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MARITIME ELECTRICAL INSTALLATIONS

NOTES ON DESIGN REQUIREMENTS

A complete shipboard electric plant is similar to the electric power generating and distribution, and utilization system of a self contained shore-based industrial installation. Electric power is required for motors driving propulsion plant, propulsion plant auxiliaries and deck machinery, interior and exterior illumination, navigation lights, ventilation and air conditioning, stores and cargo refrigeration, electric heating, galley equipment, drinking water and sanitary systems, and casualty control machinery such as fire and bilge pumps. Power must also be supplied for interior communication systems, announcing and alarm systems, radio communication, radar, and other electronic aids to navigation.

For passenger vessels, the electric power requirements extend to hotel and recreation loads, theatre and dance floor lighting, restaurant and swimming pool equipment, motion picture projection, public address systems, and stewards call systems. For passenger and crew safety, the electric installation includes automatic fire detecting and alarm systems, power-operated watertight doors.

Electric power is vital to all shipboard operations and to the safety and comfort of the passengers and crew. For this reason, shipboard electric plants must contain equipment necessary to maintain continuity of service, since a vessel at sea is isolated from external sources of electrical energy. Therefore, standby ship service generating capacity, usually equal to the rating of one of the. ship service generators, is provided. In addition, one or more, sources of emergency power, designed to automatically assume load upon loss of ship service power, are required to supply those loads that are necessary for the safety of the passengers and crew; the emergency source of power should also have additional capacity adequate to supply those loads vital to getting the propulsion plant and ship service generators back in service. Quick-starting diesel generators are usually provided for emergency power; however, storage batteries or gas turbine driven generators are satisfactory for this service. Emergency storage batteries combined with motor generator sets are required on passenger vessels to provide temporary emergency power to certain vital loads until the emergency generator can start and assume the entire emergency load.

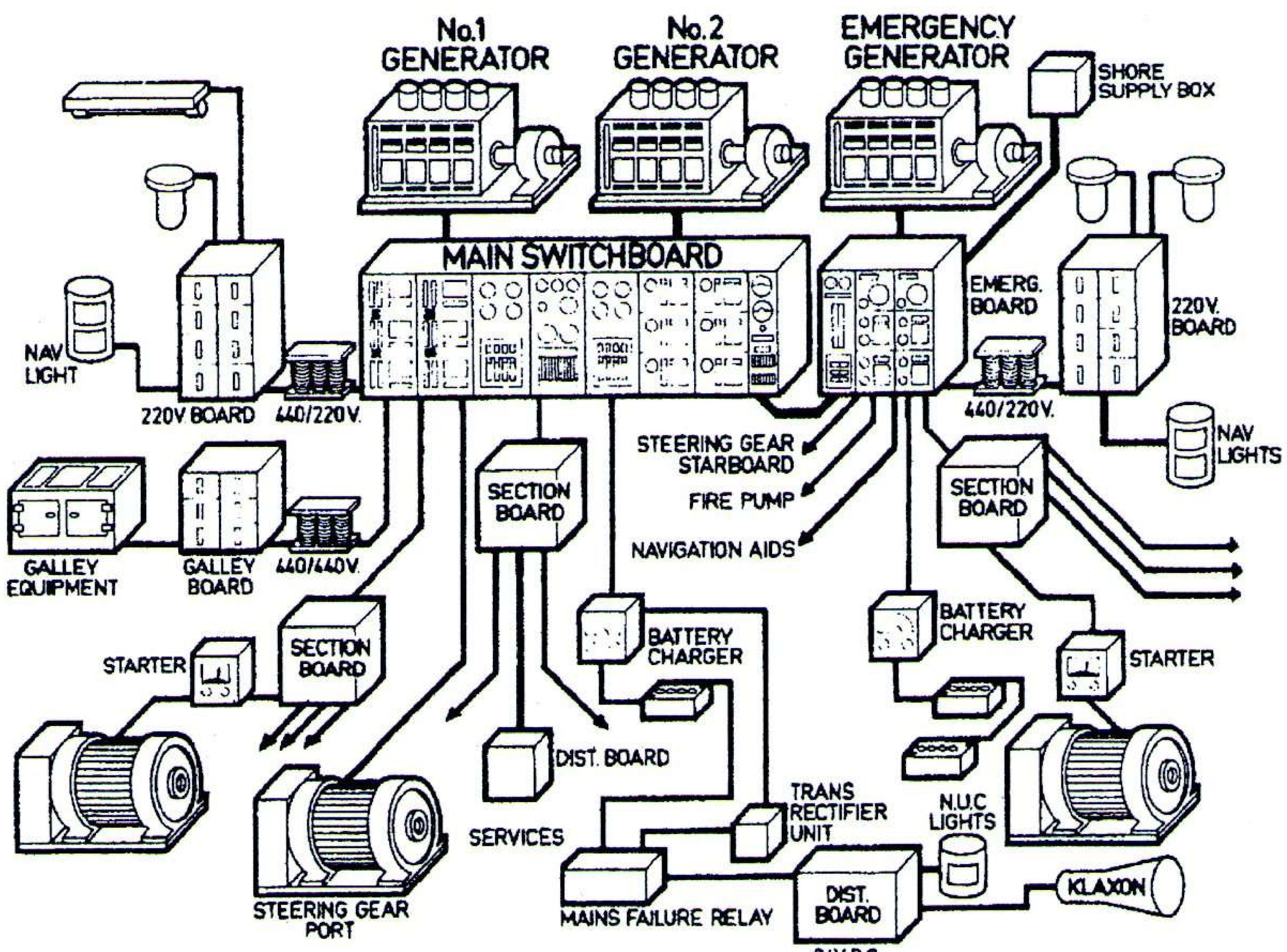
To avoid prolonged shutdown at sea, adequate spare parts should be stowed aboard ship to replace vital parts which are subject to wear and breakdown. It follows that adequate detail drawings and manuals containing instructions for operation, repair, and adjustment also should be placed aboard ship.

For greater dependability at sea, electric equipment necessary for the operation of the vessel is required to have certain marine features such as dependable operation during rolling and pitching of the vessel, mechanical parts resistant to shipboard vibration, and windings and hardware resistant to moisture and corrosion.

A shipboard electric plant includes: generating equipment; switchgear for control of the generators and distribution of power; and distribution panels, transformers, motor generators, and bus transfer equipment as necessary to provide the proper type of power to electrical loads[1].

Rules and regulations dictate the minimum requirements of a ship based electrical installation. Minimum acceptable standards are issued by various bodies including national governments, international conventions (such as SOLAS), international standards associations and classifications societies such as DNV. The main objective of rules for electrical installations is to ensure that the power system is designed, built and installed so that it provides a safe and reliable installation with respect to availability, operator/user safety and a minimum risk of fire hazards [2].

The major sub-systems of a ship's electrical installation are shown in the general diagram below [3].



[*Practical Marine Electrical Knowledge – Hall*]

One of the documents required for approval of the system design is the **single line diagram** which provides an overview of major sub-systems or even the entire electrical installation. A single line diagram for an entire electrical installation is shown below.

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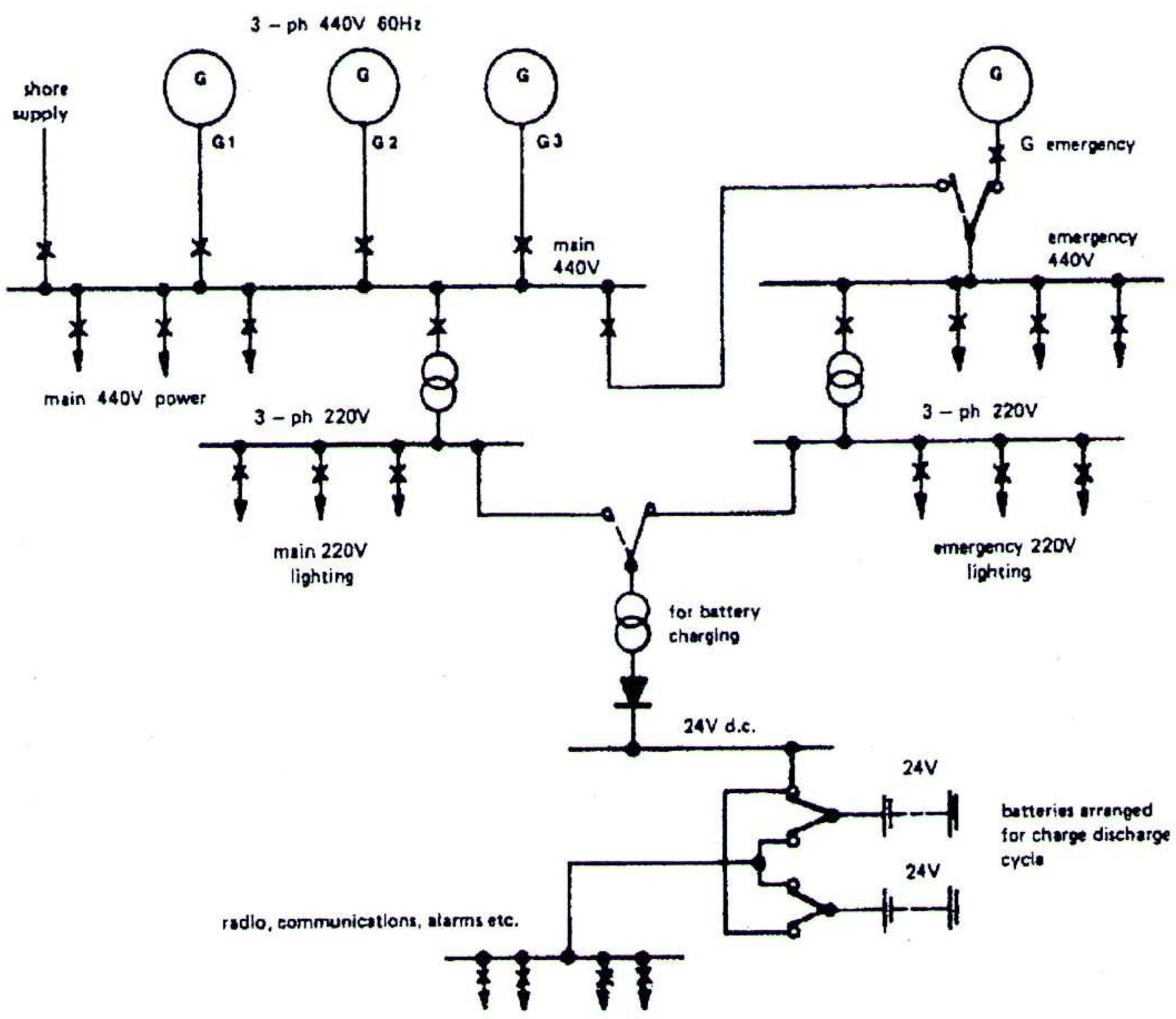

[Practical Marine Electrical Knowledge – Hall]

The vast majority of ships have an alternating current (ac) distribution system in preference to a direct current (dc) system. An ac network is cheaper to install and operate than a dc system. In particular, ac offers a higher power/weight ratio for the generation, distribution and utilisation of electricity. Simple transformers efficiently step up or step down ac voltages where required. Three phase ac is effectively converted into rotary mechanical power in simple and efficient induction motors. A ship's electrical distribution scheme generally follows shore practice. This allows normal industrial equipment to be used on board ship after being 'marinated', where necessary, to withstand the rigours of a sea life (e.g. it must withstand the vibration, humidity, high temperature, ozone, sea water, etc. found in various parts of the ship).

The majority of ships have a 3 phase, 3 wire, 440V insulated neutral system. This means that the neutral point of star connected generators is not earthed to the ship's hull. For Continental European vessels, a 380V, 3 phase system is common.

Ships with very large electrical loads have generators operating at high voltages (HV) of 3.3kV and even 6.6kV. Such high voltages are economically necessary in high power systems to reduce the size of current, and hence reduce the size of conductors required. Ships operating at such high voltages are still quite rare, but offshore oil and gas production platforms operate at up to 13.8 kV, where equipment weight saving is important. Distribution systems at these high voltages usually have their neutral points earthed through a resistor to the ship's hull.

The frequency of an ac system can be 50Hz or 60Hz. 50 Hz is a European standard frequency and 60 Hz is a US standard frequency. 60 Hz is the most common frequency

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adopted for use on board ship; the higher frequency enabling motors and generators to run at higher speeds with a consequent reduction in size for a given power rating.

Lighting and low power single phase supplies usually operate at the lower voltage of 220V although 110V is also used. These voltages are derived from 'step down' transformers connected to the 440V system.

Major electrical sub-systems on the one line diagram are described briefly below.

MAIN GENERATORS

The main generators have a capacity such that in the event of any one generating set being stopped it will still be possible to supply those services necessary to provide normal operational conditions of propulsion and safety. Minimum comfortable conditions of habitability shall also be ensured which include at least adequate services for cooking, heating, domestic refrigeration, mechanical ventilation, sanitary and fresh water.

For vessels propelled by electric power and having two or more constant voltage propulsion generating sets, the ship's service electric power may be derived from this source and additional ship's service generators need not be fitted provided that with one propulsion generator out of service, effective propulsion can be maintained.

A generator driven by a main propulsion unit (shaft generator) which is intended to operate at constant speed, e.g. a system where vessel speed and direction are controlled only by varying propeller pitch, may be considered to be one of the required generators.

Each main generator (ac generators are also called alternators) has its own circuit breaker between the generator output and main switchboard bus bars.

There are various types of alternating current generators utilized today. However, they all perform the same basic function. The types discussed below are typical of those must widely used in modern electrical equipment.

Revolving Armature

In the revolving armature a.c. generator, the stator provides a stationary electromagnetic field. The rotor acting as the armature, revolves in the field, cutting the lines of force, producing the desired output voltage. The major limitation of this design is that the output power is passed through sliding contacts (sliprings and brushes). These contacts are subject to frictional wear and sparking. In addition, they are exposed, and thus liable to arc over at high voltages. Nevertheless the revolving armature may be found in some marine generators, this arrangement often forms the exciter providing the main field current for brushless alternators. Slip rings are not required when used as the exciter in a brushless alternator.

Revolving Field

The revolving field a.c. generator is by far the most widely used type. In this generator, direct current from a separate source is passed through windings on the rotor. This

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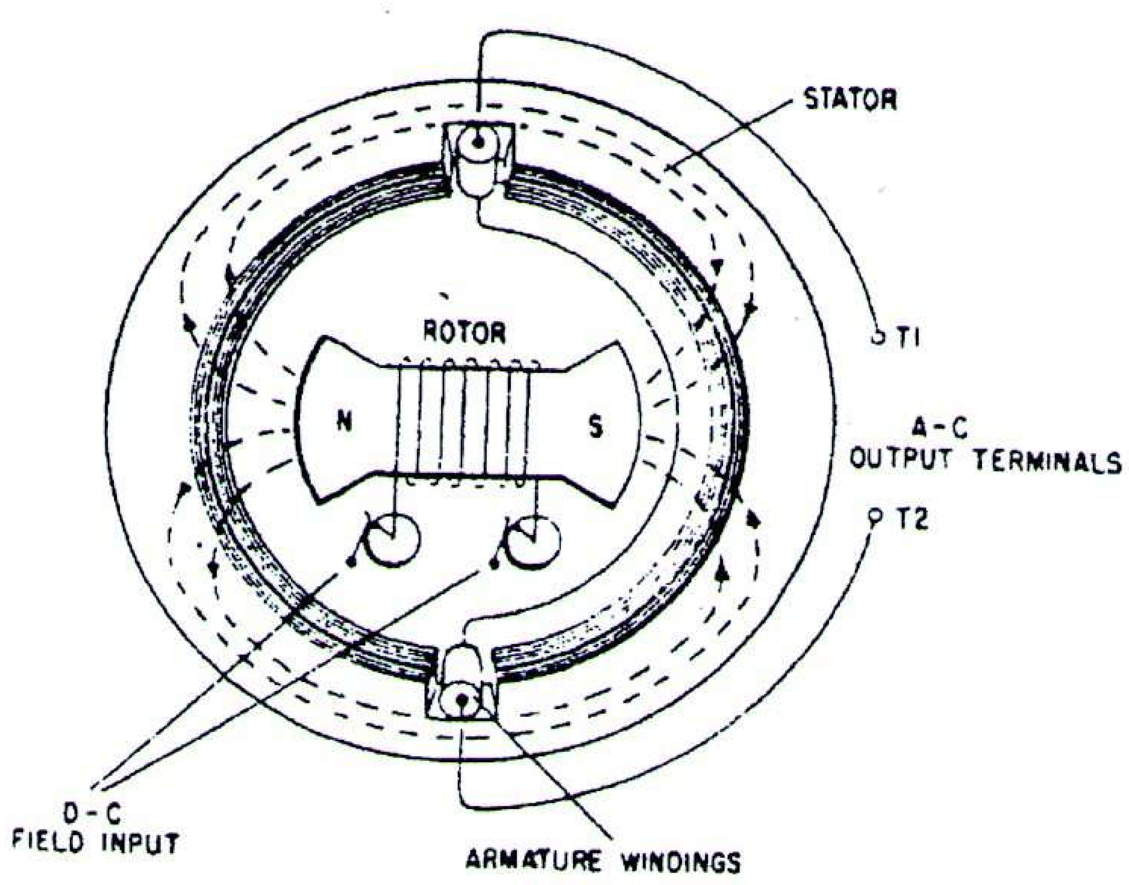
maintains a rotating electromagnetic field of fixed polarity (similar to a rotating bar magnet). The rotating bar magnetic field moves with the rotor, extends outwards and cuts through the armature windings embedded in the surrounding stator. As the rotor turns, alternating voltages are induced in the windings since magnetic fields of first one polarity and then the other cut through them. Since the output power is taken from stationary windings, the output may be obtained from fixed terminals. A simplified diagram of the rotating field alternator is shown below.



Rating of a.c. generators

The rating of an a.c. generator refers to the load it is capable of supplying. The normal load rating is the load it can carry continuously. Its overload rating is the above normal load which it can carry for specified lengths of time only. The load rating of a particular generator is determined by the internal heat it can withstand. Since heating is caused mainly by current flow, the generator's rating is identified very closely with its current capacity. A review of three phase power definitions is contained in Appendix 1.

The maximum current that can be supplied by an a.c. generator. depends upon (i) the maximum heating loss (I^2R power loss) that can be sustained in the armature and (ii) the maximum heating loss that can be sustained in the field. The armature current varies with the load. This action is similar to that of d.c. generators. In a.c. generators, however, the lagging power factor loads tend to demagnetize the field and terminal voltage is maintained only by increasing the d.c. field current. Therefore, a.c. generators are rated in terms of load current and voltage output, or kilovolt-ampere (kVA) output, at a specified frequency and power factor. The specified power factor is often 80 percent lagging. For example, a single phase a.c. generator designed to deliver 100 amperes at 1,000 volts is rated at 100 kVA. This machine would supply a 100 kW load at unity power factor or a 80 kW load at 80 percent power factor. If the a.c. generator supplied a 100 kVA load at 20 percent power factor, the required increase in d.c. field current needed to maintain the desired terminal voltage would cause excessive heating in the field.

A cargo vessel may have two main generators typically rated between 400 kVA to 1200 kVA, supplying a 440V, 60Hz three phase voltage.

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Construction

The stator, or armature, of the revolving field a.c. generator is built up from steel punchings, or laminations. The laminations of an a.c. generator stator form a steel ring that is keyed or bolted to the inside circumference of a steel frame. The inner surface of the laminated ring has slots in which the stator. winding is placed.

There are two main types of rotor construction. The first type is the salient pole rotor in which the required excitation of the machine is produced by individual projecting poles each of which is wound with its own field coil. The second type, the non salient pole is fitted with a cylindrical steel rotor in which coils are fitted to provide the necessary pole configuration.

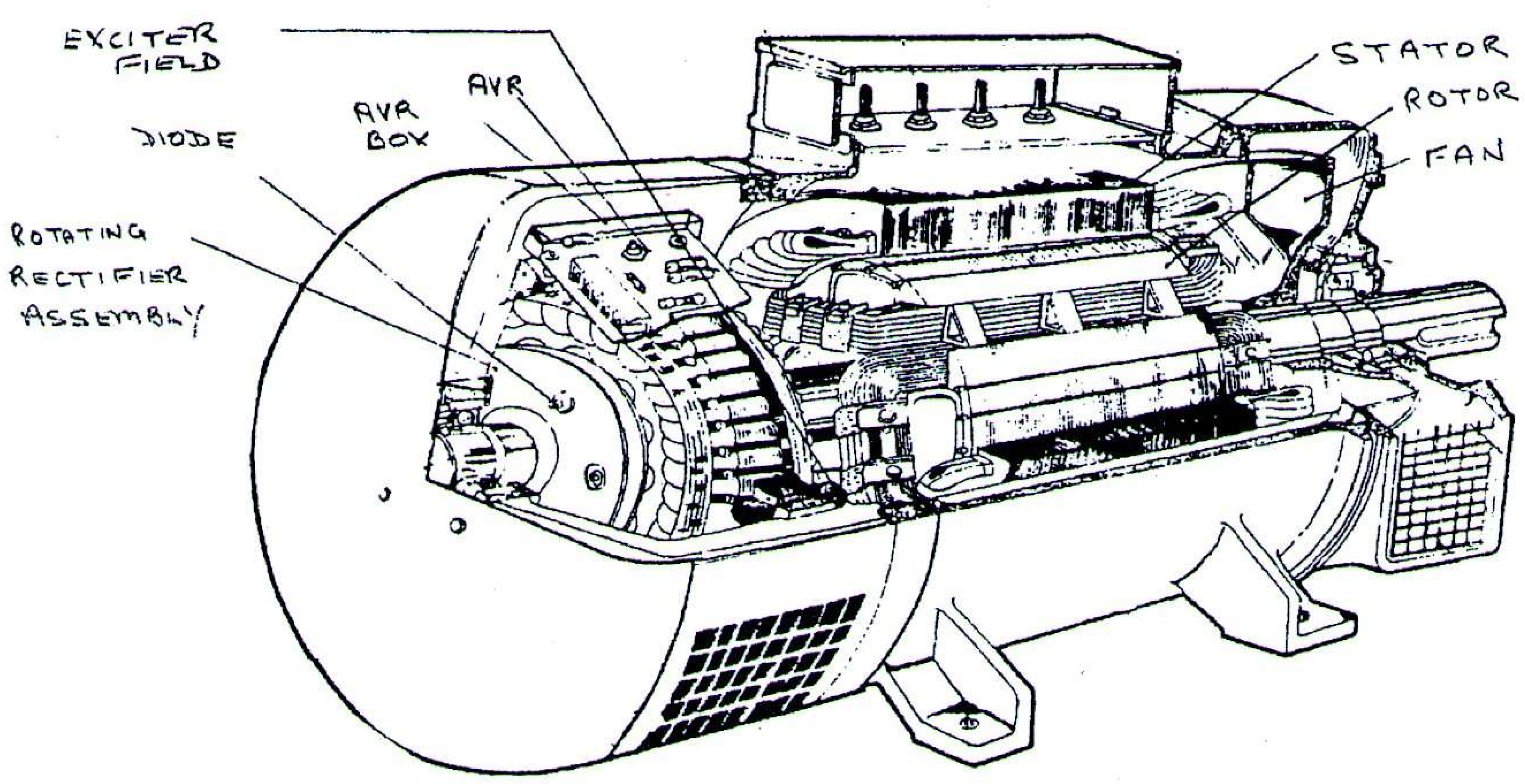
Most engine driven alternators use salient pole construction. There is an inverse relationship between the number of poles on the rotor and the generator driven speed for a specified output frequency. The relationship is:

$$frequency = np/120 \quad Hz$$

where: n is the speed of the rotor in rpm
p is the number of poles on the rotor

From the above it can be determined that for a 50Hz output at 750, 1000, 1500 rpm, 8, 6 and 4 pole rotor systems are required respectively, whilst for 60Hz operation the prime mover speed would have to be increased by 20%. Also the specific output of the a.c. generator increases with operating speed, which means that for a given electrical output an 8 pole machine would be larger that a 4 pole machine.

A 250 kVA alternator is shown below. The specifications for this machine are contained in Appendix 2.



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The main field is of the salient pole construction with four poles. The excitation for this rotating field is derived from a smaller ten pole generator which is of the revolving armature type mounted on the same shaft. Control of the main rotating field is achieved by changing the field current in the exciter. Also visible on the pole faces are the damper or amortisseur (literally 'killer') windings which are similar to the bars of a squirrel cage rotor. These windings are present to reduce the hunting above and below synchronous speed which result from the prime mover not having uniform speed over one complete revolution. When the poles are rotating past the armature at synchronous speed no voltage is induced into these short circuited windings. If however the rotor increases or decreases its speed above or below the synchronous value a voltage and large current flows in the damper winding which by Lenz's Law will oppose the force that produced it, that is the speed variation.

Enclosure protection for electrical equipment is defined in terms of the protection afforded against the ingress of solid particles and liquids. A two or three figure number such as IP15 is used to indicate the amount of protection of the enclosure. The IP Code is contained in Appendix 3.

A typical design specification for a cargo ship is included as Appendix 4.

MAIN SWITCHBOARD

Switchgear and control gear assembly for the control of a ship's service power generated by the main source of electrical power and its distribution to all electrical consumers.

A typical installation with 3 x 800 KVA generators consists of 16 individual panels each with a specific function.

1 panel with circuit breaker and protection equipment for each generator.
1 synchronising panel for paralleling each alternator.
4 x 415 volt feeder panels.
8 group starter panels for control of motor circuits (these may not necessarily be part of the main switch board).

The entire switchboard is of dead front construction and has a vibration proof framework constructed of angle steel with steel panels of 3.2mm. The complete set of 16 panels is about 8.5m long. Switchboard design/specification for a cargo ship is also contained in Appendix 4. A line diagram for the MSB of a cargo ship with three generators is shown in Appendix 5.

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EMERGENCY GENERATOR AND SWITCHBOARD

A generator forming a self contained emergency source of electrical power. This emergency source of electrical power, associated transforming equipment, if any, transitional source of emergency power, emergency switchboard and emergency lighting switchboard shall be located above the uppermost continuous deck and shall be readily accessible from the open deck. They shall not be located forward of the collision bulkhead, except where permitted by the Administration in exceptional circumstances. The location of the emergency source of electrical power, associated transforming equipment, if any, the transitional source of emergency power, the emergency switchboard and the emergency lighting switchboard in relation to the main source of electrical power, associated transforming equipment, if any, and the main switchboard shall be such as to ensure that a fire or other casualty in the space containing the main source of electrical power and switchboard will not interfere with the supply and distribution of emergency power. A summary of the emergency requirements and the layout of an emergency switchboard is contained in Appendix 5.

PROTECTION EQUIPMENT

Electrical installations must be protected against accidental overcurrents up to and including short circuit by appropriate devices. Continuity of service through discriminative action of the protective devices is required.

Devices are normally provided for overload protection (current above rated value) and short circuit protection (current many times the rated value). Discrimination ensures that the protective device nearest the fault is used to remove the supply.

References

1. *Marine Engineering, Harrington R.L (Ed)*
2. *D.N.V. Germany, Web site.*
3. *Practical Marine Electrical Knowledge, Hall D T.*

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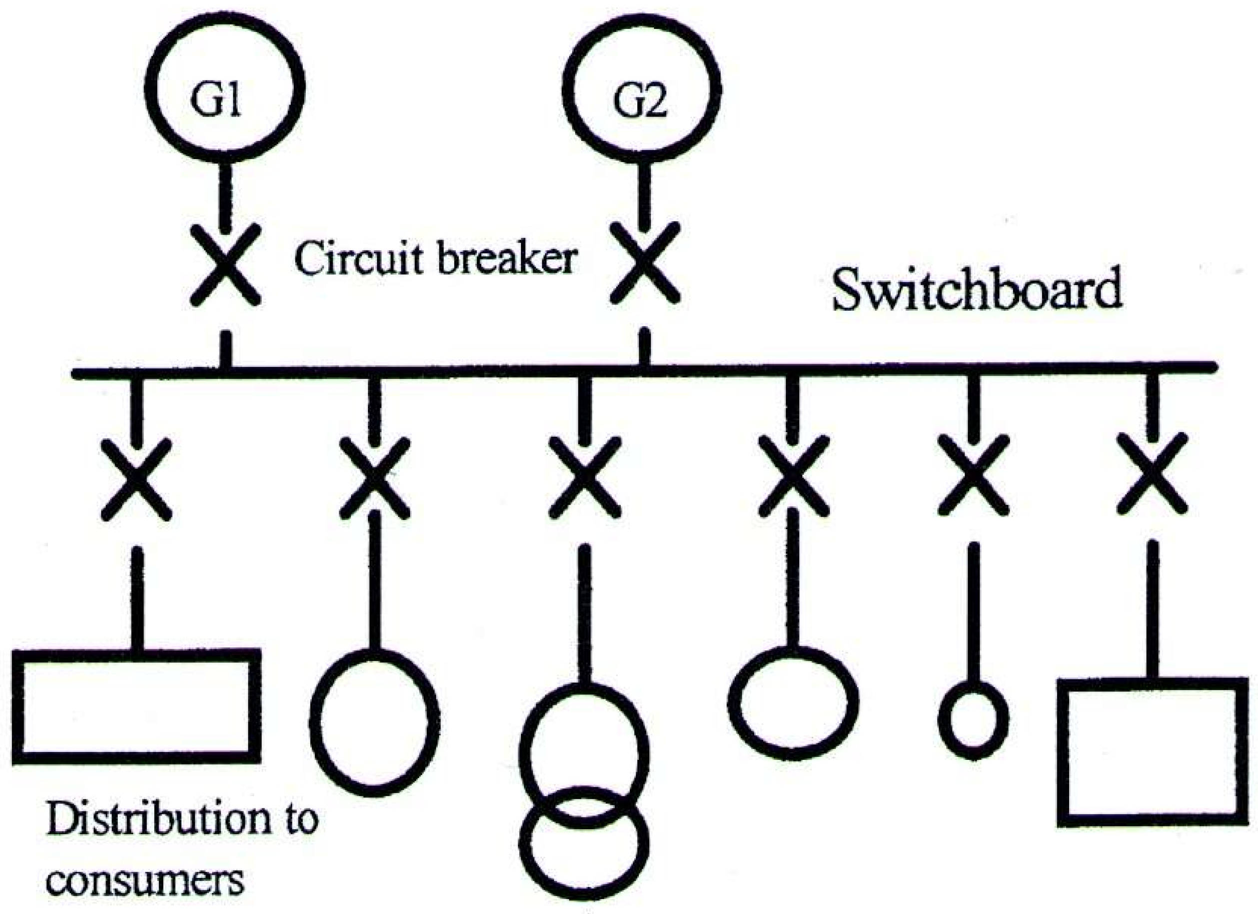
DISTRIBUTION SYSTEMS

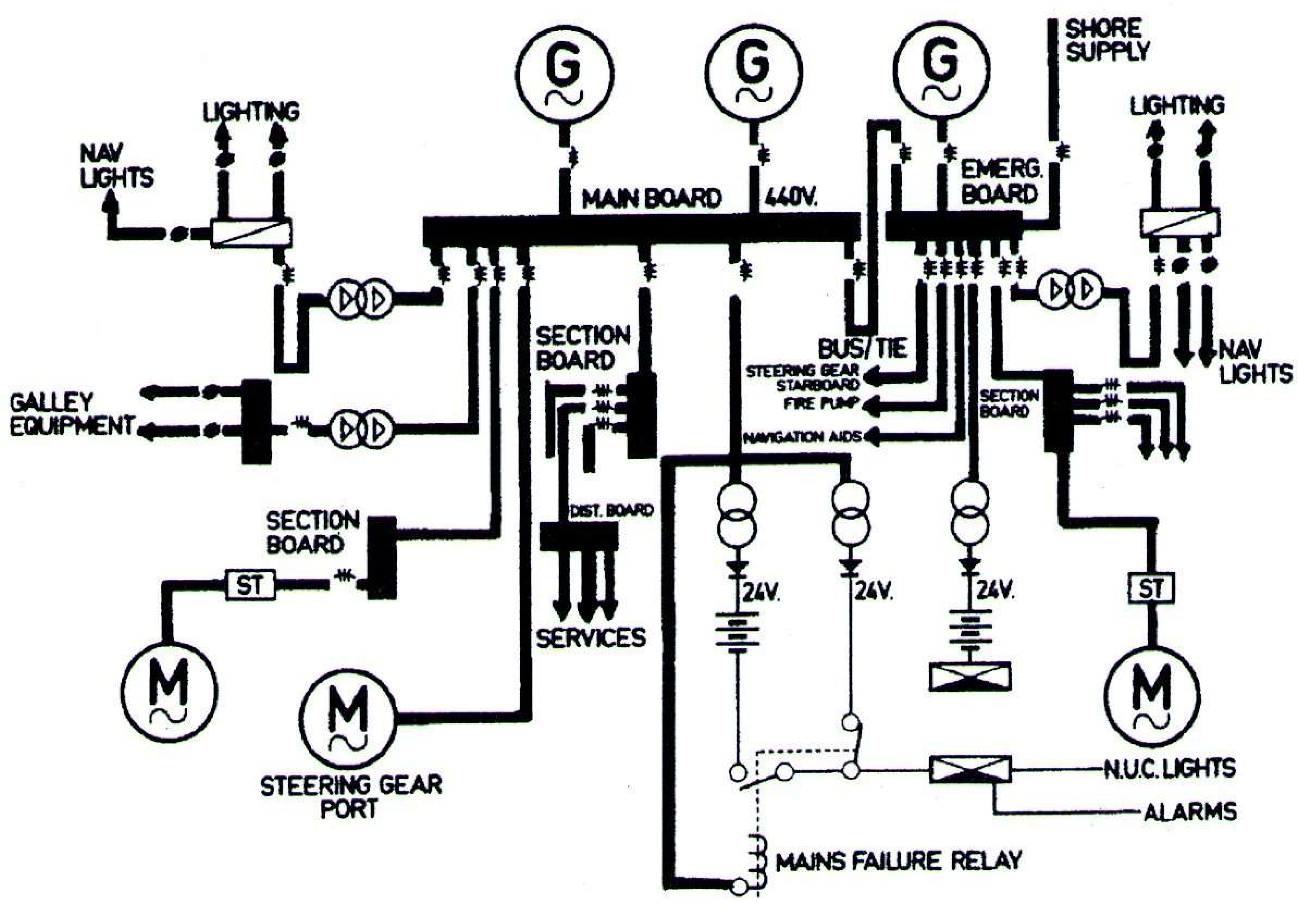
The distribution system, as the name implies is the method by which the electrical energy produced by the ship's generators is fed around the vessel to all the individual loads.

A simple distribution system is shown below



A generated voltage of 440 volts may be fed to large motors and other loads directly, whereas many other loads require a lower voltage and this is usually obtained through the use of three phase step down transformers.

A more detailed arrangement of a ship's distribution system is shown below.



[Practical Marine Electrical Knowledge – D Hall]

Outgoing circuits from a main switchboard are shown in drawing M2-3731 in Appendix 6.

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In any distribution system there are four components:

- source of power;
- transmission system;
- load or consumer of power; and
- a control system.

The alternators will feed into a main switchboard via circuit breakers, thus providing protection and enabling them to be isolated from the board, if required. The main switchboard will act as the distribution centre for the power requirements of the vessel. From the switchboard, power will be supplied to the various loads via individual circuits.

Each circuit will have its own circuit breaker / isolating device, protection devices (eg. overload relay or fuse), cables, and load.

Some outputs from the main board will supply smaller boards around the ship for local distribution. These smaller boards are called distribution boards. This reduces the amount of cables that have to run from the main switchboard. It is only required to run one set of large cables to the local distribution board. Further division and distribution is cried out from that point.

Voltage

With ac. systems three -phase distribution with an insulated neutral is still commonly employed. On medium voltage systems 440 V is usually the selected preference to 380 V because the former can result in significant economic savings due to the smaller copper sizes required. However, distribution at 415 V is sometimes used when ships have a large hotel load as this provides a line to neutral voltage of 240 V and enables standard domestic equipment and fittings to be employed. Such a system would use. four wires with the neutral earthed but without hull return. At 3.3 kV a three wire system with the neutral earthed through a resistor is normally employed.

Frequency

The two common power frequencies in use throughout the world are 50Hz and 60Hz. The frequency selected for a particular application may often be determined by the shore supplies available. For example ships continuously operating around Australia would use 50Hz. Where a choice exits the advantages usually favours the higher frequency.

The power output of a motor is proportional to its speed and therefore a 60 Hz machine will generally be more compact and have a greater power to weight ratio than its 50 Hz equivalent. Less iron is required at 60 Hz and this results in a cheaper machine.

Where a shore supply is taken it is permissible to supply a 60Hz system at 50Hz provided the voltage is reduced. Thus, ideally 440V 60Hz motors should be supplied at 380 V when only a 50Hz supply is available. At 415 V 50 Hz the same motors will run with a slightly greater temperature but, provided that the ambient temperature is not too high, it

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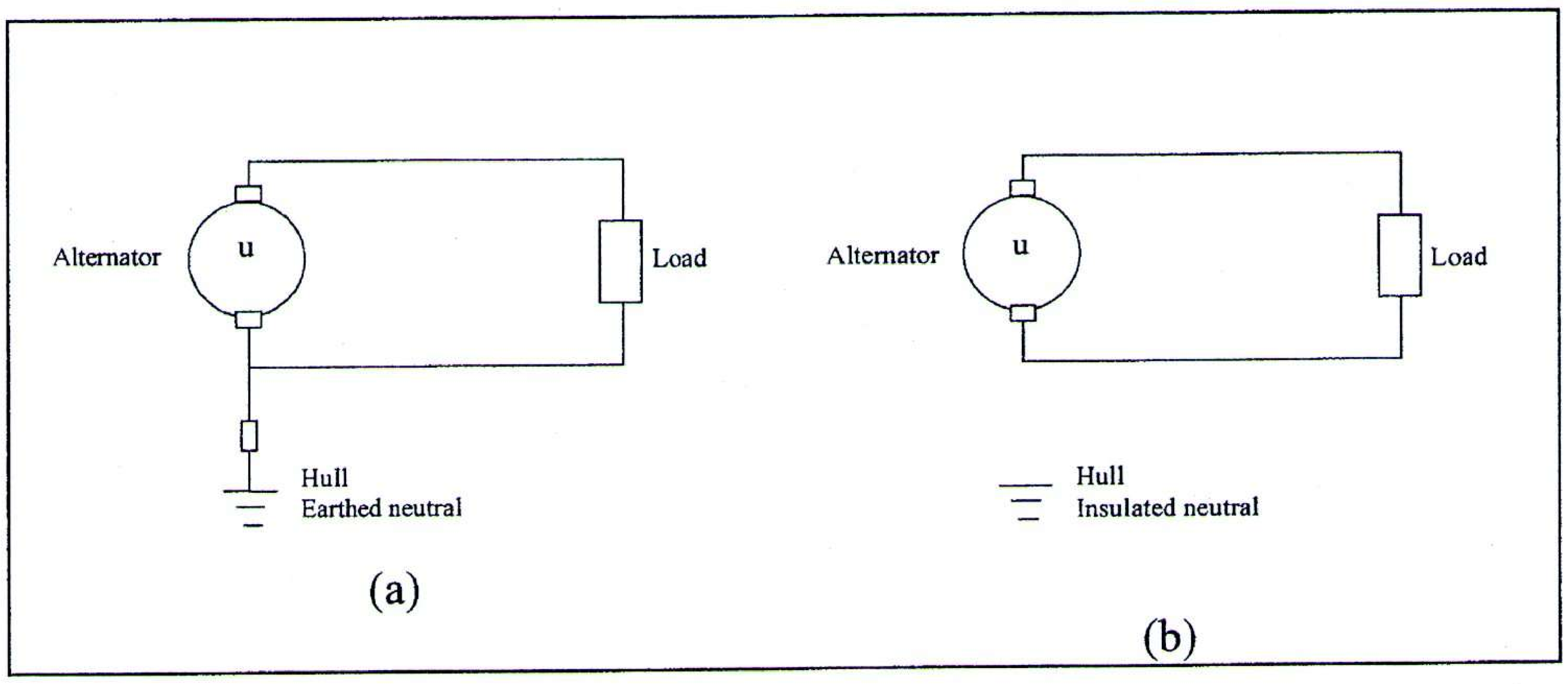
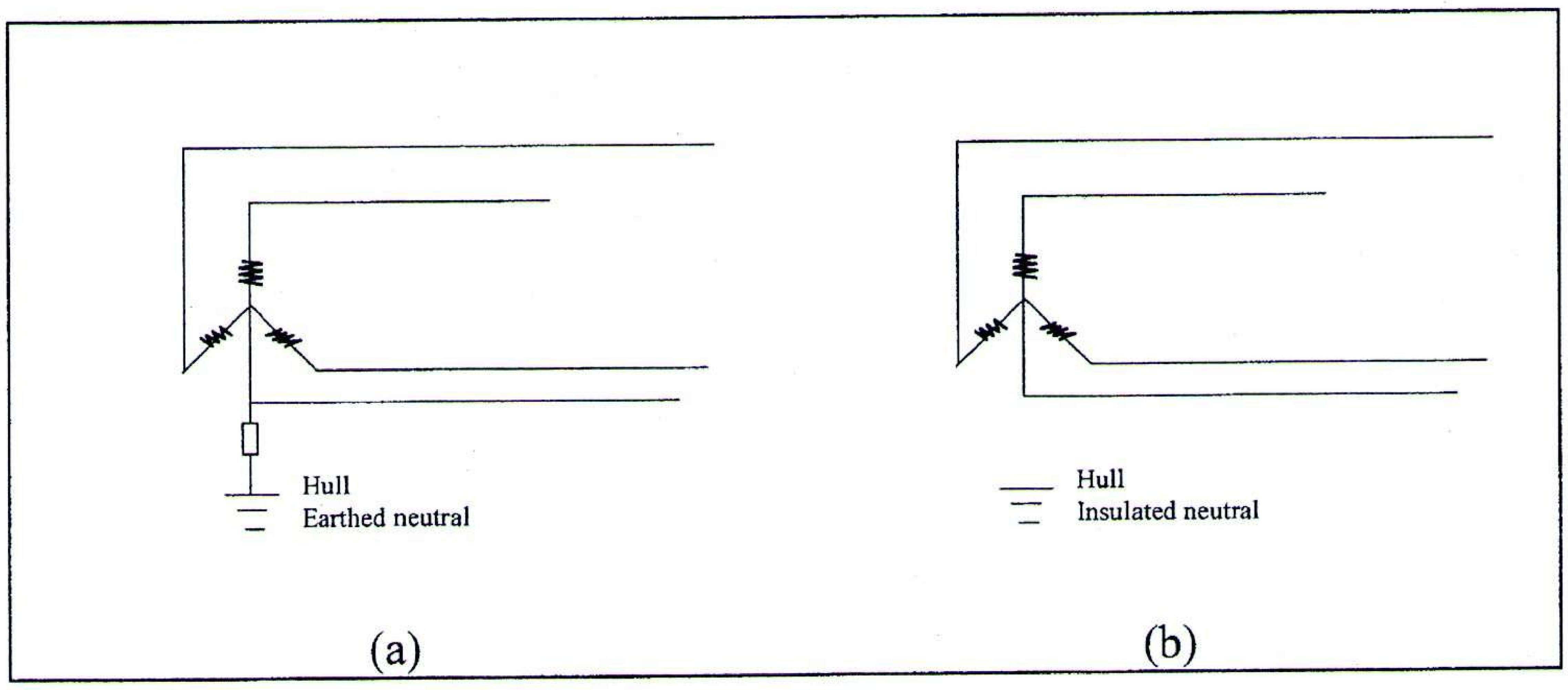
is unlikely that any damage will result. It must be accepted that induction motor speeds will be reduced by about 20%.

The operation of a 50 Hz system from a 60Hz supply is not to be recommended. The motors will run faster and therefore will produce more torque. In doing so they will demand more than their rated current and could be severely overloaded.[4]

Neutral Earthing

With very few exceptions marine electrical design engineers favour the insulation of the neutral on medium voltage systems although this is contrary to the normal practice ashore.





Insulated neutral systems are primarily adopted to avoid the risk of loss of essential services, such as steering gear and vital engine room auxiliaries in the even of an earth fault. With solid neutral earthing a phase to earth fault constitutes a short circuit on the phase concerned and causes the operation of protection equipment which will trip the circuit breaker.

4 S6 (12)

Protection of outgoing circuits

Whilst the generators are usually protected by air circuit breakers (ACB's), the outgoing distribution circuits to essential and non essential loads are protected by either moulded case circuit breakers (MCCB's), miniature circuit breakers (MCB's) or fuses.

In moulded case circuit breakers the insulated moulded housing forms an integral part upon which are mounted the various components. The operating parts are generally inaccessible for maintenance. Current ratings vary from 100A to about 2000A. The manufacturer usually markets these units in various frame sizes. For each frame size (physical size) there are a range of current ratings.

A miniature circuit breaker is the type of breaker found in section and distribution boards. The current rating is usually less than 100A.

