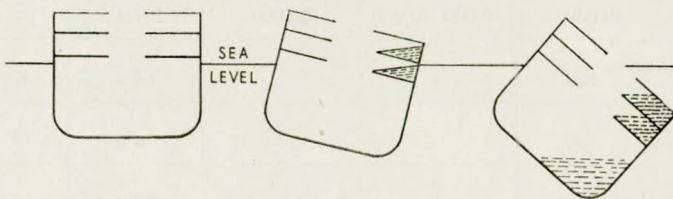


FIG. 18—Effect on lateral trim

'tween deck fires it is imperative to keep an eye on the clinometer, and should a list exceeding 20 deg. be noted, then it is imperative that the water in the 'tween deck be tapped off either by pumping, or, if necessary, by cutting holes in the plating.

Further requirements when dealing with ship fires are to reduce ventilation to the space involving the fire to a minimum. For preference, ventilator and hatch covers should not be securely fastened, but fitted as loosely as possible so as to offer relief for internal pressures. Many cases involving spontaneous combustion in a coal cargo have been made worse because once the fire has been detected, all hatches and ventilators have been opened for fear of explosion. Such explosions are extremely remote unless water is played directly on to red hot fire and even then are not inevitable. Time and time again experience has shown that a coal fire can be held in check indefinitely by reducing ventilation to a minimum and this applies to a large extent to many other types of fires in holds and 'tween decks.

Smoke helmets or breathing apparatus if available should be donned automatically when it is necessary to go into a 'tween deck or hold so as to locate the seat of a fire. This is a most hazardous task without such protection.

It is wrong to apply water automatically to a fire before the nature of the commodity concerned has been studied, for it will be recalled that salt water:—

- (a) Spoils many types of cargo.
- (b) Causes other types such as grain to swell badly, even to the extent that plates may be buckled.
- (c) May initiate dangerous reactions including explosions with metallic substances or with certain categories of dangerous goods, or again, with any combustible which is in a state of incandescence.
- (d) May cause many types of cargo to shift thereby affecting the trim of the vessel.

Before using water, consider the availability and advisability of employing steam, carbon dioxide, sulphur dioxide, or

Marine Gassing and Fire and Explosion Hazards

foam, etc., or even whether a refrigerant gas is available and is also a fire extingteur. If this latter is the case, then remember that it may be like methyl bromide in that it is decomposed by great heat to form toxic products including phosgene. These may not dissipate readily if the space concerned is partially confined, and thus a danger to personnel arises.

In general, steam should not be employed where the use of water is not advisable, although in many cases, a hold can be battened down and steam passed in so that a fire may be held in check for a sufficiently long time for the vessel to make port. Steam can often be introduced into a hold via the bilge by removing the applicable non-return valves in the valve chest and coupling up to the nearest steam points. It should be appreciated that water and steam damage cargo in varying degrees and so too does sulphur dioxide which, in the presence of water, forms a corrosive acid. Such is not the case with carbon dioxide, which does not damage any type of cargo. It is for this reason that many modern vessels are equipped with carbon dioxide installations which have heaters at the points of discharge of the gas in each hold. There is an interesting consideration in respect of these features. In general, steam secures the extinguishment of a fire more quickly if that fire exists in the upper part of a hold, whereas carbon dioxide, being heavier than air, is more effective when the fire is in the bottom of a hold. However, by heating the carbon dioxide at the discharge points, its density is lightened, in consequence of which, it is able to deal with fire at all levels in a hold.

When dealing with a fire in a hold, there is nearly always merit in soaking the hatch covers (and tarpaulins, if they are in place) with water, externally. This keeps them cool and helps to prevent them being consumed by the fire within, in consequence of which, the risk of freely ventilating the space is avoided. Wet tarpaulins or canvasses are excellent for smothering small fires.

There is often merit in cutting holes through bulkheads in order that a suitable extingteur can be applied directly to the

seat of a fire. Similarly, ventilator shafts can sometimes be employed. Flying embers or sparks may cause fires to start in other parts of a ship or, if in port, in property alongside. One man, at least, should be given the duty of guarding against this. Fire in a hold can, as a last resort, be extinguished by flooding, a practice which may introduce additional danger if in shallow water where the vessel can touch bottom. There have been cases of bottom plates having been started, in consequence of which, oil has escaped from a double bottom tank, has floated on the surface of the sea, and there caught fire with disastrous consequences.

In case of fire involving oils, there is obviously an advantage in transferring the bulk in the tank concerned to another tank if capacity is available. This reduces the amount of oil which can burn and causes a certain amount of cooling to take place. It does not eliminate the need for employing foam.

The most important precept with fire, whether on land or sea, is to capture it in the early stages. Big fires start as small fires. Accordingly, every effort should be made to knock out the fire at source in its early stages.

It is well to bear in mind wind direction when fighting fire. The vessel should either lay to or sail at slow speed with the wind abeam taking the smoke and flames to the leeward side. This ensures that smoke, flame and sparks will be carried safely away.

It is often the case that one man with a hose line going for one hour cannot effect as much good as three men with three hose lines going for 10 minutes. In other words, concerted action planned to attack the fire from all sides simultaneously is better than individual effort. This is particularly the case for deck and 'tween deck cargo fires, but difficult, of course, for fires in lower holds.

With coal cargo or bunker fires especially, but with fires involving other commodities as well, it is usually essential to locate men with hoses on the other sides of the confining bulkheads, for the heat of the fire may pass through the bulkhead

TABLE 6. COMPARISON OF ADVANTAGES AND LIMITATIONS OF GAS MASKS, HOSE MASKS, AND OXYGEN-BREATHING APPARATUS FOR PROTECTION FROM PETROLEUM VAPOURS AND FROM HYDROGEN SULPHIDE

Conditions	Gas-masks	Hose masks	Oxygen apparatus
Protection in atmospheres deficient in oxygen (less than 16 per cent oxygen).	Gas-masks do not protect against atmospheres deficient in oxygen, and should not be used therein.	Protect against all deficiencies of oxygen, since they are not dependent on air surrounding the wearer.	Protect against all deficiencies of oxygen. They are not dependent on air surrounding the wearer.
Protection in low concentrations of petroleum vapours (average 2 per cent and maximum 5 per cent in air).	Gas-masks with canister containing 600 c.c. or more of activated charcoal protect. Time of protection decreases rapidly as concentration increases.	Protect against any concentration.	Protect against any concentration.
Protection in high concentrations of petroleum vapours (exceeding 5 per cent in air).	Canister gas-masks do not give sufficient protection, and should not be used.	Protect against any concentration.	Protect against any concentration.
Protection in low concentrations of hydrogen sulphide (average 1 per cent and not exceeding 2 per cent in air).	Gas-masks with canisters containing 600 c.c. or more of soda lime or caustic soda fused on pumice granules protect. Time of protection decreases rapidly as concentration increases. Canisters containing only dry activated charcoal last only about one-fifth as long as those containing soda lime.	Protect against any concentration.	Protect against any concentration.
Protection in high concentrations of hydrogen sulphide (exceeding 2 per cent in air).	Canister gas-masks do not give sufficient protection, and should not be used.	Protect against any concentration.	Protect against any concentration.
Protection against mixtures of petroleum vapours and hydrogen sulphide in air.	Gas-masks with canisters containing a mixture of charcoal and soda lime should be used. Time of protection against petroleum vapours depends on volume of charcoal in the mixture and against hydrogen sulphide on the volume of soda lime. Recommended mixture 600 c.c. soda lime plus 900 c.c. charcoal.	Protect against any concentration.	Protect against any concentration.
Protection against other dangerous gases or vapours.	Charcoal canisters protect against organic vapours, aniline, benzene, ether, toluene, acetone, methyl ethyl ketone, furfural, etc., in concentrations similar to those of petroleum vapours. Soda lime canisters protect against acid gases, such as chlorine, hydrogen chloride, sulphur dioxide, etc. Copper sulphate on pumice stone granules protects against ammonia.	Protect against any concentration.	Protect against any concentration.

Marine Gassing and Fire and Explosion Hazards

and ignite cargo in an adjacent hold or space. This can be prevented if the bulkheads concerned are kept cool with water.

Methods of dealing with explosions

Explosions take place with instantaneous effect and so cannot be fought, although they may be followed by serious fire.

Gassings

These risks can only be dealt with in two ways:—

- (a) Gas-freeing measures.
- (b) Breathing apparatus protection.

With regard to gas-freeing measures, the length of time taken will obviously depend upon the size of the space or compartment concerned, and upon the capabilities of the gas-freeing device. This is no doubt that modern air injectors or ejectors effect gas-freeing more quickly than do windsails, the efficiency of which largely depends upon the velocity of the prevailing wind and temperature. Steam injectors, too, can be employed but require a reasonable time for cooling down afterwards, before personnel can enter the space concerned. In spite of the foregoing, windsails have the advantage of general utility, but it is advisable to draw attention to the fact that they are constructed of combustible material. They have been set on fire.

With regard to (b) it is fitting to discuss smoke helmets, self-contained breathing apparatus and gas masks of the canister type. Smoke helmets are generally available, but give the wearer a false sense of security in the presence of toxic gases. They do not give adequate protection to the wearer against carbon monoxide, for example, a product of a coal fire, etc., and so must be employed with caution. Incidentally, the wearer must be equipped with safety belt and lifeline.

