8 DESIGN AND INSTALLATION ONBOARD OF PROPULSION SYSTEMS AND AUXILIARY MARINE SYSTEMS

8.1. Introduction to technical specification, layout and onboard integration of propulsion systems and auxiliary marine systems

8.1.1. Ship's systems design development

Introduction:

Shipboard piping systems form a pervasive network that is required to support all of the ship's essential functions. These systems convey steam, fuel, lubricating oil, and cooling water to operate machinery, transport bulk cargo and ballast, provide for human health and comfort (e.g., potable-water, heating, chilled-water, and waste-collection systems), protect the safety of the ship and crew with fire-extinguishing agents and damage-control systems, and collect and remove pollutants. Piping systems are among the most complex ship systems to design and construct.

Piping systems engineers apply principles of static and dynamic stress analysis, thermodynamics, and fluid-flow theory to design safe and efficient piping networks. Beyond this, they face additional challenges. Shipboard piping systems consist not only of pipes, valves, and fittings, but also an array of components that condition and control the fluids, such as pumps, strainers, and heat exchangers. Piping systems also contain control valves, transducers, and actuators, which interact with equipment served by the systems and must be compatible with ship control and monitoring systems. Although piping-system engineers are not directly responsible for the design of all these components, they require a basic understanding of components characteristics to integrate them into a properly functioning system.

One of the more difficult tasks of a piping-system engineer is to define and continually update all of the system design requirements through progressively more detailed design phases. This task is difficult, partially because the piping system engineer initially has only a general understanding of the components that require piping services, and partially because the components engineers, who are the source of the information, may not realize the piping system engineer's need for the data. Disruptions will be exacerbated throughout the design process if changes in component characteristics, additions of new components, and deletion of components are not communicated promptly to the piping-system engineer. Thus, it is usually necessary for the piping-system engineer to actively pursue the information needed rather waiting for the information to be forwarded in a routine manner.

The ship design parameters that establish the basis for many piping-system characteristics include the following:

> a) Ship general arrangement – the overall size, hull subdivision, and space arrangement are the primary bases for the design of fire-protection and emergency-dewatering systems. Appropriate fire-extinguishing agents and distributions systems must be selected for machinery spaces, storerooms, living quarters, and cargo holds. Special-purpose areas, such as the main deck of a crude-oil tanker require specialized systems (manifolds, p-v valves, catwalk, etc.). The capacity and location of dewatering pumps are related to hull volume and the arrangement of watertight compartments. The arrangement of fuel and water transfer systems must accommodate the tank

storage capacity and arrangement selected by the naval architect. The locations of living and messing areas strongly influence the design of plumbing drainage and collection systems. Also, the height and separation of compartments served by piping systems will influence operating pressures and pipe sizes.

b) Propulsion and electric plants – the type, number, brake power, and location of propulsion and generator engines establish flow rates, pressures, and filtration requirements for fuel and lubricating-oil systems. Propulsion and generator cooling requirements, together with lesser needs of auxiliary equipment, set requirements for seawater and freshwater cooling systems. The compressed-air pressure, quality, production capacity, and storage volume must meet plant requirements for starting and controls.

c) Operations – the ship operating areas, trade routes, port facilities, and voyage length affect piping system design requirements, such as fresh water production and disinfection, waste retention and treatment capacities, liquid cargo and ballast flow rates, pollutant discharge limits, and tank capacity requirements.

d) Complement – the number of crew and passengers and the habitability standards selected form the basis for capacities of systems providing cold and hot potable water, sanitary flushing, and waste retention and processing.

e) HVAC – the heating and cooling systems total capacities establish flows of heating-steam and chilled-water systems.

f) Mission-specific systems – the purpose and mission of each ship influences the capacity and arrangement of many of the piping systems, and often require a unique system. Naval combat ships, specialized cargo carriers, fishing vessels, and icebreakers are but a few examples.

g) Special attributes – the ship owner may require special emphasis on cost reduction, weigh reduction, commonality of equipments, or other attributes in the design of piping systems.

Approximately 70% of the value added by the shipbuilder during construction of the more complex ships is related to piping systems. Thus a significant cost reduction can be realized by applying techniques to simplify the design, fabrication, assembly, and installation of piping systems. The principles of designing for production, zone outfitting, and modular construction must be applied beginning very early in the ship design process and must continue throughout all design phases. Computer-aided design and manufacturing techniques, while possibly increasing the initial design costs, also provide an opportunity for overall cost reductions, with additional benefit of providing design data of significantly superior quality.

System Design Phases:

During **concept design**, a tentative list of requirements is developed based on the available, usually very general, ship characteristics. If sufficient arrangement details have been developed, a preliminary check of the sizes and relative locations of the spaces can be made to ensure that major pipes runs can be accommodated. Since insufficient details are available to develop independent cost and weight estimates at this stage, such estimates are usually extrapolated from the data for existing ships of similar design.