Generally a fuse has:

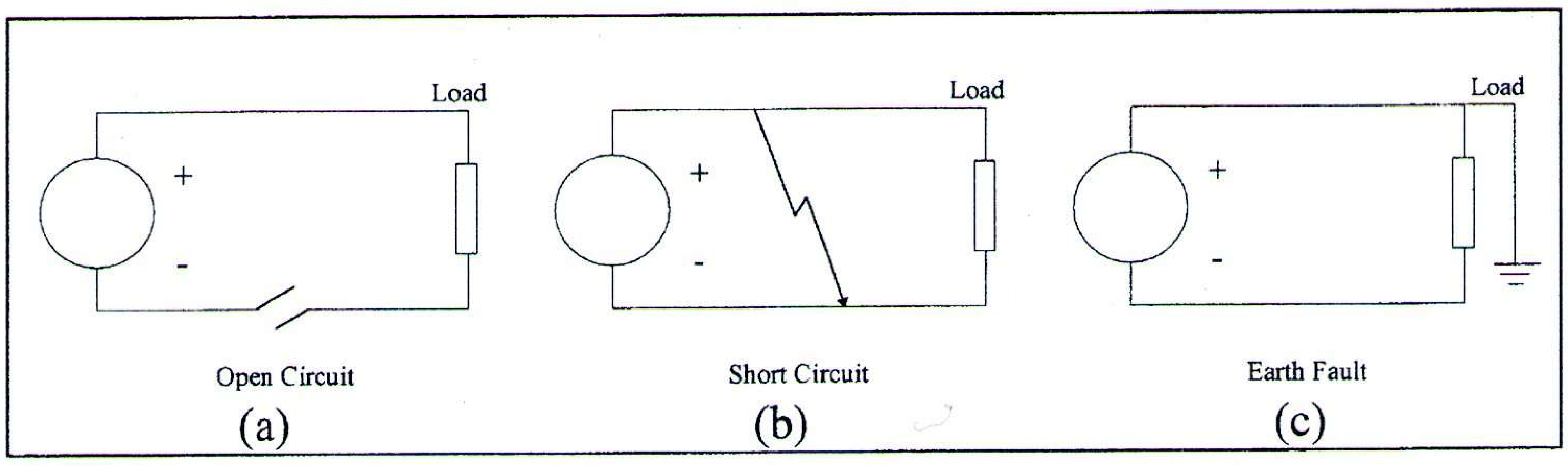
- A fault rating which is equal to or greater than the system fault level at the point of application.
- A current rating to provide adequate protection to the circuit.
- A current rating to provide discrimination to downstream protective circuits.

Discrimination is achieved when only the protective device immediately upstream of a fault operates, all other circuits remain in operation. This arrangement ensures that healthy circuits continue to operate, whereas the faulty circuit is removed from service.

Faults

An **open circuit fault** is when a cable or connection separates, breaks, or fails. This causes an interruption to the flow of the current and therefore, stops the equipment from operating. If the equipment is essential for the running or safety of the vessel, this could result in a serious situation.

In addition, loose wires or connections can come in contact with other objects or personnel, resulting in danger due to arcing and electrocution.



A short circuit fault occurs when two conductors (wires) supplying a load come in contact with each other. This causes a direct flow of current from one to the other resulting in an extremely high current.

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For example, consider a load being supplied by a 240 V power source. The resistance of the load is 24 Ω, and the resistance of the electrical cable supplying the load is 0.2 Ω. Therefore, the current flowing is obtained from the above equation as:

$$I = \frac{V}{R} = \frac{240}{24 + 0.2} = \frac{240}{24.2} = 9.92\text{Amps}$$

Now if a short occurs across the wires, then the current will by-pass the load and the new current flow will be:

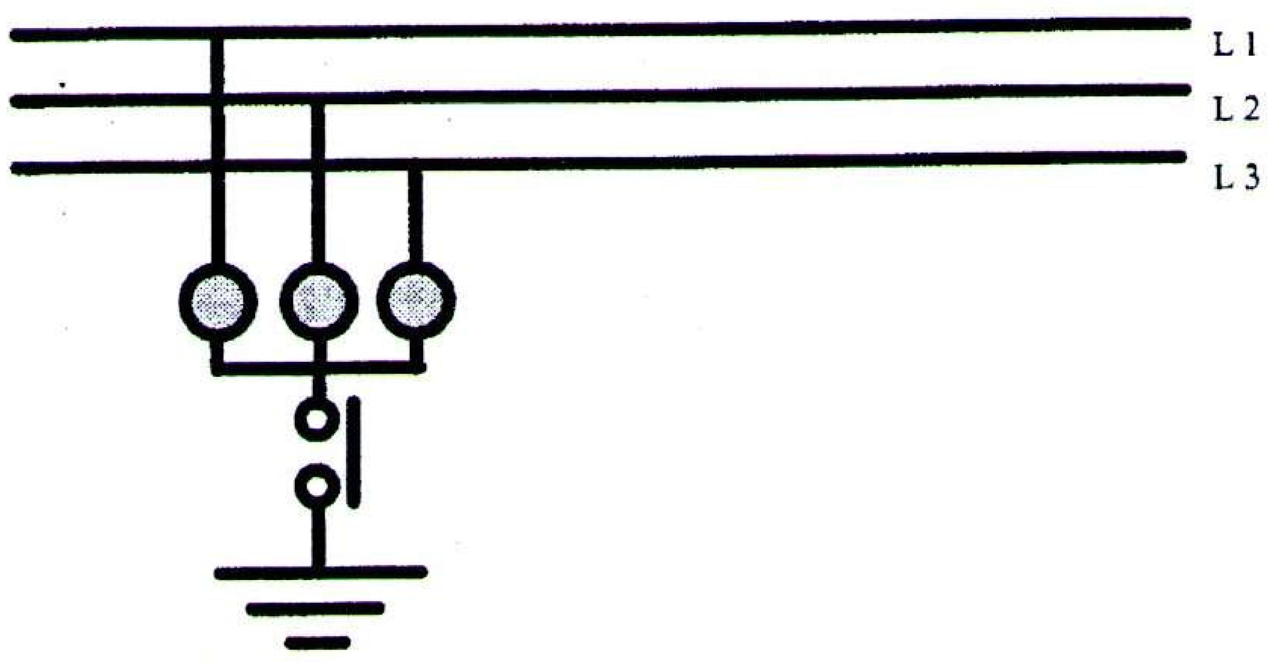
$$I = \frac{V}{R} = \frac{240}{0.2} = 1200\text{A}$$

This high current level creates a fire hazard and should be removed as soon as possible.

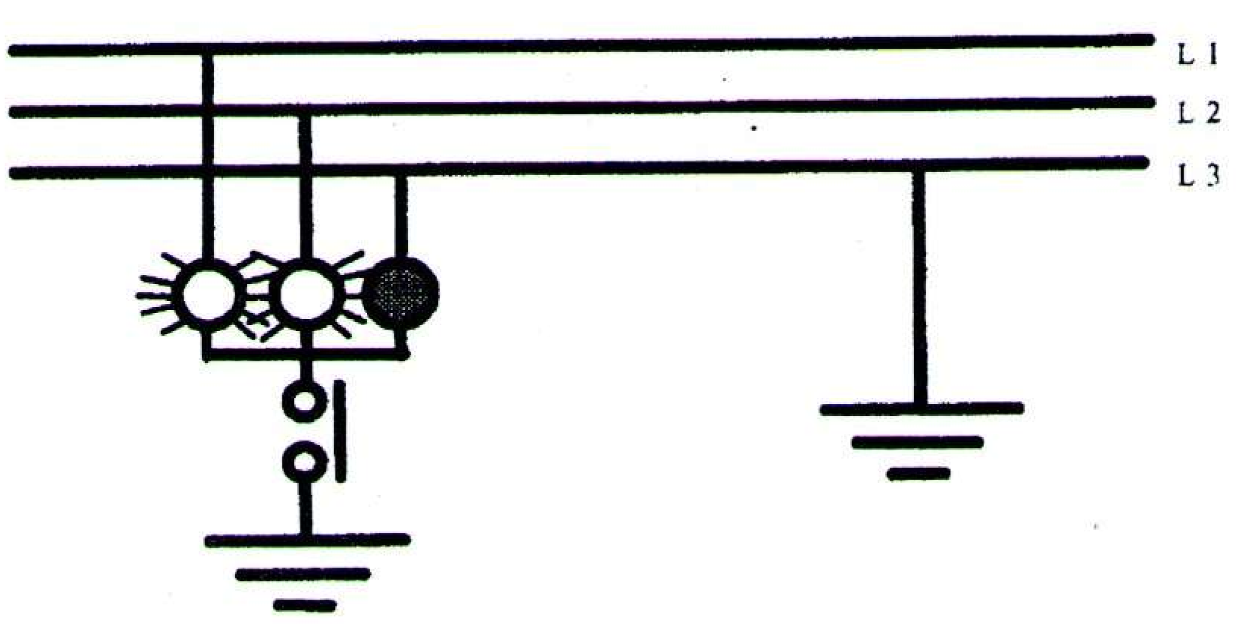
The **earth fault** is when one of the power lines comes in contact with the hull of the vessel. If the vessel has an earthed neutral, then this will cause a fuse to blow or circuit breaker to trip. However, most vessels have insulated neutrals, and these systems will continue to operate, in spite of the earth fault. If a second earth fault occurs on another line in the vessel, a short circuit current can occur from the first fault to the second via the ship's hull.

Vessels with an insulated neutral are usually fitted with earth fault indicating instrumentation to identify the presence of an earth fault.

Earth fault indicators can be a set of lamps or an instrument calibrated in kΩ to show the resistance to earth. An earth fault lamp installation for a 3 phase system is shown below.



(a)



(b)

4S6(14)

In (a) the system is healthy, (ie. no earth faults). Thus the three lamps will glow with **equal half brilliance.** This is because there are two lamps in series across each set of lines. If an earth fault occurs on one line, Figure (b), the lamp connected to the line with the earth fault will **dim**, while the other lamps will **glow brighter**. This is since the voltage of the faulty line and the hull is now the same, (due to the earth fault). However, the others have a single lamp across the lines.

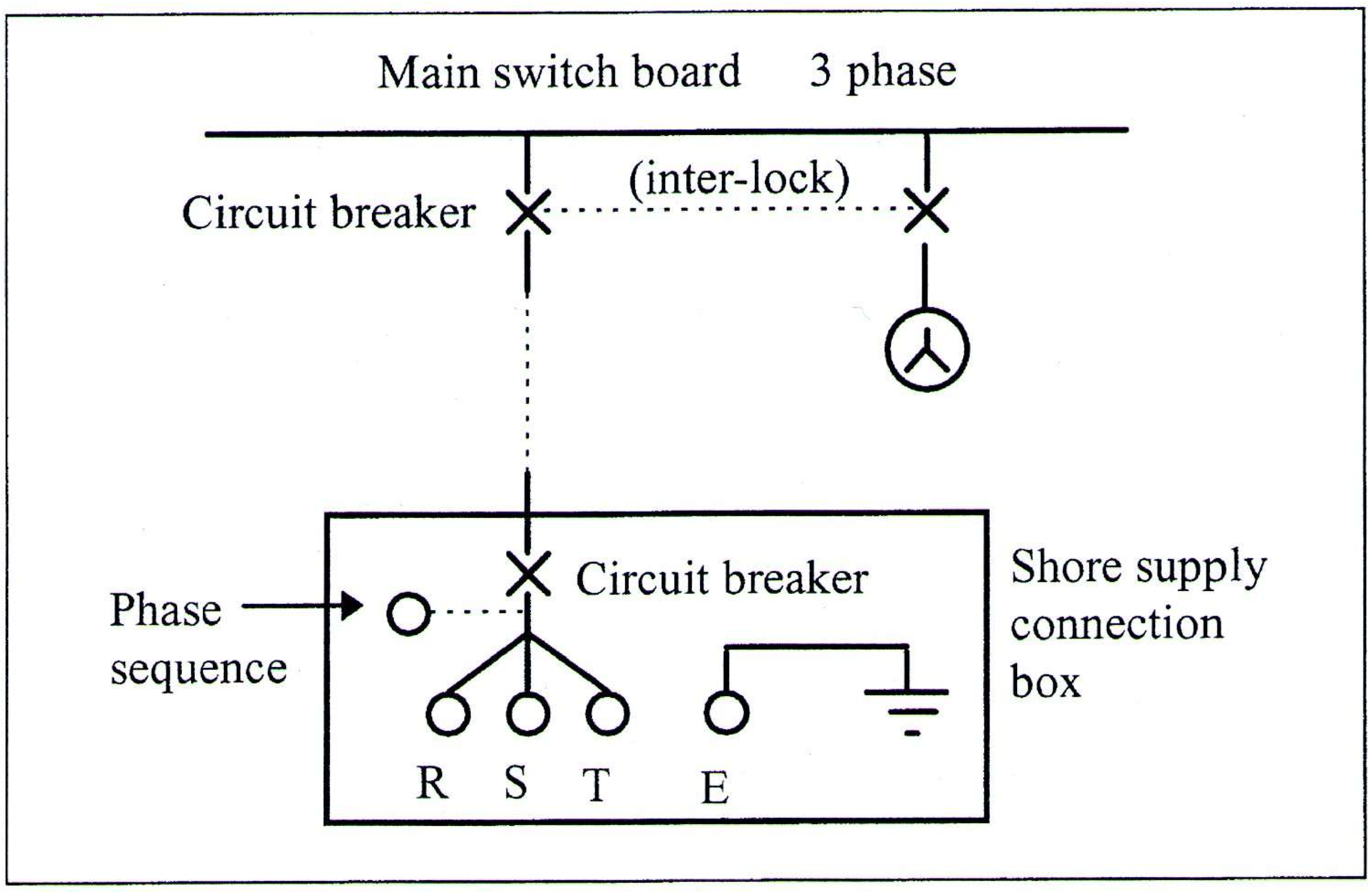
Shore Power

A shore power supply to the vessel is sometimes required due to:

- all of the ship's alternators are shut down for overhaul or maintenance;
- unable to run the alternators when dry docked or slipped; or
- during long periods of lay up adjacent to a wharf.

A shore connection box is installed to accept the shore supply cable, and usually consists of:

- Terminals or an appropriate socket to accept the shore supply cable.
- An earthing terminal to earth the ship's hull to the shore
- A phase sequence indicator. This indicates the shore supply phase sequence. A wrong shore supply phase sequence will mean that the motors will run in reverse.



Typical Shore Connection Arrangement

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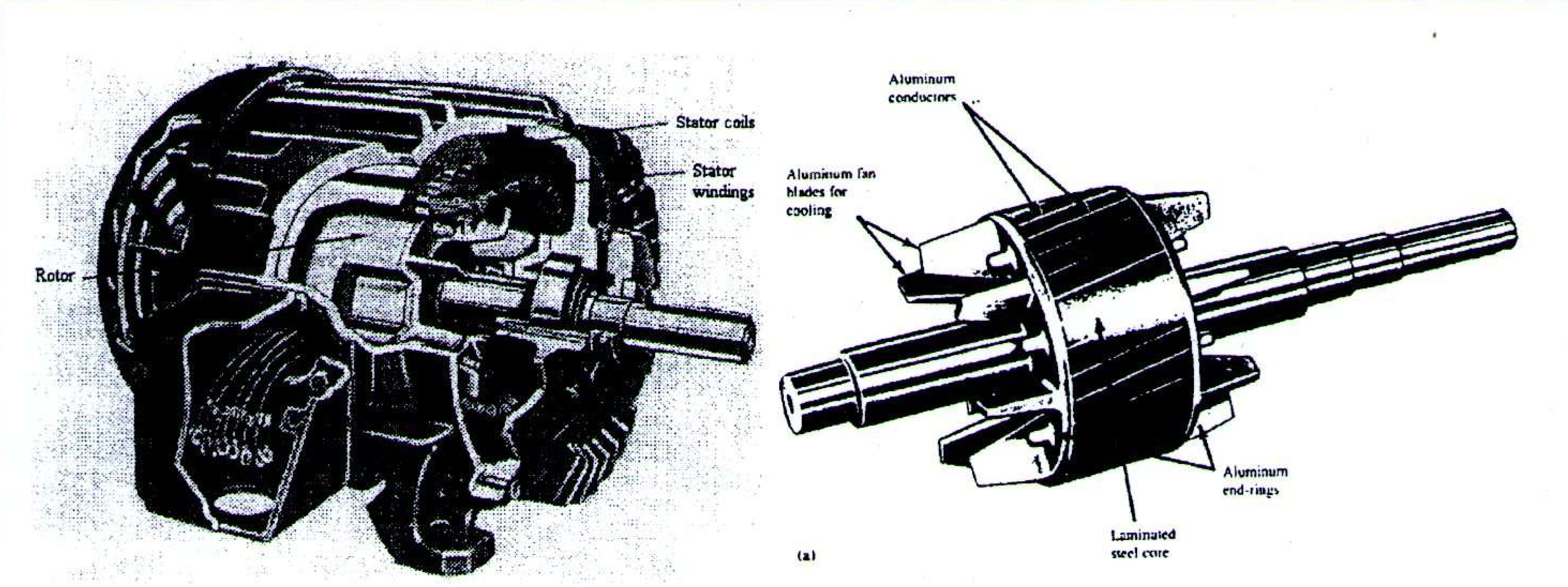
Motors

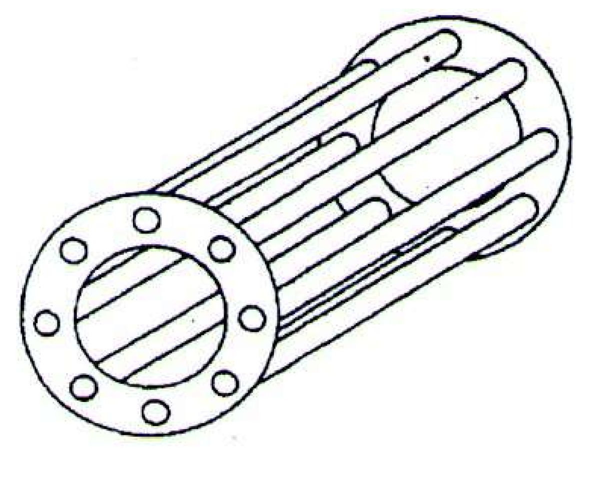
The drive power for compressors, pumps, and fans aboard vessels are usually supplied by electric motors. The most common type of motor is the **three phase induction** motor. There are other types of motors used on board such as single phase induction motors and three phase synchronous motors.

An induction motor has two main components, i.e. the stator and the rotor. The stator Figure (a) carries the three phase winding in slots cut into a laminated steel magnetic core. The ends of the stator windings are terminated in the stator terminal box, where they are connected to the incoming cable from the three phase supply.



(a) (b)

The rotor Figure (b) has a "squirrel cage" winding. This consists of conductor (copper or aluminium) bars connected together at the ends by "end rings". The conductor bars are set in a laminated steel magnetic core. The conductor bars are of the form:



When the three phase supply is connected to the stator windings, the currents which flow in the windings produce a rotating magnetic field. This rotating field sweeps past the bars of the rotor cage thus inducing voltages (and hence currents) into them. The rotor currents produce their own magnetic field which interacts with the stator field resulting in the rotor following the rotating field of the stator. The rotor must turn at a speed slightly less than the stator field otherwise there would be no 'cutting' action of stator field on rotor cage. The speed of stator field is called the synchronous speed. The difference between rotor speed and stator field speed is called the slip speed of the machine.

The induction motor is the most commonly used a.c. motor. It is simple in construction and principle of operation. It has excellent speed /torque characteristics with full load slip is about 5% of synchronous speed.

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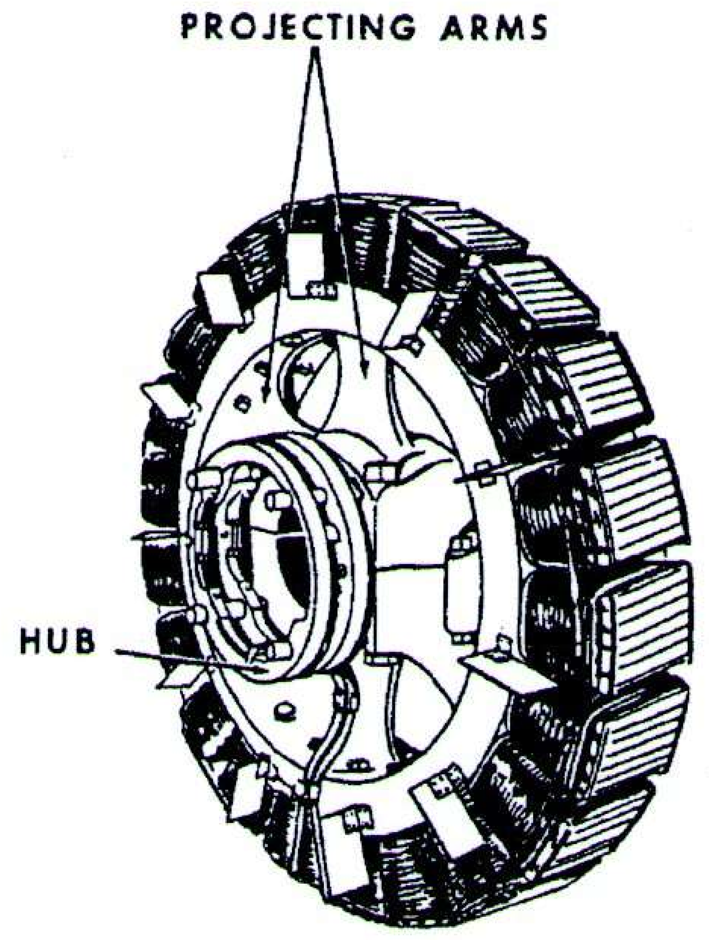
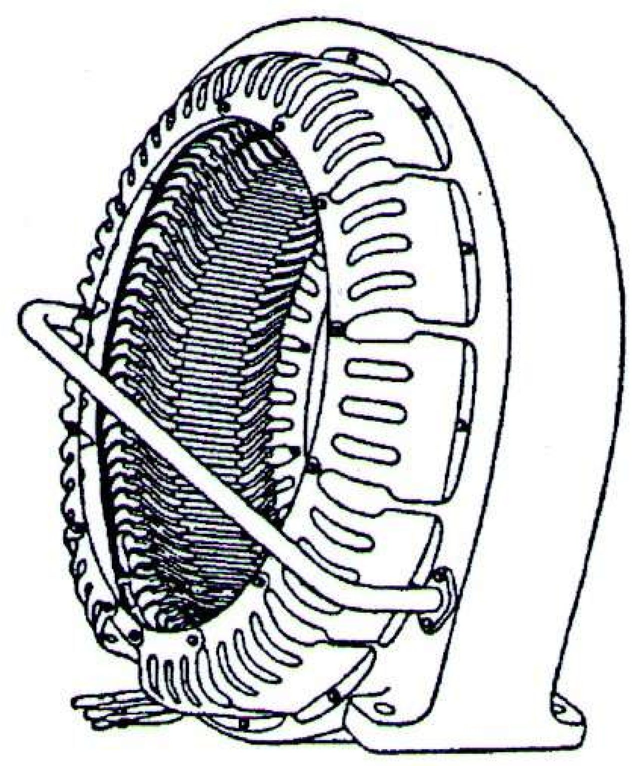
In a three phase **synchronous motor** the squirrel cage rotor is replaced with a wound rotor which effectively becomes a rotating electromagnet. The magnetic field of the rotor is due to a d.c. excitation current supplied via slip rings or through a brushless arrangement. The rotor magnetic field 'locks in' with the rotating stator field resulting in a fixed speed machine.





[Taken from Motors and Controls- J Humphries]

ELECTRIC PROPULSION

[Taken from Practical Marine Electrical Knowledge – D Hall]

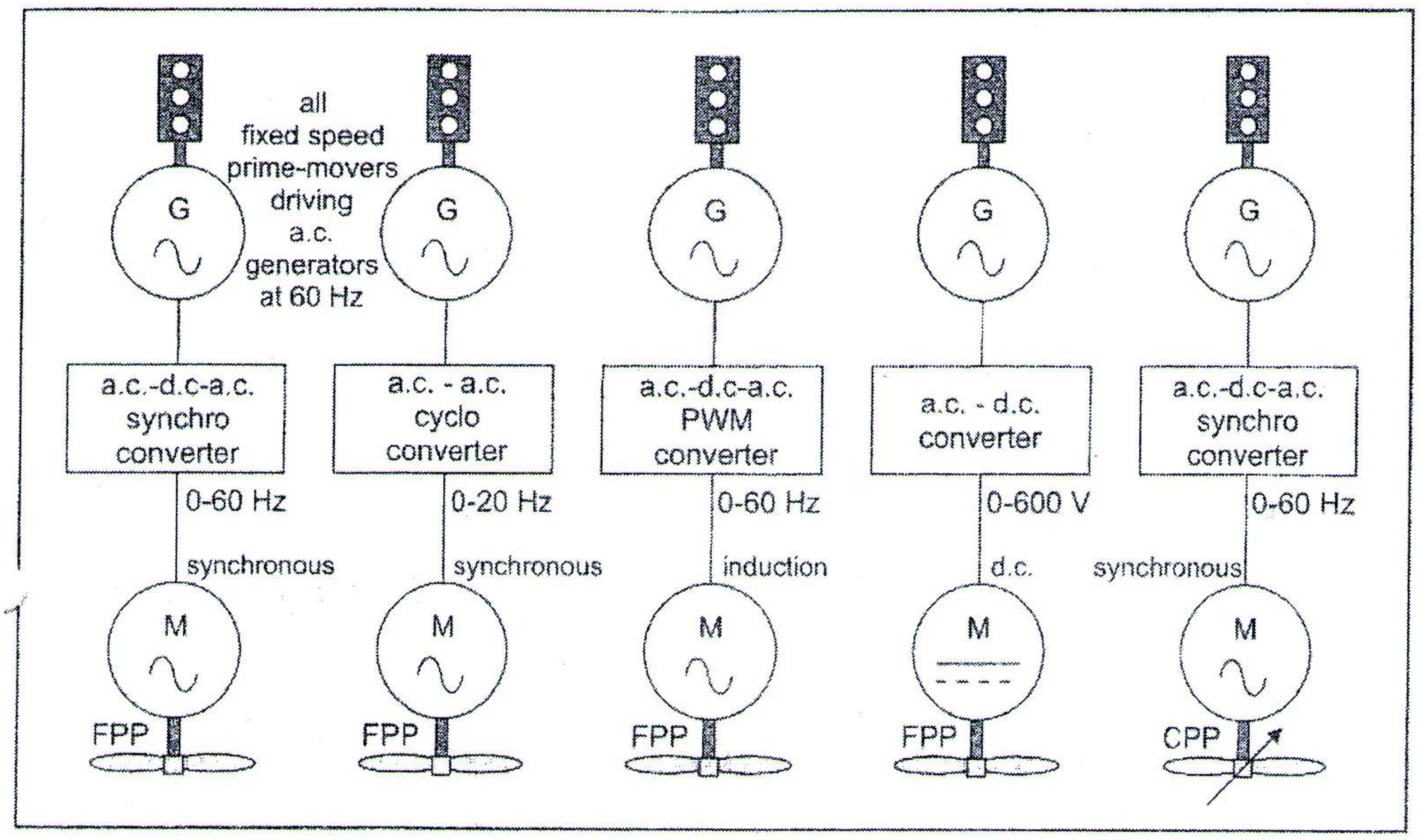


Fig. 8.3 Electric propulsion options.

For very high power, the most favoured option is to use a pair of high efficiency, high voltage a.c. *synchronous motors* with fixed pitch propellers (FPP) driven at variable speed by *frequency control* from electronic converters. A few installations have the combination of controllable pitch propellers (CPP) *and* a variable speed motor. Low/medium power propulsion (1-5 MW) may be delivered by a.c. *induction motors* with variable frequency converters or by d.c. motors with variable voltage converters.

The prime-movers are conventionally constant speed *diesel engines* driving a.c. generators to give a fixed output frequency. Gas turbine driven prime-movers for the generators are likely to challenge the diesel option in the future.

Conventionally, the propeller drive shaft is directly driven from the propulsion electric motor (PEM) from inside the ship. From experience obtained from smaller *external* drives, notably from ice-breakers, some very large propulsion motors are being fitted within rotating *pods* mounted outside of the ship's hull. These are generally referred to as *azipods,* as shown in Fig. 8.4, as the whole pod unit can be rotated through 360 degrees to apply the thrust in any horizontal direction, i.e. in *azimuth.* This means that a conventional steering plate and stern side-thrusters are not required.

Ship manoeuvrability is significantly enhanced by using azipods and the external propulsion unit releases some internal space for more cargo/passengers while further reducing hull vibration.

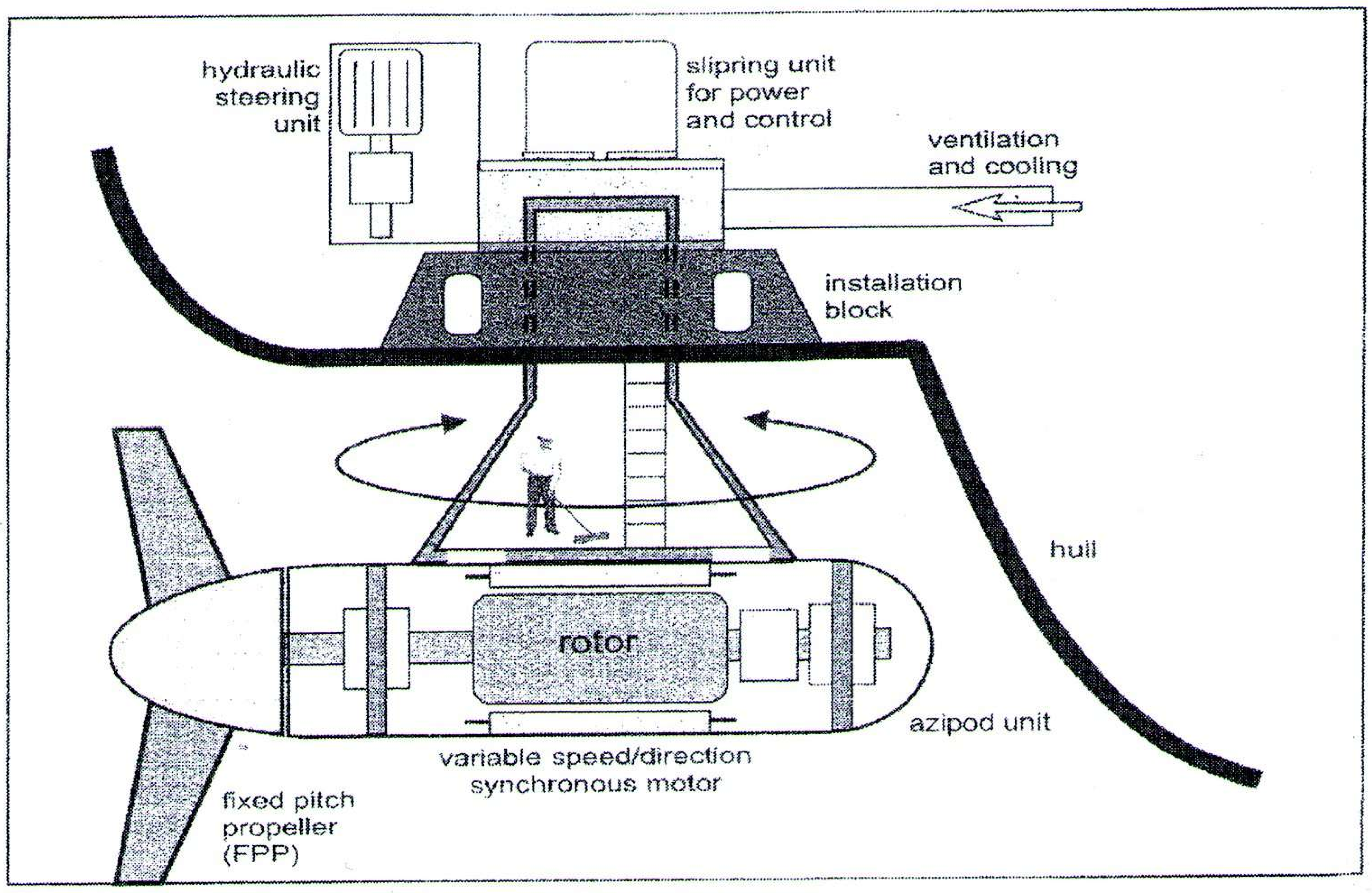


Fig. 8.4 Azipod drive unit.

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Power Supply Network

As the demand for electrical power increases on ships (particularly passenger ferries, cruise liners, and specialist offshore vessels and platforms) the supply current rating becomes too high at 440 V. To reduce the size of both steady state and fault current levels, it is necessary to increase the system voltage at high power ratings.

Note: In marine practice, voltages below 1000 V are considered LV (low voltage). HV (high voltage) is any voltage above LV. Typical marine HV system voltages are 3.3 kV or 6.6 kV but 11 kV is used on some offshore platforms and specialist oil/gas production ships e.g on some FPSO (floating production, storage and offloading) vessels.

By generating electrical power at 6.6 kV instead of 440 V the distribution and switching of power above about 6 MW becomes more manageable.
The component parts of an HV supply system are now standard equipment with HV diesel generator sets feeding an HV main switchboard. Large power consumers such as thrusters, propulsion motors, air-conditioning (A/C) compressors and HV transformers are fed directly from the HV switchboard.

An economical HV system must be simple to operate, reasonably priced and require a minimum of maintenance over the life of the ship. Experience shows that a 9 MW system at 6.6 kV would be about 20% more expensive for installation costs. The principal parts of a ship's electrical system operated at HV would be the main generators, HV switchboard, HV cables, HV transformers and HV motors. An example of a high voltage power system is shown in Fig. 8.6.

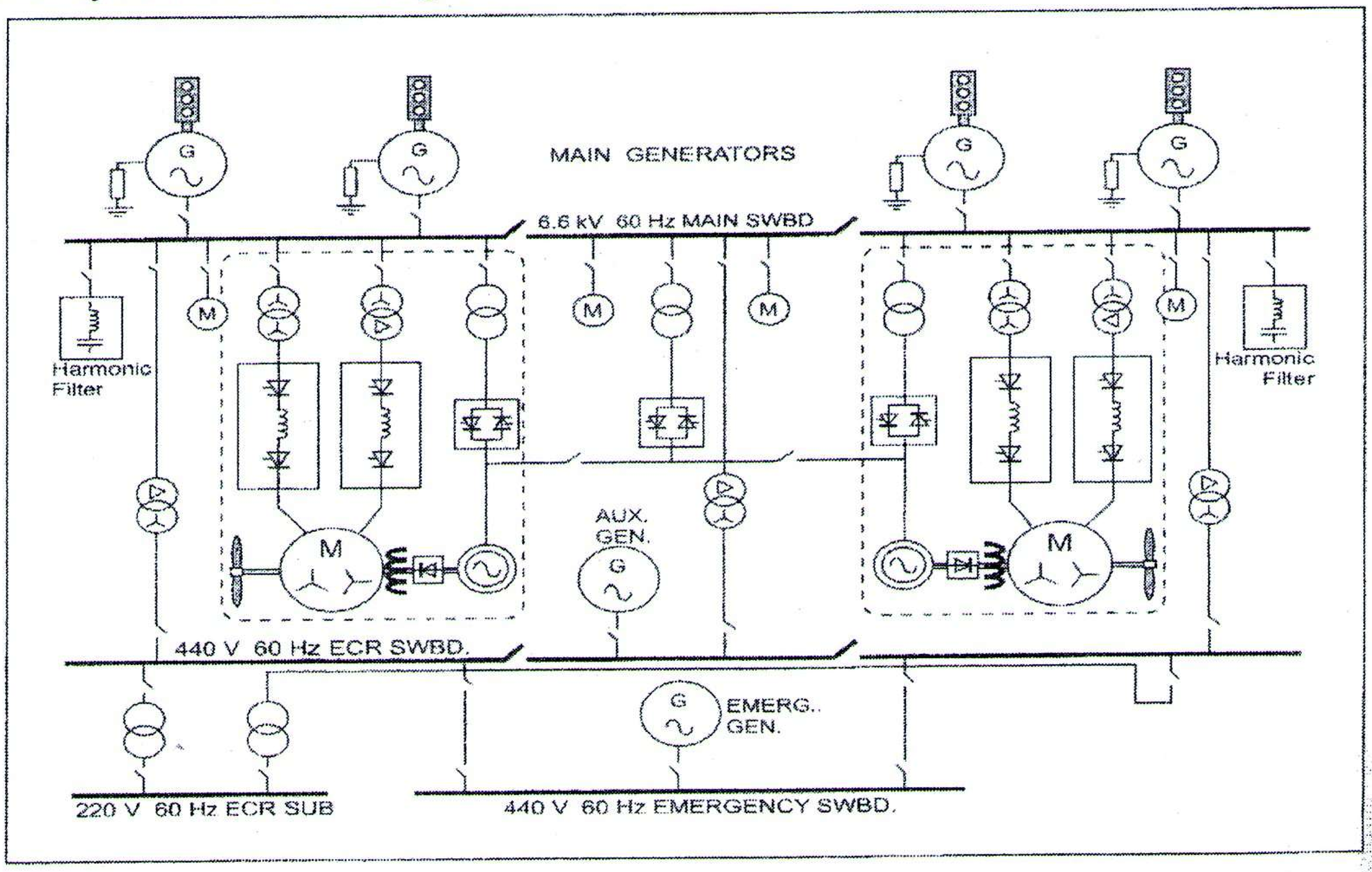

Fig. 8.6 HV power system.

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In the example shown the HV generators form a central power station for all of the ship's electrical services. On a large passenger ship with electric propulsion, each generator may be rated at about 10 MW or more and producing 6.6 kV, 60 Hz three-phase a.c. voltages.

The principal consumers are the two synchronous a.c. propulsion electric motors (PEMs) which may each demand 12 MW or more in the full away condition. Each PEM has two stator windings supplied separately from the main HV switchboard via transformers and frequency converters. In an emergency a PEM may therefore be operated as a half-motor with a reduced power output.

A few large induction motors are supplied at 6.6 kV from the main board with the circuit breaker acting as a direct-on-line (DOL) starting switch.

These motors are:

- Two forward thrusters and one aft thruster, and
- Three air conditioning compressors

Other main feeders supply the 440V engine room sub-station (ER sub) switchboard via step-down transformers. An interconnector cable links the ER sub to the emergency switchboard. Other 440V sub-stations (accommodation, galley etc.) around the ship are supplied from the ER sub. Some installations may feed the ships sub stations directly with HV and step-down to 440V 1ocally.

ELECTRICAL EQUIPMENT IN HAZARDOUS AREAS

Electrical equipment which is intended to be used in areas that are classified as hazardous locations should be approved safe and listed by a certifying authority.

A hazardous area is defined as an area which an explosive atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation, and use of potential ignition sources.[5]

The installation of electrical equipment in areas containing flammable gas or vapour and/or combustible dust, is to be minimized as for as is consistent with operational necessity and the provision of lighting, monitoring, alarm or control facilities enhancing the overall safety of the ship.[6]

To ensure 'safe' operation different methods of protection are used and they can be summarized as follows:

(a) *Exclusion:* This method involves the exclusion of the hazardous material, either gas or dust, from the apparatus so that a spark or hot surface inside the apparatus cannot cause ignition. This is achieved by sealing the apparatus

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enclosure, by the use of enclosed devices or by filling the apparatus with some substance, which may be solid, liquid or inert gas.

(b) *Explosion containment:* This method aims to contain an explosion, if it does occur, in the apparatus. A flameproof enclosure is probably the best known and most widely used of all techniques, but it is only appropriate for gas hazards.

(c) *Energy limitation:* This method uses energy limitation. Flammable gases and combustible dusts have minimum ignition energies, below which it is not possible for an arc or spark to cause an explosion. If the energy in an electrical circuit can be maintained below these levels, it cannot cause an explosion. Intrinsic safety is the most common technique used to achieve this.

(d) *Dilution:* This method involves dilution of a hazardous gas atmosphere below the lower flammable limit by ventilation. It is not appropriate for combustible dust areas.

(e) *Avoidance of' ignition source:* This method aims to prevent an ignition source from occurring. The most common technique is increased safety. This is used for apparatus or parts of apparatus, such as terminal boxes, that do not are or spark in normal service.

Safe types of electrical equipment commonly found aboard ship are as follows:

Intrinsically safe **Ex i**
This equipment uses energy limitation to provide protection. There are two categories of intrinsically safe electrical apparatus *ia* and *ib*. Essentially *ia* involves the application of more arduous testing conditions and provides a higher confidence of safety.

Increased safety **Ex e**
This equipment uses the avoidance of ignition source to provide protection.

Non Sparking **Ex n**
Similar to Ex e but not as exacting and therefore more restrictive in application.

Flameproof **Ex d**
This equipment uses the containment method to provide protection.

Pressurized enclosure **Ex p**
This equipment uses the exclusion method to provide protection.

Powder filled **Ex q**
This equipment uses the exclusion method to provide protection

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On tankers areas are classified as 'dangerous spaces' or 'normally safe' spaces. The degree of hazard presented by a dangerous space is determined by the flammable nature of the cargo being carried.

Some or the particular requirements for electrical equipment installed on tankers is described below.[6]

Dangerous zones or spaces are:

(a) Spaces containing flammable cargo and all zones or spaces adjacent to cargo tanks are regarded as dangerous zones or spaces.

(b) An enclosed or semi-enclosed space with direct access into a dangerous zone or space is regarded as a dangerous space.

(c) An enclosed space located in a dangerous zone or space may be regarded as a non-dangerous space, provided that it is separated from the flammable liquid cargo by not less than two gastight steel bulkheads or decks, is mechanically ventilated and, in addition, has no direct opening into a dangerous zone or space.

Semi-enclosed spaces

Semi-enclosed spaces are considered to be spaces limited by decks and/or bulkheads in such a manner that the natural conditions of ventilation are sensibly different from those obtained on open deck, e.g. centre castle space.

The relevant gas group and temperature classfor the safe type equipment are IIA T3.

Cargo tanks

Intrinsically safe electrical equipment.

Cofferdams adjoining cargo tanks

Intrinsically safe electrical equipment.

Electric depth-sounding devices hermetically enclosed, located clear of the cargo tank bulkhead, with cables installed in heavy gauge steel pipes with gastight joints up to the main deck.

Cargo pump rooms

Intrinsically safe electrical equipment.

Lighting. Pump rooms immediately adjoining an engine room or similar non-dangerous space may be lit through permanently fitted glass lenses or ports fitted in the bulkhead or deck so arranged as to maintain integrity of the structure. The externally mounted lighting fixture may be designed so that the gastight flanged port forms part of the fixture. The lighting fixtures and wiring are to be located in the non-dangerous space. Alternatively, flameproof lighting fittings (symbol d) may be fitted. The fittings are to be arranged on at least two independent final branch circuits to permit light from one circuit to be retained while maintenance is carried out on the other.

Motors. Electric motors driving equipment located in cargo pump rooms are to be separated from the pump room by a gastight bulkhead or deck. Flexible couplings or other means of maintaining alignment are to be fitted in the shafts between the motors and the driven unit. In addition, suitable stuffing boxes are to be fitted where shafts pass through gastight bulkheads or decks.

Enclosed or semi-enclosed spaces immediately above cargo tanks or having bulkheads above and in line with cargo tank bulkheads
Irinsically safe equipment.
Safe type lighting fittings.

Electrical equipment other than stated above may be installed in 'tween deck spaces, provided that such equipment is housed in a mechanically ventilated compartment having access solely from the deck above, and of which the floor is separated from the cargo tanks by a cofferdam and the boundaries are oiltight and gastight with respect to the cofferdam and the 'tween deck spaces.

Compartments for cargo hoses
Intrinsically safe equipment.
Safe type lighting fittings.

Spaces under cargo tanks (e.g. duct keels)
Intrinsically safe equipment.
Flameproof lighting fittings (symbol d).
Lighting fittings of the air driven type.

Zones on open deck within 3 m of any cargo oil tank outlet or vapour outlet (e.g. cargo tank hatches; sight ports; tank cleaning openings; ullage openings; sounding pipes; cargo pump rooms and cofferdams; cargo pump room entrances)

Safe type equipment which is to be suitably protected for use on deck.

Zones on open deck over all cargo tanks (including all ballast tanks within the cargo tank area) to the full width of the vessel, plus 3 m fore and aft on open dock, up to a height of 2,4 m above the dock

Safe type equipment which is to be suitably protected for use on deck.

VESSEL DOCUMENTATION

Vessel Electrical Specifications.
An extract of a specification is shown in Appendix 4.

One line diagrams.
A full set of diagrams MSB, ESB and distribution system.

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Schematic diagrams.
As contained in Appendix 6.

Electrical Load Documentation.
In order to determine the correct aggregate rating of the generators it is necessary to determine the electrical loading that will be experienced under various operating conditions.

There are three ways to ascertain the electrical load on the generators. These are empirical formulas; simulation and electrical load analysis. In a design process, the first estimate of electrical load is often made using empirical formulas, and as the design process progresses, a more detailed calculation is made with load analysis tables.

Empirical formulae can be used successfully to obtain a first estimate of the electric power demand in the pre-design stage, if the formulae are based on a sufficient number of ships with the same mission statement and comparable size. However, for the detailed design of ship and electrical systems one of the other methods is indispensable to get a more reliable result.

When empirical formulas are at hand, they can be used to determine the electric power demand or installed electric power by using, for instance, the main dimensions of the ship such as size (deadweight) or installed propulsion power. As a rule of thumb, the electric load when manoeuvring is 130 % of the electric load at sea, and the load in port (no loading or discharging) is 30 to 40 %.[8]

This full electrical load analysis is a detailed tabulation of the total connected load and the operating loads at sea, during maneuvering and in port. Operating loads are determined by applying a service factor to the expected connected load for each application for each operating condition. The service factor assigned to each application is a combined load factor and diversity factor representing the percent of its own possible maximum that is contributed to the load on the generator over a 24 hour period. Occasional loads such as fire pumps, anchor windlass, etc is assumed to have zero factor. The aggregate generating capacity, exclusive of any emergency will always be greater than the peak load determined by the analysis. The probability of installing additional loads in the future should also be considered when determining the aggregate generator capacity.[1] A typical load analysis is shown in Appendix 7.

An alternate approach uses a load factor and simultaneity factor rather than just the single service multiplier. This table is shown in Attachment D2. The load factor indicates the relative (%) load of the machinery and thus specifies how much electric power is absorbed in an actual situation. A steering gear pump for example will only occasionally be fully loaded. The load factor, which varies between 0 and 1, accounts for this. A typical load factor for a steering gear pump is 0. 1.

The simultaneity factor accounts for pieces of machinery that are not operated continuously but intermittently. Examples of these are air compressors, fuel pumps and ballast pumps. The simultaneity factor indicates the relative (%) mean operational time of

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the machinery. This factor also varies between 0 and 1. It is often possible to make a good estimation of this factor by comparing the machine capacity and the average capacity demand. As described above in many cases no distinction is made between the load factor and the simultaneity factor, and the two factors are combined into one service factor. This does, however, not provide a clear insight into the actual load demand.

The column *average absorbed power is* the product of the absorbed power, the number in service, the load factor and the simultaneity factor. The total of this column indicates the total absorbed power for the given operational condition. The estimation of the load and simultaneity factors is the most difficult part of the electric load analysis. These factors are often estimated too high, in order to minimise the risk of designing a plant with a generator capacity that is too small. This results in an overestimation of the electric power demand, and consequently the chosen generator capacity is too large.
Disadvantages are obvious:

- high investment
- low average load of the diesel generator sets, leading to specific fuel consumption that is not optimal and internal pollution of the engine.