Self-contained breathing apparatus is ideal. Men of the mines rescue and fire brigades make excellent use of these

devices, the wearer being completely immune from the effect of smoke and toxic gases for periods up to one hour. Furthermore, he has a freedom of movement denied to the wearer of the smoke helmet, since his apparatus is self-contained and so does not carry a long air pipe. However, here again, in a ship fire, the wearer should be given a belt to which is attached a lifeline.

Gas masks of the canister type. The suitability and limitations of gas masks as compared with hose masks (smoke helmets) and self-contained breathing apparatus (oxygen breathing apparatus) are set out to a limited extent in Table 6. In general, it should be considered that gas masks are of very limited value indeed as regards the hazards likely to be encountered in ships, for there is a mistaken and persistent impression that gas masks afford complete protection against any gas. This is surprising, for considerable publicity has been given to cases in which fatalities have resulted through people wearing war-time civilian respirators as protection against coal gas. In the first place, it must be understood that a gas mask affords protection against only the type of gas or gases for which it is designed (such gases are usually specified on the canister or container) and secondly, once the maximum specified concentration of gas is exceeded, protection is no longer afforded. A gas mask should not be relied upon for purposes other than those specified by the manufacturer.

The author does not claim accuracy from legal and marine points of view, but merely surveys the experience he has gained as a chemist closely associated with shipping, the fire service and a study of fire research.

He is indebted to many legal and Government publications for his information and also to several of his colleagues and friends, especially to Mr. Louis Trenchard, M.B.E., and Mr. Frank Heslop, who have provided advice on marine engineering subjects as required.

Evaporative Cooling for Marine Internal Combustion Engines*

J. F. ALCOCK, B.A., M.I.Mech.E.

Steam cooling is considered, in relation to water cooling, from three aspects.

(1) The scanty existing data on heat-flow rates at hot spots suggest that these ranges from 40,000 to 120,000 B.Th.U. per hr. per sq. ft. in medium and high-duty engines, more or less irrespective of engine size; these rates are well within the capacity of either steam or water cooling. Metal temperatures at hot spots with steam cooling are probably less than with normal low-speed water circulation, but higher than those obtainable with fast streams of cool water (over 2ft. per sec.) directed over the hot spots. This latter system seems the best for engines of great size or high rating.

(2) In the case of natural circulation with steam cooling some very approximate formulæ are derived and suggest that larger piping will probably be needed for steam cooling (with natural circulation) than water cooling with pump circulation.

The risk of steam-locking and blanketing is considered, and some simple rules are proposed for minimizing this risk. This risk should be easily eliminated by engines designed for steam cooling, but needs consideration and probably experiment with existing designs.

(3) From the point of view of cost and convenience water and steam cooling seem fairly well balanced except for the marked advantage steam cooling has as regards temperature regulation. This may markedly reduce cylinder wear under short-voyage conditions, e.g., ferry-vessels.

In large vessels, the jacket steam may be put to use, either for heating or for auxiliary power, but it is doubtful whether the cost and complication are justified.

Summing up, there does not seem to be a strong case for the general adoption of steam cooling, but it is worth consideration for certain classes of vessel. Favourable conditions are moderate rating, medium powers, and short voyages.

The report suggests some problems in connexion with hot-spot cooling and natural convection on which research is needed.

INTRODUCTION

Evaporative or steam cooling has now been under consideration for a long period; so far as can be seen without making a serious historical survey, it appears that, apart from the crude steam cooling of the hopper-cooled engine, the ball was set rolling by the Antoinette aero-engine system about 1910, followed by the Still high-pressure system and the systems of Cave-Brown-Cave and Rushmore for air and road use.

In spite of all this work, steam cooling has not come into general use, except for hopper cooling and the quasi-evaporative "pressure cooling" of aero-engines; but the only known marine application is the Still engine, an abnormal case since the steam is generated at high pressure, and therefore temperature, for steam generation; for marine use, therefore, normal steam cooling is as yet untried.

STEAM COOLING SYSTEMS

The simplest form is the hopper-type engine, shown at (a) Fig. 1, and the next step is obviously the provision of a condenser cooled by sea water (or by air) as at (b). This crude type has the advantage of simplicity and of free venting of steam from the heated surfaces, but it prevents easy access to valve gear, injectors, etc., in the head. For this reason, types (a) and (b) are mainly used with side-valve petrol engines.

Normal head accessibility is restored in type (c), where a separate "steam drum" and condenser are connected to the cylinder jacket by an "up-comer" and "down-comer". This system may be elaborated by the addition of a circulating pump as at (d). If the condenser is below the jackets, a condensate return or feed pump is needed as at (e) (Antoinette system). The Rushmore type is similar, but with no circulating pump).

In addition to these, there is the "pressure cooling" normally used with liquid-cooled reciprocating aero-engines. This is a normal water-cooling system, sealed by a relief valve set to blow at a pressure up to about 30lb. per sq. in. gauge. The radiator being too small to cool the water to 100 deg. C. (or the boiling point at the prevalent altitude), steam is generated, raising the pressure and therefore the water temperature, until the radiator can dissipate the heat supplied. This is not really steam cooling, since the radiator is full of liquid water, and would work equally well if the pressure were supplied by other means, e.g., by compressed air.

COMPARISON WITH WATER COOLING

To be adopted, steam cooling must obviously show a balance of advantage over water cooling, which is at present universal in marine service. To be fair to water cooling, an up-to-date arrangement with indirect cooling must be taken as a standard for comparison, i.e., cooling of the engine by fresh water, itself cooled by sea water in a heat-exchanger, and an adequate circulating pump sufficient to keep the tempera-

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Evaporative Cooling for Marine Internal Combustion Engines

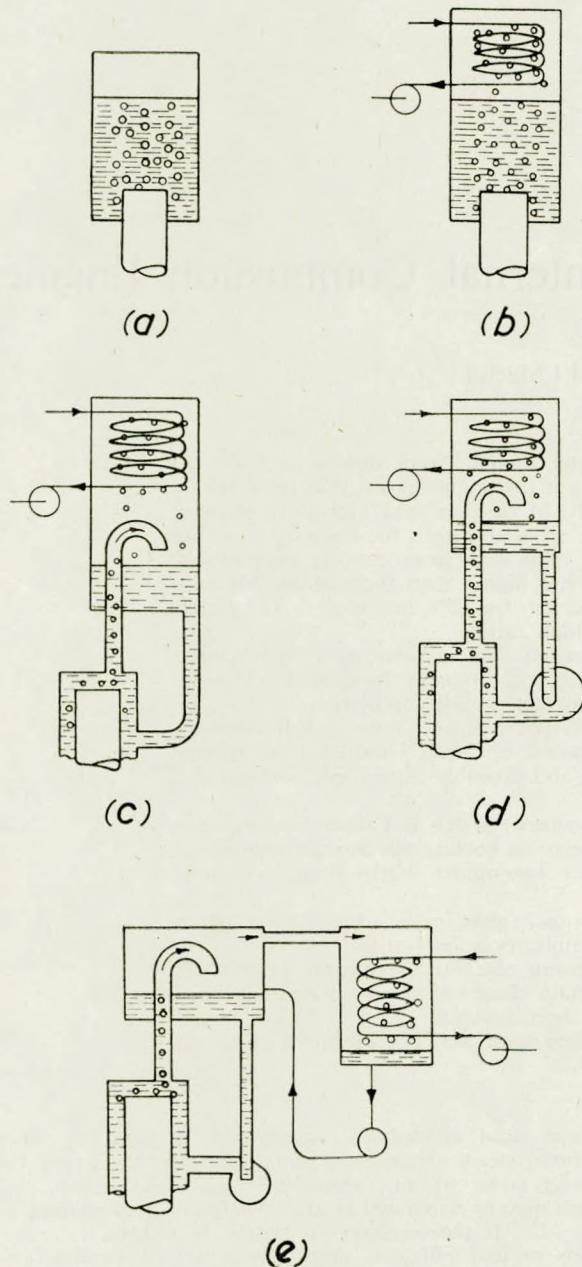


FIG. 1—Steam cooling systems

ture rise through the engine down to say 20 deg. F. Average modern practice, compromising between the avoidance of corrosion wear due to low bore temperatures and a desire to have plenty of reserve cooling in hand, would set water-inlet and outlet temperatures at full load of about 140 and 160 deg. F., respectively. These figures will hereafter be taken as representative.

It is arguable whether the typical modern water-cooling system should include a thermostat. The advantages of so doing are obvious, but one has to face the fact that thermostats are rarely used; general experience seems to show that the simple and cheap thermostats used on small engines are unreliable, while the cost and complexity of the higher-grade thermostats used in industrial process control have discouraged their general use on larger engines. It therefore seems best to take the typical water-cooled system as having no thermostat.

The chief drawbacks of this existing system, which steam cooling may hope to eliminate, are:—

- (1) Poor temperature control.
 - (2) Cost and maintenance of circulating pump.
 - (3) Difficulty of adequately cooling hot spots.
- These are considered below.

TEMPERATURE CONTROL

Here steam cooling scores heavily; the water temperature is automatically held constant at about 100 deg. C. (in an atmospheric-pressure system) regardless of load. Moreover, the engine warms up rapidly on starting because of the reduced mass of water in the system and because there is no cooling of the circulating water until the boiling temperature is reached. This will certainly reduce cold-bore or corrosion wear; what proportion this is of the total wear will depend on the service. It has been shown^{2,1} that a cold start causes as much bore wear as about sixteen hours' running, so that the gain should be considerable on ferry boats for example. At the other extreme, one would expect little benefit in ocean-going vessels with their long voyages, and none, of course, where there already exists the very desirable practice of pre-heating jackets from auxiliary boilers, etc., before starting.