During **preliminary design**, the major piping system components are selected and arranged in the ship. Preliminary estimates of the system flows, pressures, and temperatures are made to support component selection. Systems parameters may change several times during this phase to accommodate design updates; therefore, the piping engineers must close together with others who are laying out spaces, arranging machinery, and selecting equipment to ensure that a compatible design is maintained. Piping systems performance requirements are determined on the basis of the ship mission, size, operating profile, complement, main machinery, and other factors. Component selection is based on meeting the performance requirements within established goals for weight, cost, noise, shock, and reliability. Because it may not be possible to satisfy all requirements fully, trade-off studies are usually necessary to select the optimum design solution.

The approximate locations of major components and piping runs relative to the ship arrangement, and to each other, are determined during the preliminary design phase. These locations must be selected carefully because subsequent rearrangements can be prohibitively expensive in terms of design man-hours and schedule considerations. Similar or related components should be grouped (e.g., potable water pumps, tanks, desalinators, and purification equipment) to minimize piping, ease operation, and facilities off-ship assembly of equipment packages. For naval combatant designs, the separation of redundant components, for survivability reasons, is an important consideration.

Sketches of the larger piping runs, ventilation ducts and wireways are prepared to determine space requirements. As soon as a general arrangement drawing is prepared, the sizes of compartments, passageways, and trunks are reviewed, to ensure that piping and other distributive systems can be accommodated. The relative locations of components that will be connected by piping are checked to eliminate unnecessary long or complex runs, avoid pipe runs through restricted spaces, and permit gravity flow of fluid where required. Piping runs should be planned to avoid penetrating highly stressed structural members; otherwise, the structure will require reinforcement around the penetration.

During **contract design**, the piping engineer develops additional details of each system within the broad outlines fixed during the preliminary design phase, and describes each system by specifications and contracts plans. Contract drawings are developed to illustrate spatial relationships and the interconnections of system components, which may not be understood easily from written specifications. Together the specifications and contract drawings define the system sufficiently to ensure the owner's requirements for performance and quality are understood, and to permit the shipbuilder to prepare a bid. Minimum requirements to be specified include pressures, temperatures, and services supplied by each system; the number, capacity, and locations of major components; the level of redundancy required for fluid sources and flow paths; piping material schedules; fabrication, assembly, and inspection methods and the industry or government standards which must be applied; and piping system cleaning and testing requirements. In commercial practice, pipe sizes are sometimes established during contract design; more often, specially for naval ships, the determination of pipe sizes is shipbuilder's responsibility.

The first three design phases are primarily focused on performance and are often accomplished by the prospective owner or his design agent. However, the **detail design** phase is focused on construction and is usually accomplished by the shipbuilder. True to its name, this phase results in a full definition of every piping-system element, culminating in drawings that are used to manufacture or procure all parts of the systems, and install them in the ship.

Piping-System Diagrams:

The piping-system diagrams, which are begun in preliminary form during the preliminary design phase and progressively updated into detail design as more specifically applicable data become available, constitute a foundation on which the system details are based throughout the detail design phase. The system diagrams are used to ensure the systems will meet the specification requirements and that all elements of the systems are compatible with each other and with other design elements to which they are linked: e.g., controls and machinery interfaces. Piping diagrams are the starting point for the development of all piping production drawings. Piping diagrams depict system components and their interconnections in schematic form, as typically illustrated in sections 8.3 and 8.4. Information about the system arrangement in the ship is included to varying degrees, but is usually limited to the space and deck level on which a pipe or component will be located, since it is impractical to convey greater detail in the diagram format. Diagrams also include:

a) Components identification and respective symbols;

b) Material schedule;

c) Component performance ratings and pump curves;

d) Valve description;

e) System pressures, temperatures, flow rates, velocities, and pressure drops;

f) Pipe sizes;

g) Flow direction arrows;

h) Identification of compartments and bulkheads;

i) Characteristics of instruments;

j) Operating characteristics of pressure, temperature, level, and flow controls;

k) Notes invoking fabrication, cleanliness, painting, testing, and safety requirements;

l) System shock and noise requirements;

m) References to interfacing drawings, standards and procedures.

The quality and clarity of piping diagrams are important because diagrams serve so many functions during design, construction, and operation of the ship and are the primary means of understanding how the systems work and how they relate to other ship systems. Components and piping should be laid out in a logical fashion, with system flows generally from one side of the sheet to the other. Functional relationships should be shown clearly, and components of equal importance should have equal prominence. Primary pipe runs should be given the most direct paths on the sheet and be shown with heavier line widths. Parallel paths should be arranged as symmetrically as possible. Information about how the system operates should be given priority over information concerning shipboard locations.

Detailed Piping-System Drawings:

Detailed piping system arrangement drawings are prepared as soon as the diagrams are developed sufficiently. The format of piping arrangement drawings is closely related to the ship construction methods, the computer aided design system in use, and individual shipyard practices. The intended use of the drawings by the shipowner may also influence their format and content. Arrangement drawings depict piping, fittings, and components to scale as they will appear assembled and installed in the ship, and include complete material lists. Arrangements drawings are used by design engineers to review installation details such as pipe slope and pump suction flow, and to conduct pipe flexibility and flow calculations They are also used by owners and operators of ships for maintenance and crew training, and planning future modifications. Piping arrangement drawings typically show only one system or related systems on a single drawing to simplify the presentation. The development and arrangement drawings must include a process for identifying and eliminating interferences within piping systems and between piping and ducting, cableways, and other parts of the ship. For drawings that are prepared using computer aided design methods, the computer software often includes an interference check capability.