A thorough study of similar ships should form the basis for load and simultaneity factor estimates.

A more accurate electric power demand estimate can be achieved with a simulation of ship's operations under the various operational conditions. This method requires a considerable insight into the ship's operations. A simulation takes interactions between pieces of equipment into account and can model load and simultaneity factors by using stochastic probability distributions. In particular the use of probability distributions can make the method more accurate than an ordinary electric load balance.

The advantage of the stochastic probability distribution is explained with an example: the steering gear pump. The load factor was introduced in the preceding paragraph. The steering gear pump is only occasionally fully loaded; the load factor accounts for this by implying that it is partially loaded all the time. With a probability distribution the load of the pump can be modelled to be zero or full-load. After sufficiently long simulation the distribution provides insight into the expected minimum and maximum loads and the chances of exceeding a certain maximum. With this it is possible to make a well-founded choice concerning the number and capacity of the generators and transformers [8]

Short Circuit Calculations and Discrimination of Protective Devices.

The installation of large capacity electrical systems has resulted in the increase in magnitude of possible short-circuit currents throughout the electrical distribution system. To maintain continuity of electrical service, with the least possible interruption from fault currents, it is necessary to provide adequately rated circuit protective devices that are properly coordinated with each other throughout the distribution system. These protective devices are usually circuit breakers; however, fuses may be used for many applications.

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To determine the proper selection and application of circuit protective devices, a fault current analysis of the entire electrical generating and distribution system, should be made. In calculating the total magnitude of fault currents, it is necessary to determine not only the contribution of short-circuit current from the generators, but also the contribution from motors connected to the system. The contribution from induction motors decays very rapidly; however, the time of decay usually spans the time range of circuit breaker operation and should be considered.

The fault-current analysis should be based on the total number of generators, including spare units, that may be operated in parallel, the number of motors expected to be operating, and the reactance and resistance of cables and transformers in the circuit in question.

As an example, calculations for a shipboard electric plant with two 1250 kW, 450 volt. 3-phase generators operating in parallel, and an induction motor load of 1800 amps at the time of a fault and a fault occurring on the generator switchboard main bus, gives a current available at the switchboard main bus of 24,673 amps. This value is the minimum interrupting rating for the circuit protective devices installed on the generator switchboard.

Appendix 7 also contains calculations for maximum fault currents at different points of a ship's distribution system.

The fault current analysis should be extended to include calculations of minimum fault currents for remote points of the system to determine that a sufficient current is available to ensure the proper tripping of each protective device. Using the fault current analysis as a basis for the selection of protective devices, a sequence of circuit-breaker tripping can be determined that will isolate any fault in the distribution system with a minimum interruption of power to other services. In the event of a fault, the nearest protective device on the supply side of the fault should open to isolate the faulted circuit; other protective devices on the supply side of the fault should remain closed.[1]

Main & Emergency Switchboard
Drawings and schematics of layout, instrumentation etc are often required. Bus bar construction and the mechanical stresses likely to occur under short circuit conditions documentation may be needed. Also schematics of starters for essential motors and thrusters. Details of power converters, power supplies and UPS systems are also required.

Load Balance Calculations
Power consumption balance information covering operational modes: at sea; manoeuvring; special operations and emergency conditions.

Electrical Propulsion
Where electrical propulsion systems are used, additional documentation includes

- Description of operational modes

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- Calculations of propulsion motor start up times
- Power management
- Electrical propulsion motor details.

CLASSIFICATION SOCIETY DOCUMENTATION

Appendix 8 contains the general provisions for electrical installations on high speed craft issued by Germanischer Lloyd. The complete set of design documents to be submitted is shown on page 12-1.

Appendix 9 contains an extract from the specific requirements necessary for initial planning and basic design of electrical systems on drilling units issued by ABS.

References

1. *Marine Engineering, Harrington R.L (Ed)*
2. *D.N.V. Germany, Web site.*
3. *Practical Marine Electrical Knowledge, Hall D T.*
4. *Marine Electrical Practice, G.O.Watson.*
5. *Standards Australia*
6. *Lloyds Classification Regulations*
7. *D.N.V. Classification Rules*
8. *Design of Propulsion and Electric Power Generation Systems, Woud H, Stapersma D.*

2

Machinery service systems and equipment

Service systems are necessary for the main machinery and for generators in addition to the circulating systems described in the previous chapter. The supply of compressed air for starting and control systems requires the provision of compressors and air receivers. Modern residual fuels need a handling system with settling tanks, centrifuges, heating, filtration, and sometimes with homogenization and blending equipment. Lubricating oil also benefits from being centrifuged as well as being filtered.

Air compressors and systems

Air at a pressure of 20 to 30 bar is required for starting main and auxiliary diesel engines in motorships and for the auxiliary diesels of steamships. Control air at a lower pressure is required for ships of both categories and whether derived from high pressure compressors through reducing valves or from special control air compressors, it must be clean, dry and oil free.

A starting air system for main diesels (Figure 2.1) normally has two air compressors and two reservoirs with sufficient capacity for twelve main engine starts (six if a non-reversible engine). The receivers must store sufficient air for the starts without the need for top up from the compressors.

Safety valves are normally fitted to the air receivers but in some installations the reservoirs are protected against overpressure by those of the compressors. There is a requirement that if the safety valves can be isolated from the reservoirs, the latter must have fusible plugs fitted to release the air in the event of fire. Reservoirs are designed, built and tested under similar regulations to those for boilers.

Explosions can and do occur in diesel engine starting air systems. Also air start valves and other parts are sometimes burned away without explosion. These problems have been caused by cylinder air start valves which have leaked or not closed after operation and have allowed access from the cylinder to the air start system of the flame from combustion. Carbon deposits from burning fuel and oily deposits from compressors are available as substances which may be ignited and produce an explosion in the air start system. If no explosion occurs, the flame from the cylinder and high temperature air from compression can cause carbon deposits in the system to burn. Careful maintenance of air start valves, distributors and other parts is vital as is regular cleaning of air start system components to remove deposits. The lubrication of

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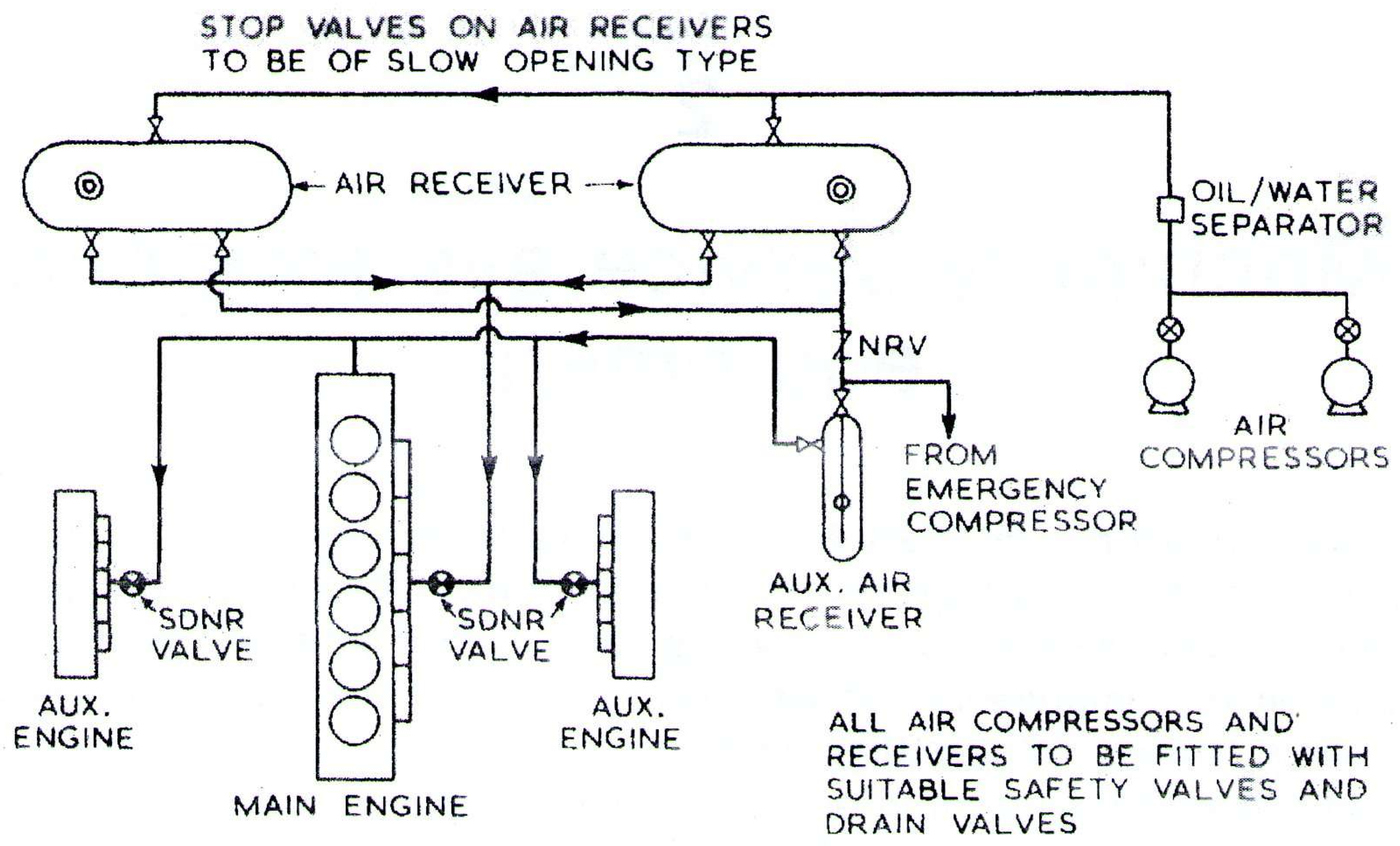

Figure 2.1 *Starting air system for main diesels*

components is limited as excess lubrication could cause the air start valves to be stuck by grease which has become hardened by the heat, and oil could accumulate in the pipes from this source. The draining of compressor coolers and air receivers is important. Drains on air start systems are also checked. Flame traps or bursting caps are fitted at each air start valve but it should be noted that protection of the latter type failed to prevent a serious explosion with the loss of seven lives in 1960.*

Starting air for auxiliary engines may be taken directly from the main engine air start receivers or from a small auxiliary receiver which can be kept at full pressure.

The low pressure control air system receiver is supplied ideally from a low pressure, oil free compressor. The supply may be obtained from the main air start reservoirs through reducing valves or pressure regulators, driers, oil traps and filters.

For steamships, the starting air arrangements for diesel auxiliary engines are similar to those in motorships. The low pressure air for instrumentation and remote control devices is likely to be supplied from a low pressure, oil free compressor.

Air compressors

A single stage compressor used to provide air at the high pressures required for diesel engine starting, would unfortunately generate compression temperatures of a level similar to those in a diesel. Such heat would be sufficient to ignite vaporized oil in the same way as in a compression-ignition engine. The heat produced in a single stage of compression would also be wasteful of energy.

*Merchant Shipping Act (1894).

This heat of compression adds energy and produces a resultant rise in pressure apart from that pressure rise expected from the action of the piston. However, when the air cools the pressure rise due to the heat generated is lost. Only the pressure from compression remains. The extra pressure due to heat, is of no use and actually demands greater power for the upward movement of the piston through the compression stroke.

Perfect cooling for the cylinder of a single stage compressor, with constant (isothermal) temperature during the process, would remove the problems, but is impossible to achieve. Multi-stage air compressor units with various cylinder configurations and piston shapes (Figure 2.2) are used in conjunction with intermediate and after cooling to provide the nearest possible approach to the ideal of isothermal compression.

Cycle of operation

On the compression stroke (Figure 2.3) for a theoretical single cylinder compressor, the pressure rises to slightly above discharge pressure. A spring-loaded non-return discharge valve opens and the compressed air passes through at approximately constant pressure. At the end of the stroke the differential pressure across the valve, aided by the valve spring, closes the discharge valve, trapping a small amount of high pressure air in the clearance space between the piston and the cylinder head. On the suction stroke the air in the clearance space expands, its pressure dropping until such time as a spring-loaded suction valve re-seats and another compression stroke begins.

Cooling

During compression much of the energy applied is converted into heat and any consequent rise in the air temperature will reduce the volumetric efficiency of

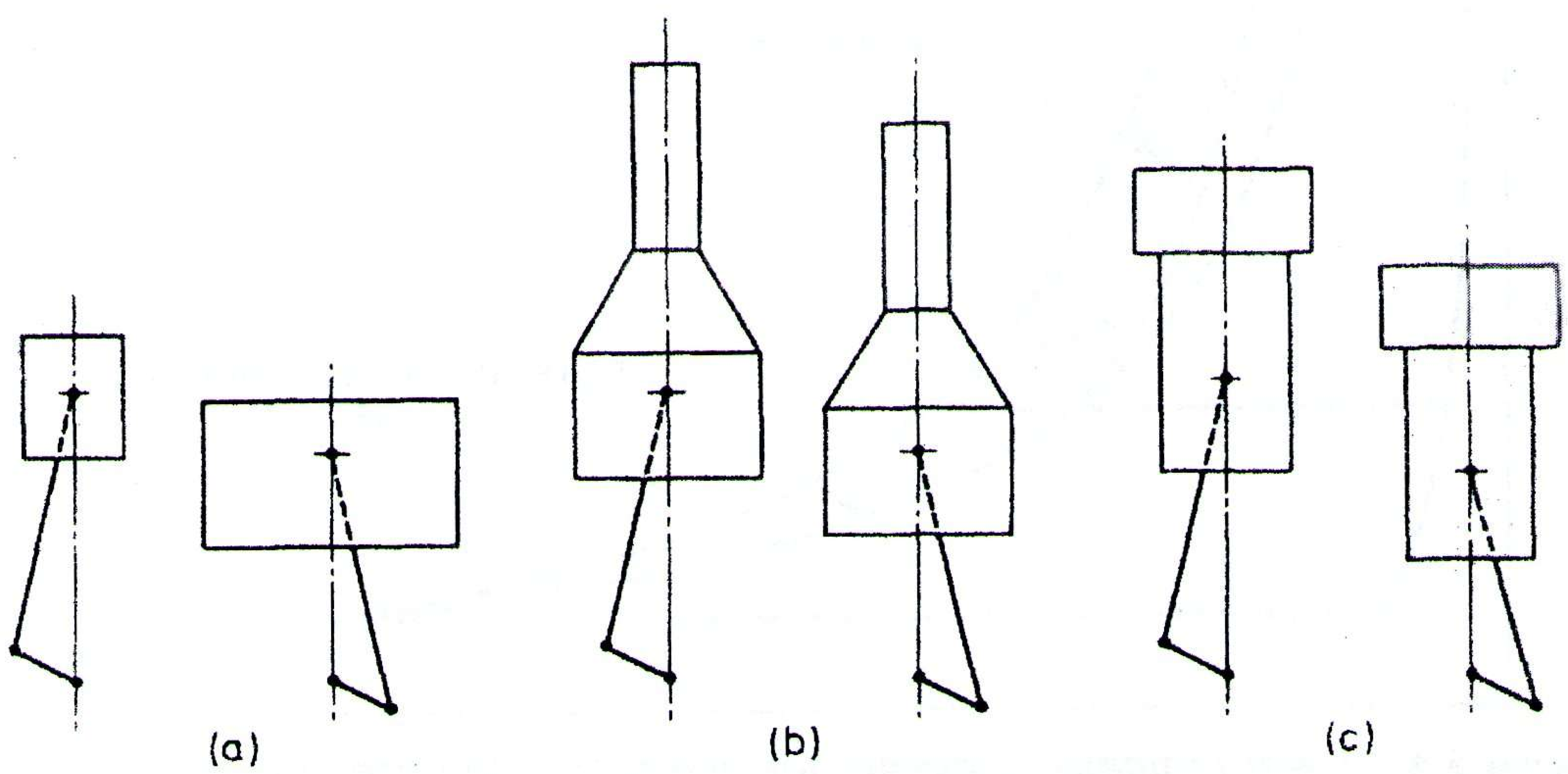

Figure 2.2 *Air compressor configurations*

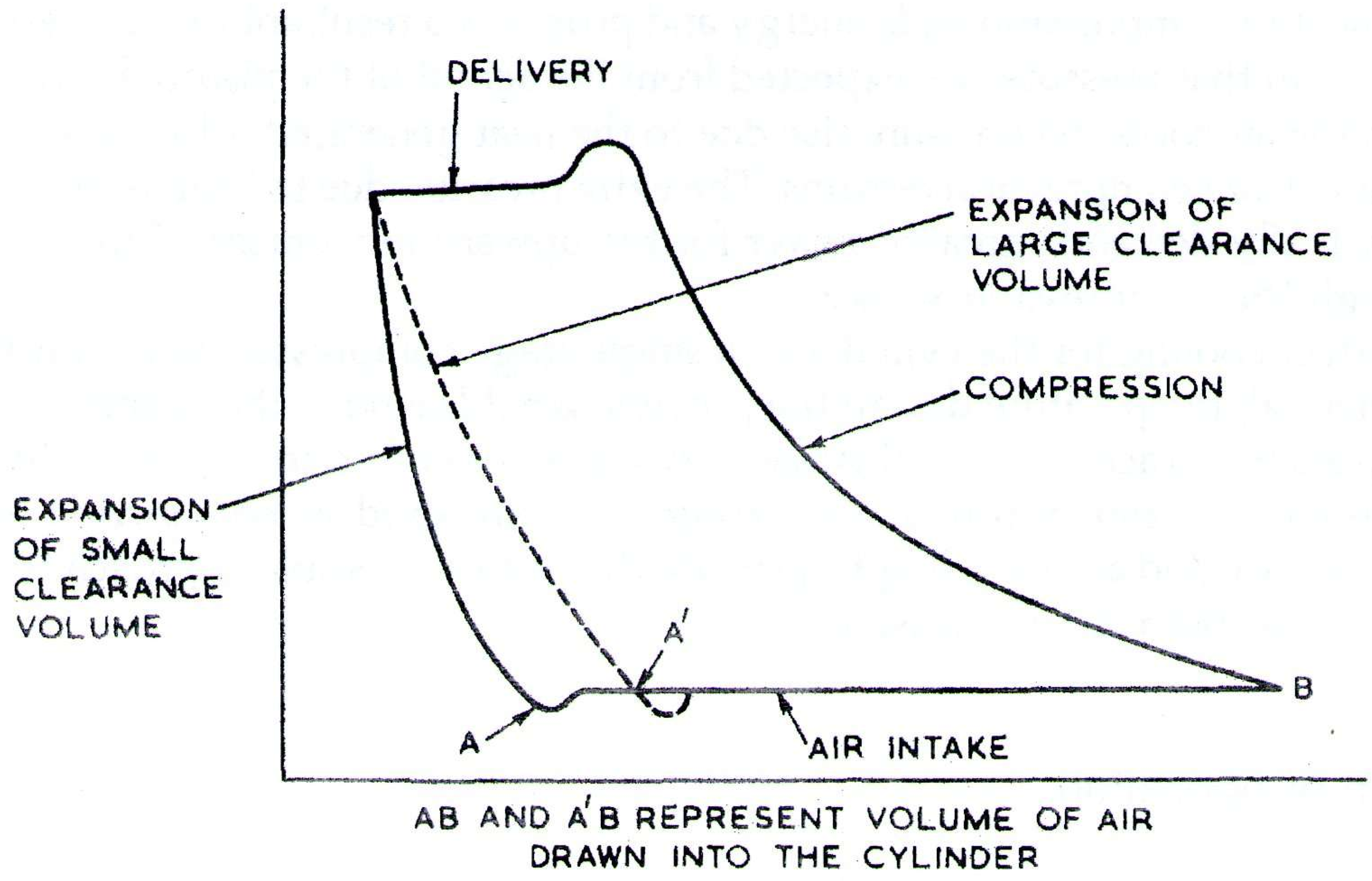

Figure 2.3 *Compressor indicator diagram (courtesy Hamworthy Engineering Ltd)*

the cycle. To minimize the temperature rise, heat must be removed. Although some can be removed through the cylinder walls, the relatively small surface area and time available, severely limit the possible heat removal and as shown in Figure 2.4 a practical solution, is to compress in more than one stage and to cool the air between the stages.

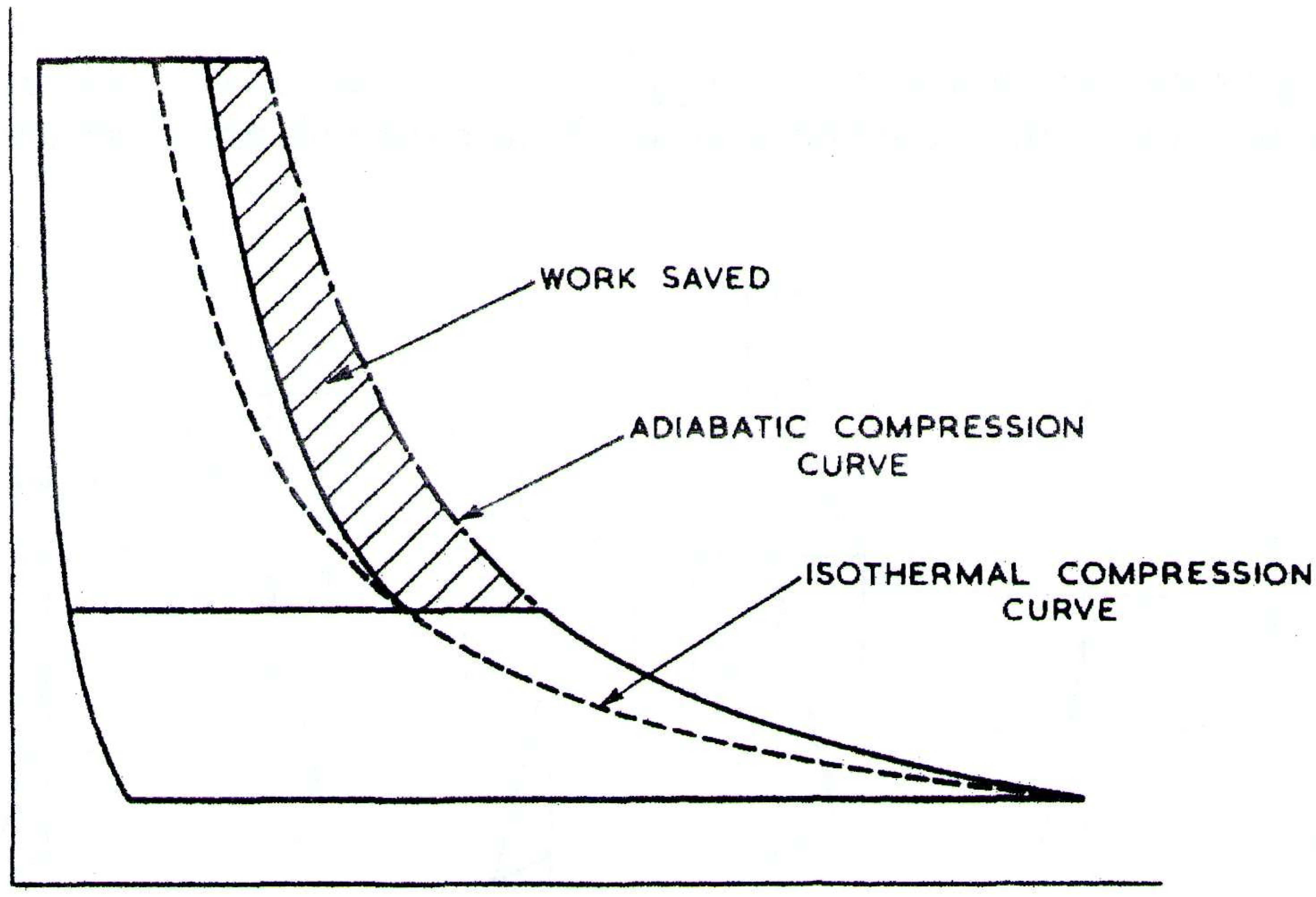

Figure 2.4 *Ideal indicator diagram for two stage compressor with intercooling (courtesy Hamworthy Engineering Ltd)*

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For small compressors air may be used to cool the cylinders and intercoolers, the cylinder outer surfaces being extended by fins and the intercoolers usually being of the sectional finned-tube type over which a copious flow of air is blown by a fan mounted on the end of the crankshaft. In larger compressors used for main engine starting air it is more usual to use water-cooling for both cylinders and intercoolers.

Sea water is commonly used for this purpose with coolant being circulated from a pump driven by the compressor or it can be supplied from the main sea-water circulating system. Sea water causes deposits of scale in cooling passages. Fresh water from a central cooling systems serving compressors and other auxiliaries is preferable (see Chapter 1).

Two stage starting air compressor

The compressor illustrated in Figure 2.5 is a Hamworthy 2TM6 type which was designed for free air deliveries ranging from 183 m^3 per hour at a discharge pressure of 14 bar to 367 m^3 per hour at 42 bar.

The crankcase is a rigid casting which supports a spheroidal graphite cast

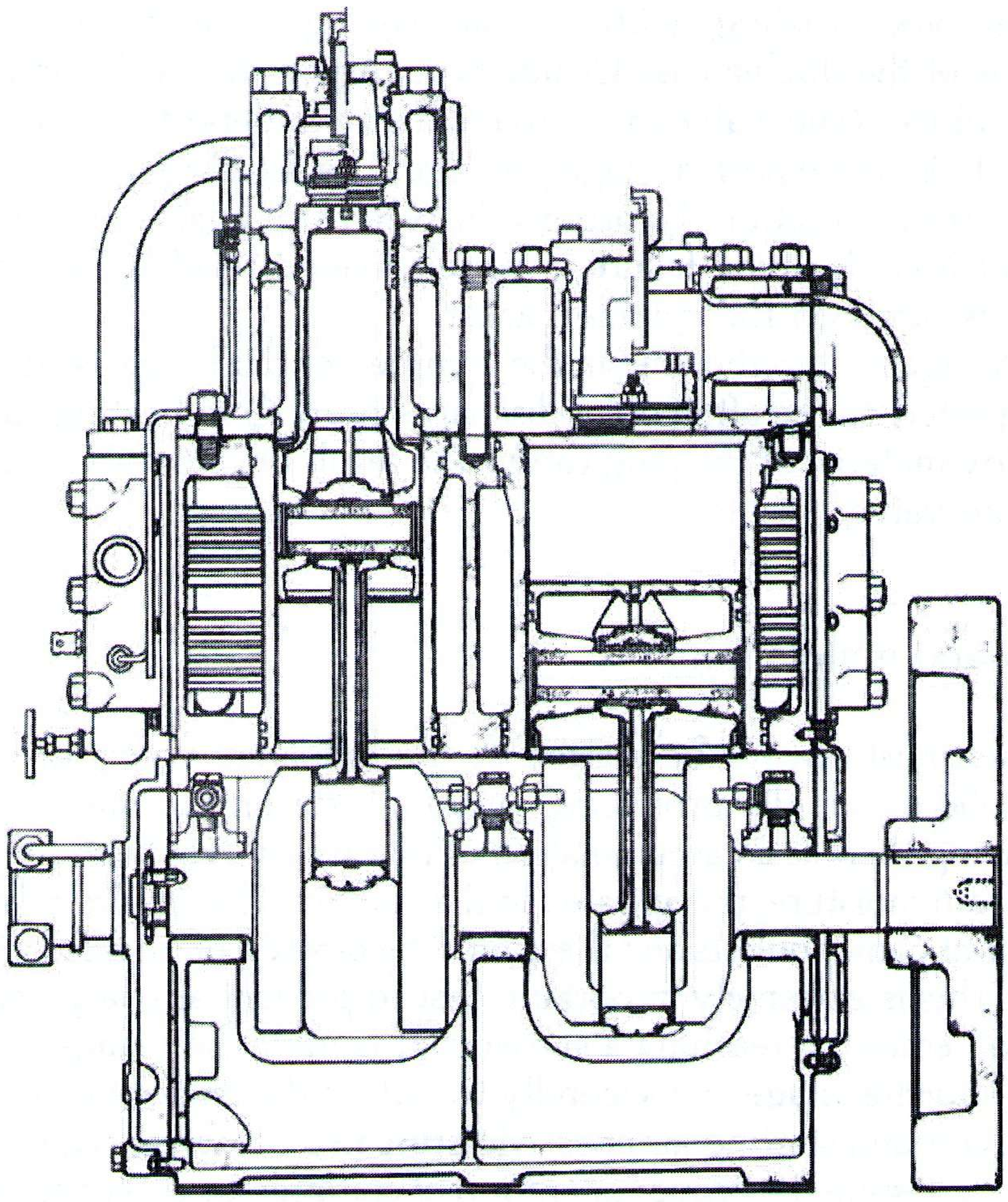

Figure 2.5 *Hamworthy 2TM6 air compressor*

iron crankshaft in three bearings. The crankshaft has integral balance weights and carries two identical forged steel connecting rods.

Both the first and second stage pistons are of aluminium alloy with cast iron compression rings. Scraper or oil control rings are fitted to return to the crankcase, most of the oil being splashed on to the cylinder walls from the bottom ends. The cylinder walls are lubricated by the splashed oil. The pistons have fully floating gudgeon pins; connecting rod top ends house phosphor bronze bushes. The bushes are an interference fit in the connecting rods and are so toleranced that the collapse of the bore when fitting is allowed for, to provide the correct running clearance. Steel backed white metal lined 'thin shell' main and crankpin bearings are used and all of the bearings are pressure lubricated by a chain driven gear pump.

Air suction and discharge valves are located in pockets in the cylinder heads. The valves are of the Hoerbiger type and are as shown in Figure 2.6. The moving discs of the valves have low inertia to permit rapid action. Ground landings are provided in the pockets on which the valve bodies seat. The bodies are held in place by set screws which pass through the valve box covers, capped nuts being fitted to the ends of the set screws. A combined air filter and silencer is fitted to the compressor air intake.

The intercooler is of the single pass type. The shell forms an integral part of the cylinder block casting, with the air passing through the tubes. The aftercooler is of the double pass U-tube type. Again the shell is integral with the cylinder block. Relief valves are fitted to the air outlets of each stage and are set to lift at 10% above normal stage pressure. The actual stage pressures vary according to the application. To protect the water side against over pressure in the event of a cooler tube failure, a spring loaded relief valve or bursting diaphragm, is fitted on the cylinder jacket.

Protection against overheating in the compressor discharge, is afforded by a fusible plug fitted on the aftercooler discharge head. Overheating sufficient to melt the alloy material of the plug can be the result of carbon build up around the discharge valve.

Operation and maintenance

Compressors must always be started in the unloaded condition otherwise pressures build up rapidly producing very high starting torques (Figure 2.7). During running there is an accumulation of oil carried over from the cylinders and water from moisture, precipitated in the coolers. The emulsion is collected in separators at cooler outlets and these must be drained off regularly, to reduce carry over. This is extremely important, first to prevent any large quantity of water and oil emulsion reaching a subsequent compression stage and causing damage to a further stage and secondly to reduce the amount carried over to the air receivers and starting air lines. Moisture in air receivers can give rise to corrosion and despite the proper operation of compressor cooler drains, a large amount tends to collect, particularly in humid conditions or wet engine rooms. It is good practice to check air reservoir drains regularly to assess the quantity

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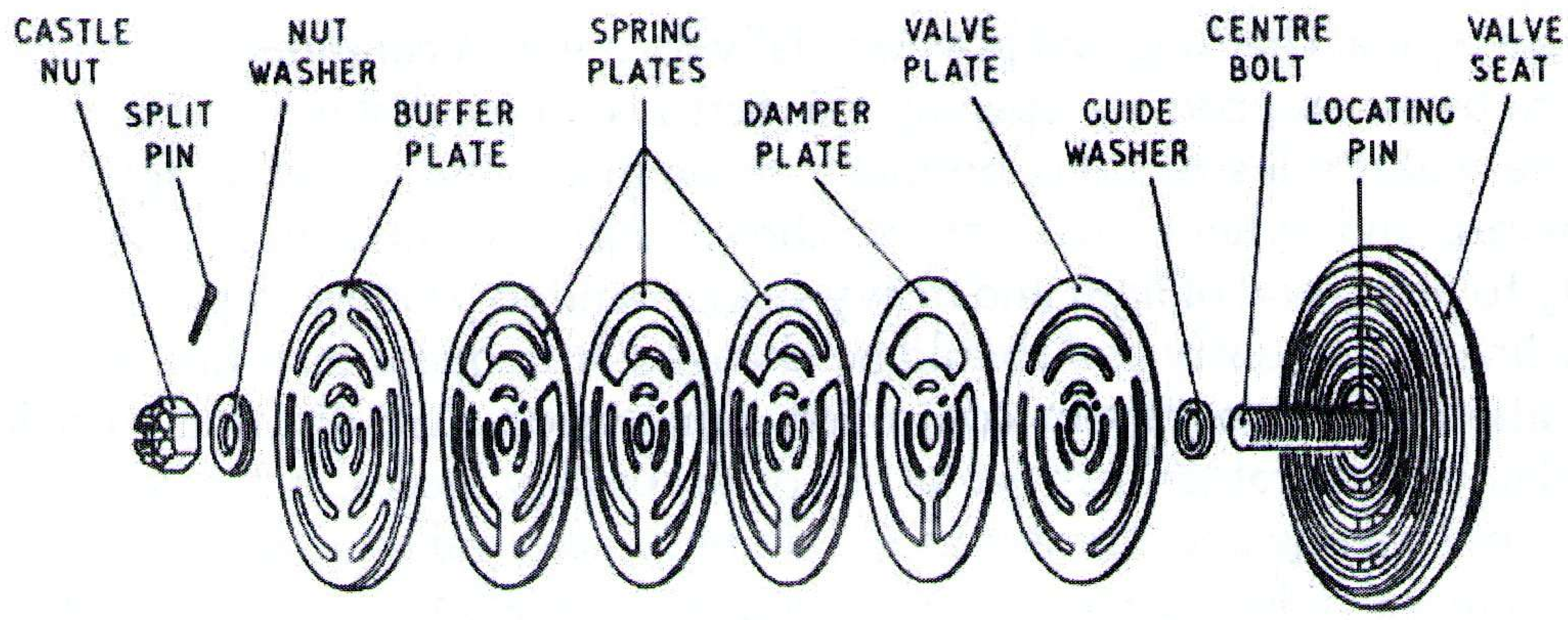

Figure 2.6 *Air compressor valve*

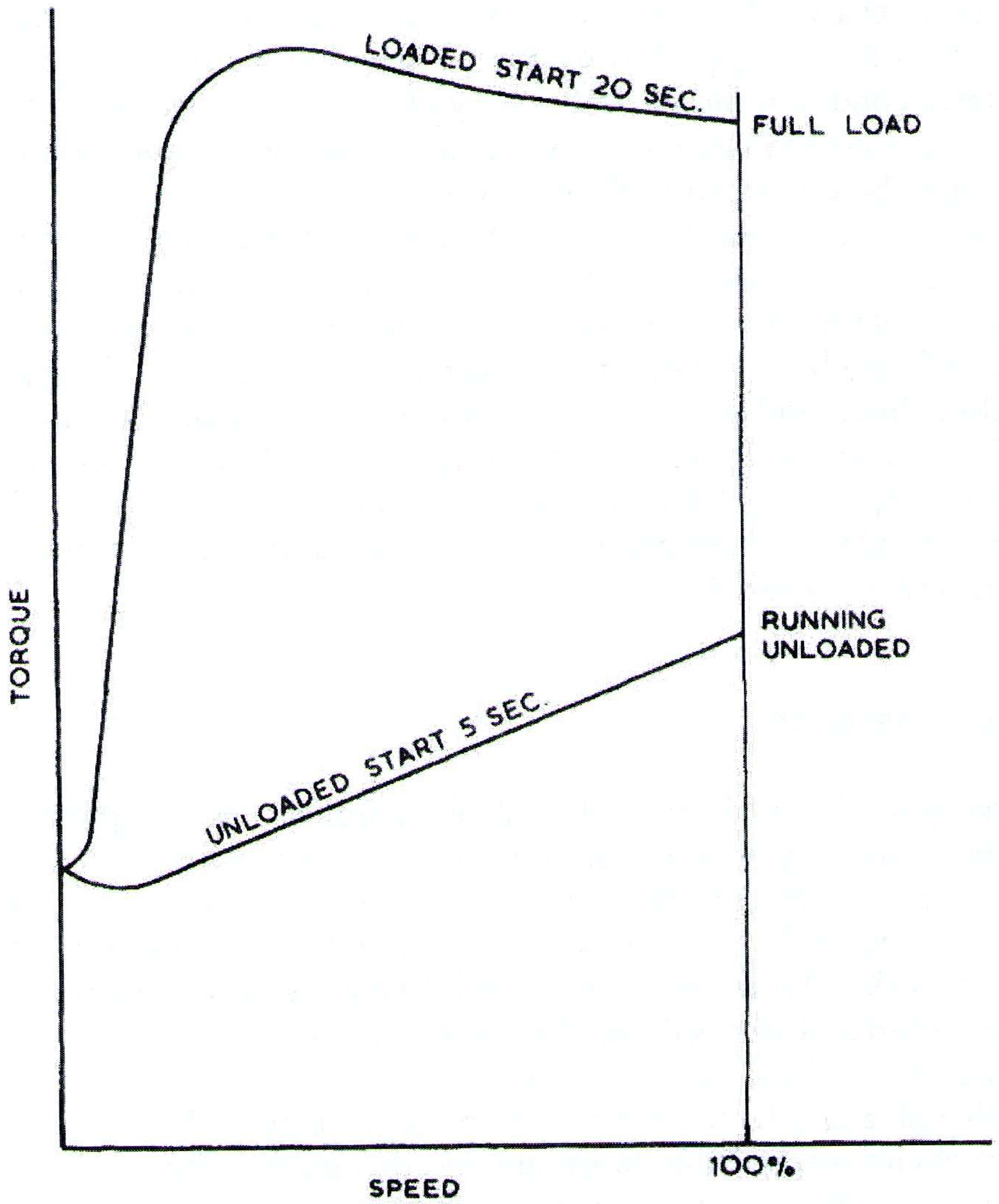

Figure 2.7 *Compressor torques*

of liquid present. In extreme conditions, drains may have to be used daily to remove accumulated emulsion. This is very important if air for control systems is derived from the main receivers, to prevent problems with the reducing valve, moisture traps and filters. Moisture traps for the control air system also require regular checking and possibly daily draining. A compressor is unloaded before being stopped by opening the first and second stage drains.

The maker's instructions normally recommend the use of a light oil for crankcase and cylinder lubrication. Diesel engine crankcase oils, which are likely to be a blend of light and heavy stocks, tend to produce deposits. The oil is inclined to emulsify and should be changed at frequent intervals. Excessive operation of automatically controlled compressors (usually due to a large number of leaks rather than actual use of air) usually means that valves require frequent cleaning and maintenance. Failure to keep valves in good condition, results in valve leakage and overheating with an associated accumulation of carbon on the valves and in valve pockets. The combination of carbon, excessive temperature and the high concentration of oxygen in compressed air can result in fire or explosion in the discharge pipe. The effect of fire in a compressor discharge, has been known to weaken the pipe causing a split through which flame, supported by the compressed air, has emerged.

Poor valve condition can be detected by observation of the stage pressures and is usually accompanied by excessive discharge temperature although the latter can also be a symptom of poor cooling.

Adequate attention must be given to the water cooling system. Overcooling can cause condensation on the cylinder walls, adversely affecting lubrication, while poor cooling, due probably to scale formation in a sea-water cooled machine, will result in a fall-off in volumetric efficiency and rapid valve deterioration. Inter- and after-coolers require periodic cleaning to remove scale (where they are sea-water cooled) and oily deposits from the air side. With respect to temperature limitation, classification societies require that the compressor should be so designed that the air discharge to the reservoir should not substantially exceed 93°C.

Automatic operation

Before the general introduction of control equipment, air compressors were stopped and started by engine room staff, as necessary, to maintain air receiver pressure. In port or at sea, this usually meant operating one compressor for about half an hour daily unless air was being used for the whistle (during fog), for work on deck or for other purposes. Whilst manoeuvring, the compressors would be started and stopped very frequently unless they were steam driven, when demand could be met by varying the speed. Some compressors were fitted with unloaders to hold the suction valve plates off their seats when receiver pressure reached the maximum and this gave a degree of automatic operation. To drain the coolers continuously during running, an automatic device was fitted to each cooler.

Compressors are now normally arranged for automatic stop and start as dictated by demand through pressure variation. Figure 2.8 shows a scheme for the automatic starting and stopping of two machines. Either machine can be selected as 'lead' machine. This will run preferentially during manoeuvring and at other times, automatically stopping and starting under the control of a

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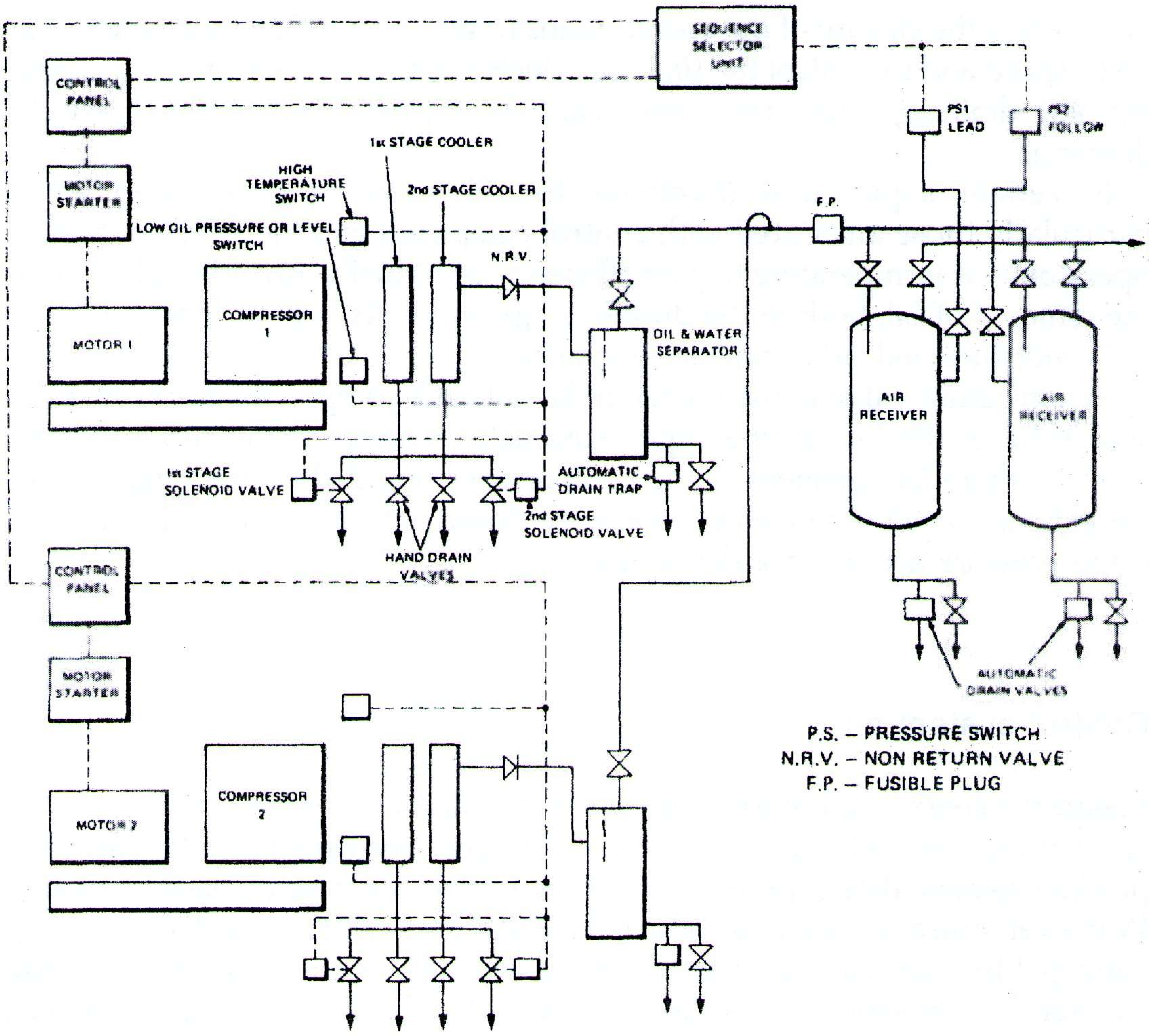

Pressure Switch Setting Bar						
Normal Working Pressure		35	30	25	8	7
Lead	Cut Out	35	30	25	8	7
	Cut In	30	25	21	7	6
Follow	Cut Out	34	29	24	7 6	6 7
	Cut In	29	24	20	6 6	5 7

Figure 2.8 *Automatic operation of air compressors (Hamworthy Ltd)*

pressure switch on the air receiver. The 'follow' machine is arranged to back-up the 'lead' machine during manoeuvring, cutting in after the 'lead' machine when the receiver pressure falls below a pre-set value (see the table in Figure 2.8). When the pressure switch stops the compressor, the drain valves open automatically.

First and second stage cooler drains (Figure 2.8) may be operated by solenoids or other means. The drain valves are also opened briefly on an intermittently timed cycle thus providing automatic draining as well as unloading.

The cooler drain valves are normally open whilst the compressors are not in use to provide unloaded starting. Two timers are located in the control panel.

One delays the closure of the cooler drains to give the compressor time to run up to speed and to control the time for which drain valves remain open during periodic draining. The other timer controls the frequency of the periodic draining.

In certain applications involving the filtration of compressed air – particularly those associated with control equipment and the safety of human operators – it is imperative that an efficiency of virtually 100% be achieved in the removal of oil, both in the droplet stage and in its vapour form, together with moisture and other pipeline impurities.

A non-return valve in the discharge line of each compressor is necessary. It should be of the low inertia type. Automatic shut-off of the cooling water supply, where independent of the compressor, should also be arranged. This could be achieved with a valve, normally closed, which is opened by the first stage pressure acting on a diaphragm.