SIMPLICITY AND COST

Types (a) and (b), Fig. 1, may be ignored as impracticable for marine service; type (c) gains by the elimination of the freshwater circulating pump. The saving in cost and power consumption is not great, but the modern engine is so congested with auxiliaries that the designer will be glad to lose one, while in large plant with separately driven circulating pumps the saving in floor space is appreciable; in all cases, the elimination of one shaft gland is welcome from the maintenance aspect. Type (c), however, necessitates a condenser above the top of the engine; where there is no headroom for this, one is forced to type (e), which is no simpler than water cooling, though the feed pump will be smaller, and for large engines cheaper, than a circulating pump.

COOLING OF HOT SPOTS

This is a well-known trouble, but one on which the evidence is largely qualitative. The first question is, what rate of heat dissipation is required at hot spots? Very few measurements of local, as apart from overall, heat-flow rates are on record, the only investigations that the author can trace being those of Ricardo², and Eichelberg and Hug³. Most of the Ricardo work was carried out on "freak" engines, very different from normal marine design, so is only indirectly applicable to the present problem. Eichelberg's work, however, was on normal Diesel designs, and is thus of direct use. A selection of typical hot-spot heat flows is given in Table 1. Most of the Eichelberg figures quoted are very rough, the temperature gradients having been measured (by the author) of small-scale isotherm maps, while the thermal conductivity of the material had to be assumed. They should, however, give the right order of magnitude.

In spite of the very wide range of type, size, and speed, the heat flows at hot spots are surprisingly close together; and it seems reasonable to take values ranging from 40,000 to 120,000 B.Th.U. per hr. per sq. ft., according to the severity of engine rating. The locations, it is true, do not include some notorious hot spots, such as bridges between valve seats and exhaust ports, but, since the higher figure just quoted corresponds to a temperature gradient of about 340 deg. F. per inch thickness of cast-iron, it is likely that higher heat flows will be impracticable, because of thermal stresses, in all but the smallest engines of normal design.

DISSIPATION OF HEAT

These heat flows must first be passed through a metal wall, usually cast-iron, of thickness up to 1.5 to 2 inch plus probably some scale of very low conductivity, and then through a "boundary layer" of water or steam-water foam to the main

* References are given on p. 334.

Evaporative Cooling for Marine Internal Combustion Engines

TABLE 1. LOCAL HEAT-FLOW RATES

Case	Source (E=Eichelberg ³)	Engine type (all Ricardo)	Bore, mm.	Stroke, mm.	R.p.m.	Piston speed, ft. per min.	I.m.ep., lb. per sq. in.	Location of heat flow	Heat flow, B.Th.U. per sq. ft. per hr. ÷ 1,000
A	E Fig. 1	Single-acting 2-stroke, port scavenge and exhaust	600	1,060	100	700	100	Top of liner Head (dia.=0.5 × bore)	43 44
B	E Fig. 4	Double-acting 2-stroke (top half), port scavenge and exhaust	380	460	412	1,200	110	Top of liner Head (dia.=0.75 × bore) Piston crown (dia.=0.5 × bore)	72 117 120
C	E Fig. 18	Single-acting 4-stroke, poppet valve	280	420	176	490	106	Liner, top Liner, down 15% stroke Liner, down 40% stroke Liner, down 100% stroke	43 10.7 6.5 4.3
D	Ricardo unpublished	Single-acting 2-stroke, exhaust valve in head, high swirl	95	111	2,250	1,650	114 114 117	Liner, down 13% stroke Liner, down 18% stroke Combustion chamber wall, bore	67 53 75
*E	Ricardo unpublished	Single-acting 2-stroke, sleeve valve, exhaust by port in cylinder over top edge of sleeve	127	140	2,400 2,600	2,200 2,390	138 139	Cylinder bore (Al. alloy, no fixed liner but sleeve valve) 6.9% below top	55 64

* It is known from experiments on petrol engines that a sleeve valve has a very powerful effect in evening out the heat flow along the cylinder length. Without a sleeve the heat flow at this position would probably be far higher.

mass of water. Ignoring for the moment the metal and scale, consider the boundary layer, first with water and then with steam cooling.

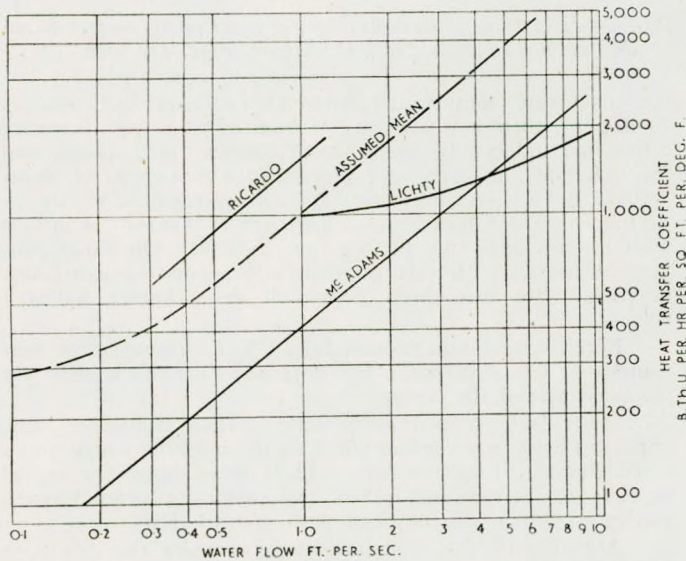


FIG. 2—Curves of heat transfer coefficient against water velocity for jacket water

Ricardo curve: Report 1159. Heat transfer in jacket of E.43. (sleeve-valve four-stroke petrol engine.)

Lichty: "Internal Combustion Engines", p. 435.

McAdams: "Heat Transmission", curve based on equation 9c, p. 183, for water in 1-inch diameter tube.

$$h = 150 (1 + 0.117) (V^1)^{0.8} / (D^1)^{0.2}$$

t = deg. F. (160 deg. F.).

V^1 = Velocity ft. per sec.

D^1 = Internal diameter, inch.

WATER COOLING

Fig. 2 gives curves from various sources for the "conductance" (heat-transfer rate/temperature difference) of the boundary layer of water over a range of flow velocities. The McAdams curve⁴ is for a 1-inch smooth-bore tube at a point wall away from eddies at entry, etc. The Ricardo curve² was taken from tests of local heat flows and local velocities in an

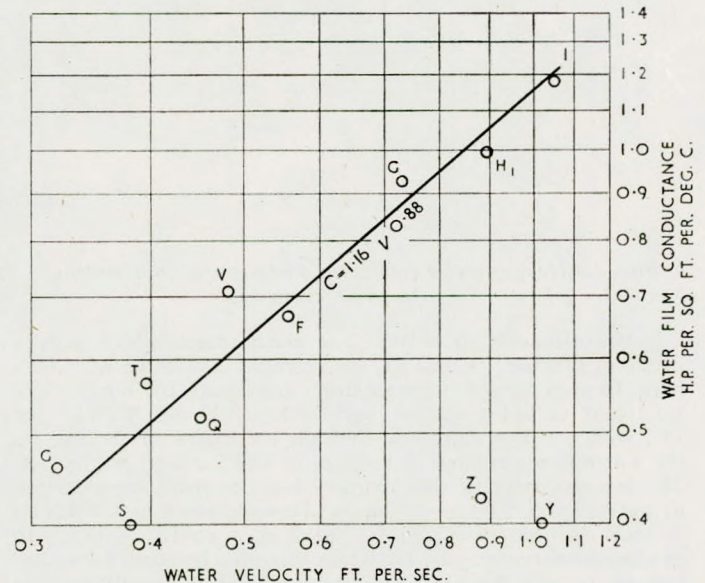


FIG. 3—E.43 heat flow tests

Relation between water-film conductance and water velocity 80 b.h.p. Mean water temperature 70 deg. C. approximately. Letters indicate couple locations. Water velocity at each point is maximum parallel to heated surface, obtained by rotating pitot head until manometer reading is maximum.

Evaporative Cooling for Marine Internal Combustion Engines

actual cylinder casting. Under these conditions, there is much greater entry, etc., turbulence and wall roughness, which may account for the heat flow being about four times greater than in a smooth tube, though this difference does seem rather high. To enable the reader to form his own opinion on this point, Fig. 3 gives the Ricardo curve with observation points added. Except for two bad "strays", one of which was later explained, the scatter is surprisingly small, considering the wide variations in turbulence which must exist at different points in a cast jacket. The agreement in the slope of the curve between Ricardo and McAdams curves is also surprisingly good. The Lichty curve⁵ on the other hand shows a very different slope; Lichty gives no information as to test conditions, etc., so there is no means of accounting for this discrepancy.

Eichelberg (Fig. 6 of Ref. 3) gives some data apparently obtained on engine jackets. The heat-transfer coefficients range from 100 to 500 B.Th.U. per hr. per sq. ft. per deg. F. at mean water flows of 0.02 ft. per sec. and under. These values are far higher than would be given by extrapolation of either the Ricardo or McAdams curves of Fig. 2, and one suspects that these very low forced velocities are being supplemented by local thermal convection. This may also explain the shape of the Lichty curve.