Construction Drawings:

Construction drawings are oriented to the requirements of the production and installation techniques practiced within shipyard . Modular construction methods may facilitated by the use of task oriented drawing that covers all systems to be installed in a portion of the ship. These drawings are oriented to the activities of the construction tradesmen, who need not be aware of how the system elements they install are related to the system as a whole. A concentrated effort to improve producibility of piping systems is made during detail design phase. Many of production methods are related to the specific practices of the building yard, but the following guidelines are generally applicable:

a) Locate and orient components with respect to each other to minimize the piping length, changes in direction, and number of joints;

b) Arrange pipes to facilitate access to joints for assembly, inspection, and testing;

c) Give priority for the most direct routing to piping that is large or made of difficult-to-fabricate material;

d) Use bends instead of elbows wherever possible;

e) Locate takedown joints at boundaries of construction units and removable access plates;

f) Plan piping assemblies to permit as much off-ship fabrication as possible;

g) Make headers to which multiple branches are connected the same size throughout their length to simplify fabrication, rather than reducing their size at each branch.

Space Arrangement of the Main Machinery Spaces:

The development of piping systems within a machinery space and the machinery space arrangement are inseparable because the locations of many machinery components are influenced by piping system considerations, and piping must be arranged with knowledge of the arrangement restrictions that govern other components in the space.

There is generally no optimum machinery space arrangement that will completely satisfy all requirements. It is the responsibility of the marine engineer to assess the alternatives and select one which offers acceptable compromises as a solution to the design problem. This is an iterative process.

One of the first decisions to be made regarding the machinery space is its location. For many ships there are two choices: the aftermost region of the ship, or the region somewhat aft of amidships. Machinery spaces of oil tankers and other ships with full lines are generally at the stern, thereby simplifying the design by allowing shorter and stiffer propeller shafting and reducing interferences with cargo handling. The hull lines aft on high-speed cargo and passengers liners are usually so fine that the propulsion will not fit within the confines of the stern region. For such ships the machinery space must be located farther forward, where the ship is sufficiently wide.

When developing a machinery space arrangement, an engineer must visualize the ship structure, piping, valves, tanks, and other components in the space as well as the propulsion and auxiliary machinery, so that utilization of a 3D model of these items is highly favored. In general the following guidelines should be adopted:

a) Develop direct routes and minimum distances for wiring and piping interconnecting the major components;

b) Accommodate the reach, sight lines, safety, and comfort of the operators;

c) Provide access for maintenance and overhaul;

d) Allow sufficient permeability for fire-extinguishing agents.

In the initial stages of design, the arrangement is based on components that are only tentative selections and whose dimensions are only approximate. Therefore a reasonable allowance should be made for variations in dimensions and unanticipated developments. In addition, since payload is not carried in the machinery space, the space must be no larger than necessary, especially in length. However, sufficient space must be reserved to:

a) Permit the installation of large piping, ventilation ducting, and power cables;

b) The proper operation and maintenance of all equipment;

c) Rapid personnel egress in an emergency;

d) Access for firefighting and other damage-control functions.

Trade-offs between the components initially selected and the available space are sometimes required to resolve conflicts. For example, although horizontal pumps are easier to support and are more readily overhauled than vertical pumps, vertical pumps may ultimately be chosen because they occupy less deck area. Trade-offs are also necessary when arranging piping, ducting, and components. Placing a component in its ideal location from the standpoint of maintenance, operation, or access may necessitate additional joints and direction changes in piping in the vicinity. The piping engineer must determine which arrangement provides the most advantageous overall compromise.

A list of strong tips is presented below for the main machinery arrangement and piping layout selection:

a) Removal clearances and routes should be studied to ascertain that components that cannot be repaired in place can be removed;

b) Sufficient space allowance should be made for thermal insulation and noise treatment of machinery and piping where necessary;

c) The location of structural elements is a major consideration in arranging machinery and piping;

d) Headroom, clearance routes, and the location of overhead support structure should be planned for hoists and tracks to provide for the maintenance of heavy component parts;

e) Gratings and walkways should be located and routed with sufficient width and overhead clearance;

f) Seawater pumps should be located sufficiently low and inboard to provide adequate suction head for all conditions of ship trim and motion;