Control system air

Pneumatic control equipment is sensitive to contaminants which may be in the air. Viscous oil and water emulsions can cause moving parts to stick and produce general deterioration of diaphragms and other parts made of rubber. Water can cause rust build up which may also result in parts sticking or being damaged by rust particles. Metallic wear and other small particles can cause damage by abrasion. Any solids mixed with oil and water emulsions can conspire to block small orifices. Clean and dry control air is thus essential for the trouble free operation of systems.

Air leaving a conventional compressor usually contains oil carried over from the cylinder and water precipitated in the coolers. The two liquids combine to form an emulsion as witnessed when testing the drains. Dust and other small particles are carried through the compressor with the air, because the suction filters are necessarily fairly coarse. Usually compressor coolers are drained automatically. The receivers may be drained automatically or by engine room staff, sometimes as often as twice per day. The emulsion removed from compressor coolers and air receivers, has a viscosity which varies with machinery space conditions. Some emulsions are very viscous and they cause most problems with sticking.

When the source of control and instrument air is main air compressors and reservoirs, then special provision is necessary to ensure that air quality is high. The reducing valve which brings the main air pressure to the 7 or 8 bar required by the control air system, can be affected by emulsion carry over and can require frequent cleaning to stop it from sticking. Automatic drain traps may be fitted to the control air system, but many have traps which require daily draining by staff.

A moderate amount of free moisture in the control air could be removed by ceramic filters but to give the desired dryness factor an absorbent type drier may be considered necessary or a drier using refrigeration.

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Control air from starting air at 15 to 40 bar

A three stage filtration system (Figure 2.9) employing a pre-filter, a carbon absorber, and an after filter, may be installed to deliver good quality air. The pre-filter contains a medium grade porous ceramic element and removes the gross atmospheric impurities from the air. The absorber is packed with activated carbon and provides a deep bed producing an evenly distributed flow for the removal of vapours (it can also remove flavours or taints). The after filter contains a fine grade porous ceramic element preventing the ingress of any migrating carbon particles to the pipeline, thereby assuring a pure supply.

Air from the main engine starting air receiver enters the filter assembly fully saturated, that is, carrying some free water and oil vapour. Virtually all of the free water and oil should be removed. Due to precipitation through the filter, more moisture will be removed from the air reducing the dew point by approximately 5°C. When the pressure reducing valve drops the pressure to 7 bar, the dew point falls sufficiently for the air to be suitable for immediate use in a control air system without the use of absorption driers. The reducing valve for this arrangement is also protected from the effects of emulsion in the air.

Oil-free and non-oil-free rotary compressors

Both these machines deliver wet air which must be dried as described above but the non-oil-free machine passes over some oil which must also be removed. This is usually effected by a pre-filter followed by a carbon absorber, which removes the oil, followed by an after filter (to remove the remaining free moisture). Either system can be found at sea.

Compressed air systems for steamships

A compressed air system is necessary to supply air for boiler soot-blower air motors, hose connections throughout the ship and possibly diesel generator starting. A general service air compressor would supply air at 8 bar but greater pressure (as for diesel ships) would be necessary for diesel starting. A general service air compressor can be shut down completely when air is not required but can be operated on either a stop/start or load/unload cycle, with the regulator controlling the pressure between 7 and 8.5 bar.

The instrument air system and general service air system should be separate and cross connected only in emergency. The instrument air is supplied typically by oil-free, water cooled compressors, arranged for discharge to the air reservoir through after coolers. Three compressors may be installed, to operate with two units running continuously on a load/unload cycle between 5.5 and 7 bar with the other unit ready on stand-by to start if the pressure in the reservoir falls below 5.3 bar. The air may be delivered to the control air system through two of three air dryers (a third drier in reserve) fitted with automatic drain traps. Air dryers based on the cooling of the air by refrigeration, have a

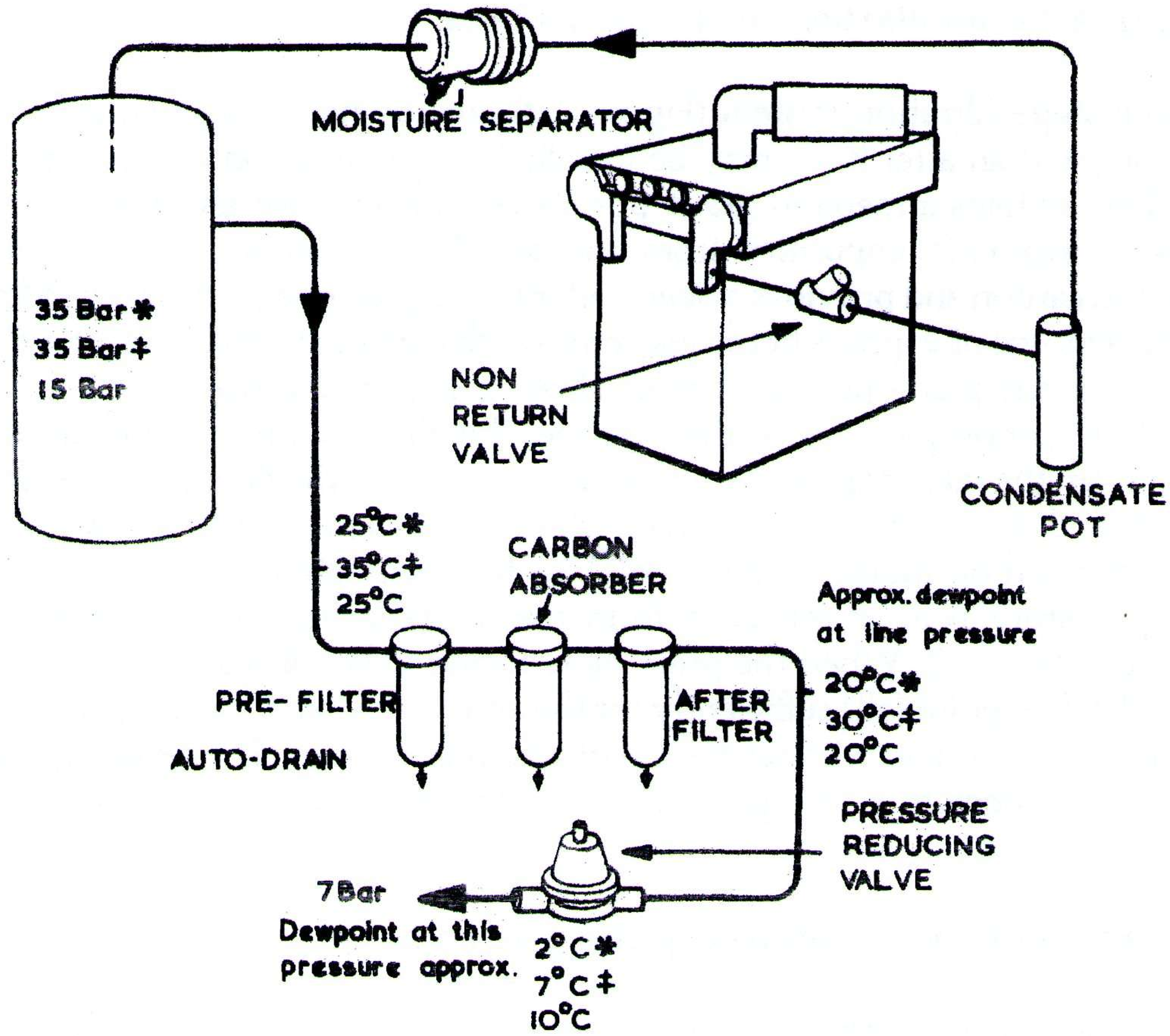

Figure 2.9 *Three stage filter for control air (Hamworthy Ltd)*

small sealed unit refrigeration compressor. In normal service they will reduce the dew point of the air to about −25°C and a high dew point alarm is fitted to warn of malfunction. The units are referred to as dehumidifiers; being rated typically at 170 m³/hr for an air consumption of about 150–160 m³/hr. Normally it is arranged that one of the units is able to carry the full load if the other units are not available. The filter element of each refrigifilter should be inspected and changed if necessary every six months.

Although the instrument air system is fitted with many individual drain traps and cocks, no moisture should be present anywhere in the system after the air dryers and if any is found the cause must be immediately investigated.

Control air consumption can be reduced at sea by shutting off the air supply to systems not in use such as tanker pumproom and cargo control room regulators and controllers.

Fuel handling and treatment

Fuels and lubricating oils are obtained from crude primarily by heating the crude oil, so that vapours are boiled off and then condensed at different temperatures. The constituents or fractions are collected separately in a distillation process. Crude oil contains gaseous fuels, gasoline (petrol), kerosene (paraffin), gas oils, distillate diesel fuels and lubricating oils which can be collected from the fractionating tower (Figure 2.10) where they condense out at the different levels maintained at appropriate temperatures. The crude is heated in a furnace, as shown at the left of the sketch.

The boiling process produces a residue which is very dense as the result of having lost the lighter parts. This high-density remainder has much the same hydrocarbon make up as the lighter fractions and is used as a fuel. Unfortunately the initial refining process not only concentrates the liquid but also the impurities.

Vacuum distillation, a second process, removes more of the lighter fractions, to leave an even heavier residue. As can be seen from Figure 2.10, the refinery can have additional conversion equipment. Vis-breaking or thermal cracking is one process using heat and pressure to split heavy molecules into lighter components giving a very dense residue. Catalytic cracking is a process that uses a powdered silica-alumina based catalyst with heating, to obtain lighter fractions, with, however, an increasingly heavy residue. In the latter process catalyst powder is continuously circulated through the reactor then to a regenerator where carbon picked up during the conversion reaction is burnt off. Unfortunately, some of the catalyst powder can remain in the residue which may be used for blending bunker fuel oils. The very abrasive silica-alumina catalytic fines have caused severe engine wear when not detected and removed by slow purification in the ship's fuel treatment system.

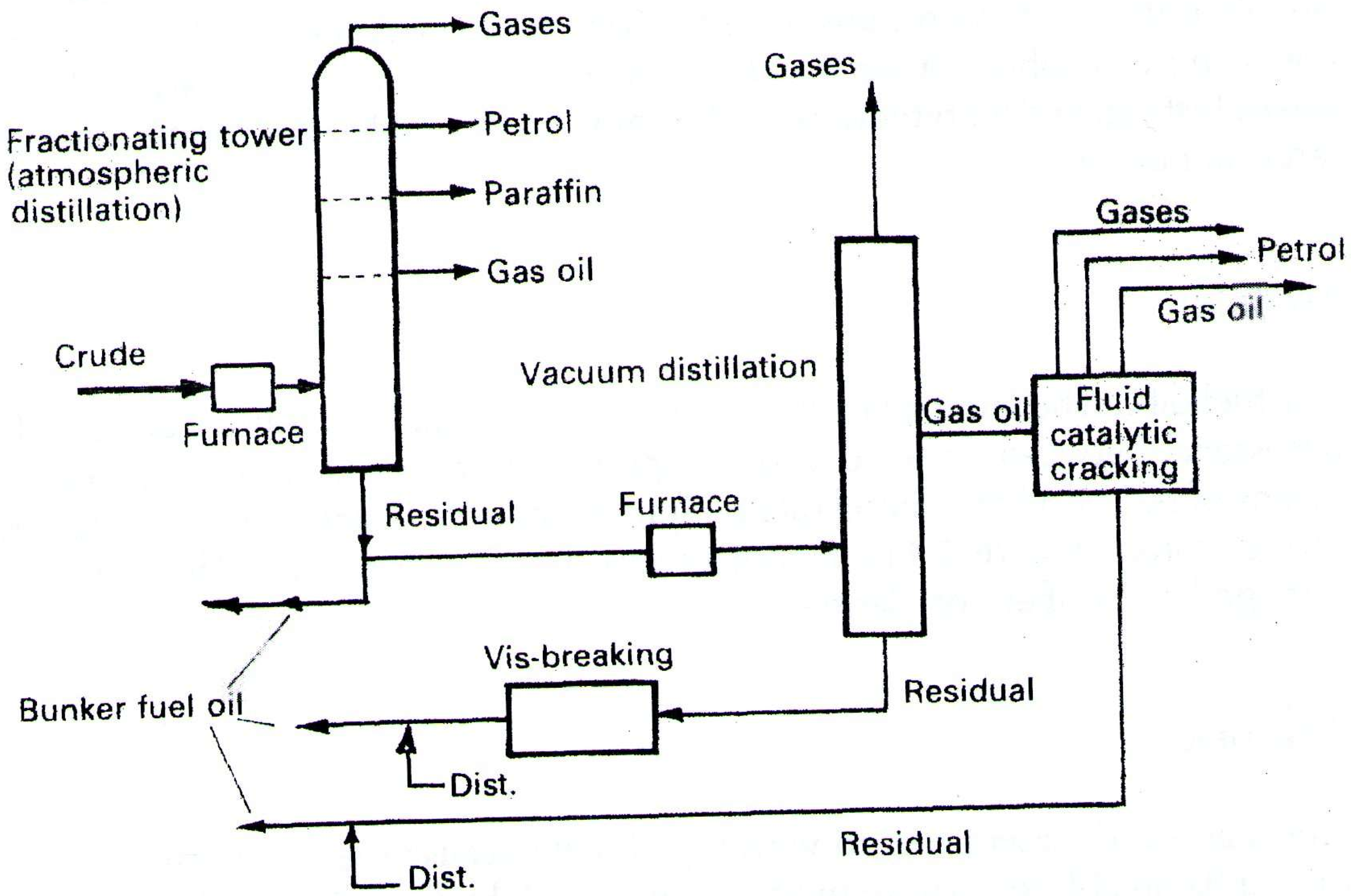

Figure 2.10 *Oil Refinery processes*

Fuel testing

Bunkers are classified as Gas Oil, Light and Marine Diesel Oil, Intermediate Fuel Oil and Marine or Bunker (C) Fuel Oil. The delivery note specifies the type of fuel, amount, viscosity, specific gravity, flash point and water content. Trouble frequently results from inferior fuels and there can be insuffient information to give warning. Fuel grading schemes and more detailed delivery notes are being used.

Some of the Classification Societies and specialist firms provide testing services and on-board testing equipment is available. A representative sample is needed to give an accurate test result and this is difficult to obtain unless a properly situated test cock is fitted in the bunker manifold where flow is turbulent. The sample is taken after flushing the test cock. Because of the variation in heavy fuel, small quantities are taken into the test container over the period of bunkering, to give a representative sample.

A full analysis can be given by the shore laboratory. On-board tests are limited to those which give reliable results and kits for specific gravity, viscosity, pour point, water content and compatibility are on the market. Flash point is found with a Pensky–Martin closed cup apparatus which has been carried on some ships.

Oil fuel transfer

The oil fuel system (see Figure 3.1 Chapter 3) provides the means for delivering fuel from the receiving stations at upper deck level, port and starboard, to double-bottom or deep bunker tanks. Sampling cocks are fitted at the deck connections to obtain a representative specimen for (a) shore analysis; (b) on board testing; and (c) retention on the ship. A filter on the downpipe removes large impurities.

Transfer

The fuel oil can be pumped from storage to settling tanks and also transferred if necessary, between forward and aft, port and starboard storage tanks, by means of heavy oil and diesel oil fuel transfer pumps. Transfer from settling to service tanks (Figure 2.11) in motorships, is via centrifuges. The latter are arranged as purifiers or clarifiers.

Fire risk

Fire is an ever-present hazard with liquid fuel because the vapour from it can form a flammable/explosive mixture with air. A hydrocarbon and air mixture containing between about 1% and 10% of hydrocarbon vapour, can be readily

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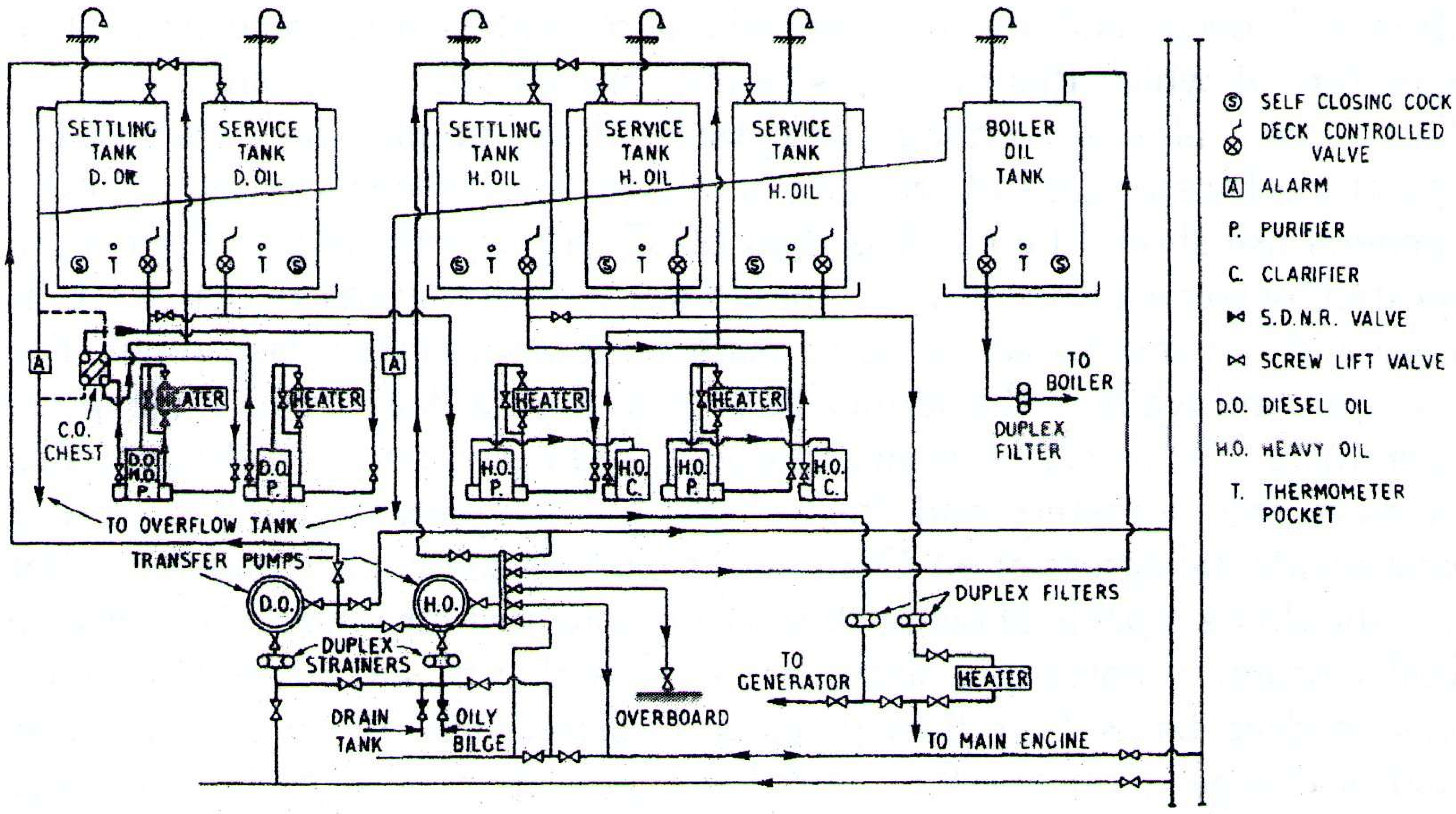

Figure 2.11 *Settling and service tanks*

ignited by a naked flame or spark. Combustion will also occur if the flammable mixture is in contact with a hot surface which is at or above the ignition temperature of the mixture. Ignition temperature for a hydrocarbon mixture may be about 400°C or less.

A crude oil will give off flammable gases such as methane, at ambient temperature, so that the space above it is very likely to contain a flammable mixture. Fuel oils are produced from crude in the refinery, when the gases such as methane are also extracted. Oil fuels are safer than the original crude oil.

Heat will cause the evolution of hydrocarbon vapour from fuel with the quantity being related to the volatility and temperature of the fuel. The hotter the fuel, the greater the amount of vapour accumulating in the space above it. The test for the closed flash point of a fuel, is based on the heating of a fuel sample in a closed container. The heat causes evolution of vapour which accumulates in the air space above the liquid and mixes with the air. A naked flame is dipped into the container at set temperature rise intervals. When the lower flammable limit (LFL) is reached (about 1% hydrocarbon vapour in air) ignition will occur and the mixture will burn with a brief blue flash. The temperature at which this occurs, is termed the closed flash point.

There are rules governing acceptable flash points and permissible temperatures for storage and handling of oil fuel. The closed flash point of fuels for general use should be not less than 60°C, but slightly higher figures are suggested by some authorities. Oil should not be heated to more than 51°C in storage and not more than 20°C beneath its known closed flash point. For purification and while in the service tank, then during delivery to the engine, temperatures are increased as necessary, to reduce viscosity. Settling tanks must have thermometers and the sounding arrangements must be proof against accidental egress of oil. Drain cocks must be self-closing and the outlet valves should be capable of being closed from safe positions outside the engine or boiler room. In passenger ships, this applies also to suction and levelling valves on deep tanks. Overflow pipes and relief valves not in closed circuit should discharge to an overflow tank having an alarm device, the discharge being visible. Tank air pipes must have 25% more area than their filling pipes and should have their outlets situated clear of fire risks. They should also be fitted with detachable wire gauze diaphragms. Provision should be made for stopping oil fuel transfer pumps from outside the machinery spaces.

From the filling station pipes descend to the oil fuel main(s). These will probably be two pipes, one for heavy oil and one for diesel fuel. The system extends forward and aft in the machinery spaces, possibly extending along the shaft tunnel and, in some ships, in a duct keel or pipe tunnel. The pipes connect to the fuel transfer pump(s) and to distribution valve (or cock) chests, from which pipes run to the fuel tanks. It was the practice to carry water ballast in empty fuel tanks and change over chests were arranged so that simultaneous connection to oil and ballast mains was not possible.

Transfer pumps draw from the oil main(s), from overflow and drain tanks and from the oily bilges – parts of the engine and boiler room bilges separated from the remainder by coamings – to which oil spillage is led. The pumps discharge to settling tanks, the oily water separator and the oil main(s). In passenger ships, it must be possible to transfer oil from any tank to any other tank without use of the ballast main, but this is possible with most systems. The heavy oil and diesel oil transfer pumps can usually by cross connected if necessary. Detail and arrangements will vary with the size, type and trade of the ship.

In steamships, the fuel is heated in the settling tanks by steam coils to assist water separation, and is then delivered to the burners through heaters and filters by the oil fuel pressure pumps.

In motorships, residual fuel is pumped from storage to one of, ideally, two settling tanks (Figure 2.11) of 24 hour capacity. Steam heating assists settling over 24 hours if possible, when any large quantities of water together with sludge, will gravitate to the bottom for removal via the drain or sludge cock. While the settling progresses in one tank, fuel from the other is being purified to the service tank which is not in use.

The purification of heavy fuel on many ships relies on one heater and a single self-sludging purifier. If problems with catalytic fines are likely or there are exceptional amounts of solid impurities, then two or even three centrifuges may be installed in series (Figure 2.12) or parallel (Figure 2.13) arrangement. With the series arrangement, the first machine acts as a purifier, removing any remaining water and most of the solids in suspension. The second machine, set up as a clarifier, removes the finer solids remaining. The parallel arrangement shown uses two machines set up as purifiers, each having a slow throughput to permit a longer dwell time for the fuel. The separators can have their own pumps but the separate pumps shown, allow flow to be controlled without restricting it. Closing in a valve to throttle flow, causes turbulence which can mix fuel and impurities more closely. Clean fuel is delivered to the service tank which is not in use. Fuel from the duty service tank passes to the engine booster pump and so to the fuel pumps and injectors, through further heaters. Diesel fuel is treated similarly but more simply, with a single stage of separation and no heating.

Sludge from centrifugal separators passes to a sludge tank from which it is removed by a pump capable of handling high viscosity matter.

It may be mentioned here, because it is not always understood, that fuel is heated for combustion, in order to bring it to a viscosity acceptable to the fuel injectors or burners.

Centrifuges

Liquids with a specific gravity or relative density difference can be separated in a settling tank by the effect of gravity and the process can be represented mathematically by

$$F_s = \frac{\pi}{6} D^3 (\rho_w - \rho_o)\, g. \qquad (1)$$

Clearly in a standing vessel the acceleration cannot be altered to enhance the

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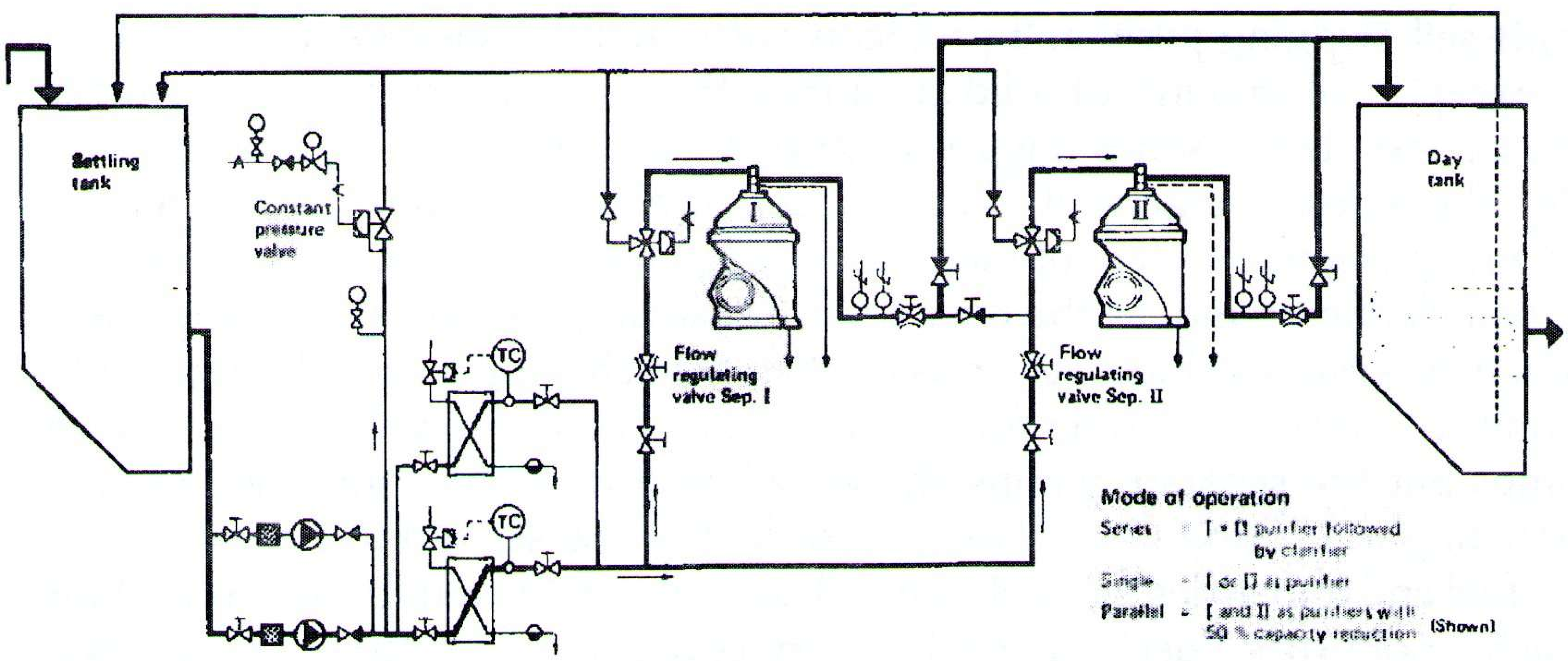

Figure 2.12 *Centrifuges arranged in series (courtesy Alpha-Laval)*

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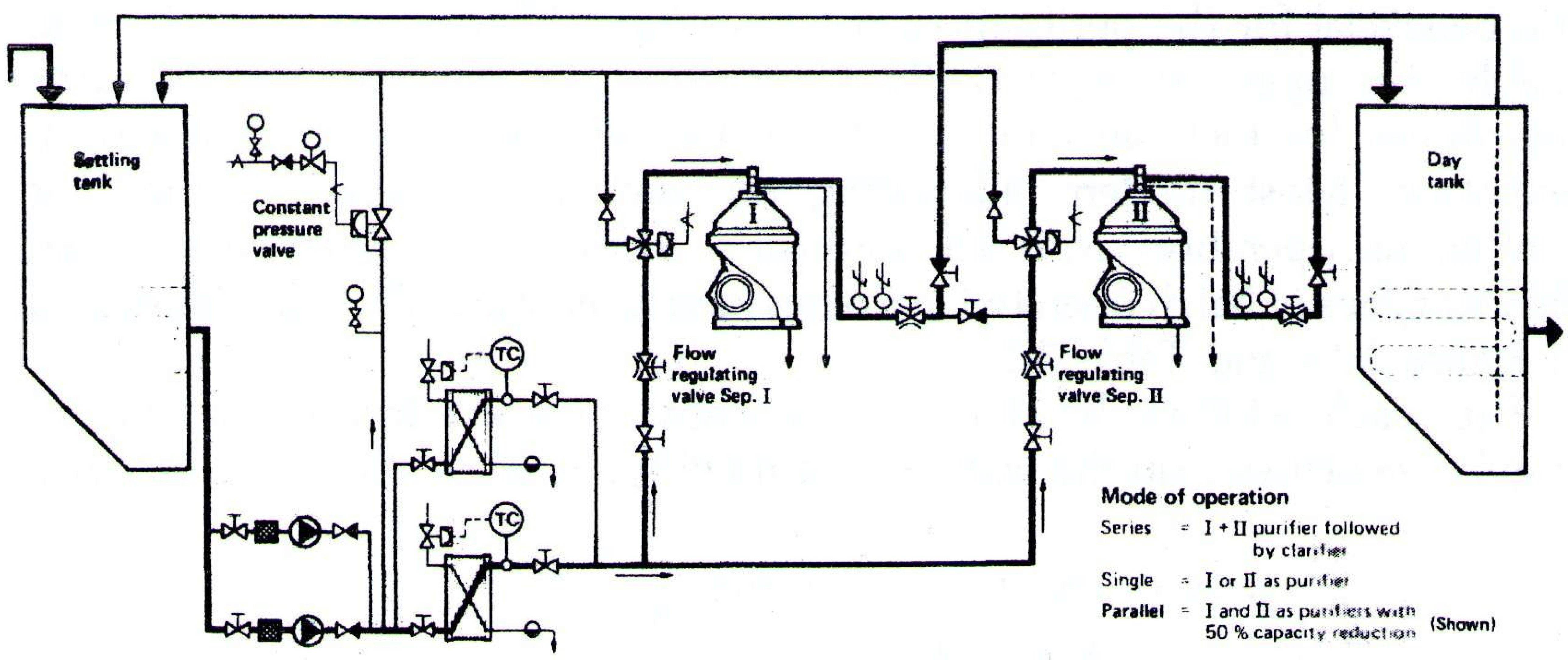

Figure 2.13 *Centrifuges arranged in parallel (courtesy Alpha-Laval)*

separation force Fs, but by subjecting the operation to centrifugal force the above expression can be replaced by

$$F_s = \frac{\pi}{6} D^3 (\rho_w - \rho_o) \omega^2 r \qquad (2)$$

where:

ω = angular velocity
r = effective radius.

Both the rotational speed and the effective radius are controllable within certain engineering limitations. Thus if a settling tank is replaced by a rotating cylinder the separating force and hence the speed of separation can be increased. This, effectively, is what happens in a centrifuge.

For many years marine centrifuges were designed for batch operation, that is the machines were run for a period during which solids accumulated in the bowl then the machine was stopped for manual cleaning. Batch centrifuging is still beneficial for the purification of lubricating oil because manual cleaning enables the operator to check the effectiveness of the operation. Modern centrifuges for fuel run continuously, being automatically sludged during operation. Most modern lubricating oil purifiers are also designed for continuous operation with an automatic self-sludging programme. Two distinct types of batch operated machines have been used. These are illustrated in Figure 2.14 and Table 2.1.

The obsolete tubular bowl machine was physically able to withstand higher angular velocities than the wide or disc bowl type, hence a higher centrifugal

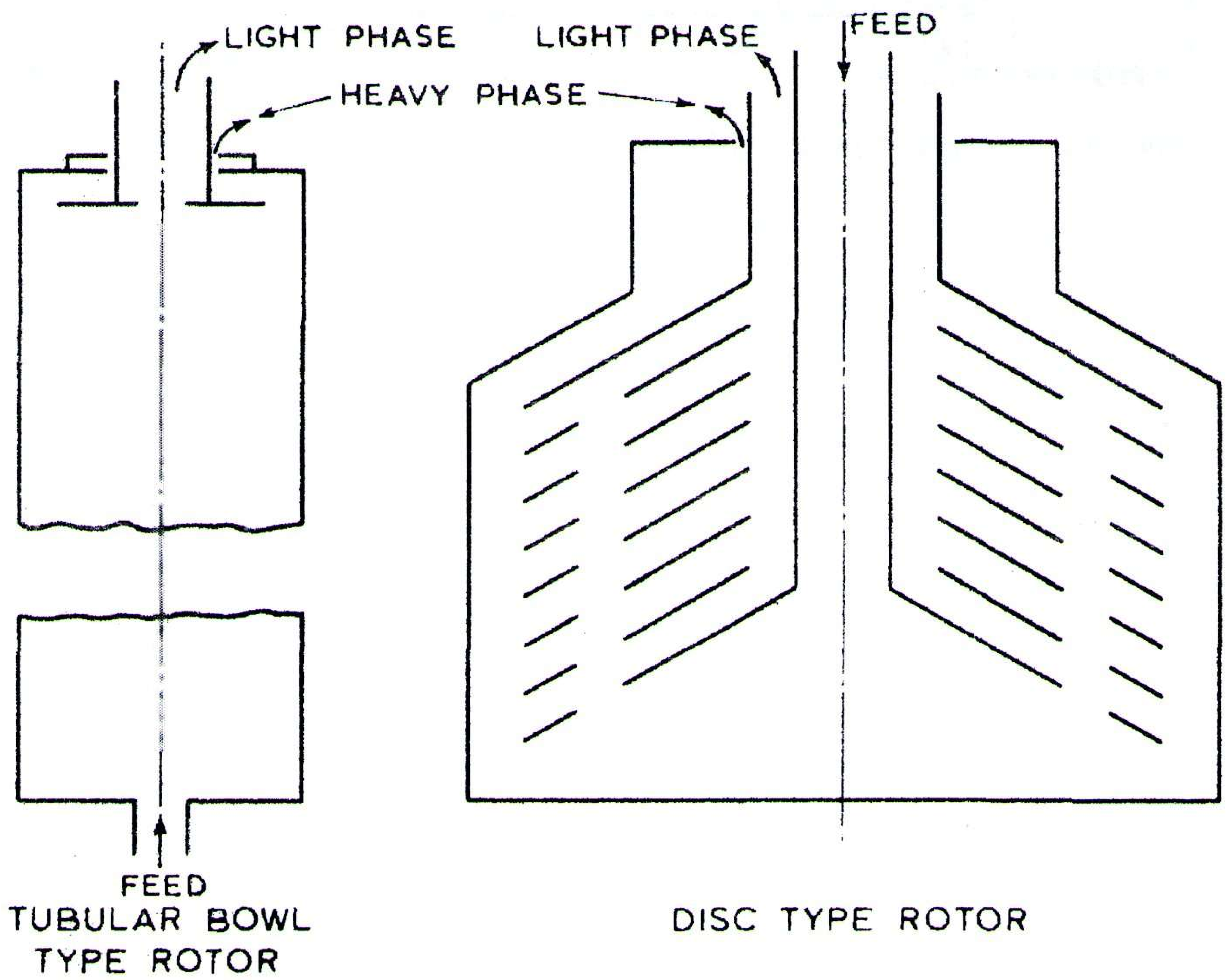

Figure 2.14 *Comparison of narrow and wide bowl types (Penwalt Ltd)*

Table 2.1 *Details of tubular and disc type centrifuges used for batch treatment of liquids*

	Maximum centrifugal force	*Bowl dia. (mm)*	*Length/dia. (of bowl)*	*Drive*
Batch tubular Bowl type	13 000 — 20 000 × g	Up to 180	Up to 7	Bowl suspended from above
Batch disc bowl Type	5 000 — 8 000 × g	Up to, say, 600	Generally < 1	Bowl supported from below

effect was available. The heavier phase (water) had only a short distance to travel before coming to the bowl wall where solids were deposited and the heavy phase liquid (water) was guided to the water discharge. However, the sludge retention volume and the liquid dwell time for a given throughput could only be increased by lengthening the bowl. This gave rise to bowl balancing and handling problems.

The wide bowl type was able retain more sludge before its performance was impaired and was much easier to clean. On the other hand settling characteristics in a wide bowl machine are relatively poor towards the bowl centre and the distance the water has to travel before reaching the wall is great.

To overcome these problems a stack of conical discs (Figure 2.15) spaced about 2–4 mm apart is arranged in the bowl. The liquid is fed into the bottom of the stack and flows through the spaces between adjacent plates. The plates then act as an extended settling surface, with the heavy impurities impinging on the under surfaces of the discs. As the particles impinge of the disc surfaces, they accumulate and eventually slide along the discs towards the periphery. At the disc stack periphery, water globules and solid particles continue to move out towards the bowl wall with the water being sandwiched between the solids and the oil, which orientates itself towards the bowl centre. The boundaries at which substances meet are known as interfaces.

The oil/water interface is very distinct and is known as the e-line. To gain the fullest advantage from the disc stack the e-line should be located outside of it. On the other hand if the e-line is located outside the water outlet baffle (top disc) discharge of oil in the water phase will take place.

Referring back to gravity separation in a settling tank, if the tank is partitioned as shown in Figure 2.16 continuous separation will take place. Since the arrangement is a very crude U-tube containing two liquids of different specific gravities, the height of the liquid in the two legs will have the relationship

$$\rho_l\,(e-l) \simeq \rho_h\,(e-h) \tag{3}$$

where:

ρ_l = density of oil
ρ_h = density of water.

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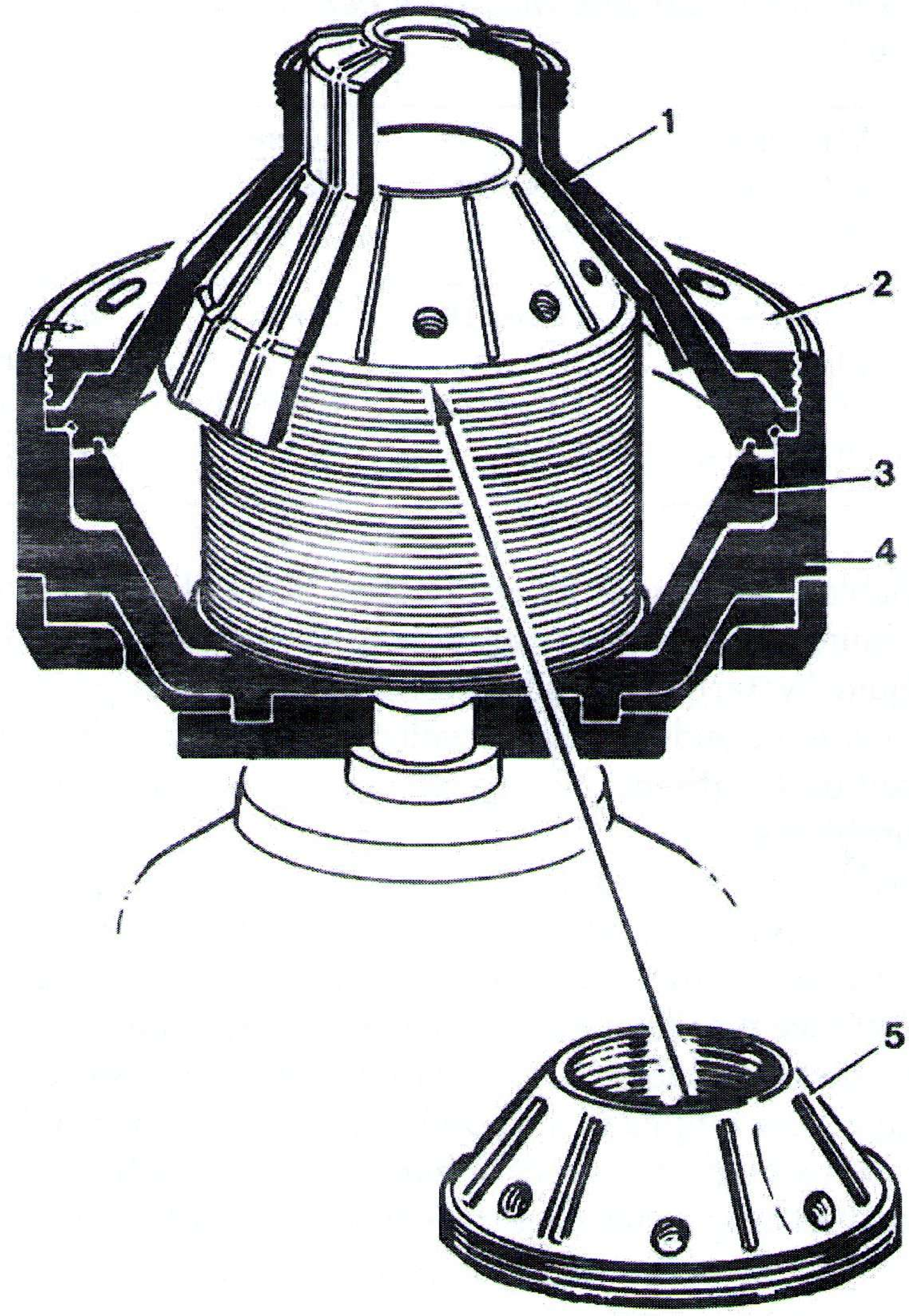

Figure 2.15 *Conical disc stack. Separator bowl: (courtesy Alpha-Laval)*

1. Bowl hood
2. Lock ring
3. Sliding bowl bottom
4. Bowl body
5. Disk stack

A very similar condition is found in the centrifuge (Figure 2.17) for which the equation is

$$\omega^2 \rho_l (e^2 - l^2) = \omega^2 \rho_h (e^2 - h^2) \qquad (4)$$

or $$\frac{\rho_h}{\rho_l} = \frac{e^2 - l^2}{e^2 - h^2} \qquad (5)$$

The mechanical design of the centrifuge requires that the e-line is confined within certain strict limits. However variations in ρ_l will be found depending upon the port at which the vessel takes on bunkers. It is necessary therefore to provide means of varying h or l to compensate for the variation in specific gravity. It is usually the dimension h which is varied, and this is done by the use of dam rings (sometimes called gravity discs) of different diameters. Normally a

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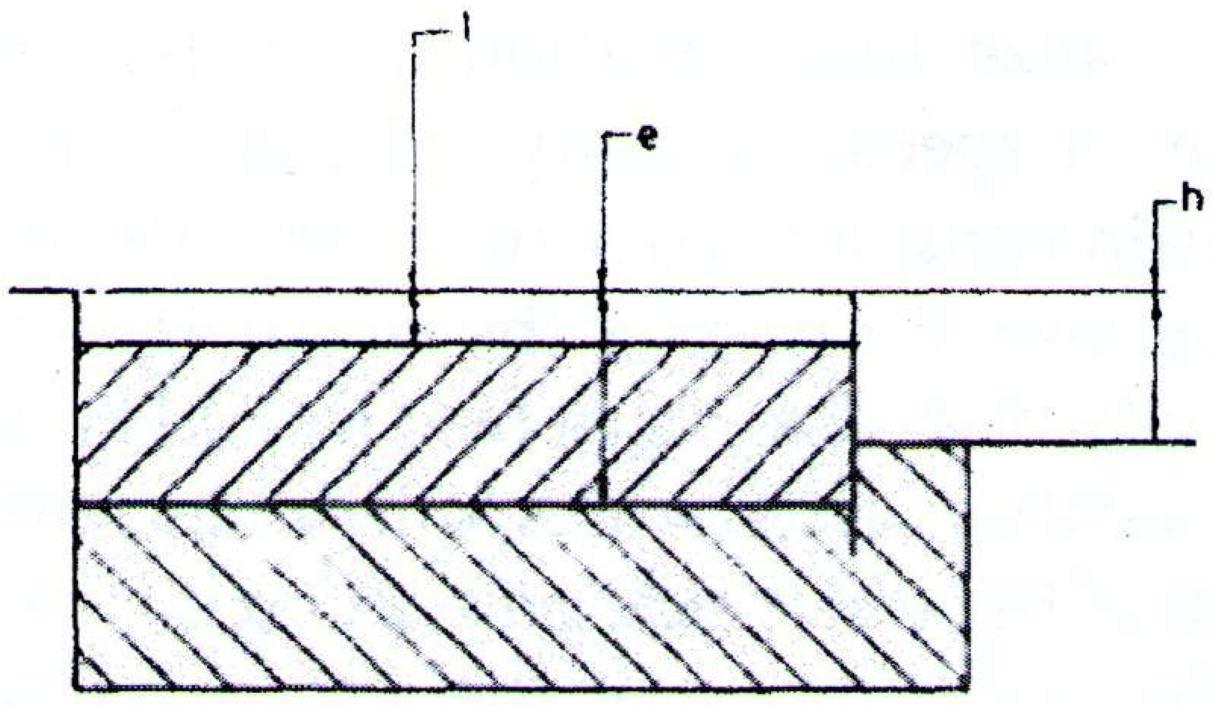

Figure 2.16 *Hydrostatic situation in gravity settling tank*

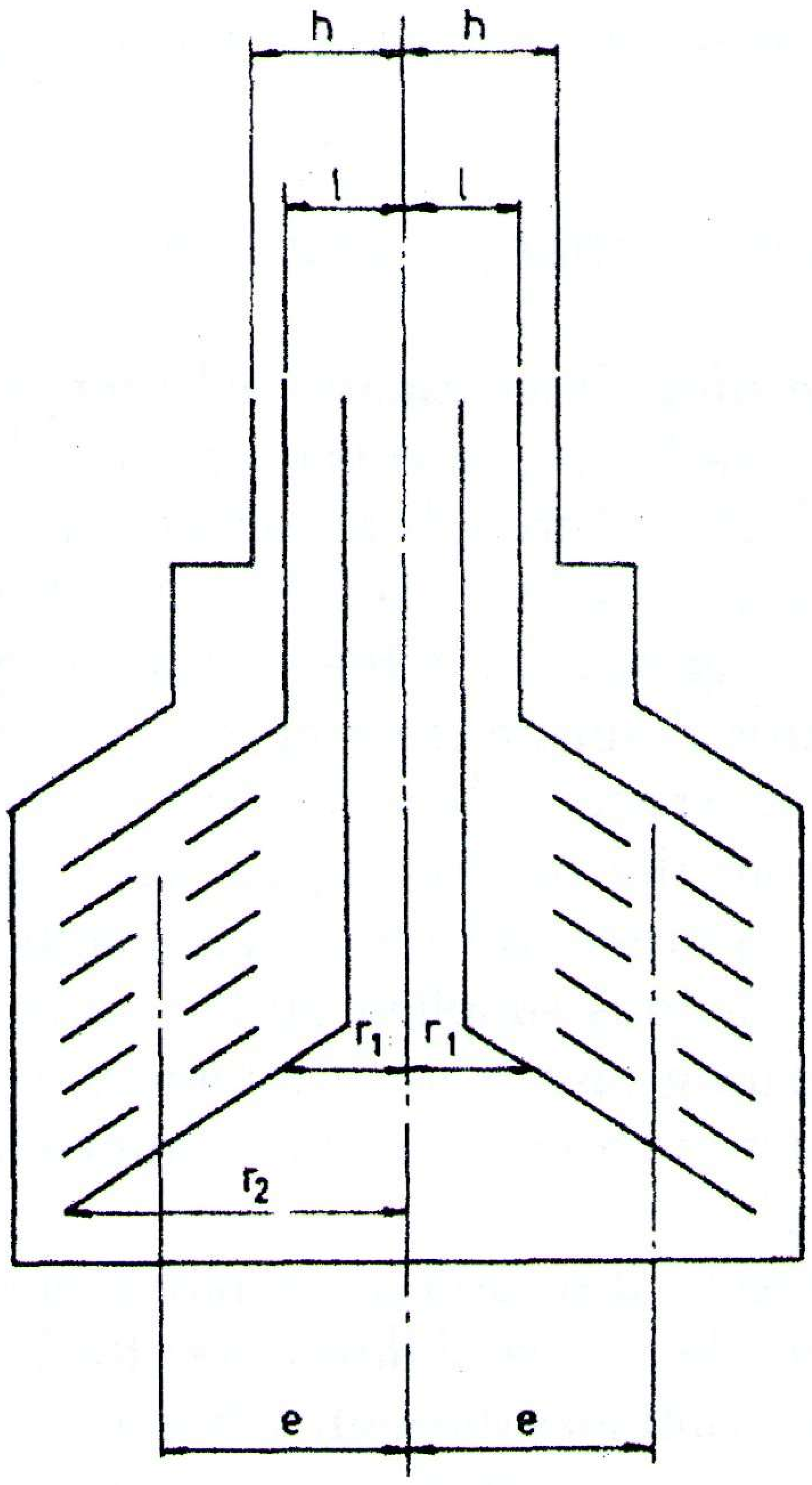

Figure 2.17 *Hydrostatic seal in a disc type centrifugal bow (Penwalt Ltd)*

table is provided in the instruction book for the machine, giving the disc diameter required for purifying oils of various specific gravities. Alternatively the disc diameter D_h may be calculated from the following formula which is derived from (5)

$$D_h = 2\sqrt{\left[l^2 \frac{\rho_l}{\rho_h} + e^2 \left(1 - \frac{\rho_l}{\rho_h}\right) \right]} \tag{6}$$

The dimension *e* can be taken as the mean radius of one thin conical plate and the heavy top conical plate (outlet baffle). If oil is discharging in the water outlet the gravity disc is too large.