Reviewing all these data, it seems likely that a curve lying somewhere between the Ricardo and McAdams curves of Fig. 2, distorted to give a thermal convection value of about 250 B.Th.U. per hr. per sq. ft. per deg. F. at zero nominal water velocity, will be fairly near the truth. The dotted curve shown in Fig. 2, will be taken as a basis for future discussion. It is also shown on a linear scale in Fig. 4, to include the zero-velocity point. This curve is probably fairly reliable down to about 0.3 ft. per sec. water velocity, but will be uncertain at lower speeds where natural convection is dominant.

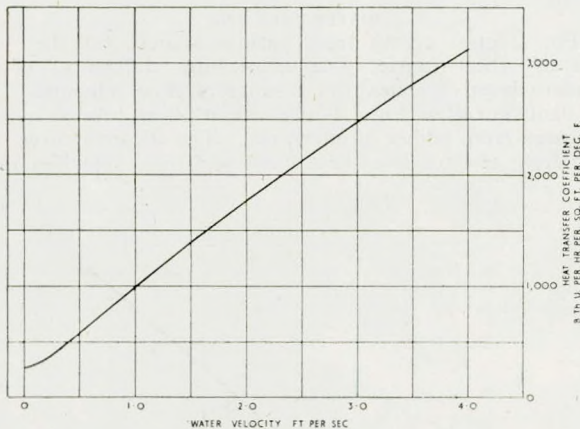


FIG. 4—Heat transfer coefficient metal-water (not boiling).
Assumed curve

Unfortunately, it is these low water speeds which usually occur in practice. Consider, for example, a cylinder of 9 inch bore, 10 inch outside diameter liner, developing 100 h.p. The total heat to jacket will be, say, 70 h.p. 178,000 B.Th.U. per hr.; with a temperature rise through the engine of 20 deg. F., the water flow per hour is 8,900 lb. or 142.5 cu. ft. per hr. At 1 ft. per sec. velocity this requires a water-space cross-section of $144 \times 142.5 / 3,600 = 5.7$ sq. in., corresponding to a width on 10 inch diameter of $5.7 / 31.4 = 0.182$ or, roughly, $\frac{1}{8}$ inch. In practice, water spaces are far wider than this because of foundry limitations and the need for cleaning, and it is unlikely that velocities higher than 0.2-0.3 ft. per sec. will exist in normal designs without special baffles.

BOILING HEAT TRANSFER

Heat transfer during evaporation is a very complex process, depending on a number of factors, such as the nature and shape

of the heating surface, which are not easily assessed. Normally, however, it is a very effective process, transferring large heat flows with a small temperature drop, so that reasonable percentage errors do not matter much. A typical curve of heat flow versus temperature difference for water at atmospheric pressure with natural convection is shown in Fig. 5⁶. Until

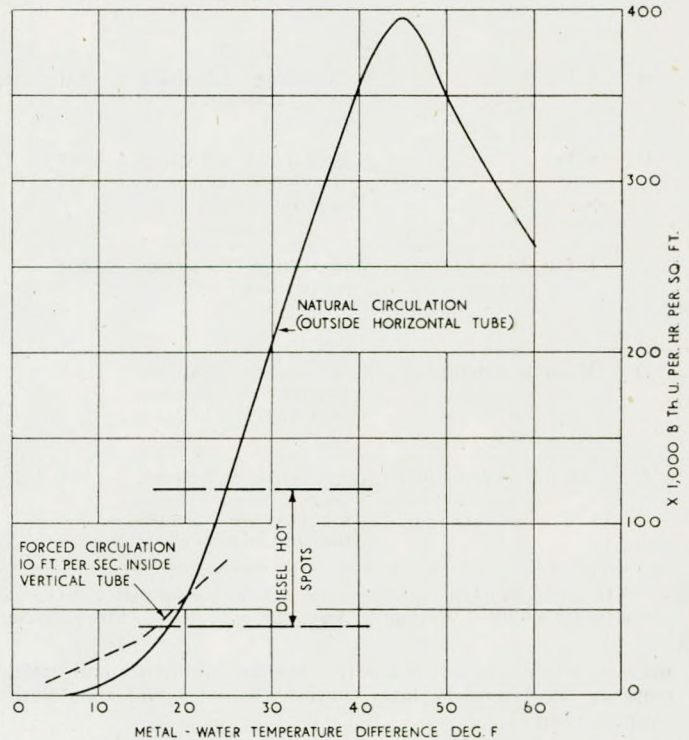


FIG. 5—Heat transfer to boiling water from metal surface based on "Heat Transmission", McAdams, Figs. 147 and 171

the metal-water temperature difference or "superheat" reaches 10 deg. F., there is a low rate of heat transfer, but thereafter convection induced by rising steam bubbles takes charge, and the heat-flow rate rises very rapidly to a maximum of about 400,000 B.Th.U. per hr. per sq. ft. at a superheat of 45 deg. F. At this rate steam generation is sufficient to blanket the surface with a steam film, and the heat flow falls off. Obviously, this "critical heat flow" is a danger point which must on no account be passed, but fortunately it is well above known hot-spot values.

Forced circulation (dotted line, Fig. 5) improves the heat transfer at low superheats, but does not have much effect on the steep part of the curve.

Other factors, such as pressure, surface conditions, etc., appear to have only a minor effect on the conditions now under consideration. The only factors likely to be dangerous are oil or scale on surfaces and lack of free escape for steam formed, neither of which can be dealt with quantitatively.

Armed with this heat-flow data, consider the case of a hot spot emitting, say, 105,000 B.Th.U. per hr. per sq. ft. and cooled by water at 150 deg. F. moving at 0.2 ft. per sec. From Fig. 4, the transfer coefficient will be about 350 B.Th.U. per hr. per sq. ft. per deg. F., giving a metal temperature 300 deg. F. above the water temperature, i.e., 450 deg. F. Obviously this will cause local boiling; applying Fig. 5, one finds that the metal temperature should be 24 deg. above boiling point or 247 deg. F. Now it is known that metal temperatures far higher than this do occur under these conditions; for example, wet metal temperatures of 395 and 336 deg. F. are recorded by Eichelberg (Figs. 1 and 4 of Ref. 3). The most likely explanation of this discrepancy is that in a fully boiling

Evaporative Cooling for Marine Internal Combustion Engines

liquid the water circulation caused by the rising bubbles has a powerful effect in promoting heat transfer (as is well known to boiler designers), and that where the bulk of the water is cold the bubbles formed at the surface are condensed before they can produce much circulation. Such an explanation is borne out by Gibson's tests⁷, in which the temperature of an aero-engine "hot spot" begins to fall as the water temperature is increased above 80 deg. C.

The exact mechanism of this blanketing effect is not clear. It can hardly be spheroidal-state boiling, and the blanketing agent may be air released from solution in the water; in this case, one would expect it to be more severe with direct sea-water cooling than with a closed circuit, in which most of the air would in time be driven off.

It seems, therefore, that the wall temperature at a hot spot with normal water cooling cannot be determined on existing heat-transfer data (this lack of knowledge suggests a useful subject for research) but the following conclusions seem fairly certain:—

- (1) With normal cooling the "water-cooled" wall at a hot spot may be well above boiling point (170 deg. F. higher in one case quoted above).
- (2) With steam cooling, i.e., where the mass of the water is boiling, temperatures more than about 50 deg. F. above boiling point are unlikely in the absence of imperfections such as oil films, steam locks, etc.

In short, steam cooling would appear to give better cooling of hot spots than does the normal low-velocity water cooling.

The possibility of dealing with hot spots by a rapid stream of cool water must, however, be considered. Taking water velocity and temperature as 4ft. per sec. and 120 deg. F., there is a heat-transfer coefficient of 3,000 B.Th.U. per hr. per sq. ft. per deg. F., and without boiling the wall temperatures would be:—

- (a) Mild hot spot, 40,000 B.Th.U. per hr. per sq. ft.
 $120 + 40,000/3,000 = 133$ deg. F.
- (b) Severe hot spot, 120,000 B.Th.U. per hr. per sq. ft.
 $120 + 120,000/3,000 = 160$ deg. F.

These are well below steam-cooling values.

Whether such low wall temperatures are necessary or desirable will depend on circumstances; this will be made clear by consideration of some particular cases.

CYLINDER LINERS (WET)

For good lubrication and low wear, the bore temperature at the top of the ring travel should not exceed about 360 deg. F. Taking the conductivity of cast-iron as 0.12 c.g.s. or 350 B.Th.U. per sq. ft. per hr. per deg. F. per 1 inch thick, the temperature gradient per inch will be:—

For normal rating (21,000 B.Th.U. per sq. ft. per hr.*)
 74 deg. F.

For severe rating (36,000 B.Th.U. per sq. ft. per hr.*)
 126 deg. F.

With atmospheric pressure steam cooling, the outside liner temperature will be about 240 deg. F. allowing for some scale in service, so the allowable temperature difference is $360 - 270 = 90$ deg. F. This steam cooling should be adequate for wall thicknesses less than:—

$90/74 = 1.2$ inch for normal rating.

$90/126 = 0.65$ inch for severe rating.

Taking typical liner thicknesses as about 6 per cent of the bore this gives limiting bores for steam cooling of about 20 inch and 11 inch for normal and severe ratings.

These figures are very approximate, since at the upper ends of liners axial heat-flow complicates the issue, but they should be of the right order of magnitude.