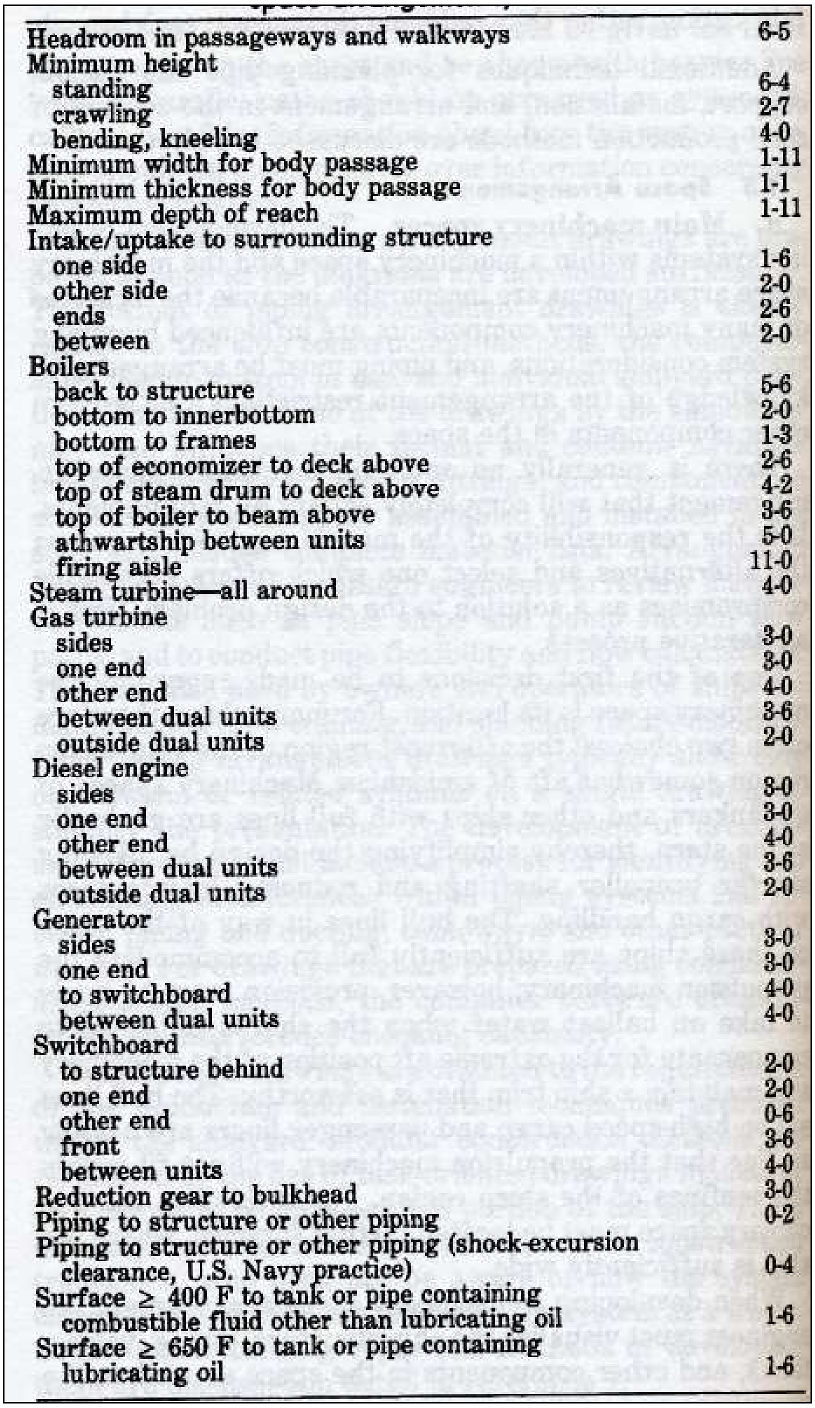
g) Sea chests should be low enough to avoid air ingestion, and close to the pumps connected to them;

h) Bilge pumps should be located low in space for adequate suction lift;

i) Main access leaders should be 60 [cm] wide and slope 60º above the horizontal;

j) Suggested clearances around major components are given in Table 8.1.

Tab. 8.1 – Suggested minimum clearances for machinery space arrangements (units [ft-in]).



Headroom in passageways and walkways	6-5
Minimum height	
standing	6-4
crawling	2-7
bending, kneeling	4-0
Minimum width for body passage	1-11
Minimum thickness for body passage	1-1
Maximum depth of reach	1-11
Intake/uptake to surrounding structure	
one side	1-6
other side	2-0
ends	2-6
between	2-0
Boilers	
back to structure	5-6
bottom to innerbottom	2-0
bottom to frames	1-3
top of economizer to deck above	2-6
top of steam drum to deck above	4-2
top of boiler to beam above	3-6
athwartship between units	5-0
firing aisle	11-0
Steam turbine—all around	4-0
Gas turbine	
sides	3-0
one end	3-0
other end	4-0
between dual units	3-6
outside dual units	2-0
Diesel engine	
sides	3-0
one end	3-0
other end	4-0
between dual units	3-6
outside dual units	2-0
Generator	
sides	3-0
one end	3-0
to switchboard	4-0
between dual units	4-0
Switchboard	
to structure behind	2-0
one end	2-0
other end	0-6
front	3-6
between units	4-0
Reduction gear to bulkhead	3-0
Piping to structure or other piping	0-2
Piping to structure or other piping (shock-excursion clearance, U.S. Navy practice)	0-4
Surface $\geq$ 400 F to tank or pipe containing combustible fluid other than lubricating oil	1-6
Surface $\geq$ 650 F to tank or pipe containing lubricating oil	1-6

A machinery arrangement for a typical medium-speed diesel plant is shown in Figures 8.1 and 8.2. The major constraints are:

a) Shaft angle;

b) Topside configuration;

c) Access to the reduction gear;

d) Operating level layout.