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It is important to realize that variation in oil temperature will cause a proportional variation in specific gravity (SG) and for this reason the oil temperature must remain constant. To some extent the feed rate will have an effect on the e-line (because it can alter the overheight of the liquid flowing over the lip of the gravity disc). Excessive feed should be avoided in any event since the quality of separation deteriorates with an increase in throughput. To prevent oil passing out of the water side on start up it is necessary to put water into the bowl until the water shows at the water discharge. The bowl of a purifier is, in effect, sealed by this water.

A clarifier is a centrifuge in which the dam ring or gravity disc is replaced by a blank disc with no aperture. The straight clarifier is intended to remove only solids, not water. Thus it has no requirement for sealing water when started.

Alfa-Laval intermittent discharge centrifuge

Figure 2.18 shows a centrifuge bowl capable of being programmed for periodic and regular dumping of the bowl contents to remove the sludge build-up. The sludge discharge takes place through a number of slots in the bowl wall. Between discharges these slots are closed by the sliding bowl bottom, which constitutes an inner, sliding bottom in the separating space. The sliding bowl bottom is forced upwards against a seal ring by the pressure of the operating liquid contained in the space below it. This exceeds the counteracting downward pressure from the process liquid, because the underside of the sliding bowl bottom has a larger pressure surface (radius R_1), than its upper side (radius R_2). Operating liquid is supplied on the underside of the bowl via a device known as the paring disc. This maintains a constant operating liquid annulus (radius R_3) under the bowl, as its pumping effect neutralizes the static pressure from the supply.

When the sludge is to be discharged, operating liquid is supplied through the outer, wider supply tube so that if flows over the lower edge of the paring chamber (radius R_4) and continues through a channel out to the upper side of a sliding ring, the operating slide. Between discharges, the operating slide is pressed upwards by coil springs. It is now forced downwards by the liquid pressure, thereby opening discharge valves from the space below the sliding bowl bottom so that the operating liquid in this space flows out (b).

When the pressure exerted by the operating liquid against the underside of the sliding bowl bottom diminishes, the latter is forced downwards and opens, so that the sludge is ejected from the bowl through the slots in the bowl wall. Any remaining liquid on the upper side of the operating slide drains through a nozzle g (c). This nozzle is always open but is so small that the outflow is negligible during the bowl opening sequence.

On completion of sludge discharge, the coil springs again force the operating slide upwards (d), thus shutting off the discharge valves from the space below the sliding bowl bottom. Operating liquid is supplied through the outer, wider tube, but only enough to flow to the space below the sliding bowl bottom and force the latter upwards so that the bowl is closed. (If too much

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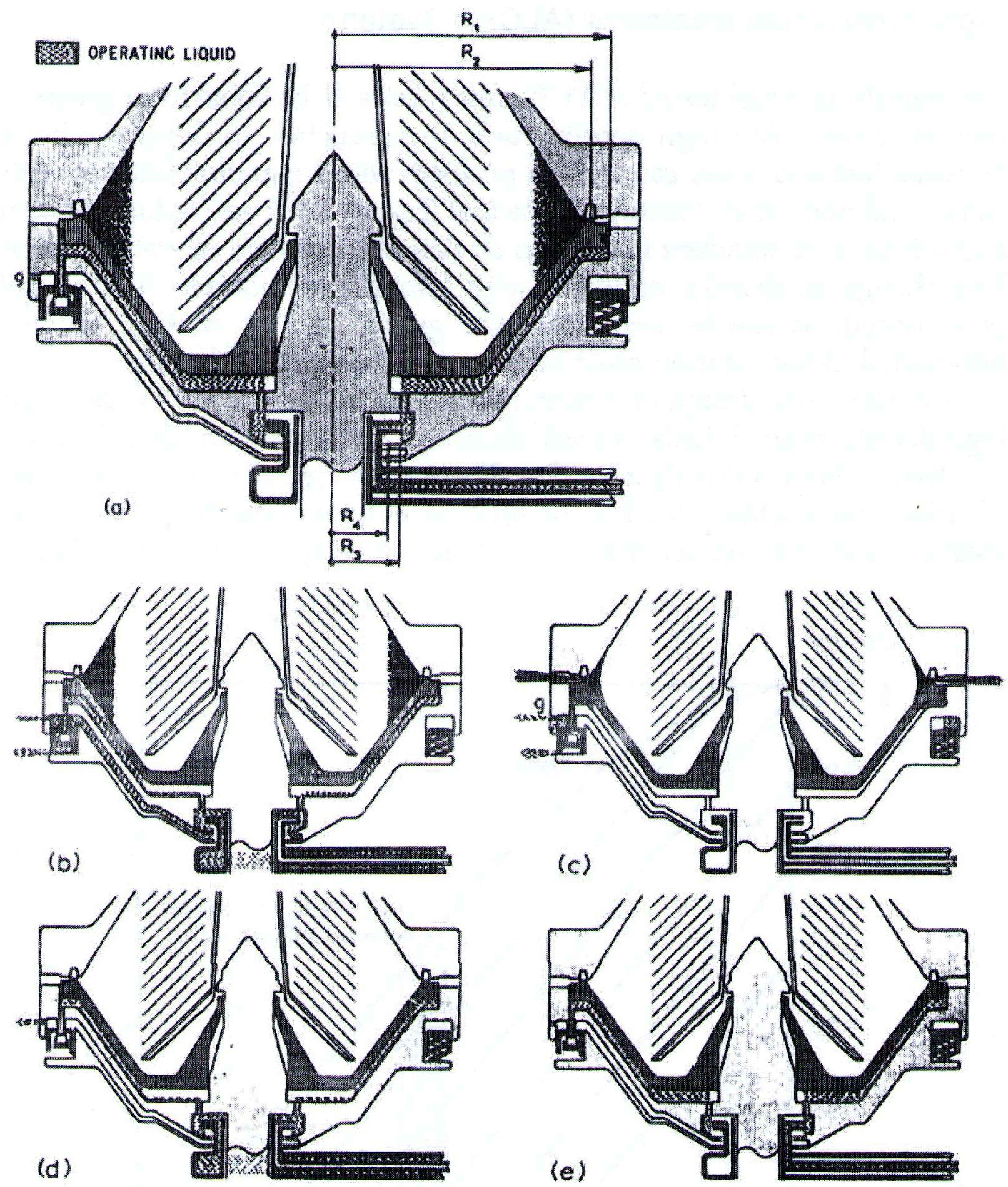

Figure 2.18 *Self-sludging centrifuge. Sequence of operation (Alpha-Laval)*

liquid is supplied, it will flow into the channel to the operating slide and the bowl will open again.)

The outer, wider inlet is now closed while the inner, narrower one is open (e). The paring disc counter-balances the static pressure from the operating liquid supply, and the bowl is ready to receive a further charge of oil. The situation is identical with that shown in the first illustration of the series but with the difference that the sludge discharge cycle is now accomplished.

Periodically the purifier bowl should be stripped and thoroughly cleaned. It is important to remember that this is a precision built piece of equipment, which has been carefully balanced and all parts should be treated with the utmost care.

High density fuel treatment (ALCAP System)

The density of a fuel tested at 15°C may approach, be equal to or greater than that of water. With high density fuels, the reduction in density differential between fuel and water can cause a problem with separation but not with the usual solid impurities. Heating of the fuel (Figure 2.19) will reduce the density and this may be sufficient in itself to obviate the problem of water separation. The change in density of water with temperature (dotted line) is not so pronounced, as can be seen from the graph, so that heating produces a differential. Some caution must be exercised in heating the fuel.

The Alfa-Laval design of centrifuge (Figure 2.20) intended for dealing with high density residual fuels, is a self-sludging machine which has a flow control disc that makes it virtually a clarifier. There are no gravity discs to be changed to make the machine suitable for fuels of different specific gravity/density. Heating is used to reduce the density (and viscosity) of the fuel so that water

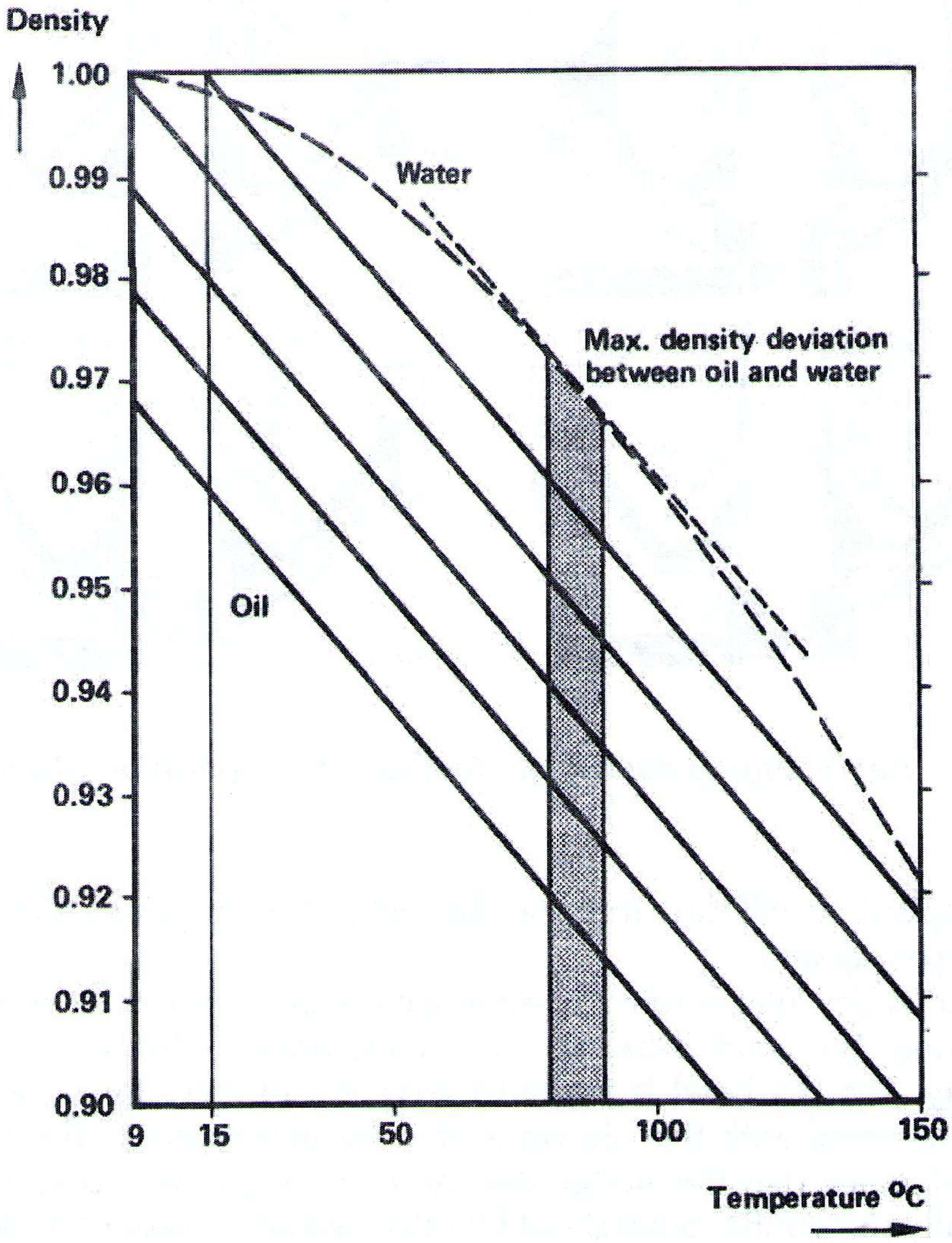

Figure 2.19 *Temperature/density graph (courtesy Alpha-Laval)*

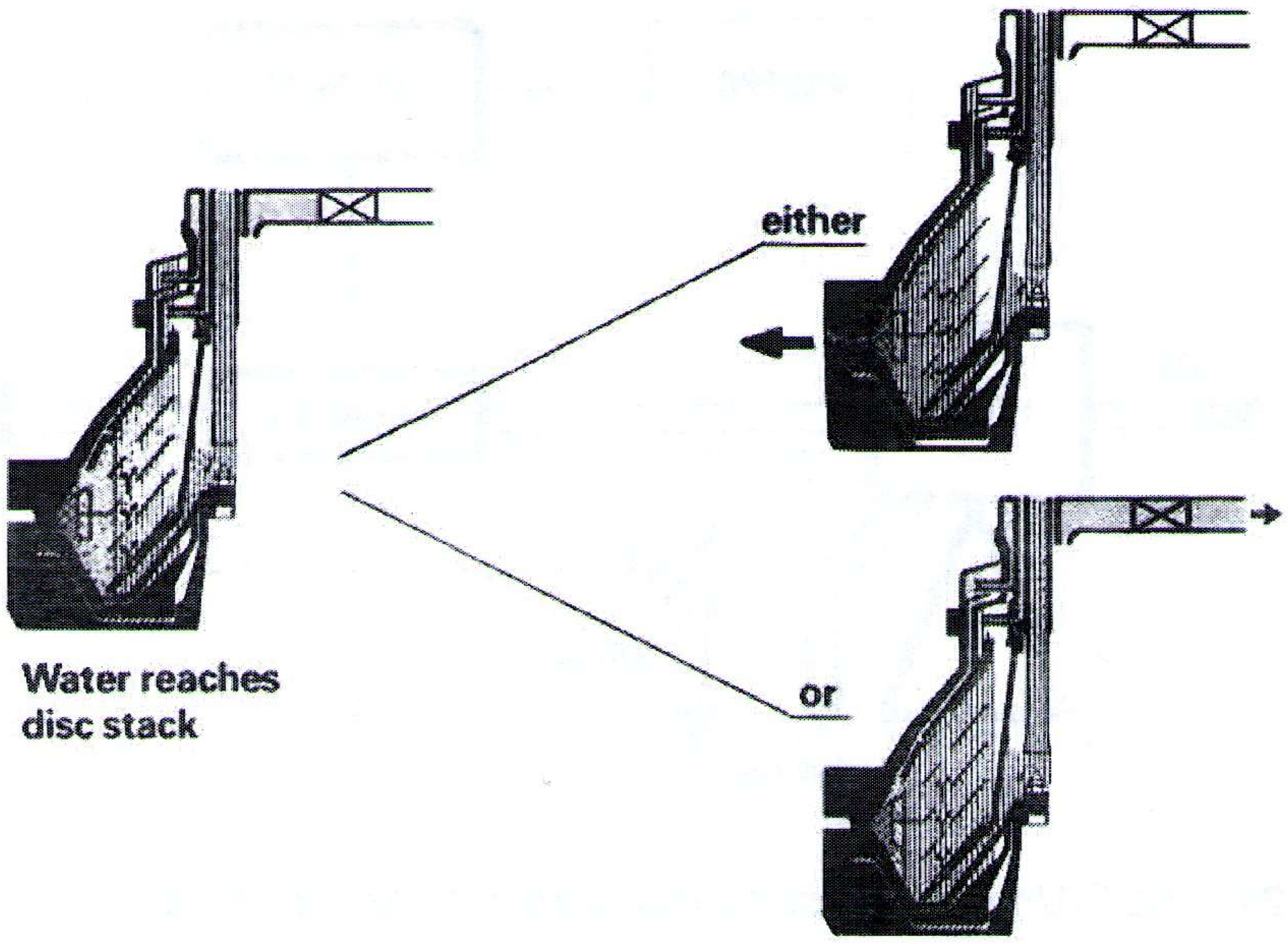

Figure 2.20 *FOPX separator showing discharge of water (courtesy Alpha-Laval)*

and sludge accumulate in the outer part of the bowl, as the result of the centrifugal effect. As the interface moves inwards, but before reaching the disc stack, water droplets flow through to reach a water sensing transducer (Figure 2.21). Via micro-processor circuitry, the transducer causes the bowl to self-sludge or the water to be discharged through the water drain valve. The system is said to be capable of handling fuels with densities as high as 1010 kg/m^3 at 15°C.

Ancillary fuel equipment

The system which delivers residual fuel from the daily service tank to the diesel or boiler, must bring it to the correct viscosity by heating. Filtration of the hot fuel is important for diesels and a homogenizer may be installed.

Fuel heater

For burning heavy fuel oil in a boiler furnace, or a compression-ignition engine, it is necessary to pre-heat it. This may be done in a shell and tube unit either with plain tubes (Figure 2.22) or tubes with fins bonded to them (Figure 2.23) and the oil flowing on the outside of the tubes. The heating medium is normally steam but additional electric heaters are useful for start up from dead ship condition.

The heating steam is used most effectively if it condenses during its passage through the heater, and donates the large amount of latent heat as it reverts from steam to water. A steam trap (see Chapter 4) is fitted at the steam outlet

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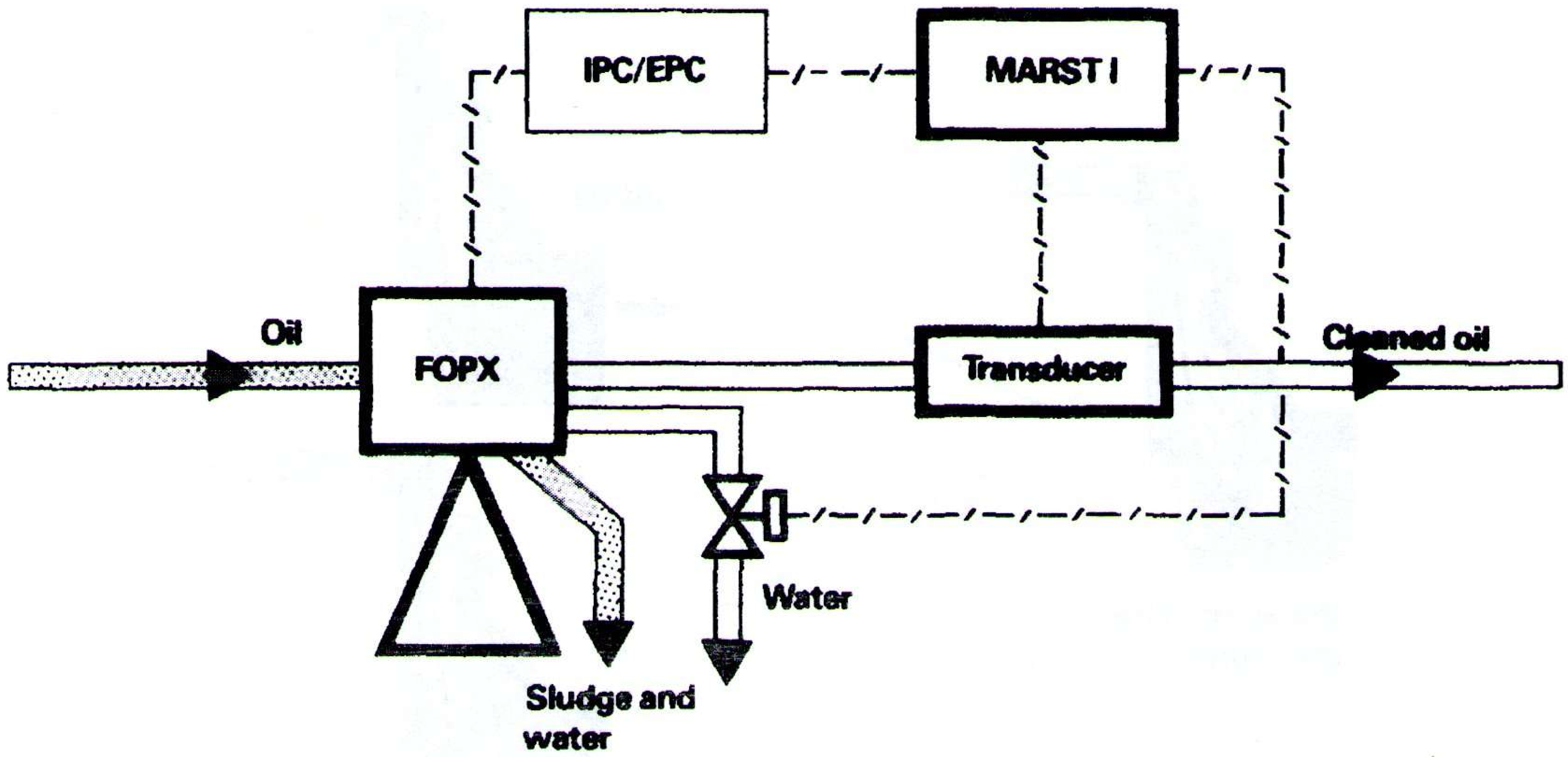

Figure 2.21 *ALCAP system showing water sensing transducer (courtesy Alpha-Laval)*

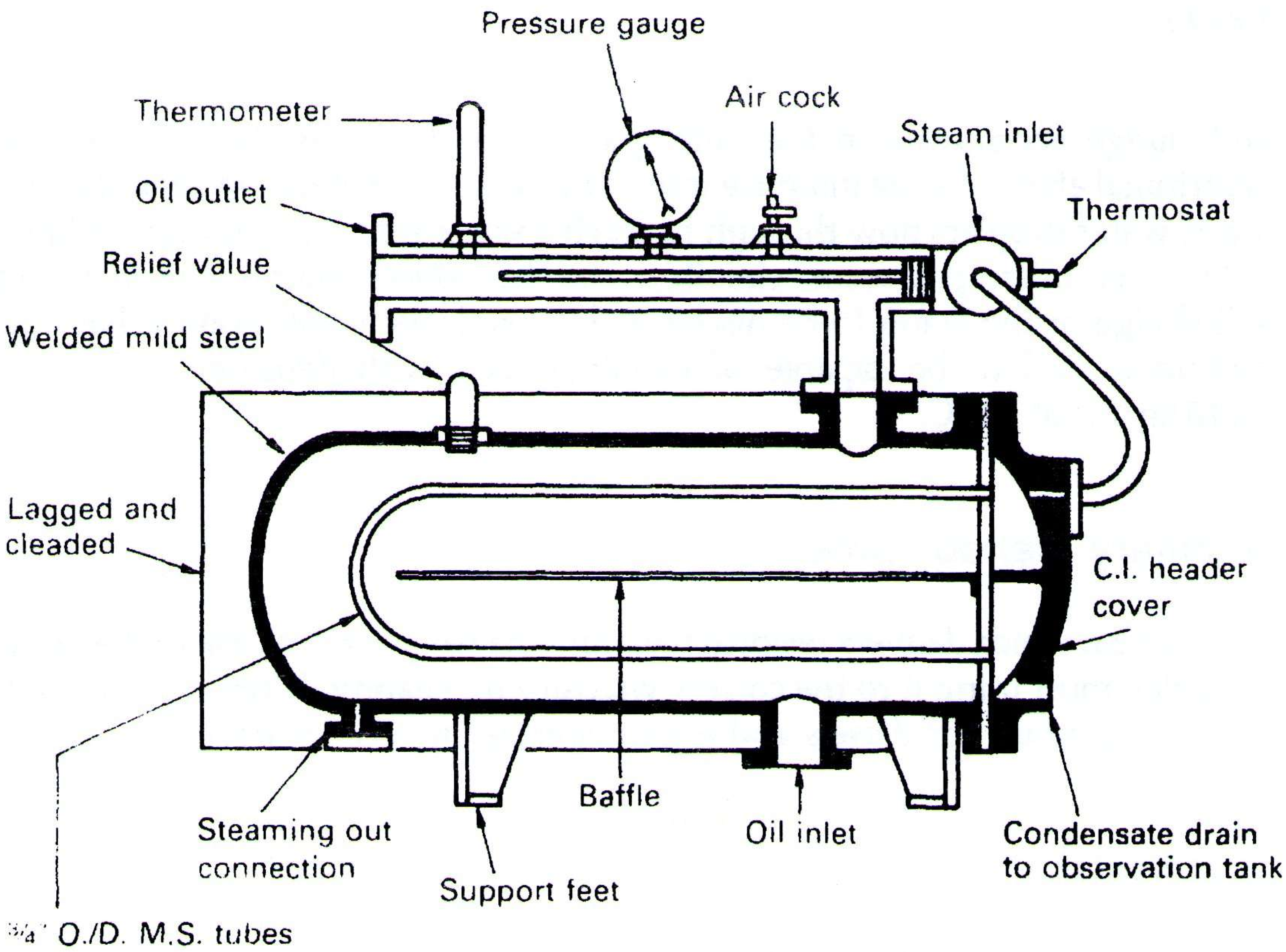

Figure 2.22 *Fuel heater with plain tubes*

from the heater, to make sure that only water returns to the observation and drain tank. If the trap fails, it is necessary to close in the steam return valve to achieve approximately the same effect (about a half or a quarter turn open).

Thermostat control may be employed for fuel heaters (Figure 2.22) with the setting based on a chart showing variation of viscosity with temperature. The charts may not of course be accurate for a particular fuel. Better results are

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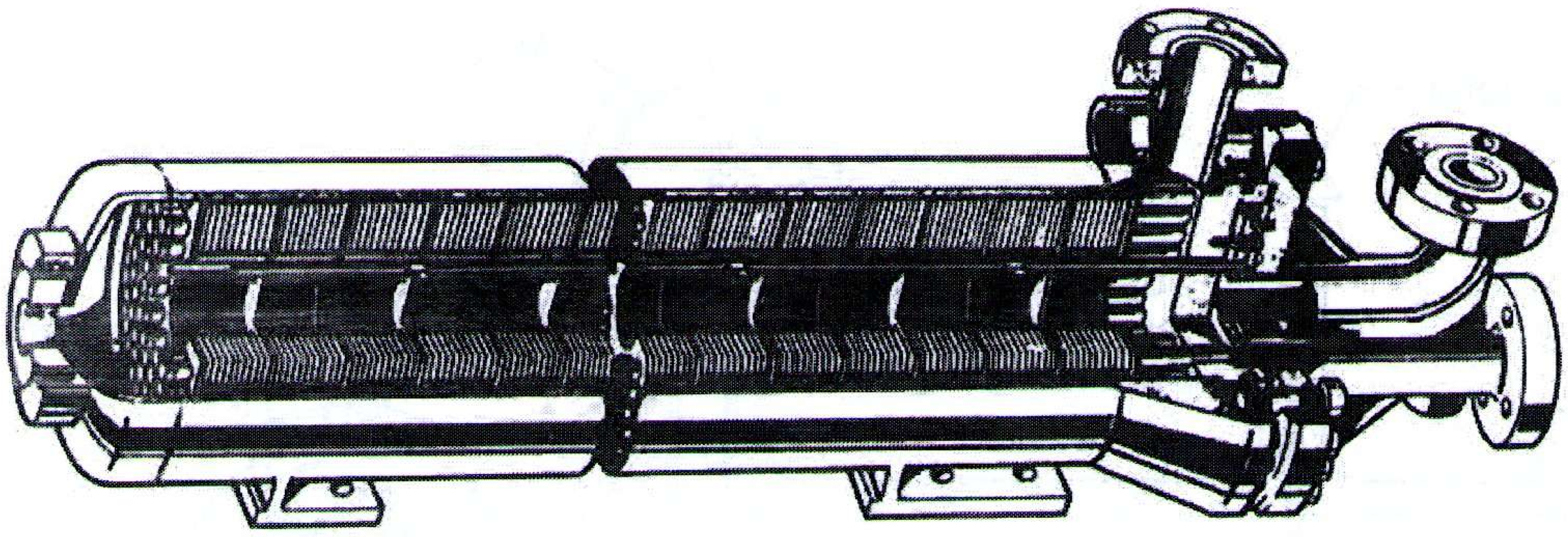

Figure 2.23 *Fuel heater with fins bonded to tubes*

achieved with viscosity controllers, which are used to control viscosity directly, through control of the steam supply.

Viscosity controllers (Viscotherm)

The basic principle of the Viscotherm viscosity monitoring device is shown in Figure 2.24. A continuous sample of the fuel is pumped at a constant rate through a fine capillary tube. As the flow through the tube is laminar, pressure drop across the tube is proportional to viscosity.

In this unit an electric motor drives the gear pump through a reduction gear, at a speed of 40 rpm. The pump is positioned in the chamber through which the fuel is passing from the heater to the fuel pumps or combustion equipment. Tapping points are provided to enable the pressure difference to be measured by means of a differential pressure gauge. The gauge is calibrated directly in terms of viscosity. Parts in contact with the fuel are of stainless steel for corrosion resistance.

A differential pressure transmitter (Figure 2.25) provides an analogue of viscosity to a pneumatic controller, which regulates the supply of fuel heating steam through a control valve.

Homogenizer

The homogenizer (Figure 2.26) provides an alternative solution to the problem of water in high density fuels. It can be used to emulsify a small percentage for injection into the engine with the fuel. This is in contradiction to the normal aim of removing all water, which in the free state, can cause gassing of fuel pumps, corrosion and other problems. However, experiments in fuel economy have led to the installation of homogenizers on some ships to deal with a deliberate mixture of up to 10% water in fuel. The homogenizer is fitted in the pipeline between service tank and engine so that the fuel is used immediately. It is suggested that the water in a high density fuel could be emulsified so that the fuel could be used in the engine, without problems. A homogenizer could not be used in place of a purifier for diesel fuel as it does not remove abrasives such

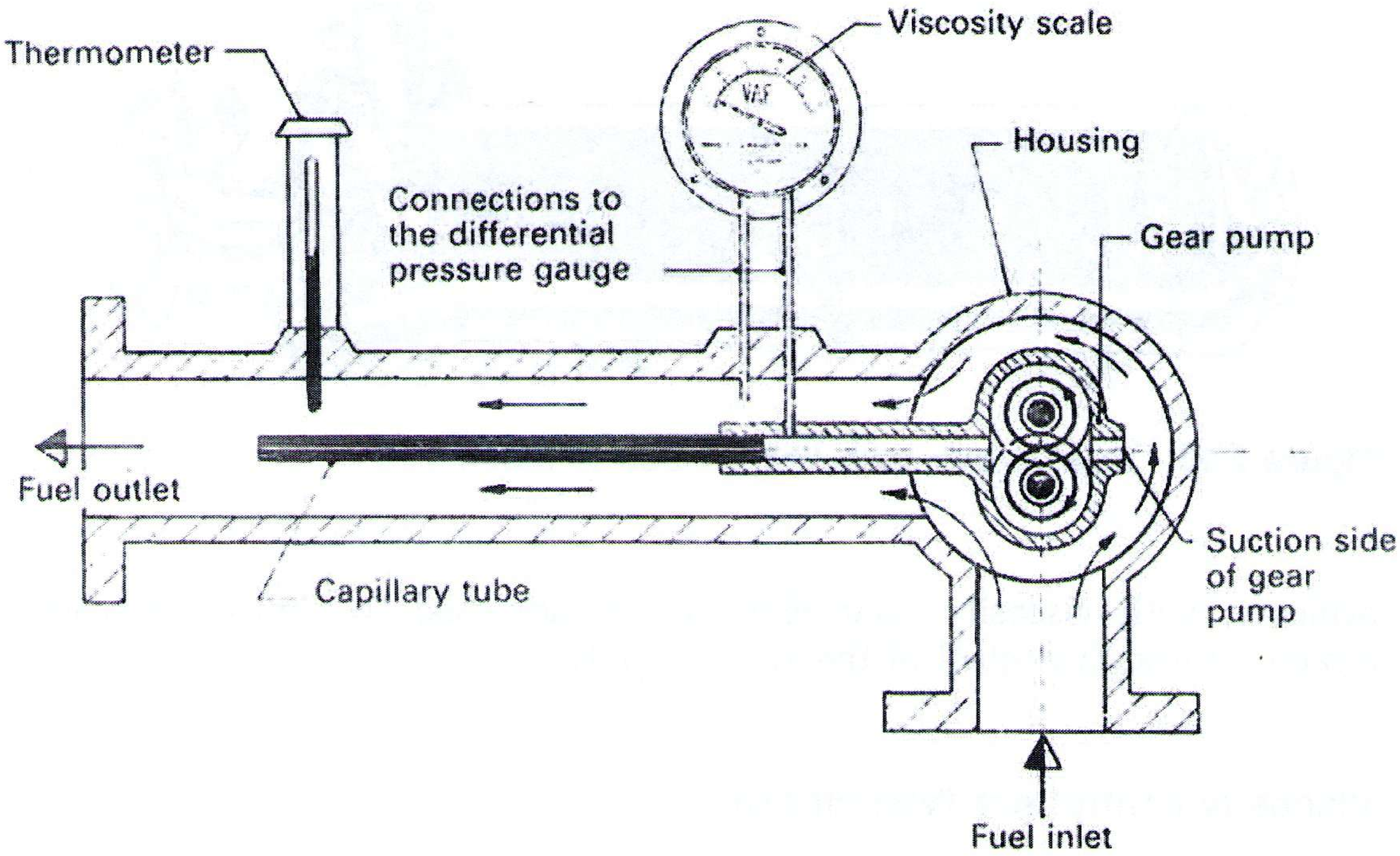

Figure 2.24 *Viscotherm viscosity monitoring device*

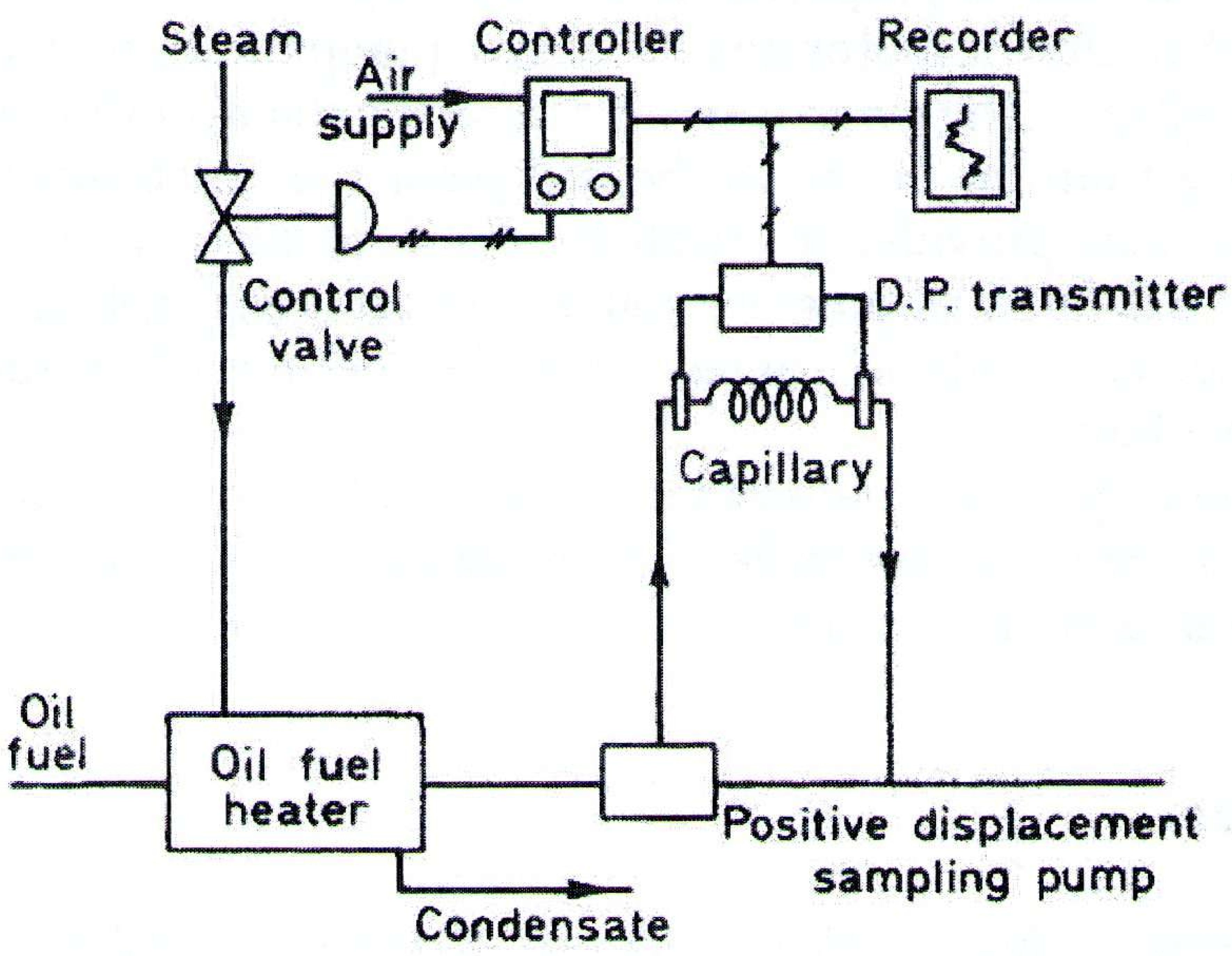

Figure 2.25 *Differential pressure transmitter*

as aluminium and silicon, other metallic compounds or ash-forming sodium which damages exhaust valves.

The three disc stacks in the rotating carrier of the Vickers type homogenizer are turned at about 1200 rev/min. Their freedom to move radially outwards means that the centrifugal effect throws them hard against the lining tyre of the homogenizer casing. Pressure and the rotating contact break down sludges and water trapped between the discs and tyre, and the general stirring action aids mixing.

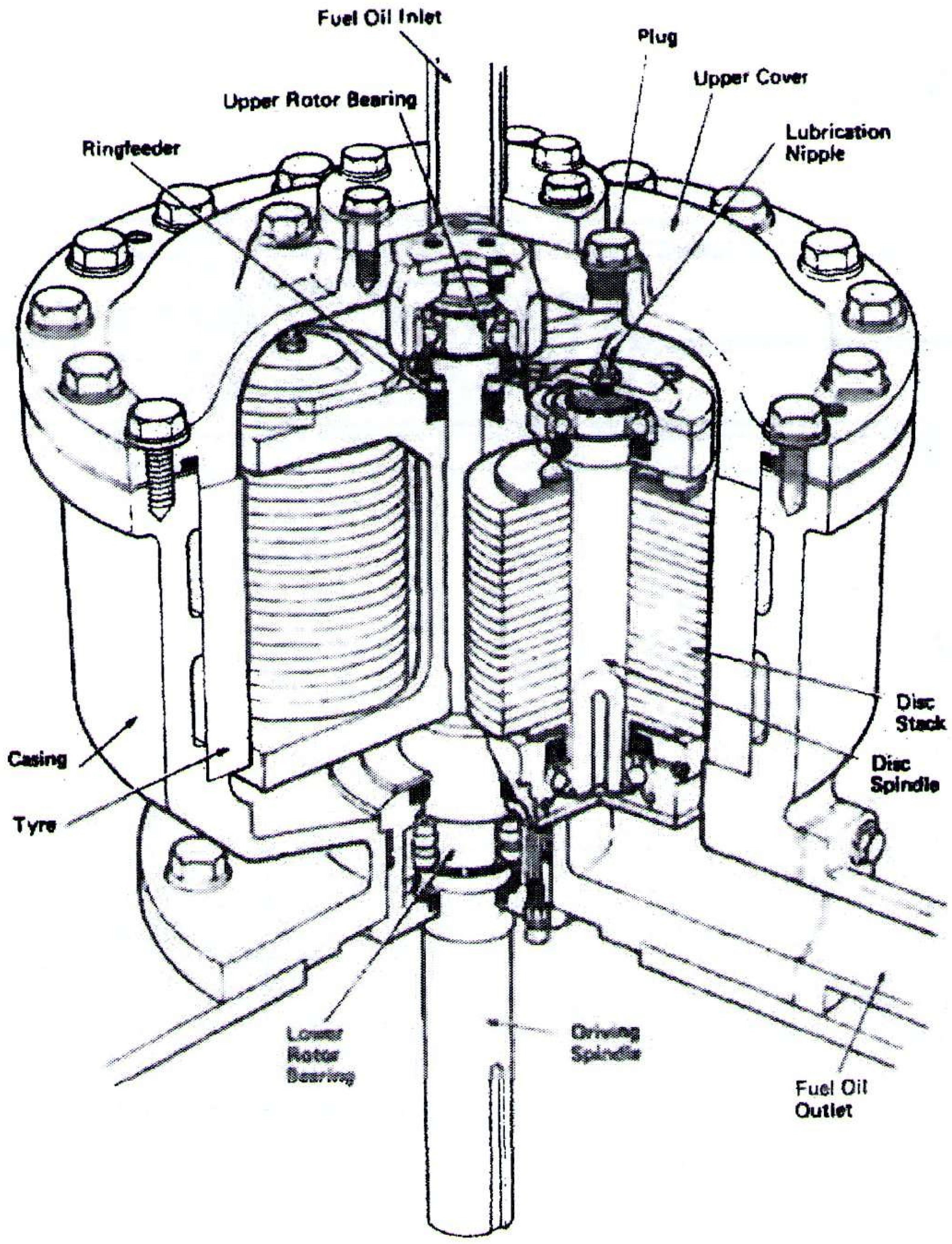

Figure 2.26 *Homogenizer (Vickers type)*

Package boiler combustion system

The elementary automatic combustion system based on a two flame burner (Figure 2.27) is used for many auxiliary boilers. The burner is drawn oversize to show detail. Various different control systems are employed for the arrangement.

The burner has a spring loaded piston valve which closes off the passage to the atomizing nozzle when fuel is supplied to the burner at low pressure. If the fuel pressure is increased the piston valve will be opened so that fuel passes through the atomizer. The system can supply the atomizer with fuel at three different pressures.

The solenoid valves are two-way, in that the fuel entering can be delivered through either of two outlets. The spill valves are spring loaded. When either one is in circuit, it provides the only return path for the fuel to the suction side of the fuel pressure pump. The pressure in the circuit will be forced, therefore to build up to the setting of the spill valve.

A gear pump with a relief arrangement to prevent excessive pressure, is used to supply fuel to the burner. Fuel pressure is varied by the operation of the system and may range up to 40 bar.

Combustion air is supplied by a constant speed fan, and a damper arrangement is used to change the setting.