INJECTOR MOUNTINGS

The temperature of the needle seat and guide are the limiting factors, but the complex heat-path from these points to

the water, and lack of quantitative data as to temperature limits, preclude even the roughest calculation. It seems probable that steam cooling will be adequate in most small engines and in moderately rated engines of medium size, but that for large highly rated engines local fast-water cooling is desirable.

CYLINDER HEADS

Here temperature differences, leading to distortion and cracking, are the trouble. Thermal stresses due to temperature drop through the metal at any one location, being a function only of the heat flow at that point, will be unaffected by the method of cooling, but those due to temperature differences between different parts of the head, e.g., the upper and lower decks, should be considerably alleviated by steam cooling.

VALVE SEATS AND GUIDES

Here the chief resistance to heat flow is conduction through the metal and across metal-to-metal contacts; this is clearly shown in Figs. 47 and 50 of reference 3. Thus the method of cooling will have only a minor effect, and the only hope of substantial improvement lies in re-design to shorten the heat-flow path through the metal.

GENERAL CONCLUSIONS ON HEAT TRANSFER

As regards cooling of hot spots, steam cooling should be much better than normal stagnant-water cooling, but inferior to fast directed-water cooling. This latter, however, is an expensive luxury; steam cooling would be cheaper and in many cases adequate.

DESIGN PROBLEMS

General Circulation

Consider the artificially simplified steam-cooling (natural-convection) system shown in Fig. 6. This consists of a U-tube connected to a header tank; heat is imparted locally at one level of the up-comer, a fair representation of an engine, in which most of the heat is transferred at the upper end. There are two resistances to flow, one, R_s , passing the steam-water mixture in the up-comer, the other, R_w , in the down-comer passing liquid water. The resistance of the rest of the pipework is negligible.

Assuming that the system is at about atmospheric pressure, that there is no slip between water and steam in the up-comer, and that the ratio of water to steam in the foam (by weight) does not exceed 100 (i.e., a rate of water circulation corresponding to a rise through the engine with water cooling of 10 deg. F.), it can be assumed (see Appendix I) without serious error that:—

- (a) The convection head causing circulation is the full

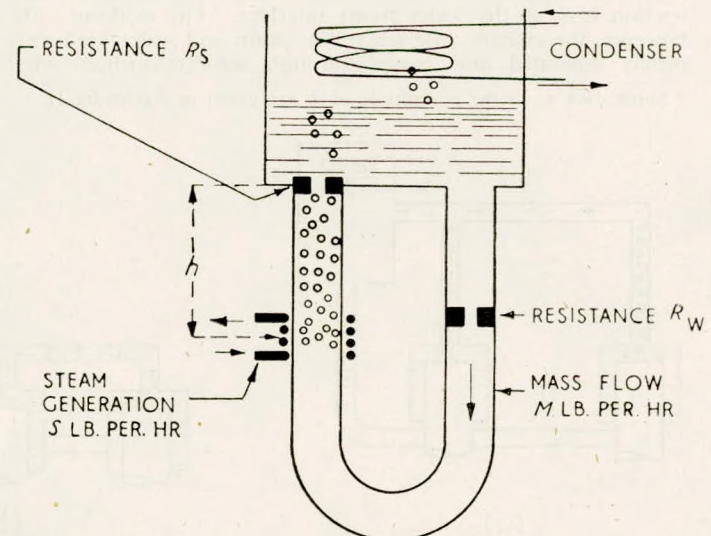


FIG. 6—Steam cooling system. Diagrammatic representation

* These are half the figures quoted in Table 1, Cases A and B, for the upper ends of liners, since the top ring is some little way down.

Evaporative Cooling for Marine Internal Combustion Engines

height of the bubble column in the up-comer (H in Fig. 6).

(b) If the up-comer and down-comer piping are roughly similar, i.e., of roughly equal resistance to a given flow of a given fluid, then the resistance of the down-comer can be neglected.

(c) The dryness fraction of the "steam" in the up-comer can be roughly estimated from the following formulæ:—

(i) Where known factors are:—

Jacket heat input E^* B.Th.U. per hr.

Up-comer resistance P_s feet of water for 1lb. per hr. flow of water.

Effective steam-column height H feet (see Fig. 6).

Dryness fraction $x = E^2 P_s / 625 H$.

(ii) Where known factors are:—

(1) H as above.

(2) Temperature rise across engine, T deg. F.

(3) Pressure rise across water pump, H_p feet of water.

(4) Ratio up-comer resistance to total circuit resistance P_s/P_t .

$$\text{Dryness fraction } x = \frac{T^2 H_p P_s}{625 H P_t}$$

The last formula is useful where the rate of water circulation cannot be conveniently measured. H_p and P_s/P_t can easily be measured by manometers tapped into the circuit at suitable points.

This calculation ignores two factors:—

(1) The pressure loss due to the increase in momentum which occurs in the evaporation zone, owing to the increase in volume and therefore velocity which occurs in this zone. This effect will tend to reduce the circulation, and thus increase the dryness.

The author's thanks are due to Mr. E. F. le Fevre, of King's College University, Durham, for drawing attention to this effect, which was not taken into account in the original version of this report. It has an appreciable influence only when the cross-sectional area at which evaporation occurs is of the same order as the area of the "equivalent single orifice" having a resistance equal to that of the up-comer. In normal designs, where the evaporation area is at least ten times that of the up-comer, the increase in dryness due to this effect is a few per cent only and can be neglected, the whole theory being obviously very approximate.

(2) The second factor is slip between steam and water, which has been assumed to be absent. At first sight it would appear that slip would increase the resistance, since it involves friction loss at the water-steam interface. On working out, however, the extreme case where the steam and water are completely separated and passed through separate orifices, one

* Some data as to the magnitude of E are given in Appendix II.

finds that the resistance is very considerably reduced (see Appendix III) or, in other words, that the flow for a given circulation head is increased.

To what extent separation occurs is not known, but Burnell¹⁰ shows that in a long pipe (about 300 diameters) it is enough to make the observed flow about 70 per cent higher than the theoretical.

Thus there are two factors which may modify the dryness values given by the above simple formulæ, one tending to increase the flow and the other to decrease it. The balance will clearly depend on circumstances, and until more knowledge is available these formulæ should be considered merely as indicating orders of magnitude.

If the last formula is applied to the case when $H = 2$ feet, $H_p = 10$ feet, $T = 10$, $P_s/P_t = 0.5$, a rather generous circulation rate by average marine standards, the dryness fraction x comes out at 0.4. There is no evidence as to the dryness fraction permissible in engine jackets, but this figure seems high by comparison with water-tube boiler practice. It may be pointed out that at atmospheric pressure a dryness of 0.4 represents 640 volumes of steam to one of water; thus the jacket contents would probably resemble a "Scotch mist" rather than a foam, and there would appear to be a risk of parts being unwetted and thus overheated through centrifugal separation of mist droplets.

It seems likely, therefore, that in most conversions of existing water-cooled engines to steam cooling, it will be necessary either to retain a circulating pump or to enlarge the water-ways in the up-comer.

Local Circulation

The wide variety of jacket arrangements and their complex form makes generalization impossible, and each case will have to be considered individually. Experience with steam boilers gives some guidance, but conditions in engine jackets are so different that boiler experience is not very helpful. From consideration of the literature on the subject, particularly the paper by Lewis and Robertson⁸, the following points seem to be worth mentioning:—

Jackets in Parallel

With a number of independent jackets in parallel on a common down-comer, there is some risk that the gross convection head set up in one jacket will be just balanced by the net convection head (i.e., gross head less resistance) set up by the other jackets. In this case circulation in one jacket stops and, though the increase in convection head due to the non-escape of steam should restore the balance, it appears that the action may be in some cases erratic and allow over-heating. To avoid this risk the following precautions seem desirable:—

(a) Collector piping, both up-comer and down-comer, feeding several jackets should be large enough to set up only a small proportion of the total resistance to

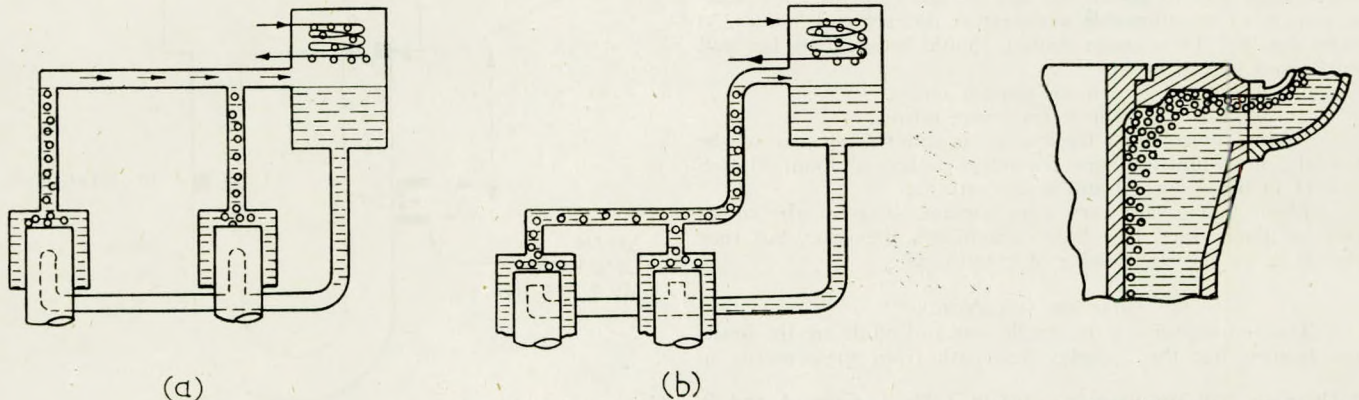


FIG. 8—Possible steam blanketing of top end of line

FIG. 7

Evaporative Cooling for Marine Internal Combustion Engines

flow. This minimizes the effect of one cylinder on another.