In addition, space must be allowed for the overhaul of pistons, cylinder heads, turbochargers, and other major component parts; for piping connections to, and maintenance of, engine-attached auxiliaries, such as cooling-water pumps and fuel pumps; and for the removal of tube bundles from intercoolers and aftercoolers. The angle and size of engine-exhaust connections must be considered to allow a direct routing of exhaust ducting; this is also a consideration for intake-air piping, which is frequently provided for the larger engines. If the plant has an exhaust-gas heat-recovery system, a significant volume of space above the engine is needed for the boiler. If the engine has an integral sump, sufficient space musty be provided to locate the tank underneath the engine. If a separate sump is to be provided, its location should be close to the engine and sufficient low to prevent backflow of oil to the engine after shutdown. If the engine or reduction gear is resiliently mounted, the added height and greater engine deflection due to the mounts must be taken into consideration.

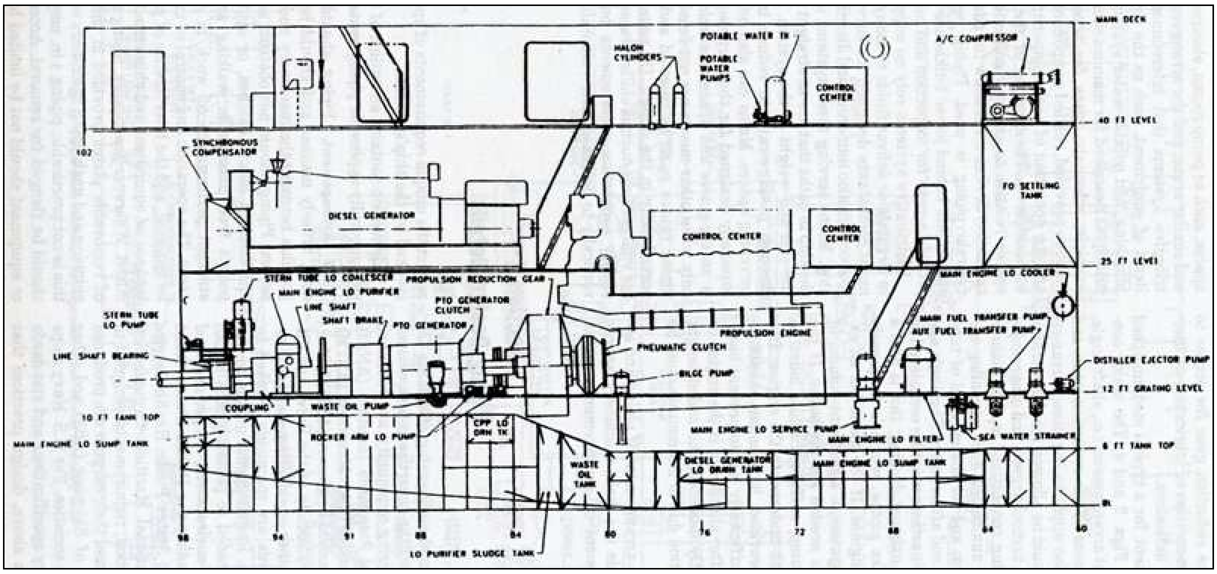


Fig. 8.1 – Medium-speed diesel plant machinery arrangement – elevation of centerline, looking to port.