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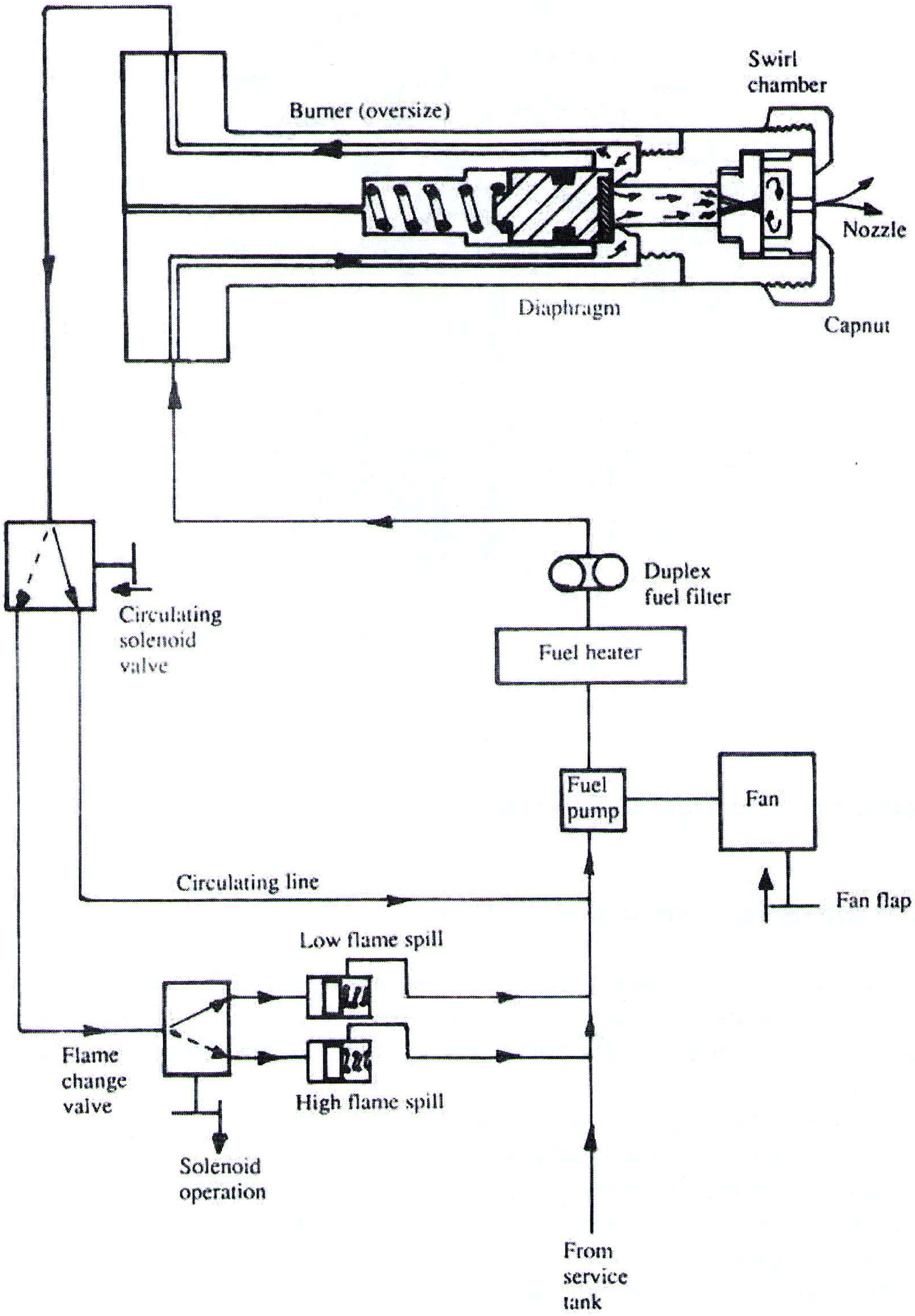

Figure 2.27 *Elementary automatic combustion system*

System operation

Control of the setup may be through various combinations of electrical, electronic or mechanical systems. An electrical control scheme is employed in this description. Electrical circuits are arranged so that when the boiler is switched on (assuming water level and other factors are correct) the system will

(1) heat up and circulate the fuel; (2) purge the combustion space of unburnt gas; and (3) ignite the flame and, by controlling it, maintain the required steam pressure.

When the boiler is started, current is supplied first to the fuel heater. The electric heating elements are thermostatically controlled and when oil in the heater reaches the required atomizing temperature, another thermostat switches in the fan and oil circulating pump. Air from the fan purges the combustion spaces for a set time, which must be sufficient to clear any unburnt gases completely. If not removed an air/gas explosive mixture may be present, so that flame ignition could result in a dangerous blowback. The oil circulates from the pump and heater through the system via the oil circulating valve. This ensures that the oil flows through the burner until it is hot and thin enough to atomize.

When the oil circulating solenoid is operated, the fuel no longer returns to the suction side of the pump but is delivered to the low flame spill through the oil change valve. With the ignition arc 'on', oil pressure builds up sufficiently to push open the piston valve in the burner. The atomized fuel is ignited and once the flame is established, control of the oil change valve and fan damper depends on steam pressure. With low steam pressure, the oil control valve is actuated to deliver the fuel to the high flame spill. Pressure increases until this spill opens and the higher pressure forces a greater quantity of fuel through the burner. When steam pressure rises, the fuel is switched back to the low flame spill. The fan damper is operated at the same time to adjust the air delivery to the high or low flame requirement. The solenoid or pulling motor for the operation of the high/low flame is controlled by a pressure switch acted on by boiler steam pressure.

Boilers with automatic combustion systems have the usual safety valves, gauge glasses and other devices fitted for protection with additional special arrangements for unattended operation.

The flame is monitored by a photo-cell and abnormal loss of flame or ignition failure, results in shut down of the combustion system and operation of an alarm. Sometimes trouble with combustion will have the same effect if the protective glass over the photo-cell becomes smoke blackened.

Water level is maintained by a float-controlled feed pump. The float chamber is external to the boiler and connected by pipes to the steam and water spaces. There is a drain at the bottom of the float chamber. A similar float switch is fitted to activate an alarm and shut-down in the event of low water level (and high water level on some installations). Because float chambers and gauge glasses are at the water level, they can become choked by solids which tend to form a surface scum on the water. Gauge glasses must be regularly checked by blowing the steam and water cocks through the drain. When float chambers are tested, caution is needed to avoid damage to the float. Frequent scumming and freshening will remove the solids which are precipitated in the boiler water by the chemical treatment.

The boiler pressure will stay within the working range if the pressure switch is set to match output. If a fault develops or steam demand drops, then high steam pressure will cause the burner to cut out and the fuel will circulate as for warming through.

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Incorrect air quantity due to a fault with the damper would cause poor combustion. Air delivery should therefore be carefully monitored.

Many package boilers burn a light fuel and heating is not required. Where a heater is in use, deviation from the correct temperature will cause the burner to be shut off.

The automatic combustion system is checked periodically and when the boiler is first started up. The flame failure photo-cell may be masked, so to test its operation or some means – such as starting the boiler with the circulating solenoid cut out – may be used to check flame failure shut down. Cut outs for protection against low water level, excess steam pressure, loss of air and change of fuel temperature are also checked. Test procedures vary with different boilers. At shut down the air purge should operate; the fan being set to continue running for a limited time.

Fuel blender for auxiliary diesels

Conventionally, the lower cost residual fuels are used for large slow speed diesel main engines and generators are operated on the lighter more expensive distillate fuel. The addition of a small amount of diesel oil to heavy fuel considerably reduces its viscosity and if heating is used to further bring the viscosity down then the blend can be used in generators with resultant savings.

The in-line blender shown in Figure 2.28 takes fuels from heavy oil and light diesel tanks, mixes them and supplies the mix directly to auxiliary diesels. Returning oil is accepted back in the blender circulating line. It is not directed back to a tank where there would be the danger of the two fuels settling out.

Fuel is circulated around the closed loop of the system by the circulating pump against the back pressure of the p.s. (pressure sustaining) valve. Thus there is supply pressure for the engine before the valve and a low enough

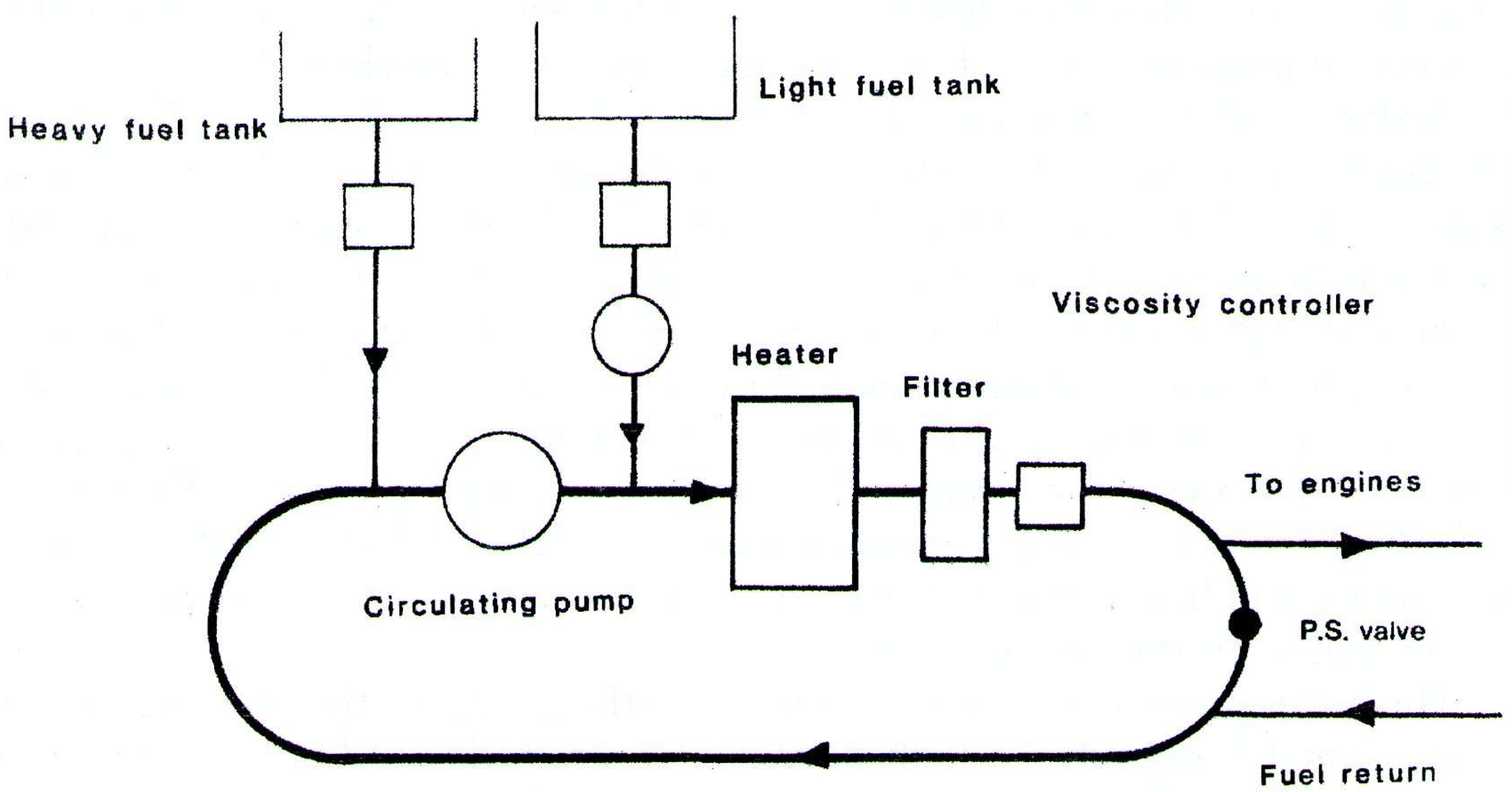

Figure 2.28 *In-line fuel blender (Sea-Star)*

pressure after it, to allow returning oil back into the loop. Sufficient light diesel is injected into the loop by the metering pump for light load running. As increased load demands more fuel, this is drawn in from the heavy oil tank by a drop in loop pressure on the suction side of the circulating pump. The extra fuel made necessary as the load increases is supplied from the residual fuel tank. At full load the ratio may be 30% diesel with 70% heavy fuel.

A viscotherm monitors viscosity and controls it through the heater. The hot filter removes particles down to 5 micron size and there are other filters on the tank suctions. Constant circulation and remixing of the blend and the returning fuel prevents separation.

The diesel is started and runs light on distillate fuel. As the load increases, heavy fuel is added.

Lubricating oil and treatment

Mineral oils for lubrication are, like fuel, derived from crude during refinery processes. Basic stocks are blended to make lubricants with the desired properties and correct viscosity for particular duties. Additives are used to enhance the general properties of the oil and these include oxidation and corrosion inhibitors, anti-corrosion and rust prevention additives, foam inhibitors and viscosity index (VI) improvers. The latter lowers the rate of change of viscosity with temperature.

Basic mineral oil is the term commonly used for oils with the additives mentioned above. These additives enhance the general properties of the oil.

HD or detergent type oils are derived in the same way as basic mineral oils by blending and the use of additives to enhance general properties but additional additives are used to confer special properties. Thus detergent-dispersant ability and the use of alkaline additives make these oils suitable for use in diesel engines.

Detergent type or HD lubricating oils

The main function of detergent-dispersant additives in a lubricating oil is to pick up and hold solids in suspension. This capability can be applied to other additives such as the acid neutralizing alkaline compounds as well as solid contaminants. Thus detergent oils hold contaminants in suspension and prevent both their agglomeration and deposition in the engine. This function reduces ring sticking, wear of piston rings and cylinder liners, and generally improves the cleanliness of the engine. Other functions include reduction of lacquer formation, corrosion and oil oxidation. These functions are achieved by the formation of an envelope of detergent oil round each particle of solid contaminant. This envelope prevents coagulation and deposition and keeps the solids in suspension in the oil.

In engines of the trunk piston type with a combined lubrication system for bearings and cylinders, in addition to the deposition of the products of incomplete combustion which occurs on pistons, piston rings and grooves, some of these products can be carried down into the crankcase, contaminating the crankcase oil with acid products and causing deposit build up on surfaces and in oil lines. Detergent oils are, therefore, widely used in this type of engine.

The detergent additives used today are, in most cases, completely soluble in the oil. There is a tendency for the detergent to be water soluble, so that an emulsion may be formed particularly if a water-washing system is used while purifying.

Manufacturers of centrifuges have carried out a considerable amount of research work in conjunction with the oil companies on the centrifuging of basic mineral and detergent lubricating oils using three different methods of centrifuging. These are purification, clarification and purification with water washing. The following is a summary of the findings and recommendations based on the results which were obtained.

When operating either as a purifier (with or without water washing) or as a clarifier, all particles of the order of 3–5 microns and upwards are completely extracted, and when such particles are of high specific gravity, for example iron oxide, very much smaller particles are removed. The average size of solid particles left in the oil after centrifuging are of the order of only 1–2 microns. (One micron is a thousandth part of a millimetre.) Particles left in the oil are not in general of sufficient size to penetrate any oil film in the lubricating oil system.

A centrifuge should be operated only with the bowl set up as a purifier, when the rate of contamination of the lubricating oil by water is likely to exceed the water-holding capacity of the centrifuge bowl between normal bowl cleanings.

When the rate of water contamination is negligible the centrifuge can be operated with the bowl set up as a clarifier. No sealing water is then required and this reduces the risk of emulsification of HD oils. Any water separated will be retained in the dirt-holding space of the bowl.

For basic mineral oils in good condition, purification with water washing can be employed to remove water soluble acids from the oil, in addition to solid and water contaminants. This method may be acceptable for some detergent lubricating oils but it should not be used without reference to the oil supplier.

Continuous bypass systems for diesel-engine and steam-turbine installations are illustrated in Figures 2.29 and 2.30.

Batch and continuous lubricating systems

For small or medium units without a circulatory lubricating system, the oil can be treated on the batch system. As large a quantity of oil as possible is pumped from the engine or system to a heating tank. The heated oil is passed through the purifier and back to the sump.

For removing soluble sludge, a system combining the batch and continuous systems is effective. The oil is pumped to a tank, where it is allowed to settle for 24 or 48 hours. The oil may be heated by steam coils and basic mineral oils in good condition may be water washed. After settling sludge is drawn off, and the oil is run through the purifier and back to the tank on a continuous system before being finally delivered back through the purifier to the sump.

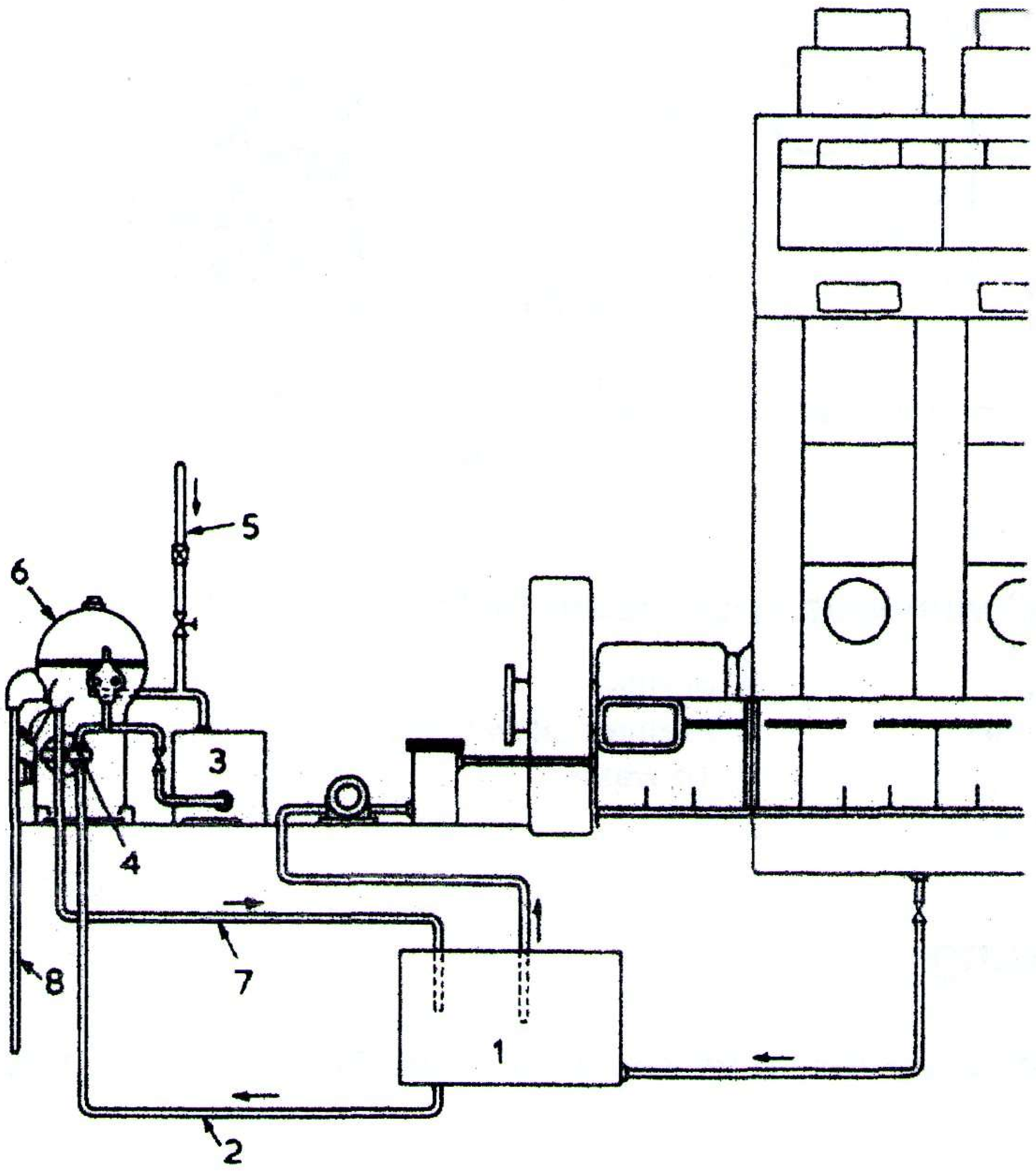

Figure 2.29 *Continuous by-pass purification for a diesel engine (Alfa-Laval Co. Ltd.)*

1. Sump tank for dirty oil from engine
2. Dirty oil to purifier
3. Heater
4. Pump
5. Hot water piping
6. Purifier
7. Purified oil
8. To waste

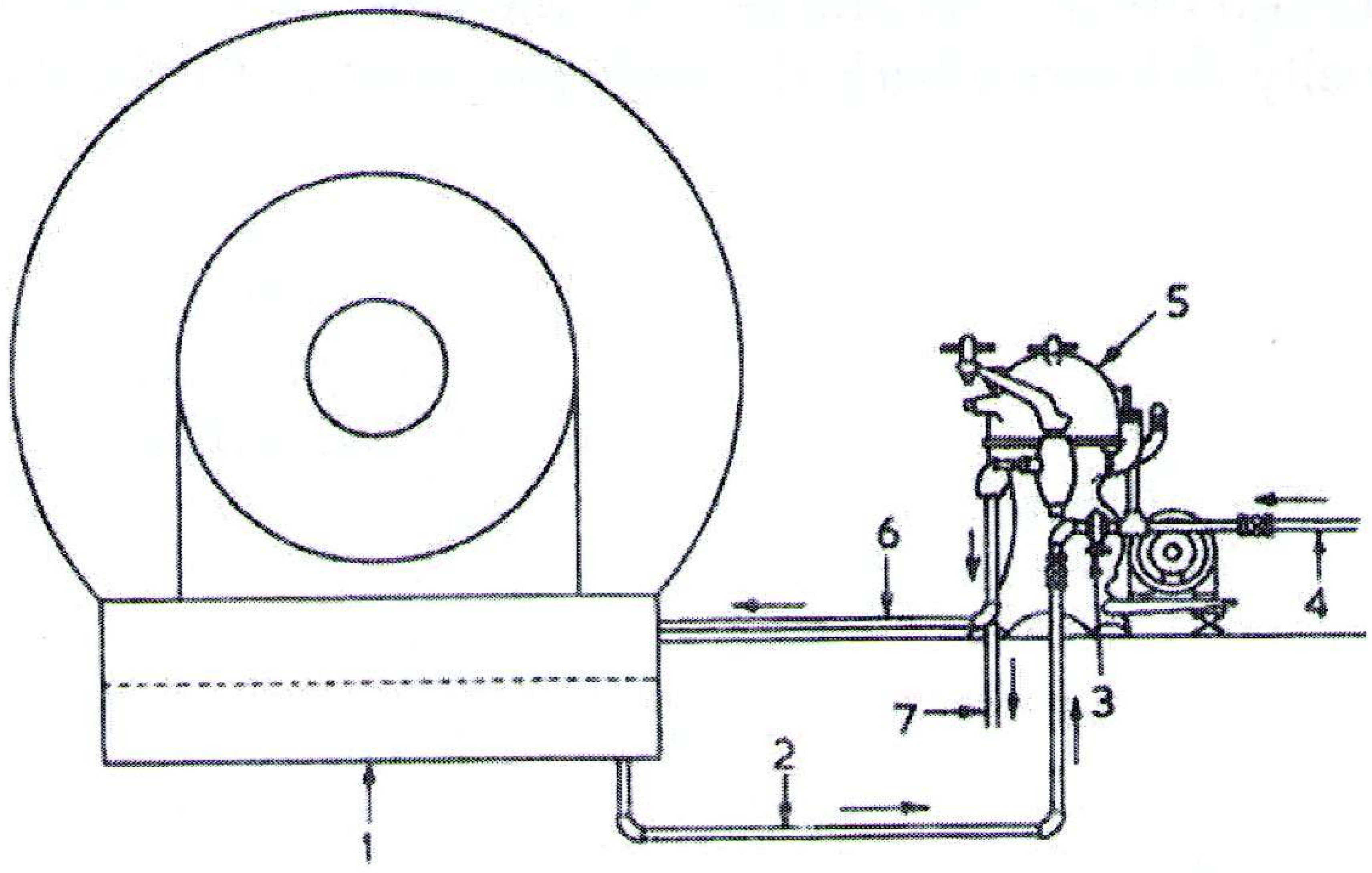

Figure 2.30 *Continuous pour steam-turbine*

1. Turbine oil tank
2. Dirty oil to purifier
3. Oil pump
4. Hot water piping
5. Purifier
6. Purified oil to turbine
7. To waste

Further reading

The Merchant Shipping Act, 1894 Report of Court (No. 8022) m.v. 'Capetown Castle' O.N. 166402.

3

Ship service systems

Some of the equipment in the machinery space is dedicated to servicing the ship in general and providing amenities for personnel or passengers. Thus the bilge system is available to clear oil/water leakage and residues from machinery and other spaces as well as to provide an emergency pumping capability. The domestic water and sewage systems provide amenities for personnel.

Bilge systems and oily/water separators

The essential purpose of a bilge system, is to clear water from the ship's 'dry' compartments, in emergency. The major uses of the system, are for clearing water and oil which accumulates in machinery space bilges as the result of leakage or draining, and when washing down dry cargo holds. The bilge main in the engine room, has connections from dry cargo holds, tunnel and machinery spaces. Tanks for liquid cargo and ballast are served by cargo discharge systems and ballast systems respectively. They are not connected to the bilge system unless they have a double function, as for example with deep tanks that are used for dry cargo or ballast. Spectacle blanks or change over chests are fitted to connect/isolate spaces of this kind, as necessary. Accommodation spaces are served by scuppers with non-return valves which are fitted at the ship's side.

Bilge system regulations

Regulations prescribe the requirements for bilge systems and the details of a proposed arrangement must be submitted for approval to the appropriate government department or classification society. The number of power operated bilge pumps (usually three or four) that are required in the machinery spaces is governed by the size and type of ship. For smaller vessels one of the pumps may be main engine driven but the other must be independently driven. A bilge ejector is acceptable as a substitute provided that, like the pumps, it is capable of giving an adequate flow rate. At least 120 m/min (400 ft/min) through the pipe is a figure that has been required. Pipe cross section is also governed by the rules, which means that this, combined with linear flow, dictates a discharge rate. Bilge ejectors are supplied with high pressure sea water from an associated pump.

The diameters of bilge main and branch pipes, are found as stated above from formulae based on ship size and the Classification Societies generally prescribe the bore of the main bilge line and branch bilge lines and relate the bilge pump capacity of each pump to that required to maintain a minimum water speed in the line. Fire pump capacity is related to the capacity of the bilge pump thus defined:

Bilge main dia. $d_1 = 1.68\sqrt{L(B+D)} + 25$ mm
Branch dia. $d_2 = 2.16\sqrt{C(B+D)} + 25$ mm
d_2 not to be less than 50 mm and need not exceed 100 mm.
d_1 must never be less than d_2

where

L = length of ship in m;
B = breadth of ship in m;
D = moulded depth at bulkhead deck in m;
C = length of compartment in m.

Each pump should have sufficient capacity to give a water speed of 122 m/min through the Rule size mains of this bore. Furthermore each bilge pump should have a capacity of not less than

$$\frac{0.565}{10^3} d_1^2 \text{ m}^3/\text{h}$$

The fire pumps, excluding any emergency fire pump fitted, must be capable of delivering a total quantity of water at a defined head not less than two-thirds of the total bilge pumping capacity. The defined head ranges from 3.2 bar in the case of passenger ships of 4000 tons gross or more to 2.4 bar for cargo ships of less than 1000 tons gross.

Pumps installed for bilge pumping duties must be self-priming or able to be primed. The centrifugal type with an air pump is suitable and there are a number of rotary self-priming pumps available. Engine driven pumps are usually of the reciprocating type and there are still in use many pumps of this kind driven by electric motors through cranks.

The bilge pumps may be used for other duties such as general service, ballast and fire-fighting, which are intermittent. The statutory bilge pumps may not be used for continuous operation on other services such as cooling, although bilge injections can be fitted on such pumps and are a requirement on main or stand-by circulating pumps.

Common suction and discharge chests permit one pump to be used for bilge and ballast duties. The pipe systems for these services must, however, be separate and distinct. The ballast piping has screw lift valves so as to be able to both fill and empty purpose-constructed tanks with sea water. The bilge system is designed to remove water or oily water from 'dry' spaces throughout the vessel and is fitted with screw-down non-return valves to prevent any flooding back to the compartment served. The two could not be connected because they are incompatible. At the pump suction chest, the bilge valve must be of the screw down non-return type to prevent water from entering the bilge line from sea water or ballast suctions.

Materials which can be used are also given in the construction rules. When steel is used, it requires protection inside and out and both surfaces should be galvanized. The preparation of the surfaces for galvanizing is important as is the continuity of the coating. The external painting of steel pipes may be the only protection used to prevent rust arising from contact with water in the bilges. Flanged joints are made between sections of pipe and support must be adequate. Branch, direct and emergency bilge suctions are provided to conform with the regulations and as made necessary by the machinery space arrangement.

Bilge and ballast system layout

In the system shown, (Figure 3.1) the bilge main has suctions from the port and starboard sides of the engine room, from the tunnel well and from the different cargo holds. There are three pumps shown connected to the bilge main. These are the fire and bilge pump, the general service pump and the auxiliary bilge pump. These pumps also have direct bilge suctions to the engine room port side, starboard side and tunnel well respectively. The ballast pump (port side for'd) could be connected to the bilge main but is shown with an emergency bilge suction only. The main sea-water circulating pump at the starboard side of the machinery space also has an emergency suction. This emergency suction or the one on the ballast pump is required by the regulations. The ballast pump is self-priming and can serve as one of the required bilge pumps as well as being the stand-by sea-water circulating pump.

The auxiliary bilge pump is the workhorse of the system and need not be one of the statutorily required bilge pumps. For this installation, it is a low capacity, smooth flow pump which is suited for use in conjunction with the oily/water separator. All bilge suctions have screw down non-return valves with strainers or mud boxes at the bilge wells. Oily bilges and purifier sludge tanks have suitable connections for discharge to the oily water separator or ashore.

The system is tailored to suit the particular ship. Vessels with open floors in the machinery space may have bilge suctions near the centre line and in such cases, wing suctions would not be necessary provided the rise of floor was sharp enough.

The essential safety role of the bilge system means that bilge pumps must be capable of discharging directly overboard. This system is also used when washing down dry cargo spaces.

When clearing the water and oil which accumulates in machinery space bilges, the discharge overboard must be via the oily/water separator and usually with the use of the special bilge pump, i.e. the auxiliary bilge pump of the system shown.

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The following paragraphs are extracted from the International Convention for the Safety of Life at Sea 1974 Chapter 11-1 Regulation 18 which relates to passenger ships:

The arrangement of the bilge and ballast pumping system shall be such as to prevent the possibility of water passing from the sea and from water ballast spaces into the cargo and machinery spaces, or from one compartment to another. Special provision shall be made to prevent any deep tank having bilge and ballast connections being inadvertently run up from the sea when containing cargo, or pumped out through a bilge pipe when containing water ballast.

Provision shall be made to prevent the compartment served by any bilge suction pipe being flooded in the event of the pipe being severed, or otherwise damaged by collision or grounding in any other compartment. For this purpose, where the pipe is at any part situated nearer the side of the ship than one-fifth the breadth of the ship (measured at right angles to the centre line at the level of the deepest subdivision load line), or in a duct keel, a non-return valve shall be fitted to the pipe in the compartment containing the open end.

All the distribution boxes, cocks and valves in connection with the bilge pumping arrangements shall be in positions which are accessible at all times under ordinary circumstances. They shall be so arranged that, in the event of flooding, one of the bilge pumps may be operative on any compartment; in addition, damage to a pump or its pipe connecting to the bilge main outboard of a line drawn at one-fifth of the breadth of the ship shall not put the bilge system out of action. If there is only one system of pipes common to all the pumps, the necessary cocks or valves for controlling the bilge suctions must be capable of being operated from above the bulkhead deck. Where in addition to the main bilge pumping system an emergency bilge pumping system is provided, it shall be independent of the main system and so arranged that a pump is capable of operating on any compartment under flooding condition; in that case only the cocks and valves necessary for the operation of the emergency system need be capable of being operated from above the bulkhead deck.

All cocks and valves mentioned in the above paragraph of this Regulation which can be operated from above the bulkhead deck shall have their controls at their place of operation clearly marked and provided with means to indicate whether they are open or closed.

Oil/water separators

Oil/water separators are necessary aboard vessels to prevent the discharge of oil overboard mainly when pumping out bilges. They also find service when deballasting or when cleaning oil tanks. The requirement to fit such devices is the result of international legislation. Legislation was needed because free oil and oily emulsions discharged in a waterway can interfere with natural processes such as photosynthesis and re-aeration, and induce the destruction of the algae and plankton so essential to fish life. Inshore discharge of oil can cause damage to bird life and mass pollution of beaches. Ships found discharging water containing more than 100 mg/litre of oil or discharging more than 60 litres of oil per nautical mile can be heavily fined, as also can the ship's Master.

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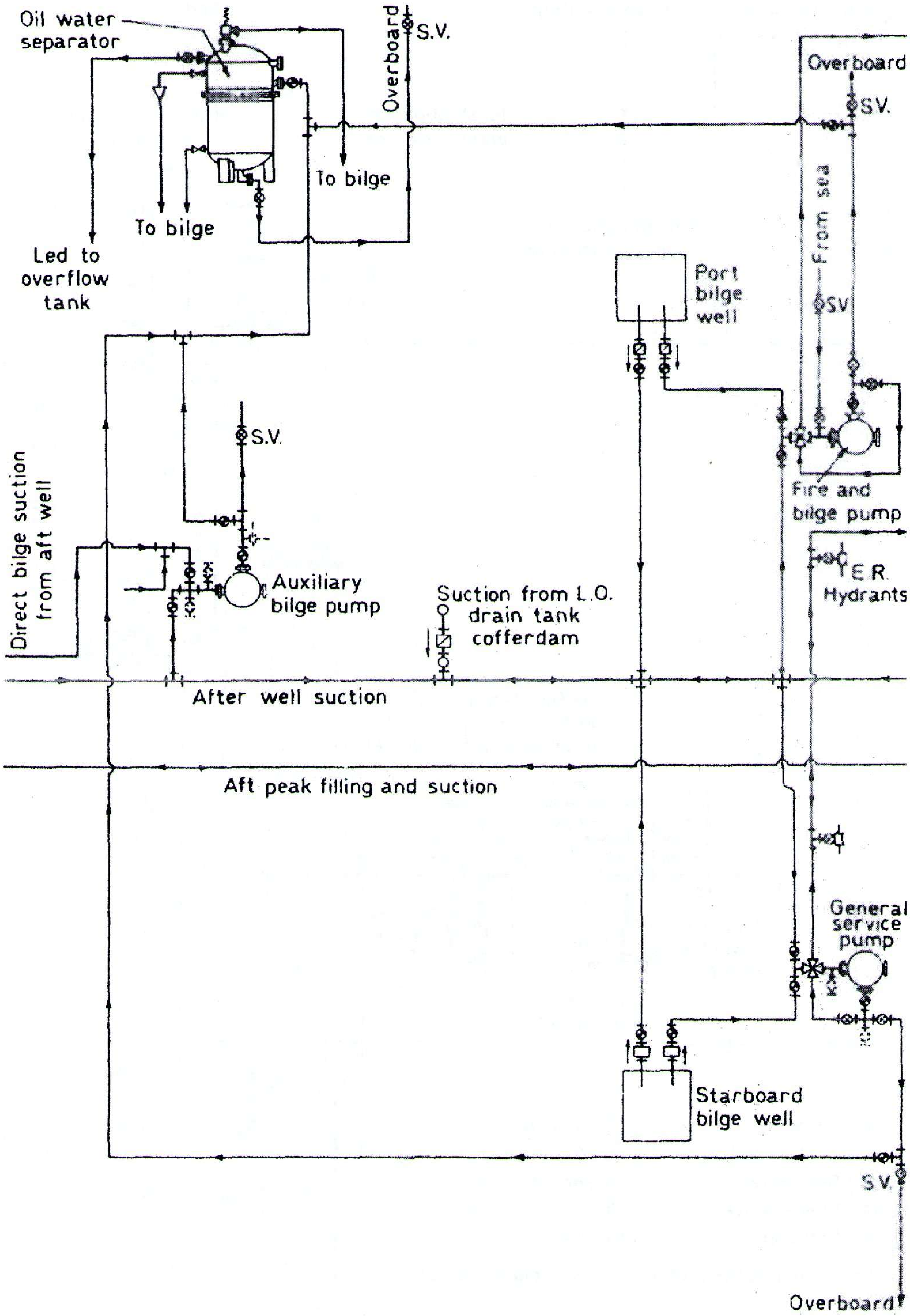
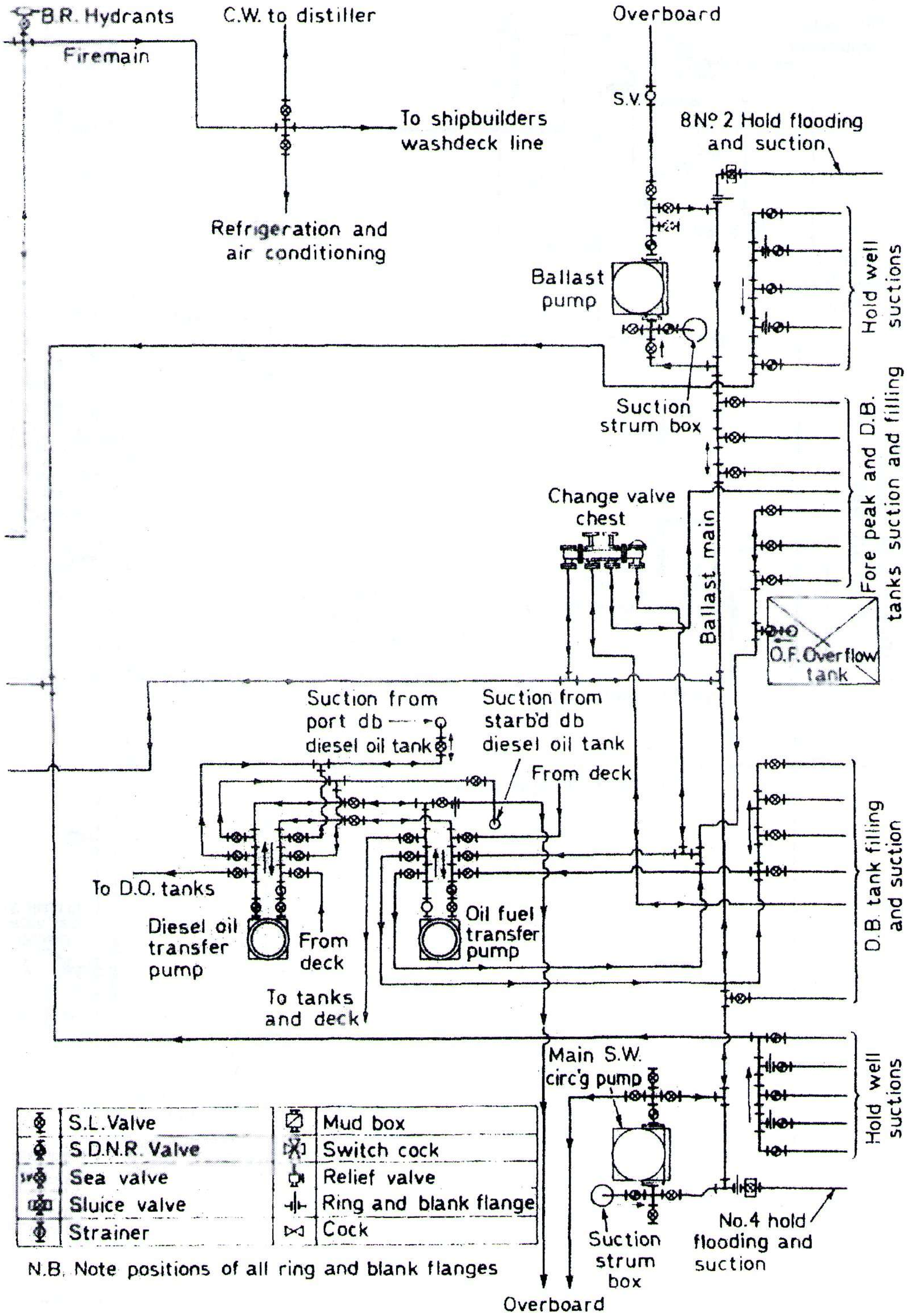


Figure 3.1 *Bilge, ballast and fuel main*


B.R. Hydrants
Firemain
C.W. to distiller
To shipbuilders washdeck line
Refrigeration and air conditioning
Overboard
S.V.
8 No. 2 Hold flooding and suction
Ballast pump
Hold well suctions
Suction strum box
Fore peak and D.B. tanks suction and filling
Change valve chest
Ballast main
O.F. Overflow tank
Suction from port db diesel oil tank
Suction from starb'd db diesel oil tank
From deck
To D.O. tanks
Diesel oil transfer pump
From deck
Oil fuel transfer pump
To tanks and deck
D.B. tank filling and suction
Main S.W. circ'g pump
Hold well suctions
S.L. Valve
S.D.N.R. Valve
Sea valve
Sluice valve
Strainer
Mud box
Switch cock
Relief valve
Ring and blank flange
Cock
N.B. Note positions of all ring and blank flanges
Suction strum box
No. 4 hold flooding and suction
Overboard

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In consequence it is important that an oil/water separator is correctly installed, used and maintained. It is generally accepted that oil is less dense than water and this is the basis of the design of devices to separate the two liquids. Some of the modern heavy fuels however, have a density at 15°C which approaches, is the same as or is even higher than that of water and this has added to the problems of separation in oil/water separators and in centrifuges. The operation of oil/water separators relies heavily on gravity and a conventional difference in densities. Centrifuges by their speed of rotation, exert a force many times that of gravitational effect and the heater (see previous chapter) reduces density in comparison with that of water.

Oil/water separators and centrifuges are both employed for the purpose of separating oil and water but there are major differences. Oil/water separators are required to handle large quantities of water from which usually, small amounts of oil must be removed. Various features are necessary to aid removal of the oil from the large bulk of water particularly when the difference in densities is small.

Centrifuges are required to remove (again usually) small quantities of water from a much larger amount of oil. Additionally the centrifuge must separate solids and it must, with respect to fuel, handle large quantities at the rate at which the fuel is consumed.

Principle of operation

The main principle of separation by which commercially available oil/water separators function, is the gravity differential between oil and water.

In oily water mixtures, the oil exists as a collection of globules of various sizes. The force acting on such a globule, causing it to move in the water is proportional to the difference in weight between the oil particle and a particle of water of equal volume. This can be expressed as:

$$F_s = \frac{\pi}{6} D^3 (\rho_w - \rho_o) g \qquad (1)$$

where:

F_s = separating force
ρ_w = density of water
ρ_o = density of oil
D = diameter of oil globule
g = acceleration due to gravity.

The resistance to the movement of the globule depends on its size and the viscosity of the fluids. For small particles moving under streamline flow conditions, the relationship between these properties can be expressed by Stoke's Law:

$$F_r = 3 \pi v \mu d \qquad (2)$$

where:

F_r = resistance to movement
μ = viscosity of fluid
v = terminal velocity of particle
d = diameter of particle.

When separation of an oil globule in water is taking place F_s will equal F_r and the above equations can be worked to express the relationship of the terminal (or in this case rising) velocity of the globule with viscosity, relative density and particle size:

$$v = \left(\frac{g}{18\mu}\right)(\rho_w - \rho_o)\, d^2 \qquad (3)$$

In general, a high rate of separation is encouraged by a large size of oil globule, elevated temperature of the system (which increases the specific gravity differential of the oil and water and reduces the viscosity of the oil) and the use of sea water. Turbulence or agitation should be avoided since it causes mixing and re-entrainment of the oil. Laminar or streamlined flow is beneficial.

In addition to the heating coils provided to optimize separation, there are various other means used to improve and speed up operation. The entrance area in oil/water separators is made large so that flow is slow and large slugs of oil can move to the surface quickly. (The low capacity pump encourages slow and laminar flow.) Alternation of flow path in a vertical direction continually brings oil near to the surface, where separation is enhanced by weirs which reduce liquid depth. Angled surfaces provide areas on which oil can accumulate and form globules, which then float upwards. Fine gauze screens are also used as coalescing or coagulating surfaces.

Pumping considerations

A faster rate of separation is obtained with large size oil globules or slugs and any break up of oil globules in the oily feed to the separator should be avoided. This factor can be seriously affected by the type and rating of the pump used. Tests were carried out by a British government research establishment some years ago on the suitability of various pumps for separator feed duties and the results are shown in Table 3.1.

It follows that equal care must be taken with pipe design and installation to avoid turbulence due to sharp bends or constrictions and to calculate correctly liquid flow and pipe size to guarantee laminar flow.

The Simplex-Turbulo oil/water separator

The Simplex-Turbulo oil/water separator (Figure 3.2) consists of a vertical cylindrical pressure vessel containing a number of inverted conical plates. The oily water enters the separator in the upper half of the unit and is directed

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Table 3.1 *Pump suitability for oil/water separator duty*

Type	*Remarks*
Double vane Triple screw Single vane Rotary gear	Satisfactory at 50 per cent derating
Reciprocating Hypocycloidal	Not satisfactory: modification may improve efficiencies to 'satisfactory' level
Diaphragm Disc and shoe Centrifugal Flexible vane	Unsatisfactory

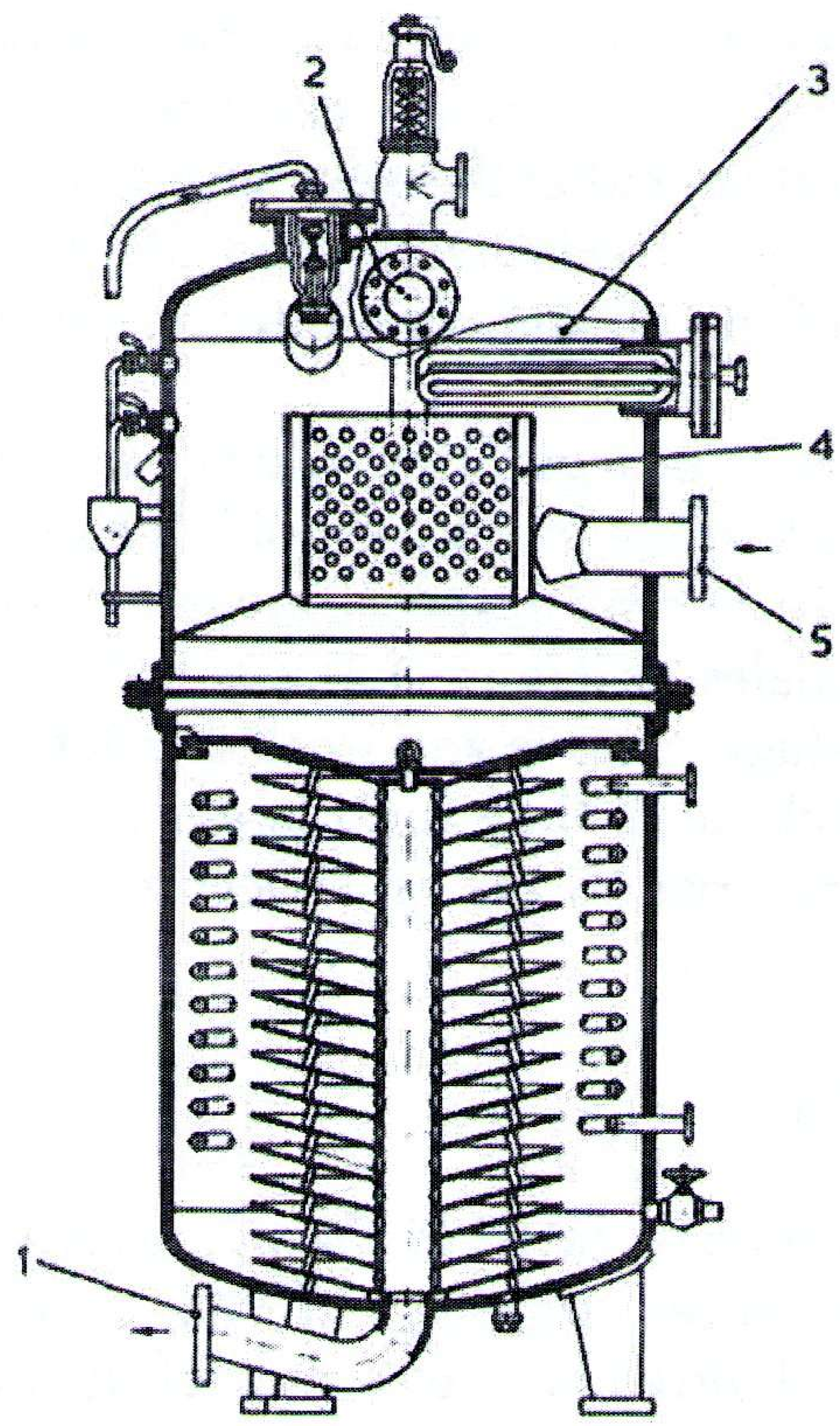

Figure 3.2 *Simplex-Turbulo oil/water separator*

1. Clean water run-off connection
2. Outlet
3. Oil accumulation space
4. Riser pipes
5. Inlet connection

downwards to the conical plates. Large globules of oil separate out in the upper part of the separator. The smaller globules are carried by the water into the spaces between the plates. The rising velocity of the globules carries them upwards where they become trapped by the under-surfaces of the plates and coalesce until the enlarged globules have sufficient rising velocity to travel along the plate surface and break away at the periphery. The oil rises, is caught underneath an annular baffle and is then led up through the turbulent inlet area by risers to collect in the dome of the separator. The water leaves the conical plate pack via a central pipe which is connected to a flange at the base of the separator.