- (b) Since these blockages are most likely where dissimilar conditions exist in different jackets, the exhaust-manifold jacket, which differs greatly from the cylinder jackets, should have its own up-comer to the "steam drum".
- (c) Where possible, individual cylinder up-comers should rise as far as possible before joining a collector, e.g., (a), Fig. 7, is preferable to (b), since any increase in heat input in one cylinder will cause a greater increase in circulation head for that cylinder and thus more readily restore the balance.

Top End of Liner

With the usual cylinder construction, shown diagrammatically in Fig. 8, there is obviously a tendency to blanket the top of the liner and the underside of the "deck" with steam generated lower down the liner, and this tendency will be aggravated by the limited steam-outlet area usually provided. In general, about 25-35 per cent of the steam will be generated below this point, and its volume will be considerable. Any appreciable blanketing at this dangerous hot spot would be a serious matter, and ample steam passage at this point seems desirable.

In long multi-cylinder blocks, this blanketing might be accentuated, in the case of bad fore-and-aft trim due to ship damage, by the tendency of the steam to collect at the upper end of the block. A list would, of course, have the same effect in thwartwise-mounted auxiliary engines.

This point seems of sufficient importance to justify experiments on a model cylinder with a glass jacket; quite a simple model, on the lines shown in Fig. 9, would give useful information.

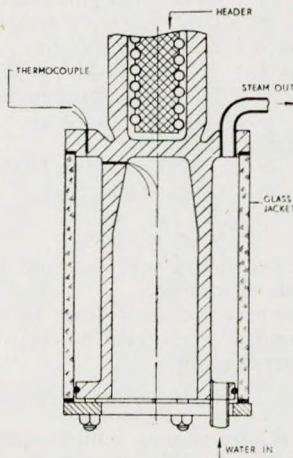


FIG. 9—Steam cooling. Suggested model cylinder

Cylinder Head

If this is fed, as usual, from the cylinder jacket, the feed will be a fairly tenuous spray or foam, most of its volume being steam. The feed has to turn through one or more corners before reaching the heated surfaces, and there will be some centrifugal separation of the water, which may leave hot spots dry. This tendency will have to be considered during design, and here again simple model experiments should be of use.

MISCELLANEOUS PROBLEMS

Scale

The general tendency is for more scale to form when boiling than when heating water, but with closed circuits in both cases scale should always be negligible (except when caused by the ever-present temptation to make up with sea water). As regards oil contamination due to gasket seepage, there may be a

tendency for boiling to scrub the oil off the hot surfaces, though the author knows of no evidence of this.

Size of Heat Exchanger

The rate of heat transfer from condensing steam is far greater than the rate from water flowing at normal velocities. This will make the condensing surface smaller than that of the equivalent fresh-water cooler, but in practice the main resistance will be on the sea-water side, since a liberal allowance has to be made for fouling; thus the difference in practice will not be very great. In either case, the heat exchanger is too small for its size or cost to be a major issue.

Use of Steam

Steam is a more convenient medium for auxiliary heating than is hot water, and this may be an asset in some cases. The assessment of this gain is, however, a point for the naval architect rather than the engineer. Another possibility is the use of the steam for power, e.g., to drive a supercharger or scavenging blower. The pressure in the jackets will preferably be kept low to avoid both liner-overheating and piping troubles, and the best way would probably be to generate at, say, 20 lb. per sq. in. gauge and superheat as far as possible by the exhaust gas. The Rankine cycle efficiency from 20 lb. gauge, 660 deg. F. to 27 inch vacuum is 21 per cent. Allowing for net jacket-plus-exhaust-boiler heat equal to the s.h.p. and a turbine efficiency of 60 per cent, which is as much as one can expect in a small size, the turbine h.p. would be about 12 per cent of the shaft h.p., which would comfortably drive the average supercharger, with perhaps enough left over for the at-sea electricity requirements of a cargo vessel. Apart from the saving in fuel, an advantage is that a steam turbine forms a convenient direct drive for a centrifugal supercharger, making a very compact unit, though it is arguable whether the advantages are worth the complication.

Freezing

In cold climates, there is a risk of freezing of the fresh water used either for steam cooling or indirect water cooling. In the latter case, the use of glycol and other anti-freezes is well known. Swan⁹ states that 30 per cent ethylene glycol solution was successfully used in an aircraft steam-cooling system. There is some temperature increase, of course, due to the higher boiling point of the fluid plus possibly an addition due to its greater viscosity.

After-boiling

A fair amount of heat is stored in the metal of a running engine, and is transmitted to the coolant when the engine stops. With normal water cooling the circulating water is usually well below boiling point and can absorb a fair amount of heat before boiling, but with steam cooling this is obviously not the case and boiling will continue. With independently driven sea-water pumps the steam so formed will be condensed in the normal manner, but where the pump is engine-driven the sea water in the condenser must have enough reserve capacity to absorb the stored heat.

CONCLUSIONS

The most promising field for steam cooling seems to be in moderately rated engines of medium or fairly large size. In this range, steam cooling appears to have distinct, though not overwhelming, advantages, particularly as regards temperature control. For really severe conditions, fast water cooling seems better, though more expensive.

Individual designs will need thorough examination as regards water and steam-flow areas, blanketing risks, etc. At present there is little basic information to go on, but this could be, to some extent at least, remedied by simple and inexpensive model experiments.

Information on the conditions prevailing at "hot spots" is deplorably scanty, and further research on this subject would be of value in relation not only to steam cooling, but to normal

Evaporative Cooling for Marine Internal Combustion Engines

water cooling as well. Such an investigation would be a suitable subject for University research.

ACKNOWLEDGMENTS

The author would like to express his thanks to the British Shipbuilding Research Association, on whose behalf the investigation was carried out, for permission to publish this material. He also acknowledges with thanks the aid of Mr. le Fevre of Durham University, who pointed out some errors in the original version, and of Mr. C. R. Baines and other members of the staff of Ricardo and Co. who assisted in the compilation.

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APPENDIX I

CIRCULATION RATES

In the system of Fig. 6 let:

Total circulation	= m lb per hr.
Steam generation	= s lb. per hr.
Specific vol., steam	= V_s cu. ft. per lb.
Specific vol., water	= V_w cu. ft. per lb.
Dryness fraction = s/m	= x
Ratio V_s/V_w	= y

Head of water to pass 1lb. per hr. water through

Steam restriction	$R_s = P_s$,
Water restriction	$R_w = P_w$.

Circulation Head

Volume steam per hour through up-comer outlet = sV_s
 = $xm V_s = xy V_w m$.

Volume water per hr. = $(m - s) V_w = m(1 - x) V_w$.
 Total volume = $mV_w(xy + 1 - x)$.

Ratio (vol. water/total vol. in up-comer) = $\frac{1 - x}{xy + 1 - x}$.

Head of water in up-comer for height difference H , Fig. 6
 = $H \frac{(1 - x)}{xy + 1 - x}$.

Head of water in down-comer = H .

$$\begin{aligned} \text{Net head causing circulation } H_n &= H \left(1 - \frac{1 - x}{xy + 1 - x} \right) \\ &= H \frac{xy}{xy + 1 - x}. \end{aligned} \quad (1)$$

At atmospheric pressure y is about 1,600 while x is unlikely to be less than 0.01 (99lb. water per lb. steam); xy will not be less than 16 and no serious error will be incurred by neglecting $(1 - x)$. Thus approximately:—

$$H_n = H, \quad (1a)$$

i.e., so far as circulation head is concerned the up-comer may be taken as full of dry steam.

Loss of Head through resistances R_s, R_w

For each of the resistances R_s, R_w with specific heads (for unit mass flow of water) P_s, P_w , respectively,
 Loss of head $H_w = P_w m^2$. (2)

$$\text{Loss of head } H_s = P_s m^2 \frac{P_w}{P_s},$$

where p_w, p_s are densities of water and foam respectively.

Total volume flow in up-comer = $mV_w(xy + 1 - x)$.

$$\text{Density } p_s = 1/[V_w(xy + 1 - x)].$$

$$\begin{aligned} \text{Therefore } p_w/p_s &= (xy + 1 - x) \\ \text{and } H_s &= P_s m^2 (xy + 1 - x) \end{aligned} \quad (3)$$

Neglecting $(1 - x)$ as before

$$H_s = P_s m^2 xy \quad (3a)$$

and total circuit resistance

$$H = H_s + H_w = m^2 (P_s xy + P_w). \quad (4)$$

$$\text{Flow } m = \sqrt{[H/(P_s xy + P_w)]}. \quad (5)$$

In the average case P_s and P_w will be of the same order of magnitude, and since xy is not less than 16, it will be accurate enough for most purposes to neglect P_w . In this case

$$m = \sqrt{[H/(P_s xy)]}, \quad (5a)$$

or, since

$$\begin{aligned} y &= 1,600 \text{ approximately,} \\ m &= 0.025 \sqrt{[H/(P_s x)]}. \end{aligned} \quad (5b)$$

But if heat input = E B.Th.U. per hr.

and latent heat $L = 1,000$ B.Th.U. per lb.

then $s = E/1,000$ approximately,

$$x = s/m = E/(1,000m). \quad (6)$$

Substituting in equation (5b),

$$m = 0.025 \sqrt{[1,000m H/(P_s E)]},$$

$$m = 0.625 H/(P_s E). \quad (7)$$

Also

$$\begin{aligned} x &= E/(1,000m) \\ &= E^2 P_s / (625 H). \end{aligned} \quad (8)$$

If, as is common in practice, E is not known, it will in general be practicable to measure

(a) the temperature rise T (deg. F.) across the engine;

(b) the head, H_p , generated by the water-pump.