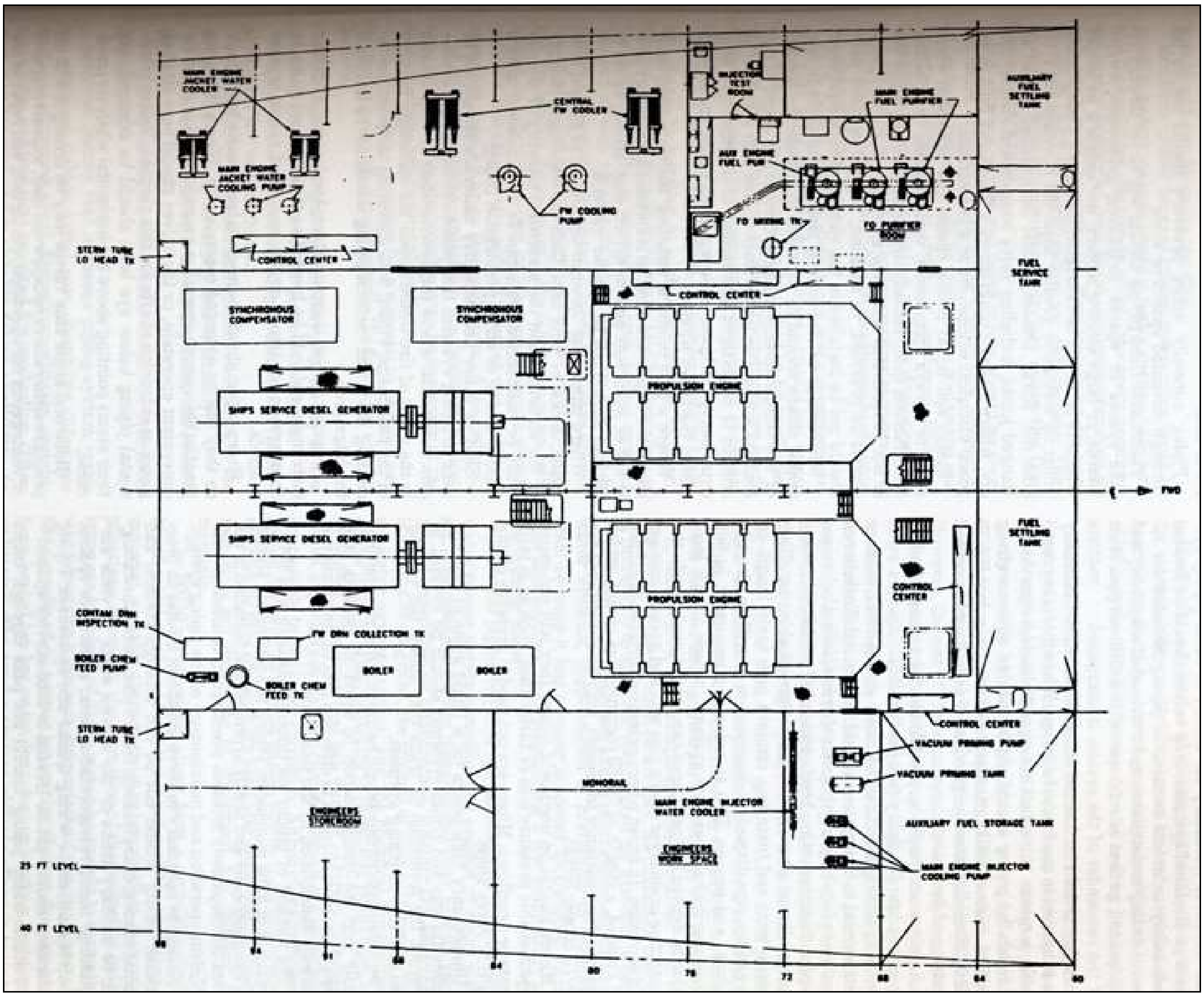


Fig. 8.2 – Medium-speed diesel plant machinery arrangement – plan view at operating level.

8.1.2. Piping design details

This section contains an outline of the more significant and generally applicable piping systems requirements divided by the following attributes:

a) Arrangement;

b) Materials;

c) Pipe size selection;

d) Pipe wall thickness;

e) Flexibility and support;

f) Joints;

g) Valves and valves operators;

h) Orifices;

i) Insulation and color code for identification of pipelines;

j) Sea connections;

k) Watertight bulkheads.

a) Arrangement

a.1) Piping should be arranged in a neat, orderly manner and should be run as directly as possible between the machinery and components that it serves;

a.2) Piping should not obstruct or interfere with the operation of doors, hatches, or scuttles;

a.3) Piping should permit free passage in walking areas and the unobstructed performance of work in designated working areas;

a.4) Wherever practicable, piping should be kept clear of removable plates provided in the ship structure for shipping and unshipping machinery or equipment. Where this is not practicable, piping 4-10 [cm] nominal size and larger should be flanged for removal;

a.5) Piping should be portable in way of machinery and equipment that require dismantling for periodic overhaul, and wherever necessary for access to other piping systems or electrical systems. Stop valves should be located judiciously to isolate sections of piping intended for removal during maintenance and overhaul of machinery and equipment, so that interference with continued operation of the reminder of the system in minimized;

a.6) Piping should be located where it would not normally be subjected to mechanical damage. When this is impracticable, a means to protect the piping should be provided;

a.7) Insulated piping should not be located where wetting due to normal leakage, condensation, or splashing is likely. Shielding must be provided if necessary to prevent wetting of insulation;

a.8) Piping arrangements which cause excessive turbulence detrimental to the system should be avoided. Turbulence can be reduced by using gradual transitions in pipe diameter or using bend instead of elbows;

a.9) Unnecessary high points (in liquid system) or low points (in gas and liquid systems should be avoided to prevent the formation of traps that inhibit the venting and draining of piping systems;

a.10) Pump suction piping should be arranged to rise continuously into the pump suction to avoid air pockets, and should not have changes in direction that cause an uneven velocity distribution at the pump inlet;

a.11) The amount of piping led through messing and living spaces should be minimized;

a.12) Except as necessary to serve the space, insofar as practicable, piping should not be run through medical and dental spaces; chain lockers; freshwater, fuel, lubricating-oil, or sanitary tanks or the services areas or voids surrounding them; refrigerated spaces; electronics spaces; control stations; or wiring trunks and enclosures;

a.13) Potable-water piping should not pass through tanks other than those containing potable water. Piping other than potable water should not pass through potable-water tanks unless the through piping is isolated from the potable water by a trunk or a larger pipe that is open at the end;

a.14) Where pipes pass through watertight bulkheads, decks, or tank tops, both watertight integrity of the structure and the structural integrity of the pipe must be maintained;

a.15) Pressure gauges, thermometers, level gauges, and other instruments should be located so that they are visible to an operator at the associated valves or other controls;

a.16) Every effort should be made to locate handwheels so they can be operated conveniently. Where this is not practicable, remote operating gear should be provided for convenient operation, or the valves should have attached gears or extensions shafts for this purpose. Valves in horizontal piping below eye level should be arranged with their stems pointing above the horizontal wherever practicable;

a.17) Manifolds should be used where many pipes must be joined together, such as where pump suction joins several tank tailpipes. Manifolds, reduce the space required, reduce the number of field joints, and ease operation by co-locating valve handwheels;

a.18) Inlet piping to safety and relief valves should be short and direct;

a.19) Vents from flammable fluid tanks and atmospheric reliefs from toxic and inert gas systems should not terminate where their discharge can be picked up by ventilation or forced-draft air intakes, or where their discharge would otherwise damage machinery or equipment or endanger personnel;

a.20) Tailpipes should terminate at the lowest point in tanks and should be installed in such a manner as to guard against their coming into hard contact with the bottom of the tank should the bottom of the tank deflect upward. The end of each suction tailpipe should be enlarged to provide an area not less than 1.5 times the inside area of the tailpipe.