Two test cocks are provided to observe the depth of oil collected in the separator dome. When oil is seen at the lower test cock, the oil drain valve must be opened. An automatic air release valve is located in the separator dome. An electronically operated oil drainage valve is also frequently fitted. This works on an electric signal given be liquid level probes in the separator. Visual and audible oil overload indicators may also be fitted. To assist separation steam coils or electric heaters are fitted in the upper part of the separator. Where high viscosity oils are to be separated additional heating coils are installed in the lower part.

Before initial operation, the separator must be filled with clean water. To a large extent the conical plates are self-cleaning but periodically the top of the vessel should be removed and the plates examined for sludge build-up and corrosion. It is important that neither this separator nor any other type is run at over capacity. When a separator is overloaded the flow becomes turbulent, causing re-entrainment of the oil and consequent deterioration of the effluent quality.

To meet the requirement of legislation which came into force in October 1983 and which requires that the oil content of bilge discharges be reduced in general to 100 ppm and to 15 ppm in special areas and within 12 nautical miles of land, a second stage coalescer (Figure 3.3) was added in some designs. Filter elements in the second stage remove any small droplets of oil in the discharge and cause them to be held until they form larger droplets (coalesce). As the larger globules form, they rise to the oil collecting space.

Oil content monitoring

In the past, an inspection glass, fitted in the overboard discharge pipe of the oil/water separator permitted sighting of the flow. The discharge was illuminated by a light bulb fitted on the outside of the glass port opposite the viewer. The separator was shut down if there was any evidence of oil carry over, but problems with observation occurred due to poor light and accumulation of oily deposits on the inside of the glasses.

Present-day monitors are based on the same principle. However, whilst the eye can register anything from an emulsion to globules of oil a light-sensitive photo-cell detector cannot. Makers may therefore use a sampling and mixing pump to draw a representative sample with a general opaqueness more easily registered by the simple photo-cell monitor. Flow through the sampling chamber is made rapid to reduce deposit on glass lenses. They are easily removed for cleaning.

Bilge or ballast water passing through a sample chamber can be monitored

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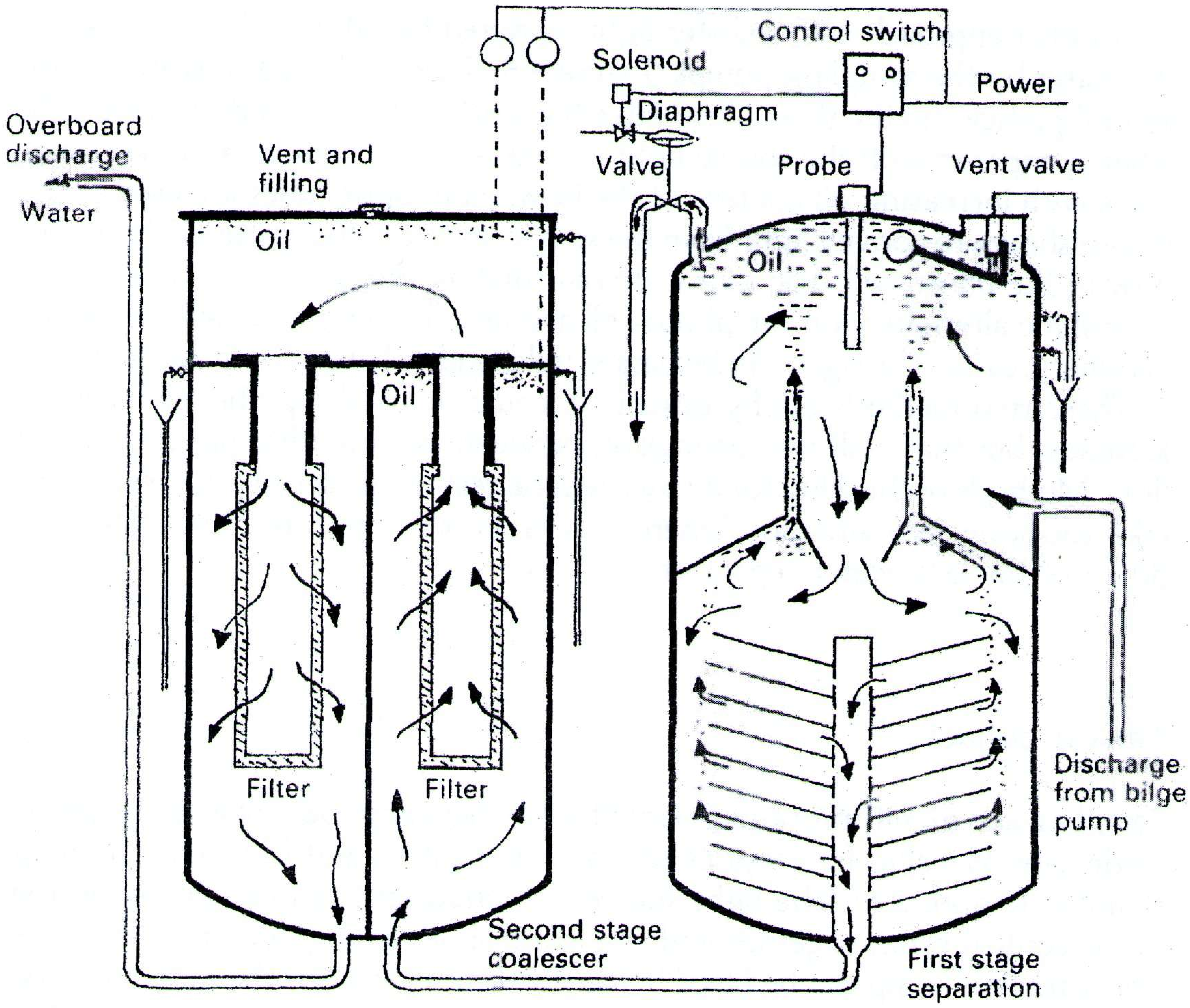

Figure 3.3 *Simplex-Turbulo oil/water separator with coalescer*

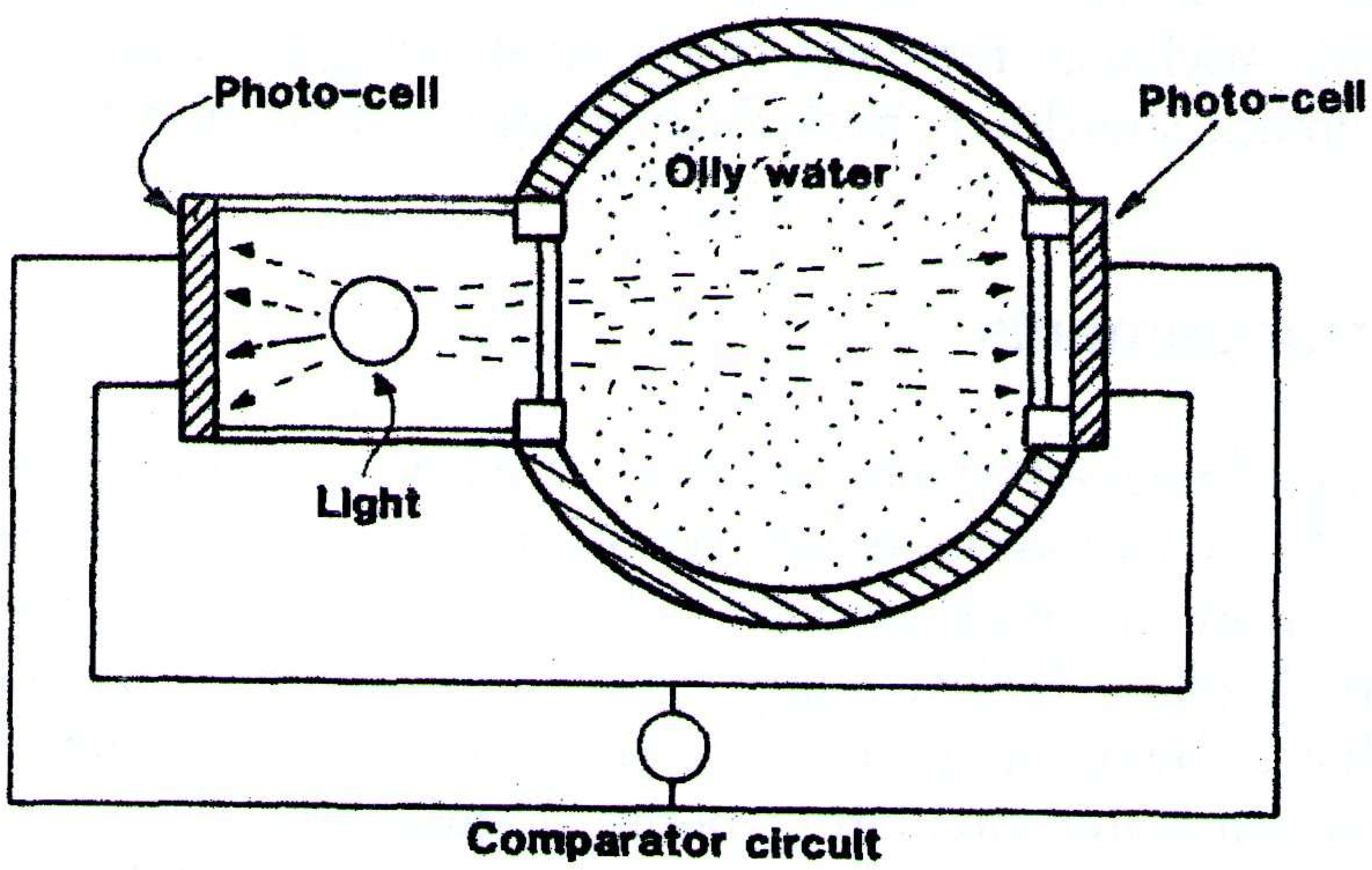

Figure 3.4 *Monitor for oily water using direct light*

by a strong light shining directly through it and on to a photo-cell (Figure 3.4). Light reaching the cell decreases with increasing oil content of the water. The effect of this light on the photo-cell compared with that of direct light on the reference cell to the left of the bulb, can be registered on a meter calibrated to show oil content.

Another approach is to register light scattered by oil particles dispersed in the water by the sampling pumps (Figure 3.5). Light reflected or scattered by any oil particles in the flow, illuminates the scattered light window. This light when compared with the source light increases to a maximum and then decreases with increasing oil content of the flow. Fibre optic tubes are used in the device shown to convey light from the source and from the scattered light window to the photo-cell. The motor-driven rotating disc with its slot, lets each light shine alternately on the photo-cell and also, by means of switches at the periphery, causes the signals to be passed independently to a comparator device.

These two methods briefly described, could be used together to improve accuracy, but they will not distinguish between oil and other particles in the flow. Methods of checking for oil by chemical test would give better results but take too long in a situation where excess amounts require immediate shut down of the oily water separator.

Tanker ballast

Sampling and monitoring equipment fitted in the pump room of a tanker can be made safe by using fibre optics to transmit light to and from the sampling chamber (Figure 3.6). The light source and photo-cell can be situated in the cargo control room together with the control, recording and alarm console. The sampling pump can be fitted in the pumproom to keep the sampling pipe short and so minimize time delay. For safety the drive motor is fitted in the machinery space, with the shaft passing through a gas-tight seal in the bulkhead.

Oil content reading of the discharge is fed into the control computer together with discharge rate and ship's speed to give a permanent record. Alarms, automatic shutdown, back-flushing and recalibration are incorporated.

Ballast arrangements

The ballasting of a vessel which is to proceed without cargo to the loading port is necessary for a safe voyage, sometimes in heavy weather conditions. On arrival at the port the large amount of ballast must be discharged rapidly in readiness for loading. Ballast pump capacity is governed by the volume of water that has to be discharged in a given time. The ballast pump is often also the stand-by sea-water circulating pump (Figure 3.1) but very large ballast discharge capacity is necessary for some ships. Vessels with tanks available for either ballast or oil fuel are fitted with a change-over chest or cock (see Chapter 4) designed to prevent mistakes. An oily water separator on the ballast pump discharge would prevent discharge of oil with the ballast from a tank that had been used for fuel or oil cargo.

Ballast carried in the empty cargo tanks of crude oil carriers has potential for pollution when discharged, particularly if cargo pumps are used for the purpose. Only very large oil/water separators have the capacity to reduce this

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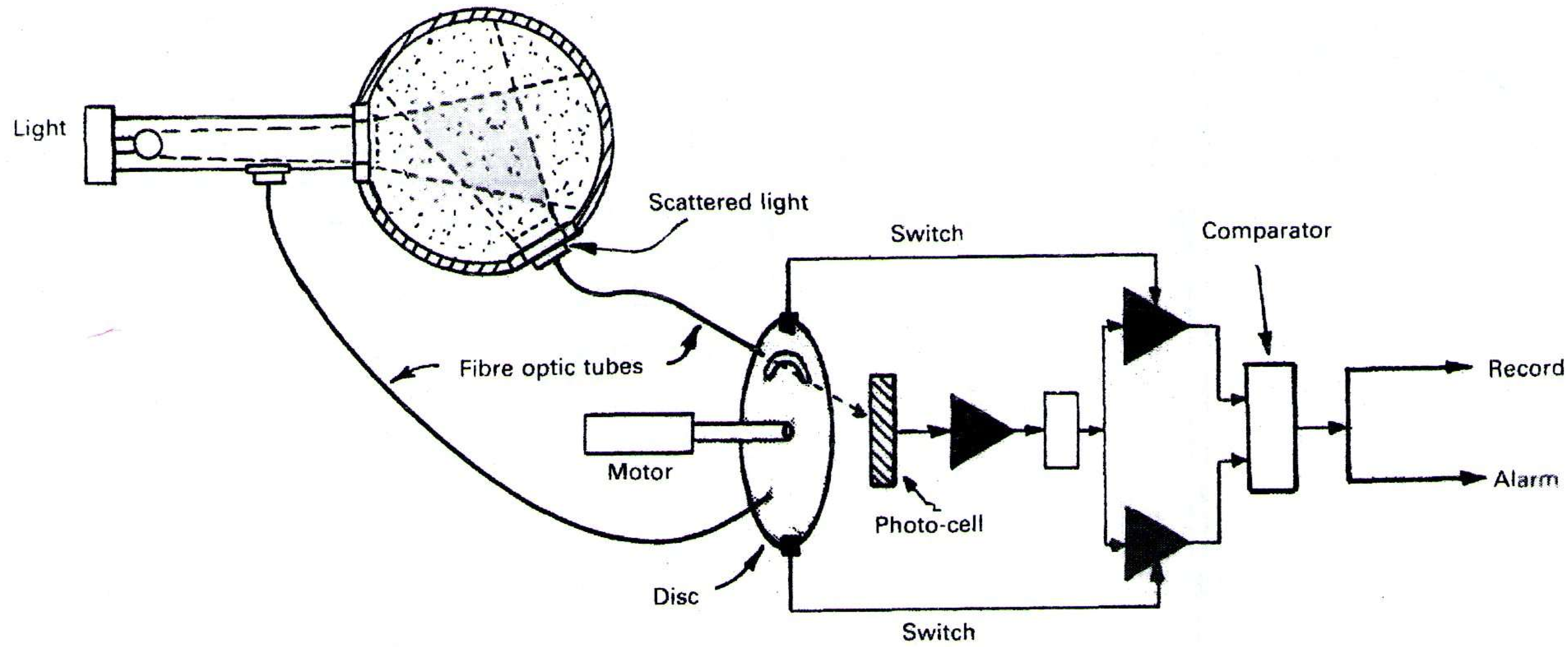

Figure 3.5 *Monitor based on scattered light (courtesy Sofrance)*

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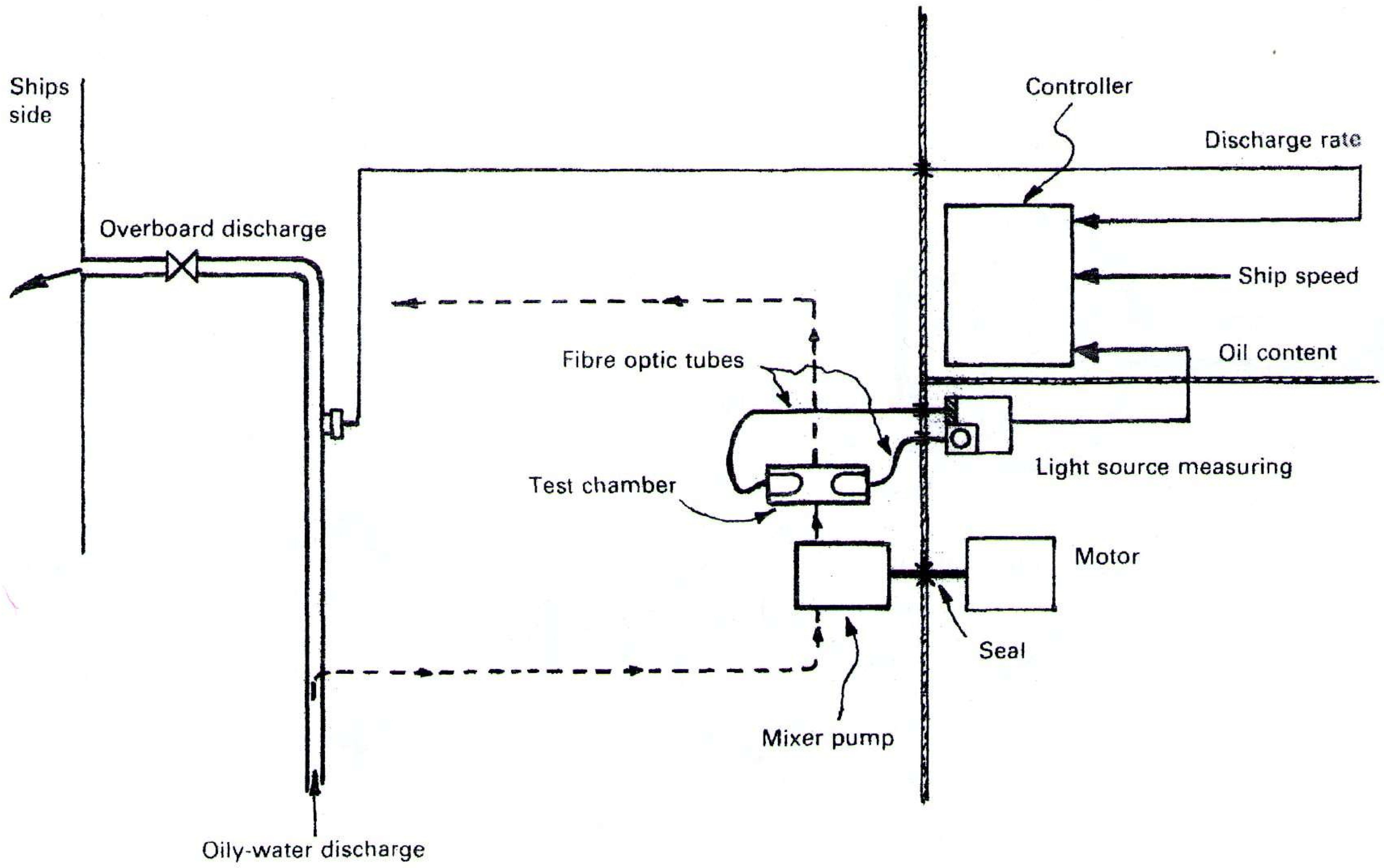

Figure 3.6 *Seres monitoring system for tanker ballast*

pollution. Segregated ballast tanks with dedicated ballast pumps prevent the problem. An example of a ballast pump for a segregated ballast tank, is given in Chapter 6.

Fore and aft peak tanks, double bottom and deep tanks used for ballast in dry cargo vessels as well as ballast spaces in bulk liquid carriers, can be dangerous due to lack of oxygen or the presence of harmful gases. Oxygen may be depleted by corrosion and harmful gases may be produced by organisms or pollutants in the water. The ballast water from some areas has been found to carry dangerous bacteria.

Ballast tank air and overflow pipes must be of the required size relative to the filling lines, that is, 25% greater in area and, in any case, not less than 50 mm bore. They are fitted at the highest part of the tank or at the opposite end to the filling connection. Tanks used for fuel storage also have to fulfil the requirements for fuel tanks. Nameplates are attached to the tops of all air pipes and sounding pipes must have means of identification. The latter are to be of steel with a striker plate at the bottom and must conform to the various rulings. The pipelines for ballasting must be of adequate strength and if of steel, protected by galvanizing or other means. The ballasting of some tanks, such as those in the double bottoms, is carried out by running up by opening appropriate valves, rather than by pumping. Remotely operated valves are installed with modern ballast systems. Pump and valve controls are then centrally located.

Centrifugal pumps with water ring primers, used for ballast pumping, are suitable for use as statutory bilge pumps.

Domestic water systems

Systems using gravity tanks to provide a head for domestic fresh and sanitary water, have long been superseded by schemes where supply pressure is maintained by a cushion of compressed air in the service tanks (Figure 3.7). The trade name Pneupress is commonly used to describe the tanks and system.

Fresh water

The fresh water is supplied to the system, by one of two pumps which are self-priming or situated at a lower level than the storage tanks. The pump starters are controlled by pressure switches which operate when pressure in the service tank varies within pre-determined limits as water is used. The pump discharges through filters to a rising main, branched to give cold and hot supplies, the latter through a calorifier. A circulating pump may be fitted in circuit with the steam or electrically heated calorifier. An ultra-violet light sterilizer is fitted adjacent to the Pneupress tank of some systems. Ultra-violet light acts in such an arrangement, as a point of use biocide. Although effective as a means of killing bacteria, it does not apparently provide protection in the long term. The Department of Transport requirement for protection of fresh

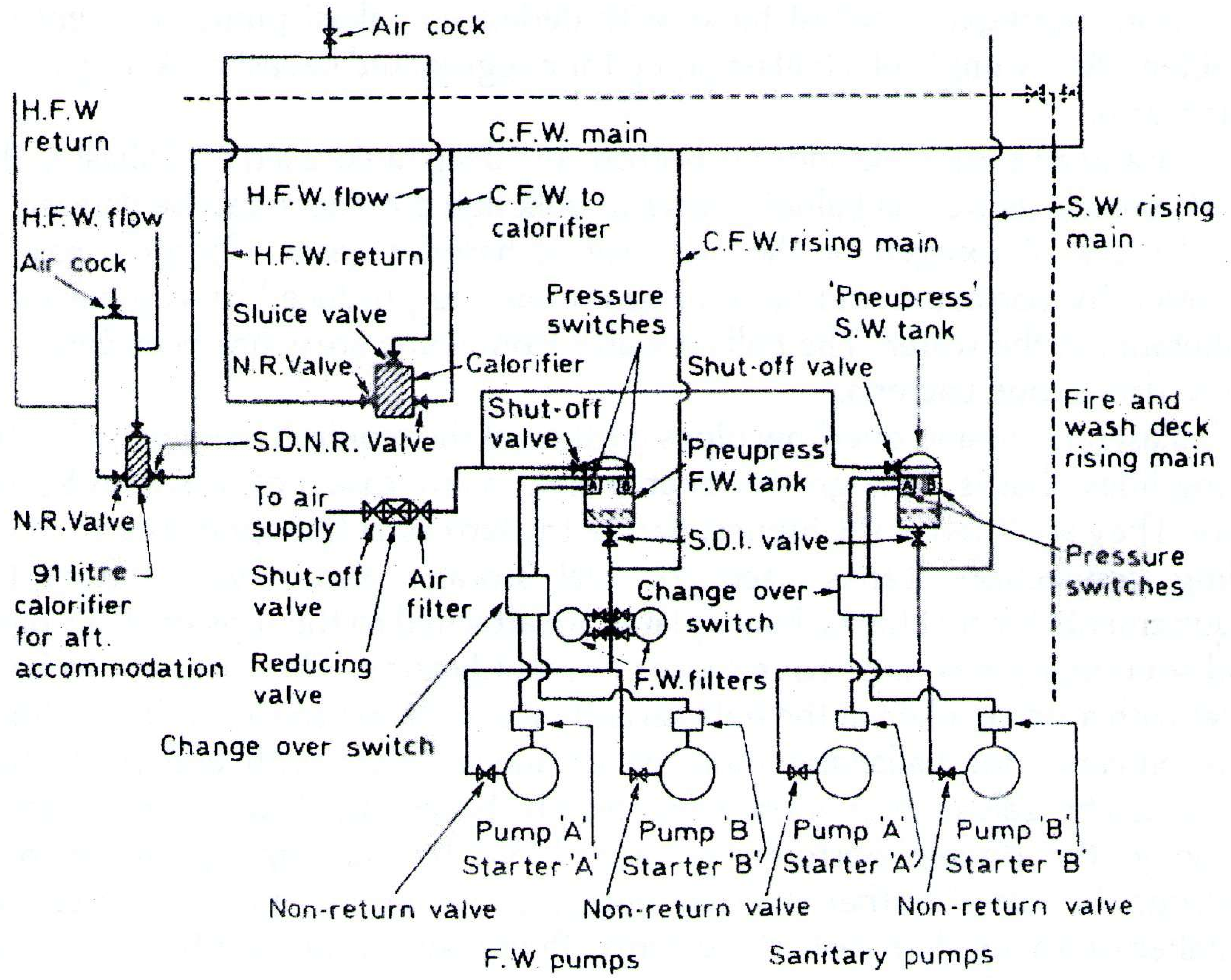

Figure 3.7 *Domestic fresh and sanitary water system*

water in storage tanks, is that chlorine dosing or the Electro-Katadyn method, be used. Guidance on the procedures to ensure that fresh water is safe for consumption is provided by M notices listed at the end of the chapter.

Sanitary water

The sanitary system operates on the same Pneupress principle as that described for fresh water. Pumps, if supplying sea water, are protected by filters on the suction side which require regular cleaning. A few sanitary systems use fresh or distilled water to reduce corrosion in pipes and flushing valves, particularly in vacuum systems where water consumption is minimal. Treated liquid effluent is recirculated in the chemical sewage treatment system described later in the chapter (p. 108); this also operates with a Pneupress system.

Water production

A considerable amount of fresh water is consumed in a ship. The crew uses on average about 70 litre/person/day and in a passenger ship, consumption can be as high as 225 litre/person/day. Water used in the machinery spaces as make up for cooling system losses may be fresh or distilled but distilled water is essential for steam plant where there is a water tube boiler. Steamship consumption for the propulsion plant and hotel services can be as high as 50 tonnes/day.

It is now common practice to take on only a minimal supply of potable water in port and to make up the rest by distillation of sea water. The saved storage capacity for water, is available for cargo and increases the earning power of the ship. A vessel which carries sufficient potable water for normal requirements is required, if ocean-going, to carry distillation plant for emergency use.

Modern low pressure evaporators and reverse osmosis systems give relatively trouble-free operation particularly in comparison with the types that were fitted in older ships. They are sufficiently reliable to provide, during continuous and unattended operation, the water needed for the engine room and domestic comsumption. An advantage of low pressure evaporators is that they enable otherwise wasted heat from diesel engine jacket cooling water to be put to good use.

Reverse osmosis systems were installed to give instant water production capacity without extensive modifications (as with vessels commandeered for hostilities in the Falklands War). They are used to advantage on some passenger cruise vessels and are fitted in ships which may remain stopped at sea for various reasons (tankers awaiting orders – outside 20 mile limit).

Warning is given in M Notice M620 that evaporators must not be operated within 20 miles of a coastline and that this distance should be greater in some circumstances. Pollution is present in inshore waters from sewage outfalls, disposal of chemical wastes from industry, drainage of fertilizers from the land and isolated cases of pollution from grounding or collision of ships and spillage of cargo.

Low pressure evaporators

The main object of distillation is to produce water essentially free of salts. Potable water should contain less than 500 mg/litre of suspended solids. Good quality boiler feed will contain less than 2.5 mg/litre. Sea water has a total dissolved solids content in the range 30 000–42 000 mg/litre, depending on its origin but the figure is usually given as 32 000 mg/litre.

Low pressure evaporators for the production of water can be adapted for steamships but operate to greatest advantage with engine cooling water on motorships. The relatively low temperature jacket water entering at about 65°C and leaving at about 60°C will produce evaporation because vacuum conditions reduce the boiling temperature of sea water from 100°C to less than 45°C.

The single effect, high vacuum, submerged tube evaporator shown in Figure 3.8 is supplied with diesel engine cooling water as the heating medium. Vapour evolved at a very rapid rate by boiling of the sea-water feed, tends to carry with it, small droplets of salt water which must be removed to avoid contamination of the product. The demister of knitted monel metal wire or polypropylene collects the salt-filled water droplets as they are carried through by the air. These coalesce forming drops large enough to fall back against the vapour flow.

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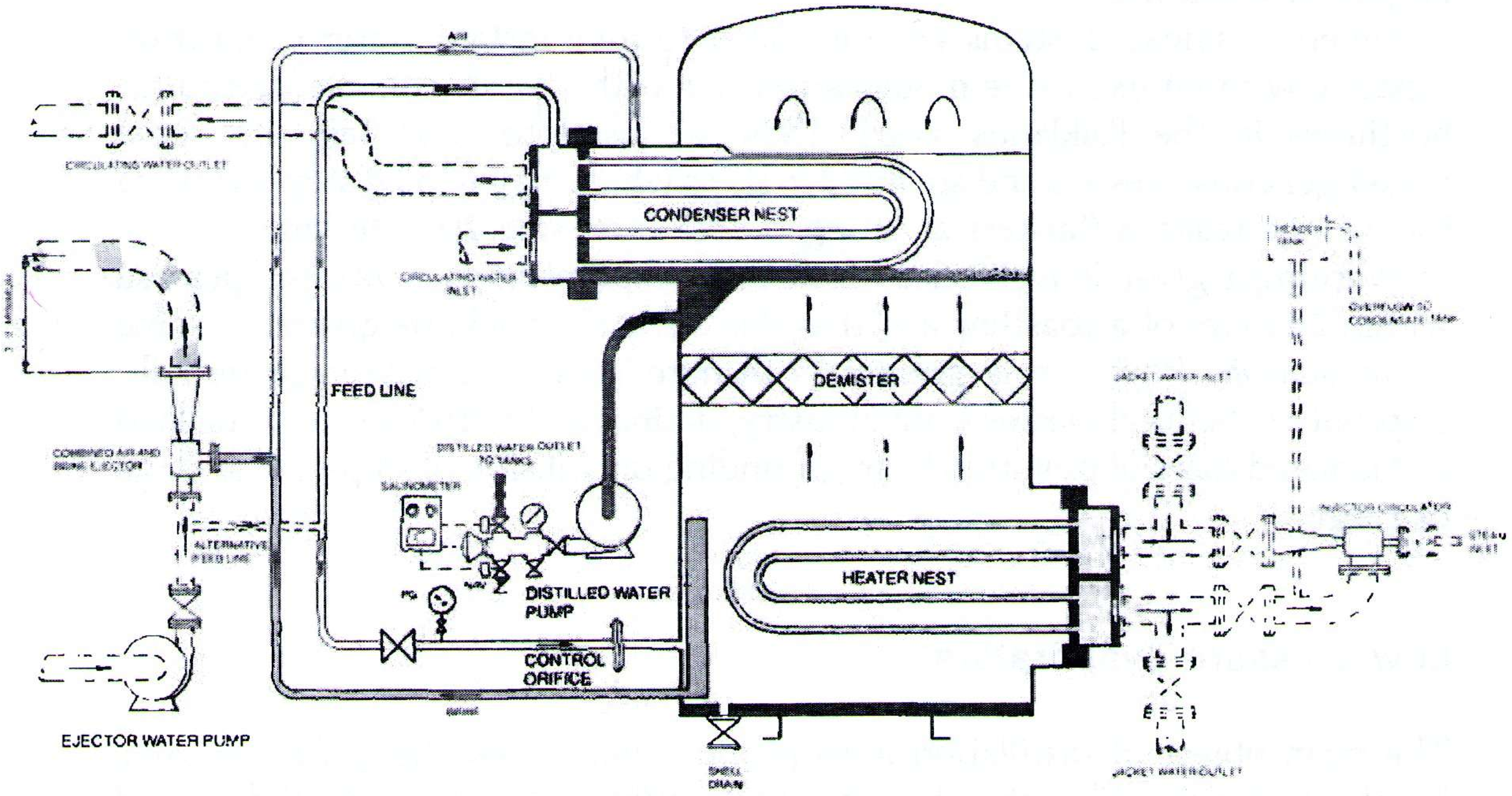

Figure 3.8 *High vacuum, submerged tube evaporatory (movac Mk2 – Caird & Rayner)*

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Evaporation of part of the sea water leaves a brine the density of which must be controlled by continual removal through a brine ejector or pump. Air and other gases released by heating of the sea water, but which will not condense, are removed by the air ejector. The evaporator shown has a single combined ejector for extraction of both brine and air.

One of the gases liberated is CO_2 from calcium bi-carbonate in the sea water. Loss of carbon dioxide from calcium bi-carbonate, leaves plain calcium carbonate which has poor solubility and a tendency to form soft, white scale. Other potential scale-forming salts are calcium sulphate and magnesium compounds.

Scale is not a major problem where submerged heating coils reach a temperature of only 60°C. This heat is too low for formation of magnesium scales and provided brine density is controlled, calcium sulphate will not cause problems. Continuous removal of the brine by the brine pump or ejector, limits density. Approximately half of the sea-water feed is converted into distilled water, the quantity of brine extracted is equivalent to the remainder of the feed delivered. The level of water in the evaporator is maintained constant by means of a brine weir, over which excess passes to the ejector.

The small quantity of soft calcium carbonate scale can be removed by periodic cleaning with a commercially available agent or the evaporator can be continually dosed with synthetic polymer to bind the scale-forming salts into a 'flocc' which mostly discharges with the brine. Use of continuous treatment will defer acid cleaning to make it an annual exercise. Without continuous treatment, cleaning may be necessary after perhaps two months. Steam heated evaporators with their higher heating surface temperature, benefit more from chemical dosing, because magnesium scales form when surfaces are at 80°C or more.

Salinometer

The condensate or product, if of acceptable quality, is delivered to the appropriate tanks by the distilled water pump. Quality is continuously tested by the salinometer both at start up and during operation. If the device registers an excess of salinity it will dump the product and activate the alarm using its solenoid valves. The product is recirculated in some installations.

The electric salinometer

Pure distilled water may be considered a non-conductor of electricity. The addition of impurities such as salts in solution increases the conductivity of the water, and this can be measured. Since the conductivity of the water is, for low concentrations, related to the impurity content, a conductivity meter can be used to monitor the salinity of the water. The instrument can be calibrated in units of conductivity (micromhos) or directly in salinity units (older instruments in grains/gall., newer instruments in ppm or mg/litre) and it is on this basis that electric salinometers (Figure 3.9) operate. The probe type electrode cell (Figure 3.10) is fitted into the pipeline from the evaporator, co-axially through a retractable valve which permits it to be withdrawn for examination and cleaning. The cell cannot be removed while the valve is open and consists of two stainless steel concentric electrodes having a temperature compensator located within the hollow inner electrode. It operates within the limits of water pressure up to 10.5 bar and water temperatures between 15° and 110°C.

The incoming a.c. mains from control switch S2 through fuses FS, feed transformer T. A pilot lamp SL1 on the 24 V secondary winding indicates the circuit is live.

The indicating circuit comprises an applied voltage across the electrode cell and the indicator. The indicator shows the salinity by measuring the current which at a preset value actuates the alarm circuit warning relay. The

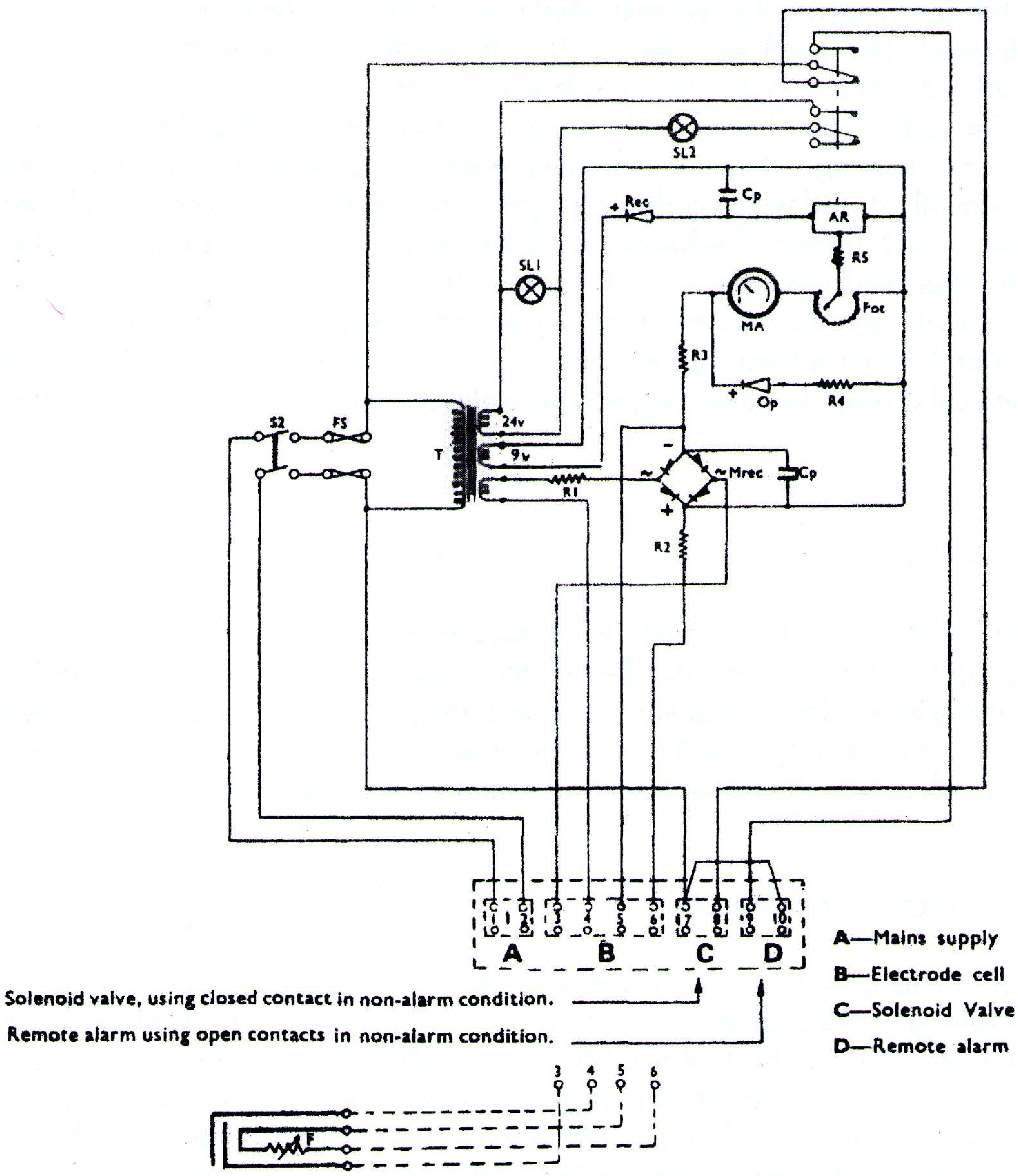
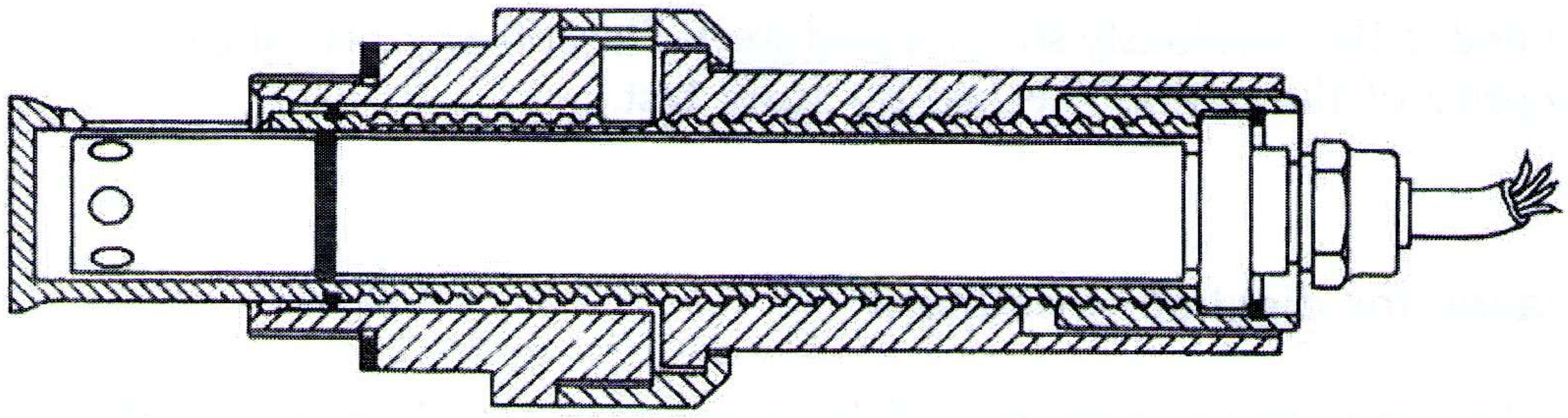


Figure 3.9 *Schematic diagram of salinometer (W. Crockatt & Sons Ltd)*



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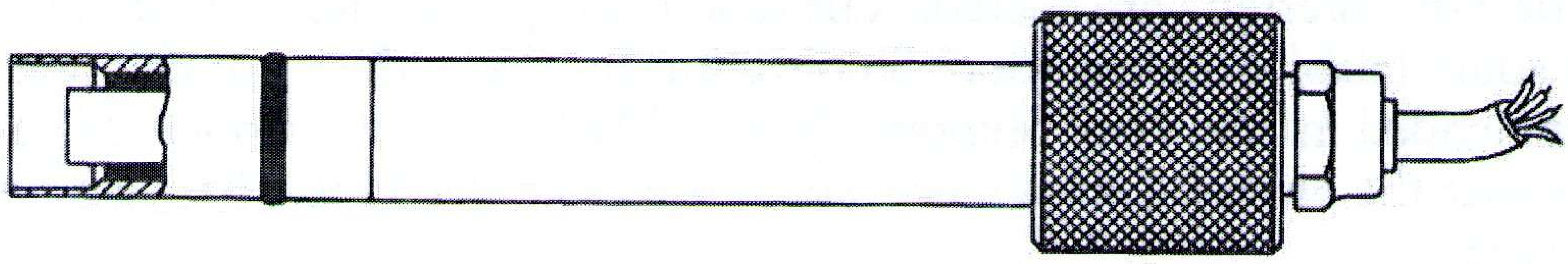

(b)

Figure 3.10 *Probe type electrode cell*

transformer cell tapped voltage is applied across a series circuit comprising the bridge rectifier Mrec, the current limiting resistor R1 and the electrode cell.

The current from rectifier Mrec divides into two paths, one through the temperature compensator F via resistor R2 and the other through the alarm relay potentiometer (Pot) indicator MA and resistor R3, the two paths joining in a common return to the low potential side of the rectifier.

The indicator is protected from overload by a semi-conductor in shunt across the indicator and potentiometer. When the water temperature is at the lower limit of the compensated range the total resistance of the compensator is in circuit and the two paths are as described above. As the temperature of the water rises, the resistance of the compensator device drops progressively, the electrical path through the compensator now has a lower resistance than the other and a large proportion of the cell current. The compensator therefore ensures that the alteration in the balance of the resistances of the two paths corresponds to the increased water conductivity due to the rise in temperature and a correct reading is thus obtained over the compensated range.

The alarm setting is adjustable and the contacts of the warning relay close to light a lamp or sound a horn when salinity exceeds the acceptable level.

The salinometer is also arranged to control a solenoid operated valve which dumps unacceptable feed water to the bilge or recirculates. The salinometer and valve reset automatically when the alarm condition clears.

Corrosion

The shell of the evaporator may be of cupro-nickel or other corrosion resistant material but more commonly, is of steel. The steel shell of evaporators is prone to corrosion. Protection is provided in the form of natural rubber, rolled and bonded to the previously shot-blasted steel. The adhesive is heat cured and the integrity of the rubber checked by spark test.