Then with water-cooling:

$$\text{Water mass flow} = \frac{E}{T} = \sqrt{[H_p/(P_s + P_w)]}$$

since both R_s and R_w are passing liquid water;

i.e., $E = T \sqrt{[H_p/(P_s + P_w)]}$.

Substituting in equation (8),

$$x = \frac{T^2 H_p P_s}{625 H P_t} \quad (9)$$

where

$$P_t = P_s + P_w,$$

and

$$m = E/(1,000x)$$

$$\begin{aligned} &= T \sqrt{[H_p/(P_s + P_w)]} \left(1,000 \frac{625 H}{T^2 H_p} \frac{P_s + P_w}{P_s} \right) \\ &= \frac{0.625 H}{T \sqrt{H_p}} \frac{\sqrt{(P_s + P_w)}}{P_s}. \end{aligned} \quad (10)$$

The ratio $P_s/(P_s + P_w)$ can usually be calculated to a sufficient degree of accuracy or could be measured by suitable tappings.

Example

Suppose temperature rise through engine = 10 deg. F.

Pump pressure = 10 feet water = 4.5lb. per sq. in. approx.

$$P_s = P_w, P_s/(P_s + P_w) = 0.5, H = 2 \text{ feet.}$$

$$\begin{aligned} \text{then } x &= \frac{100}{625} \times \frac{10}{2} \times \frac{1}{2} \\ &= 0.4. \end{aligned}$$

Evaporative Cooling for Marine Internal Combustion Engines

This is probably too dry, which suggests that the average water-cooling system piping is on the small side for steam cooling by natural convection.

APPENDIX II

TOTAL HEAT TO COOLANT

This naturally depends on a host of factors, some general such as m.e.p., r.p.m., others specific such as degree of swirl or turbulence, length of cooled exhaust passage in cylinder or head casting. This makes accurate generalizations impossible, but the author has found that to a first approximation the following rough rules hold:—

(1) For any given engine the gross heat loss, to jackets*, to oil cooler, and to atmosphere ("radiation" from external surfaces) is roughly a simple function of the gross consumption, more or less regardless of changes of speed or torque *per se*, e.g., an engine will have about the same total heat loss at 50lb. i.m.p. 1,000 r.p.m. as at 100lb. i.m.p. 500 r.p.m. if the fuel per hour is the same under these two conditions.

(2) The gross heat loss varies as about the two-thirds power of the fuel per hour, or, put in a form more convenient for comparison between engines of different size, the ratio (jacket, etc., heat/fuel heat) varies inversely as the cube root per hour per litre of cylinder capacity.

(3) Expressed on this basis, the heat losses for engines of widely different sizes and speeds differ much less than one might expect. To illustrate this, Fig. 10 shows data collected from engines of cylinder size ranging from 1.6 to 70 litres. These

Ref. No.	Engine type	Bore, mm.	Stroke, mm.	Cylinder swept vol., litres
1	Single-acting, four-stroke poppet valve, high swirl Ricardo Comet Mk. III.	121	140	1.61
2	As above, boosted to 2.0 atmos. abs.	127	140	1.78
3	As above, boosted to 2.5 atmos. abs.	127	140	1.78
4	As above, boosted to 3.0 atmos. abs.	127	140	1.78
5	Double-acting, two-stroke, Hug's experiments, low or no swirl	380	460	52.1
6	Single-acting, four-stroke, sleeve valve, boosted to 2.3 atmos., high swirl	127	140	1.78
7	Single-acting, two-stroke, sleeve valve, high swirl	127	140	1.78
8	Single-acting, four-stroke, poppet valve, no swirl	204	306	10.10
9	Single-acting, four-stroke, poppet valve, low or no swirl	406	535	69.5
10		260	320	17.0

N.B. Engines for curves 1 to 4 are practically identical.

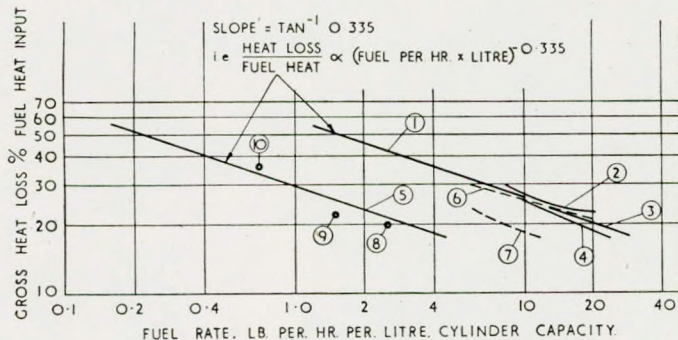


FIG. 10—Various Diesel engines. Relation between heat loss to jackets, etc., and fuel rate

* Not including jacketed exhaust pipes.

show, firstly, remarkable agreement in conforming to the inverse cube-root relationship, and, secondly, a range of only about two to one in absolute value, i.e., between curves (1) and (5) corresponding to cylinders of 1.6 and 52 litres, respectively. Moreover, such differences as exist can largely be explained by differences in engine design; thus the uppermost lines (1), (2), (3), (4), (6) all relate to small high-swirl four-strokes, and line (7) to a medium-swirl two-stroke of the same size (1.8 litres). The difference between these types suggests that an engine of the same size but with little or no swirl would give a heat loss more or less in line with line (5) and points (8), (9), (10), which all relate to much larger cylinders of 10-70 litres. This suggests that on this basis of comparison scale effect is either small or non-existent, but it would be unwise to generalize too decisively on such limited data.

APPENDIX III

EFFECT OF WATER SEPARATION IN UPTAKE

With mixture steam and water flowing through given restriction under given p.d.,* is flow greater if steam and water are:—

- (a) completely separate,
- (b) completely mixed?

This is more easily solved if posed as follows:—

With same total mass flow and p.d. in each case, which condition needs greater flow area?

General

For any given p.d., area required $a = km\sqrt{v}$, where $k =$ constant, $m =$ mass flow, $v =$ vol. per lb. relative to water.

In both cases, let x be dryness fraction, $y =$ ratio (specific vol. steam/spec. vol. water); p.d. is assumed too low for appreciable expansion of steam.

Case (a). Steam and Water Separate

$$\begin{aligned} \text{Water: } V_w &= 1, \text{ mass} = 1 - x & a_w &= k(1 - x). \\ \text{Steam: } V_s &= y, \text{ mass} = x, & a_s &= kx\sqrt{y}. \\ & & a_w + a_s &= a_t = k(x\sqrt{y} + 1 - x). \end{aligned}$$

Case (b). Steam and Water Mixed

$$\begin{aligned} \text{Mixture: } V &= xy + 1 - x, \text{ mass} = 1. \\ a_m &= k\sqrt{xy + 1 - x}. \end{aligned}$$

It can be shown that where, as in the present case, $x < 1$, then a_m is always greater than a_t , i.e., the mixed fluids require more flow area under a given p.d. than when separate; for a given area and p.d. the mass flow is greater when the fluids are separate. Proof† is as follows:—

$$\begin{aligned} \frac{a_m^2 - a_t^2}{k^2} &= xy + 1 - x - (x\sqrt{y} + 1 - x)^2 \\ &= x(1 - x)(\sqrt{y} - 1)^2. \end{aligned}$$

Since $0 < x < 1$, x and $1 - x$ are positive;

also $(\sqrt{y} - 1)^2$ is positive.

Thus $a_m^2 - a_t^2 > 0$, i.e., $a_m > a_t$.

Relation between Flow Areas, a_t, a_m

$$\begin{aligned} a_m &= k\sqrt{xy + 1 - x}. \\ a_t &= k(x\sqrt{y} + 1 - x). \end{aligned}$$

$$\begin{aligned} \frac{1}{k^2}(a_m^2 - a_t^2) &= xy + 1 - x - x^2y - 2x\sqrt{y}(1 - x) - (1 - x)^2 \\ &= xy + x - x^2 - x^2y - 2x\sqrt{y}(1 - x) \\ &= x(1 - x)(1 + y - 2\sqrt{y}) \\ &= x(1 - x)(1 - \sqrt{y})^2. \end{aligned}$$

If x is positive and < 1 , $(a_m^2 - a_t^2) > 0$

Therefore when $x < 1$, $a_m > a_t$ (since a_m and a_t are > 0).

* Pressure difference.

† For this proof, and for that of the formula which follows, the author's thanks are due to his colleague, Mr. C. R. Baines.

Evaporative Cooling for Marine Internal Combustion Engines

Since $x < 1$ and y is of the order of 10^3 ,

$$a_m = k\sqrt{xy} \text{ approximately.}$$

Therefore

$$\frac{a_t}{a_m} = \frac{x\sqrt{y+1-x}}{\sqrt{xy}} = \sqrt{x} + \frac{1-x}{\sqrt{xy}}$$

At atmospheric pressure $y = 1,600$ approx.

$$\text{Thus } a_t/a_m = \sqrt{x} + \frac{1-x}{40\sqrt{x}}$$

Example: — $x = 0.16$, $\sqrt{x} = 0.4$,

$$a_t/a_m = 0.4 + 0.84/(40 \times 0.4) = 0.4525.$$

i.e., area required with fluids separated is less than half that needed with fluids mixed.