b) Materials

In order for a material to perform satisfactorily, it must possess the following characteristics:

b.1) Sufficient strength or load-carrying ability at the operating temperature to resist the imposed loads;

b.2) Retention of suitable ductibility and impact properties at all operating temperatures;

b.3) Satisfactory corrosion and erosion resistance in the media that it contacts internally and externally;

b.4) Resistance to galling with mating materials in moving contact;

b.5) Inability to contaminate fluids contacted internally or externally.

Additional factors that influence piping-system material selections include initial cost, durability (life-cycle cost), ease of making joints, fitting compatibility, weight, availability, and lead time required for production. Often more than one material is suitable for an application, in which case the relative importance of all factors must be weighted to determine the preferred selection.

Seawater piping requires special attention because seawater causes severe corrosion and erosion of many metals. Steels are specially susceptible to sweater corrosion. Although galvanizing, epoxy coatings, or rubber linings can be used to increase the service lives of steel in a seawater environment, these measures are expensive to implement and difficult to maintain.

The 90-10 copper-nickel alloys form a protective oxide layer, which prevents further corrosion of the underlying material. However, the formation of the protective oxide layer can be inhibited if seawater contains pollutants.

Plastics and composite materials offer the advantages of lower weight and cost and freedom from corrosion compared with metals. The materials in this category commonly used in shipboard applications are polyvinyl chloride (PVC) and glass-reinforced plastic (GRP). However, they are more susceptible to fire damage than metals and may produce toxic gases. Also, most piping made of plastics or composites has a lower structural rigidity than metal piping, reducing its ability to resist loads imposed during, transport, assembly, and service.

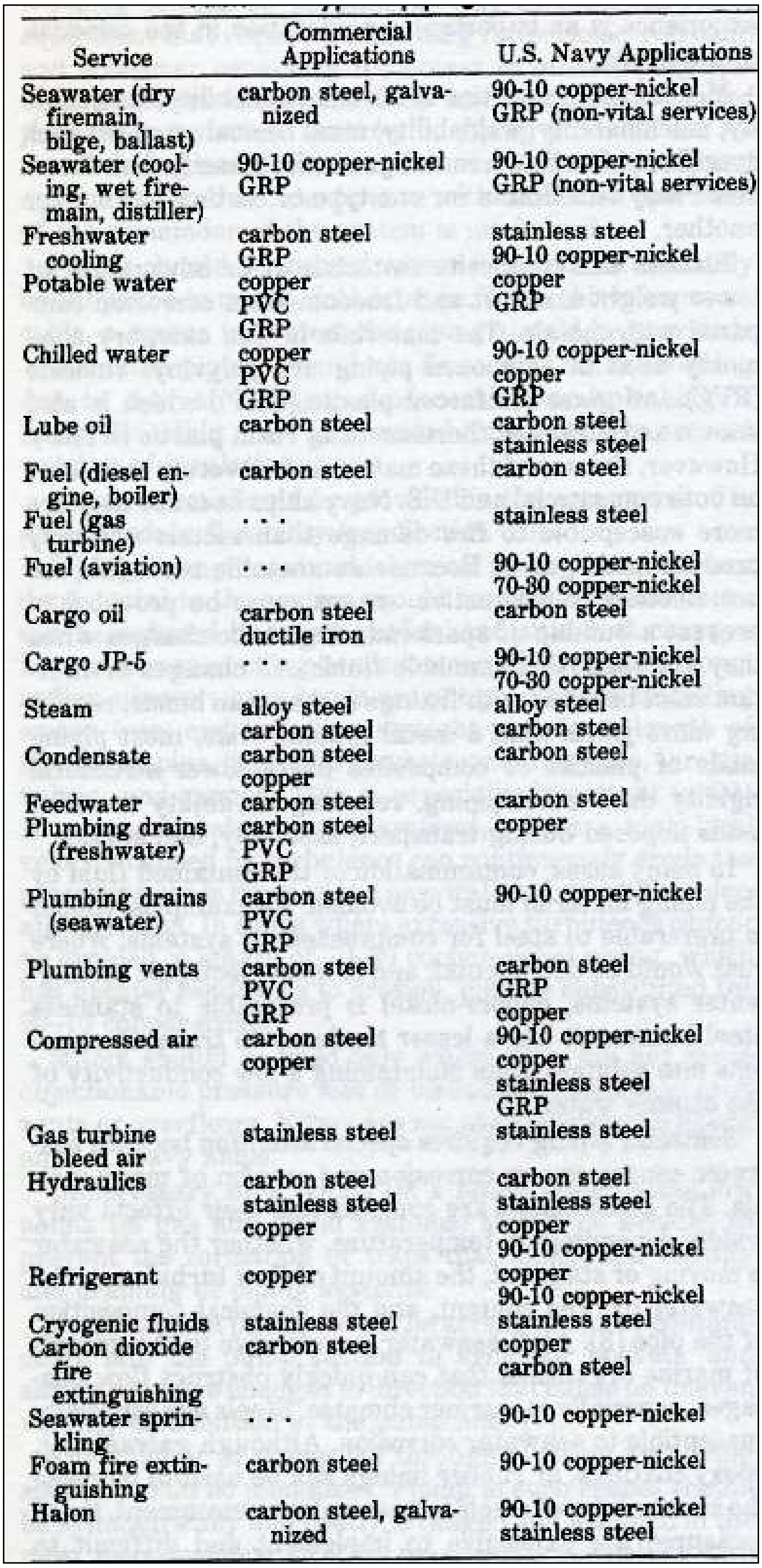
Galvanic corrosion can severely attack metals that are exposed to an electrolyte. To minimize the effects of galvanic corrosion in seawater piping systems materials close together in galvanic series should be selected or any means of isolation should be provided.