Reason for distillate treatment

The low operating temperature of the evaporator described, is not sufficient to sterilize the product. Despite precautions near the coast, harmful organisms may enter with the sea water and pass through to the domestic water tank and system. Additionally there is a likelihood that while in the domestic tank, water may become infested with bacteria, due to a build up of a colony of organisms from some initial contamination. Sterilization by the addition of chlorine, is recommended in Merchant Shipping Notice M1214. A later notice, M1401, states that the Electro-Katadyn process in use since the 1960s, has also been approved.

Another problem with distilled water is that having none of the dissolved solids common in fresh water it tastes flat. It also tends to be slightly acidic due to its ready absorption of carbon dioxide (CO_2). This condition makes it corrosive to pipe systems and less than beneficial to the human digestive tract.

Chlorine sterilization and conditioning

Initial treatment (Figure 3.11) involves passing the distillate through a neutralite unit containing magnesium and calcium carbonate. Some absorption of carbon dioxide from the water and the neutralizing effect of these compounds, removes acidity. The addition of hardness salts also gives the water a better taste. The sterilizing agent chlorine, being a gas, is carried into the water as a constituent of sodium hypochlorite (a liquid) or in granules of calcium chloride dissolved in water. The addition is set to bring chlorine content to 0.2 ppm. While the water resides in the domestic tank, chlorine should preserve sterility. In the long term, it will evaporate so that further additions of chlorine may be needed.

The passage of water from storage tanks to the domestic system, is by way of a carbon filter which removes the chlorine taste.

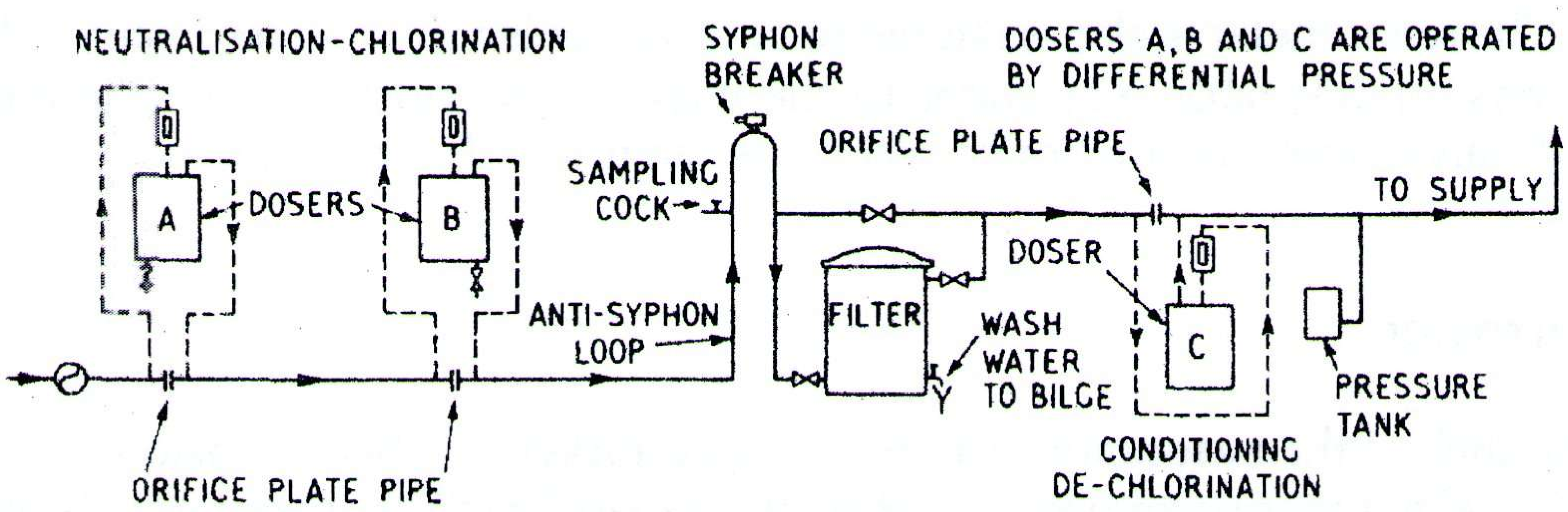

Figure 3.11 *Chlorine sterilization and conditioning*

Electro-katadyn method of sterilization

The Electro-katadyn process (Figure 3.12) accepted as an alternative to chlorination (see M1401) involves the use of a driven silver anode to inject silver ions (Ag^+) into the distilled water product of the low temperature evaporator. Silver is toxic to the various risk organisms. Unlike the gas chlorine, it will not evaporate but remains suspended in the water.

The sterilizer is placed close to the production equipment with the conditioning unit being installed after the sterilizer and before the storage tank.

The amount of metal released to water passing through the unit, is controlled by the current setting. If a large volume has to be treated, only part is bypassed through and a high current setting is used to inject a large amount of silver. The bypassed water is then added to the rest in the pipeline. With low water flow, all of the water is delivered through the device and the current setting is such as to give a concentration of 0.1 ppm of silver. The silver content of water in the domestic system, should be 0.08 ppm maximum.

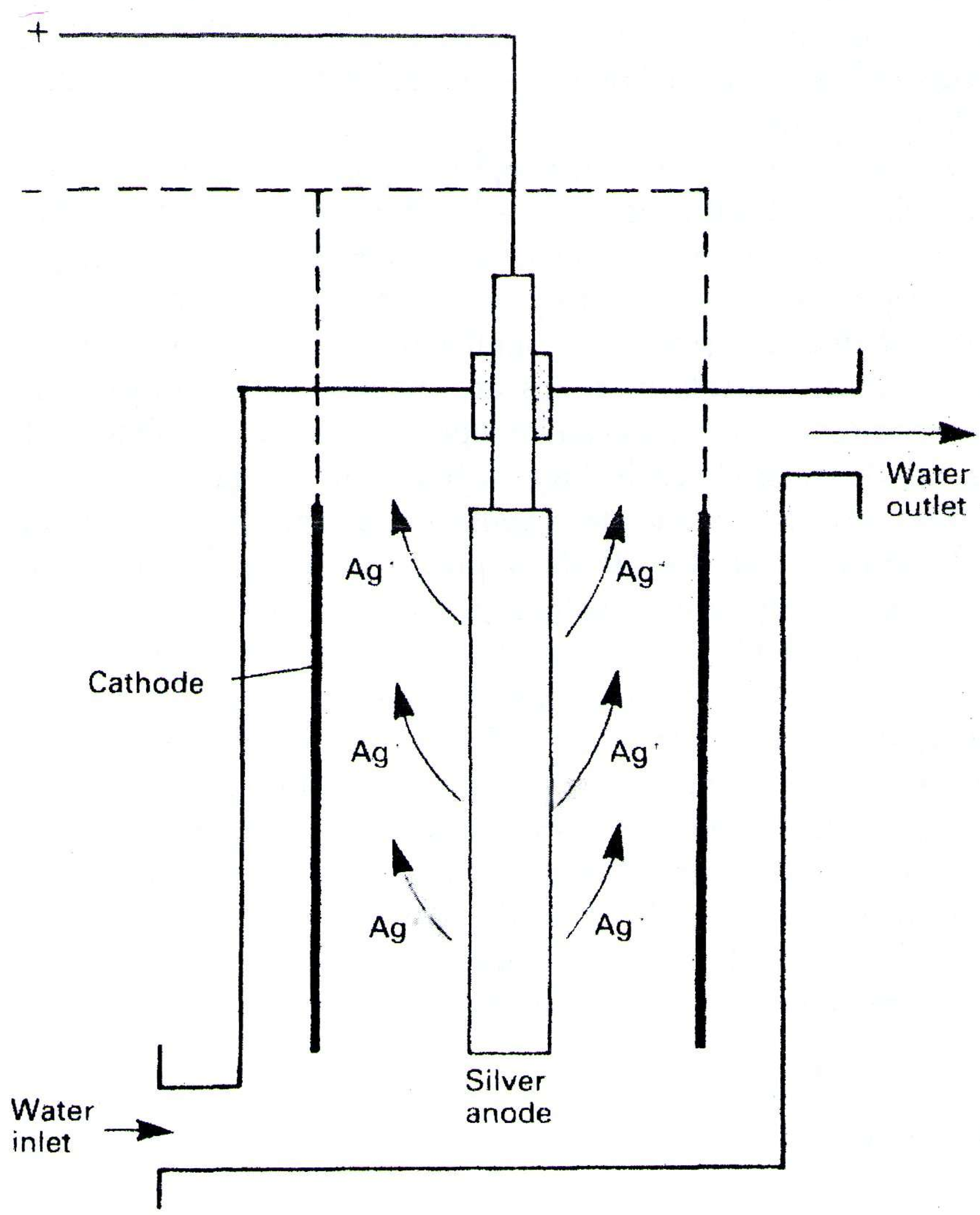

Figure 3.12 *Electro-katadyn sterilization*

Ultra-violet sterilizer

A means for sterilizing potable water at the point of use, is provided on many offshore installations and ships, by an ultra-violet radiation unit which is positioned after the hydrophore tank and as close as possible to the tap supply points. The stainless steel irradiation chamber contains low pressure mercury vapour tubes, housed in a quartz jacket. Tubes are wired in series with a transformer for safety. A wiper is fitted within the chamber to clean the jackets and lamp observation window. Units of a similar type are used for pretreatment disinfection in some reverse osmosis plant.

Flash evaporators

The evaporator described above, boils sea water at the saturation temperature corresponding to the uniform pressure through the evaporation and condensing chambers. With flash evaporators (Figure 3.13) the water is heated in one compartment before being released into a second chamber in which the pressure is substantially lower. The drop in pressure changes the saturation temperature below the actual temperature, so that some of the water instantly flashes off as vapour.

Steam in the chamber at sub-atmospheric pressure is condensed by contact with tubes circulated with the salt feed and is removed by a distillate pump. Suitably placed baffles and demisters, similar to those already described, prevent carry-over of saline droplets. The arrangements for continuous monitoring of distillate purity are similar to those described above.

If two or more vessels in series are maintained at progressively lower absolute pressures, the process can be repeated. Incoming salt feed absorbs the latent heat of the steam in each stage, with a resultant gain in economy of heat and fuel. This is known as cascade evaporation, a term which is self-explanatory. Figure 3.13 shows a two stage flash evaporator distiller. The flash chambers are maintained at a very low absolute pressure by ejectors, steam or water operated; the salt feed is heated initially by the condensing vapour in the flash chambers, subsequently in its passage through the ejector condenser (when steam-operated ejectors are used) and is raised to its final temperature in a heater supplied with low pressure exhaust steam. Brine density is maintained, as in the case of the evaporator-distillers described previously, by an excess of feed over evaporation and the removal of the excess by a pump. The re-circulation of brine may be provided for in plant.

It should be noted that when distillate is used for drinking it may require subsequent treatment to make it potable.

Reverse osmosis

Osmosis is the term used to describe the natural migration of water from one side of a semi-permeable membrane into a solution on the other side. The

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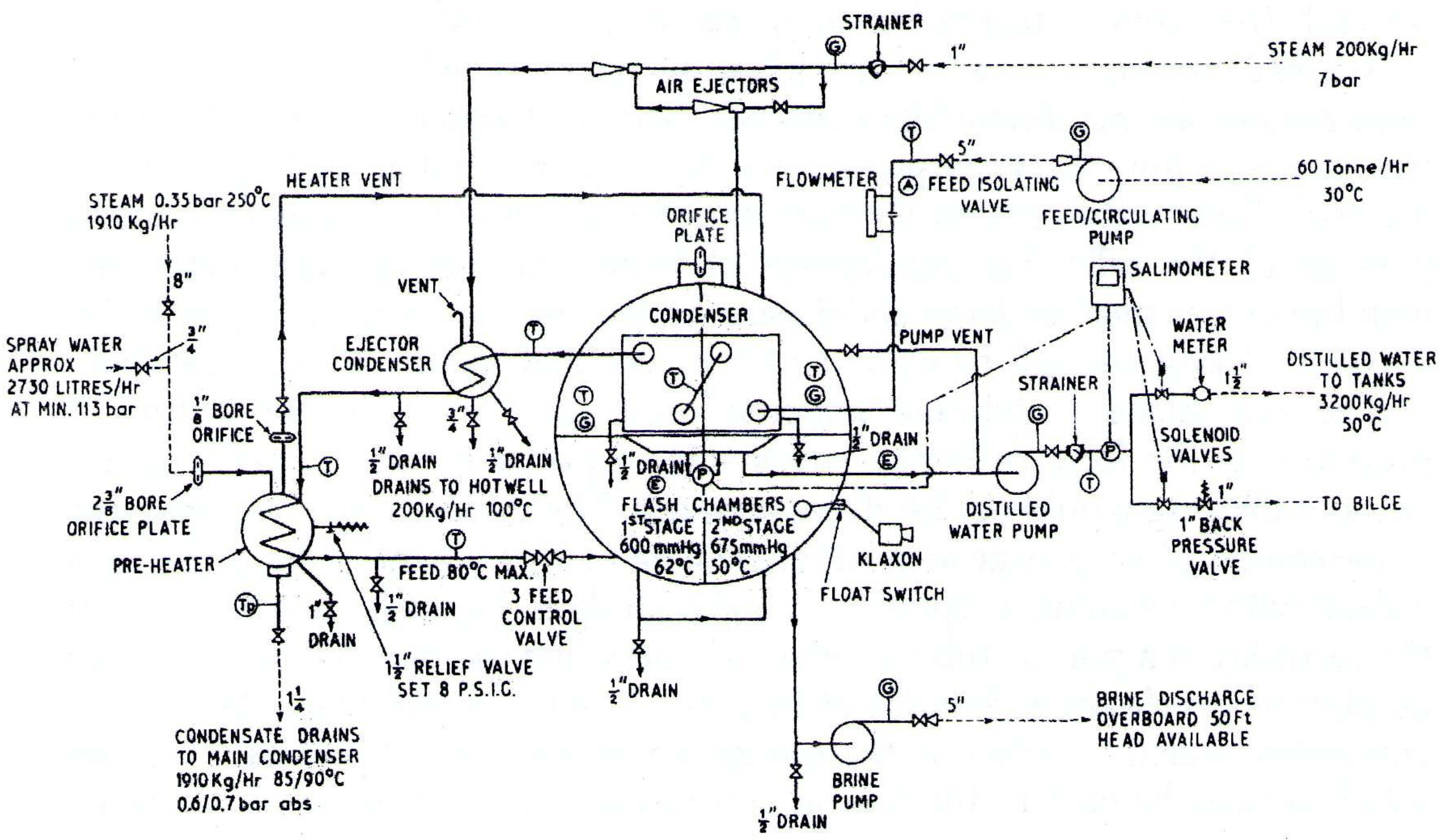

Figure 3.13 *Flow diagrams – cascade evaporator (Caird & Rayner Ltd)*

phenomenon occurs when moisture from the soil passes through the membrane covering of the roots of plants, with no loss of nutrient liquid from the plant. The membrane acts as a one way barrier, allowing the passage of water but not of the nutrients dissolved in the liquid within the root. Osmosis can be demonstrated in a laboratory with a parchment-covered, inverted thistle funnel partly filled with solution and immersed in a container of pure water. The liquid level in the funnel rises as pure water passes through the parchment and into the solution. The action will continue despite the rise of the head ofthe salt solution relative to that of the pure water. Osmotic pressure can be obtained by measuring the head of the solution when the action ceases.

The semi-permeable membrane and the parchment are like filters. They allow the water molecules through but not the larger molecules of dissolved substances. The phenomenon is important not only for the absorption of water through the roots of plants but in animal and plant systems generally.

Reverse osmosis is a water filtration process which makes use of semi-permeable membrane-like materials. Salt (sea) water on one side of the membrane (Figure 3.14) is pressurized by a pump and forced against the material. Pure water passes through but the membrane is able to prevent passage of the salts. For production of large amounts of pure water, the membrane area must be large and it must be arranged in a configuration which makes it strong enough to withstand the very high pump pressure needed.

The man-made membrane material used for sea-water purification is produced in the form of flimsy polyamide or polysulphonate sheets, which without backing would not be strong enough. The difficulty of combining the requirements of very large area with adequate reinforcement of the thin sheets is dealt with by making up spirally wound cartridges (Figure 3.15b). The core of the cartridge is a porous tube to which are attached the open edges of a large number of envelopes each made of two sheets of the membrane material. The envelopes, sealed together on three sides, contain a sheet of porous substance which acts as the path to the central porous tube for water which is squeezed

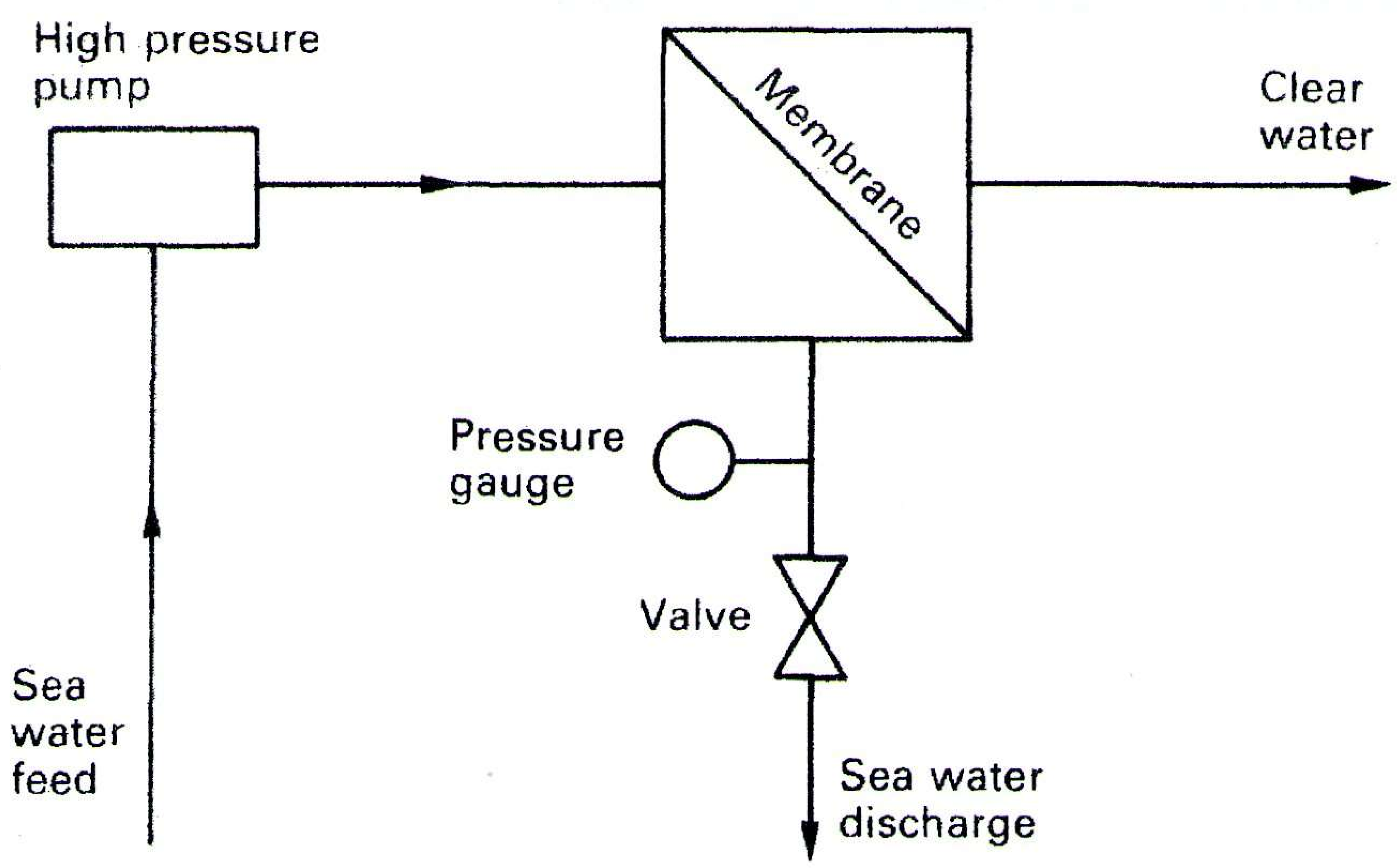

Figure 3.14 *Reverse osmosis principle*

through the membranes. The envelopes are separated by coarse gauze sheets. Assembled envelopes and separators initially have the appearance of a book opened so that the covers are in contact, the spine or binding forming a central tube. The finished cartridge is produced by rotating the actual central tube, so that envelopes and separators are wrapped around it in a spiral, to form a cylindrical shape. Cartridges with end spacers, are housed in tubes of stainless steel (Figure 3.15a) or other material. Output of the reverse osmosis plant is governed by the number of cartridge tubes in parallel. Quality is improved by installing sets of tubes in series.

One problem with any filtration system, is that deposit accumulates and gradually blocks the filter. Design of the cartridges is therefore such that the sea-water feed passes through the spiral windings and over the membrane sheets with a washing action that assists in keeping the surfaces clear of deposit. A dosing chemical, sodium hexametaphosphate, is also added to assist the action.

The pump delivery pressure for a reverse osmosis system of 60 bar (900 lb/in^2) calls for a robust reciprocating or gear pump. The system must be protected by a relief arrangement.

Pre-treatment and post-treatment

Sea-water feed for reverse osmosis plant, is pretreated before being passed through. The chemical sodium hexametaphosphate is added to assist the wash through of salt deposit on the surface of the elements and the sea water is sterilized to remove bacteria which would otherwise become resident in the filter. Chlorine is reduced by the compressed carbon filter while solids are removed by the other filters.

Treatment is also necessary to make the water product of reverse osmosis potable. The method is much the same as for water produced in low temperature evaporators.

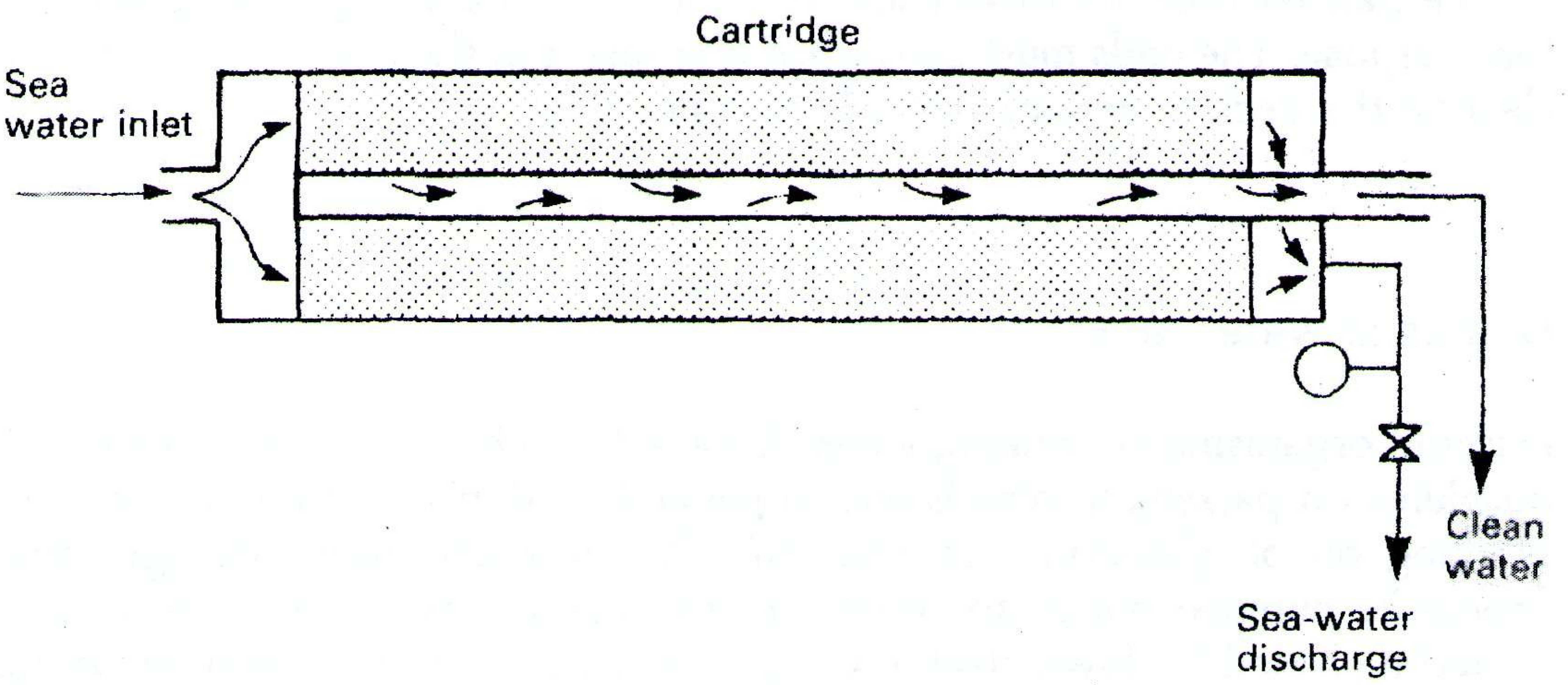

Figure 3.15a *Cartridge for reverse osmosis*

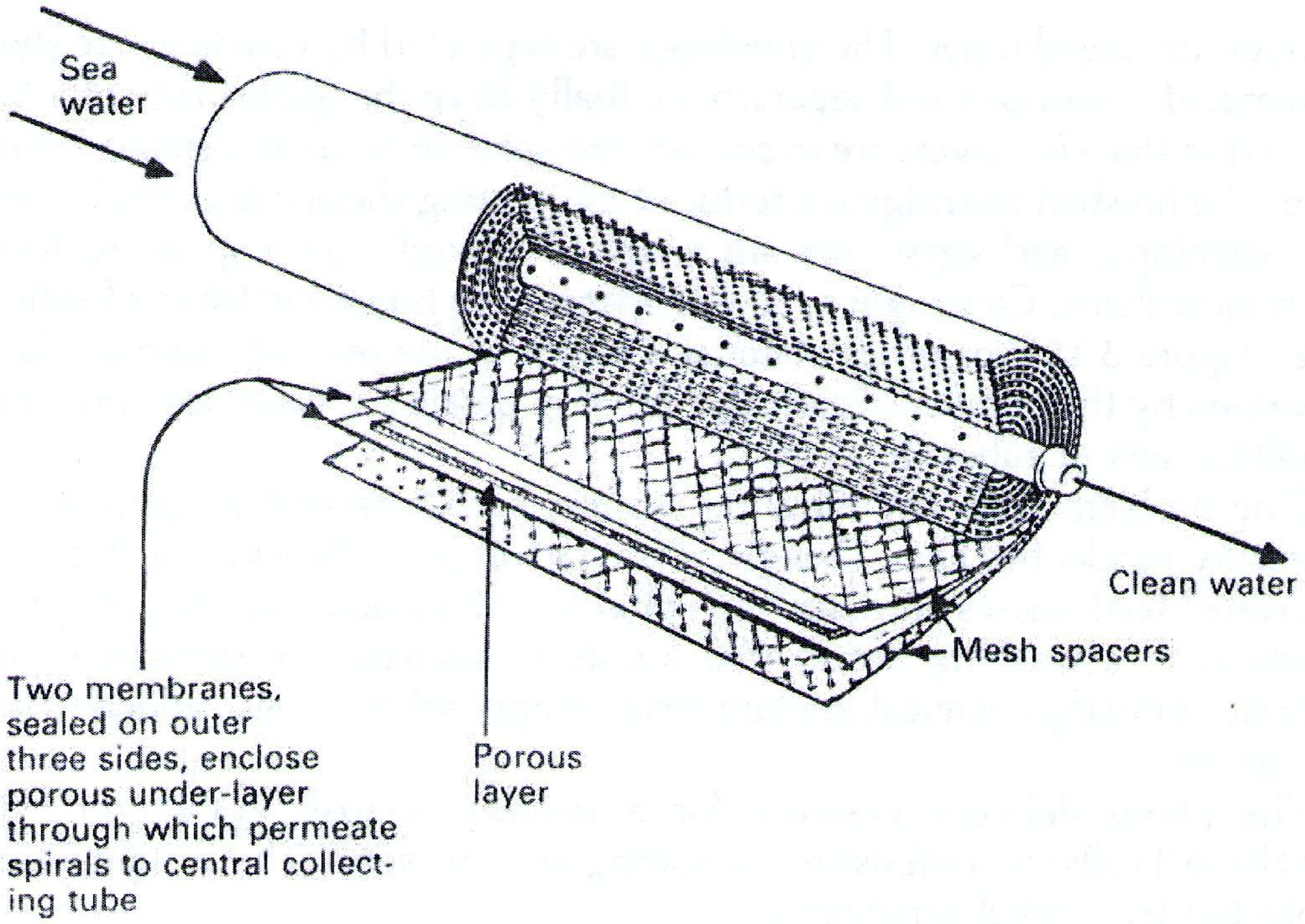

Figure 3.15b *Spirally wound cartridge for reverse osmosis*

Treatment of water from shore sources

There is a risk that water supplied from ashore may contain harmful organisms which can multiply and infect drinking or washing water storage tanks. All water from ashore, whether for drinking or washing purposes, is to be sterilized. When chlorine is used, the dose must be such as to give a concentration of 0.2 ppm. The Department of Transport recommends in Merchant Shipping Notice number M1214 that because of the risk from legionella bacteria entering the respiratory system by way of fine mist from a shower spray, all water including that for washing only, should be treated by sterilization.

The transfer hose for fresh water is to be marked and kept exclusively for that purpose. The ends must be capped after use and the hose must be stored clear of the deck to reduce the risk of contamination.

Domestic water tanks

Harmful organisms in drinking water storage tanks have caused major health problems on passenger vessels and in general to ship's crews and personnel working on oil platforms. To eliminate this problem, water storage tanks should be pumped out at six-month intervals and, if necessary, the surfaces should be hosed to down clean them. At the 12-month inspection, recoating may be needed in addition to the cleaning. Washing with a 50 ppm solution of

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chlorine is suggested. Super-chlorinating when the vessel is drydocked, consists of leaving a 50 ppm chlorine solution in the tank over a four hour period, followed by flushing with clean water.

The steel tank surfaces may be prepared for coating by wire brushing and priming. Subsequently a cement wash is applied or an epoxy or other coating suitable for use in fresh water tanks.

Sewage systems

The exact amount of sewage and waste water flow generated on board ship is difficult to quantify. European designers tend to work on the basis of 70 litres/person/day of toilet waste (including flushing water) and about 130–150 litres/person/day of washing water (including baths, laundries, etc.). US authorities suggest that the flow from toilet discharges is as high as 114 litres/person/day with twice this amount of washing water.

The breakdown of raw sewage in water is effected by aerobic bacteria if there is a relatively ample presence of oxygen, but by anaerobic bacteria if the oxygen has been depleted. When the amount of sewage relative to water is small, dissolved oxygen in the water will assist a bio-chemical (aerobic) action which breaks down the sewage into simple, clean components and carbon dioxide. This type of action is produced in biological sewage treatment plant in which air (containing 21% oxygen) is bubbled through to sustain the aerobic bacteria. The final discharge from an aerobic treatment plant has a clean and clear appearance.

The discharge of large quantities of raw sewage into restricted waters such as those of inland waterways and enclosed docks, will cause rapid depletion of any oxygen in the water so that aerobic bacteria are unable to survive. When the self-purification ability of the limited quantity of water is overwhelmed in this way, breakdown by putrefaction occurs. Anaerobic bacteria, not reliant on oxygen for survival are associated with this action which results in the production of black, turgid water and gases which are toxic and flammable. The process is used deliberately in some shore sewage treatment works to produce gas which is then used as fuel for internal combustion engines on the site.

The very obvious effects of sewage discharge in waterways and enclosed docks prompted the Port of London Authority and others to establish regulations concerning sewage discharge and to provide facilities ashore for ships' crews. The lavatories were vandalized and the scheme was found to be impractical. Legislation imposed nationally by the USA (through the Coast Guard) and the Canadian Government was more effective and together with the anticipation of the ratification of Annexe IV of the 1973 IMCO Conference on Marine Pollution was probably more responsible for the development of holding tanks and on board sewage treatment plant.

Some plants are designed so that the effluent is retained in the vessel for discharge well away from land, or to a receiving facility ashore; others are designed to produce an effluent which is acceptable to port authorities for discharge inshore. In the former type, the plant consists of holding tanks which receive all lavatory and urinal emptyings, including flushing water, while

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wash-basins, showers and baths are permitted to discharge overboard. Some are designed to minimize the amount of liquid retained by flushing with recycled effluent. It is claimed that such a system only requires about 1% of the retaining capacity of a conventional retention system.

Effluent quality standards

To discharge sewage in territorial waters the effluent quality may have to be within certain standards laid down by the local or national authorities. These will usually be based on one or more of three factors, namely the bio-chemical oxygen demand (BOD), suspended solids content and e-coliform count of the discharge.

Bio-chemical oxygen demand

The bio-chemical oxygen demand (BOD) is determined by incubating at 20°C, a sample of sewage effluent which has been well-oxygenated. The amount of oxygen absorbed over a five-day period is then measured. The test is used in this context to evaluate the effectiveness of treatment as it measures the total amount of oxygen taken up as final and complete breakdown of organic matter by aerobic bacteria in the effluent occurs. The quantity of oxygen used equates to the amount of further breakdown required.

Suspended solids

Suspended solids are unsightly and over a period of time can give rise to silting problems. They are usually a sign of a malfunctioning sewage plant and when very high will be accompanied by a high BOD. Suspended solids are measured by filtering a sample through a pre-weighed pad which is then dried and re-weighed.

Coliform count

The e-coliform is a family of bacteria which live in the human intestine. They can be quantified easily in a laboratory test the result of which is indicative of the amount of human waste present in a particular sewage sample. The result of this test is called the e-coli. count and is expressed per 100 ml.

Holding tanks

Simple holding tanks may be acceptable for ships which are in port for only a very brief period. The capacity would need to be excessively large for long stays because of the amount of flushing water. They require a vent, with the

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outlet suitably and safely positioned because of gas emissions. A flame trap reduces risk. Inhibiting internal corrosion implies some form of coating and, for washing through of the tank and pump after discharge of the contents at sea, a fresh water connection is required.

Elsan holding and recirculation (zero discharge) system

A retention or holding tank is required where no discharge of treated or untreated sewage is allowed in a port area. The sewage is pumped out to shore reception facilities or overboard when the vessel is proceeding on passage at sea, usually beyond the 12 nautical mile limit.

Straight holding tanks for retention of sewage during the period of a ship's stay in port were of a size large enough to contain not only the actual sewage but also the flushing water. Each flush delivered perhaps 5 litres of sea water. Passenger vessels or ferries with automatic flushing for urinals required very large holding tanks.

Problems resulting from the retention of untreated wastes relate to its breakdown by anaerobic bacteria. Clean breakdown by aerobic organisms occurs where there is ample oxygen, as described previously. In the conditions of a plain retention tank where there is no oxygen, anaerobic bacteria and other organisms thrive. These cause putrefaction, probably with corrosion in the tank and production of toxic and flammable gases.

The Elsan type plant (Figure 3.16) has an initial reception chamber in which separation of liquid and solid sewage takes place. Wastes drop on to a moving perforated rubber belt (driven by an electric motor) which the liquid passes through but solids travel with the belt to fall into a caustic treatment tank. Solids are then transferred by a grinder pump to the sullage or holding tank. The liquid passes via the perforated belt to treatment tanks which contain chlorine and caustic based compounds. These chemicals make the liquid effluent acceptable for use as a flushing fluid. The Pneupress arrangement which supplies liquid for flushing the toilets can deliver recirculated fluid or, when the vessel is on passage, sea water.

Capacity of the holding tank is 2 litres per/person/day. The tank is pumped out at sea, or to shore if the ship is in port for a long period. Tank size is small because liquid effluent passes mainly to the flushing system (excess overflows to the sullage tanks).

Biological sewage treatment

A number of biological sewage treatment plant types are in use at sea but nearly all work on what is called the extended aeration process. Basically this consists of oxygenating by bubbling air through or by agitating the surface. By so doing a family of bacteria is propagated which thrives on the oxygen content and digests the sewage to produce an innocuous sludge. In order to exist, the bacteria need a continuing supply of oxygen from the air and sewage

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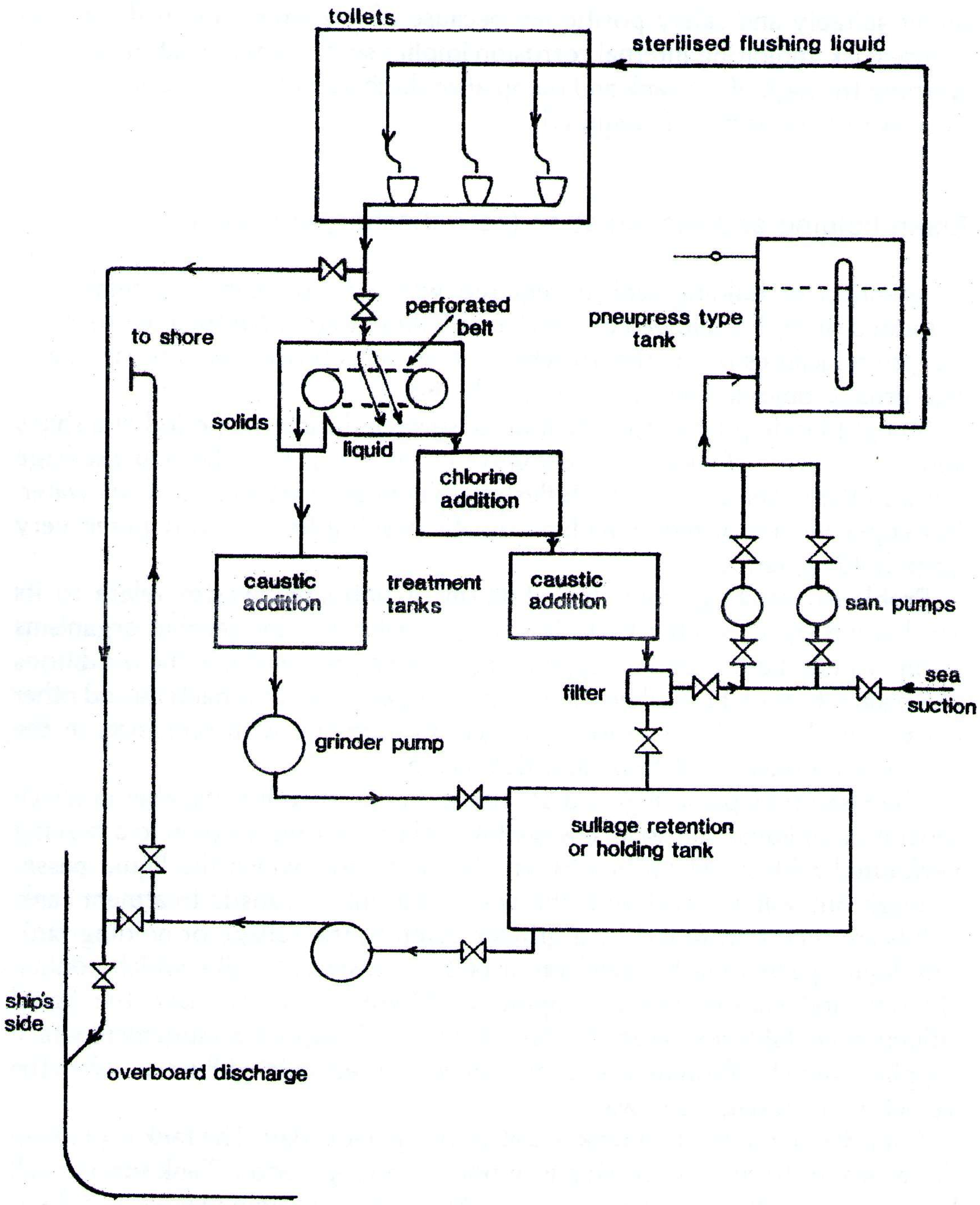

Figure 3.16 *Elsan type sewage plant*

wastes. If plant is shut down or bypassed or if the air supply fails, the bacteria die and the plant cannot function correctly until a new bacteria colony is generated. Change of flushing liquid – as when a ship moves from a sea-water environment to fresh water – drastic change of temperature or excess use of lavatory cleaning agents can also affect the bacteria colony. The process of regeneration can take several days depending on the level of harm caused.

Bacteria which thrive in the presence of oxygen are said to be aerobic. When oxygen is not present, the aerobic bacteria cannot live but a different family of bacteria is generated. These bacteria are said to be anaerobic. Whilst they are equally capable of breaking down sludge, in so doing they generate gases such as hydrogen sulphide and methane. Continuing use of a biological sewage system after a failure of the air supply, could result in propagation of anaerobic bacteria and processes. The gases produced by anaerobic activity are dangerous, being flammable and toxic.

Extended aeration plants used at sea are package plants consisting basically of three inter-connected tanks (Figure 3.17). The effluent may be comminuted (i.e. passed through a device which consists of a rotating knife-edge drum which acts both as a filter and a cutter) or simply passed through a bar screen from where it passes into the first chamber. Air is supplied to this chamber via a diffuser which breaks the air up into fine bubbles. The air is forced through the diffuser by a compressor. After a while a biological sludge is formed and this is dispersed throughout the tank by the agitation caused by the rising air bubbles.

The liquid from the aeration tank passes to a settling tank where under quiescent conditions, the activated sludge, as it is known, settles and leaves a clear effluent. The activated sludge cannot be allowed to remain in the settling tank since there is no oxygen supplied to this area and in a very short time the collected sludge would become anaerobic and give off offensive odours. The sludge is therefore continuously recycled to the aeration tank where it mixes with the incoming waste to assist in the treatment process.

Over a period of time the quantity of sludge in an aeration tank increases due to the collection of inert residues resulting from the digestion process, this

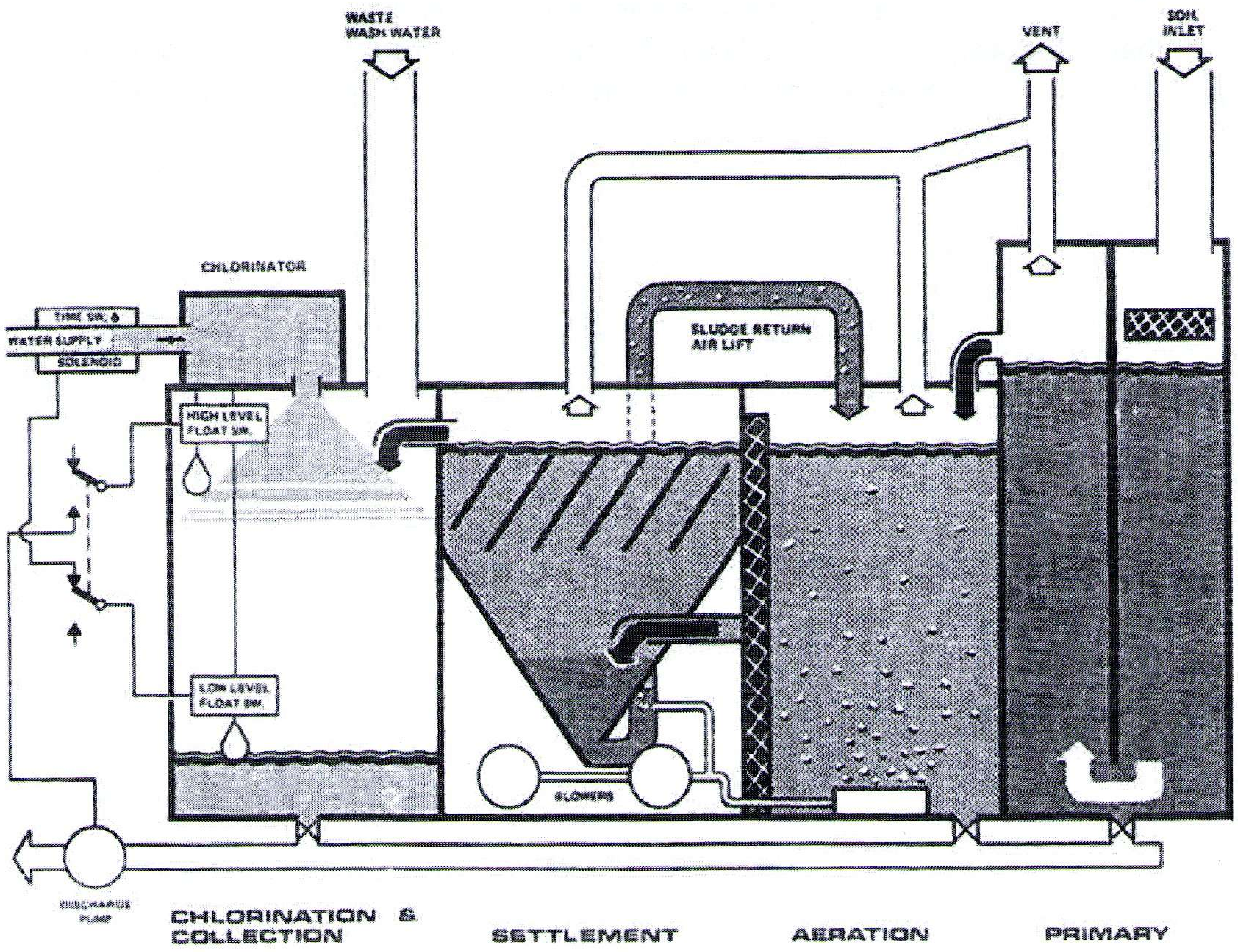

Figure 3.17 *Biological sewage treatment plant (Hamworthy)*

build up in sludge is measured in ppm or mg/litre, the rate of increase being a function of the tank size. Most marine biological waste treatment plants are designed to be desludged at intervals of about three months. The desludging operation entails pumping out about three quarters of the aeration tank contents and refilling with clean water.

The clear effluent discharged from a settling tank must be disinfected to reduce the number of coliforms to an acceptable level. Disinfection is achieved by treating the clean effluent with a solution of calcium or sodium hypochlorite, this is usually carried out in a tank or compartment on the end of the sewage treatment unit. The chlorinator shown in Figure 3.17 uses tablets of calcium hypochlorite retained in perforated plastic tubes around which the clean effluent flows dissolving some of the tablet material as it does so. The treated effluent is then held in the collection tank for 60 minutes to enable the process of disinfection to be completed. In some plants the disinfection is carried out by ultra-violet radiation.

Further reading

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