OBITUARY

WILLIAM BENNETT ANNING (Member 4321) was born in Liverpool in 1878. He went to sea very early in life sailing before the mast with his father and going round the world by the age of ten. He served his apprenticeship at Messrs. Cammell, Laird and Co., Birkenhead, and then joined the Hall Line, Ltd., with whom he served until the outbreak of the 1914-18 war. He then joined the R.N.V.R. as Engineer Lieutenant, serving on "Q" Boats. After demobilization he became an engineer surveyor for the General Accident, Fire and Life Assurance Corporation until his retirement in 1945. He was elected a Member in 1921. He died on the 20th February 1950.

FREDERICK ALFRED BATES (Member 4503) was born in 1902 and was educated at Rye Grammar School. He served his apprenticeship with Messrs. R. and H. Green and Silley Weir, Ltd., London. He went to sea in 1923 serving with Messrs. Furness, Withy and Co., Ltd., the British Tanker Co., and the Khedivial Mail Steamship and Graving Dock Co., Ltd., until 1929 when he joined Messrs. Cox and Co. (Engineers) Ltd., Falmouth, as an engineer estimator. In 1936 he went to Wellington, New Zealand, as emergency shift engineer and construction engineer to the Wellington City Corporation in connexion with the erection of a steam power station. In 1937 he was appointed Assistant Engineer to Messrs. W. Christie and Grey, Ltd., London. In 1941 he joined the Merchant Ship Repairs Branch of the Admiralty as Temporary Technical Assistant, transferring in 1942 to the Norwegian Shipping and Trade Mission. In 1946 he was appointed Com-

mercial Manager at Barry Docks of the Penarth Pontoon Slipway and Ship Repairing Co., Ltd. and Hodges (Barry) Ltd., which appointment he held until his death. He was elected a Graduate in 1922 and a Member in 1927. He died on the 16th August 1950.

ALEXANDER NAIRN REID (Member 10108) was born in 1894. He served his apprenticeship with Messrs. Barclay, Curle and Co., Ltd., Glasgow, from 1910 until the outbreak of war in 1914 when he joined the Royal Navy, serving as an E.R.A. After the war he joined the Hall Line Ltd., Liverpool, serving at sea until 1924. In 1925 he obtained his first shore appointment as Assistant Superintendent Engineer and Surveyor to Messrs. David Alexander and Sons (Grove Line). This appointment terminated in March 1930 when he joined the staff of Messrs. Carpenter and Tuck, Cardiff, but he returned to the former company in 1931 as Superintendent Engineer. His last appointment was in November 1945 as Superintendent Engineer with Messrs. Raeburn and Verel, Ltd., managers for the Monarch Steamship Co. Mr. Reid received a presentation from the underwriters in December 1947 in recognition of his services in connexion with serious damage to the S.S. *Norman Monarch* early in that year. He was elected a Member in 1944. He died in August 1950.

CORRIGENDUM

TRANSACTIONS, August 1950, Vol. 62, No. 8, p. 292, last paragraph in left-hand column, delete "the 'smooth turbulent' condition. If there is roughnesses".

INSTITUTE ACTIVITIES

AUTUMN GOLF MEETING

The Autumn Golf Meeting was held at Hadley Wood Golf Club on Thursday, 12th October 1950. Twenty-eight members took part in the day's events, and were favoured with brilliant sunshine lasting all day.

The morning was devoted to a Stroke Competition, in which Mr. H. A. Dawson gained first place with a net score of 71; Mr. R. B. Pinkney won the second prize with a net score of 72.

In the afternoon a Bogey Greensome Competition was held, in which Messrs. F. P. Bell and J. A. Rhynas finished all square, and Messrs. W. J. Borrowman and J. H. F. Edmiston took second place with a score of one down.

The prizes were presented by Mr. A. Robertson, Convener of Social Events, after tea, when by unanimous consent a hearty vote of thanks was accorded to the following prize donors: Messrs. E. F. J. Baugh, E. W. Ditchburn, J. A. Goddard, W. Q. Henriques, R. B. Pinkney, W. Wilton and A. Robertson.

A hearty vote of thanks was accorded to the Directors, Secretary and staff of Hadley Wood Golf Club for the excellence of the arrangements made for the meeting.

MEMBERSHIP ELECTIONS

Elected 9th October 1950

MEMBERS

Sydney Maxwell Bayley
Alfred Household Bennett
George Watt Elliott
George Gilmour
Arthur George Gull
Robert Harrison
Gordon Richard Hodge
Sidney Kitchener Howe
Robert William Howie
Harold Ernest Jones
Edward Lea
Francis William Pounder
Victor Cooke Robinson
Thomas Richard James Tidnam, Lt.-Com'r(E), R.N.
Herbert William Darville Vernon
James Brewis Woodeson, O.B.E.

ASSOCIATE MEMBERS

William Ewart Cousins
Eric Danks
Gordon Kenworthy-Neale

ASSOCIATES

Fred Albert Bathie
James Stephen Cook
Edgar Francis Lawrence Debono
Neville Alfred Dawson

George David James Garside
Alexander Gilmore
George Stuart Hawkins
Alfred Thomas Oswald Howell
Joseph Lawrence Hufton
Arthur John Ingram
Kenneth Jones
Ernest McComb
Joseph McMillan
Edward Thomas Marshall
George Mercer
Albert Solomon Meyers
Narayana Luxmi Narasimhan
David Mills Phillips
Kenneth George Pullen
William Allan Saddler
Henry Rogerson Simmonds, Sub. Lieut.(E), R.N.Z.N.
Ernest Thomas Smith
Thomas Stabler Sopp
Abdul Qadeer Warraich
Roland Whitehead

GRADUATES

Alan John Bibby
William Arthur Currie
Daniel John Morgan

STUDENT

Gian Chand Sahni

TRANSFER FROM ASSOCIATE TO MEMBER

John Donald Cameron
George Codd
William Innes Scott
Harry Dale Williams

TRANSFER FROM GRADUATE TO MEMBER

Maurice O. N. Simmonds

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER

John Adam
Bimal Kumar Maitra

TRANSFER FROM GRADUATE TO ASSOCIATE

Sydney Christopher Gosling
Eric Hall
John Lawson
Donald Inglis Walsh
Ernest Watson

TRANSFER FROM STUDENT TO ASSOCIATE MEMBER

Ivan Dudley George Graham, Lieut.(E), R.N.

TRANSFER FROM STUDENT TO ASSOCIATE

Guy Scott Sanders-Hewett



Sir Alexander Murray Stephen, M.C., B.A.
(President)

SIR ALEXANDER MURRAY STEPHEN

Sir Alexander Murray Stephen, born in Glasgow in 1892, was educated at Kelvinside Academy, Cargilfield, and Fettes College; and thereafter at King's College Cambridge, where he studied engineering, and took First Class Honours in the Engineering Tripos in 1914. He was also captain of his College Rugby XV, and occasionally played for the University.

At the start of the 1914-1918 war, he joined the Royal Garrison Artillery, and went to France just in time to take part in the Battle of Loos in 1915. Thereafter he was in action in France for nearly three years, being mentioned in Despatches, and receiving the Military Cross. He was promoted to the rank of Major, with the command of a battery of 9.2 howitzers. In April of 1918 his battery were in support of the Portuguese, when they were overwhelmed, and he was taken prisoner; the rest of the war he spent in a prison camp in Germany.

After the war he took up hockey, and played for Scotland against Ireland and Wales in 1920. He also assisted his father and brother as one of the crew, in the International Yacht Races on the Clyde for the Seawanhaka Cup.

Immediately after the war he returned to shipbuilding and joined the firm of Alexander Stephen and Sons in which he is one of the sixth generation of Stephens to serve. In 1921 he became a director and, when his father died in 1932, he succeeded him as Chairman.

In the shipbuilding industry he has held many positions including President of The Clyde Shipbuilders' Association, 1937-1939, President of The Shipbuilding Employers' Federation, 1938-1939, President of The Shipbuilding Conference, 1946-1948, Chairman of the Council of British Shipbuilding Research Association, 1948-1950, President of the Institution of Engineers and Shipbuilders in Scotland, 1943-1945, and Member of Council of the Institution of Naval Architects.

Sir Murray was knighted in 1946. He was a member of the Advisory Committee of the Ministry of Transport on Shipbuilding during the 1939-1945 war, and has since 1946 been a member of the Shipbuilding Advisory Committee which succeeded it. He has been a member of the Commonwealth Shipping Committee for some years.

In Glasgow, he has been Deacon of the Incorporation of Hammermen, a Director of the Chamber of Commerce, a Director of the Victoria Infirmary and a Director of the Merchants House.

Since 1948 he has been a Member of the University Grants Committee.

In addition to the above-mentioned public activities, Sir Murray has been a director of various companies, including the L.M.S. Railway Company, Clyde Valley Electric Power Company, Steel Company of Scotland, Ltd., R. and J. Dick, Ltd., and several investment companies.

Apart from his present office as President to which he was elected this year, Sir Murray has been a Member of the Institute since 1944. In 1922 he married Miss Kathrene Paton Mitchell, and he has two sons and a daughter.