In zones where excessive turbulence is expected a 70-30 copper-nickel piping, which has greater resistance to erosion, may replace a 90-10 copper-nickel.

In many cases, contamination of the contained fluid by piping material must be avoided. As examples, copper is preferable to steel for compressed air systems, where rust would be detrimental; and in most-electronic cooling water systems, copper-nickel is preferable to stainless steel because it has lesser tendency to transmit metal ions to solution, thus maintaining a low conductivity of the cooling water.

Typical material selections for piping systems in naval and commercial service are given in Table 8.2.

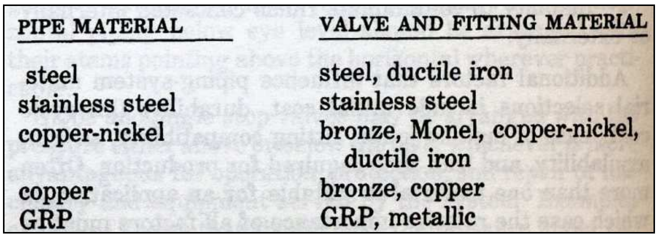
Tab. 8.2 – Typical piping materials.



Service	Commercial Applications	U.S. Navy Applications
Seawater (dry firemain, bilge, ballast)	carbon steel, galvanized	90-10 copper-nickel GRP (non-vital services)
Seawater (cooling, wet firemain, distiller)	90-10 copper-nickel GRP	90-10 copper-nickel GRP (non-vital services)
Freshwater cooling	carbon steel GRP	stainless steel 90-10 copper-nickel
Potable water	copper PVC GRP	copper GRP
Chilled water	copper PVC GRP	90-10 copper-nickel copper GRP
Lube oil	carbon steel	carbon steel stainless steel
Fuel (diesel engine, boiler)	carbon steel	carbon steel
Fuel (gas turbine)	. . .	stainless steel
Fuel (aviation)	. . .	90-10 copper-nickel 70-30 copper-nickel
Cargo oil	carbon steel ductile iron	carbon steel
Cargo JP-5	. . .	90-10 copper-nickel 70-30 copper-nickel
Steam	alloy steel carbon steel	alloy steel carbon steel
Condensate	carbon steel copper	carbon steel
Feedwater	carbon steel	carbon steel
Plumbing drains (freshwater)	carbon steel PVC GRP	copper
Plumbing drains (seawater)	carbon steel PVC GRP	90-10 copper-nickel
Plumbing vents	carbon steel PVC GRP	carbon steel GRP copper
Compressed air	carbon steel copper	90-10 copper-nickel copper stainless steel GRP
Gas turbine bleed air	stainless steel	stainless steel
Hydraulics	carbon steel stainless steel copper	carbon steel stainless steel copper 90-10 copper-nickel
Refrigerant	copper	copper 90-10 copper-nickel
Cryogenic fluids	stainless steel	stainless steel
Carbon dioxide fire extinguishing	carbon steel	copper carbon steel
Seawater sprinkling	. . .	90-10 copper-nickel
Foam fire extinguishing	carbon steel	90-10 copper-nickel
Halon	carbon steel, galvanized	90-10 copper-nickel stainless steel

Material for valves and fittings should be compatible with the associated piping material to provide similar strength, facilitate joint fabrication, and control galvanic corrosion. Typical combinations are shown in Table 8.3.

Tab. 8.3 – Typical valves and fittings materials for different piping systems.



PIPE MATERIAL	VALVE AND FITTING MATERIAL
steel	steel, ductile iron
stainless steel	stainless steel
copper-nickel	bronze, Monel, copper-nickel, ductile iron
copper	bronze, copper
GRP	GRP, metallic

c) Pipe size selection

Pipe sizes are selected primarily so that:

c.1) Flow resistance in a system is such that design flow rates and pressures are achieved using reasonable pump or compressor ratings (or, for gravity flow, reasonable gradients);

c.2) The accompanying fluid velocities do not produce unacceptable turbulence, erosion or noise.

Pipe sizes are determined iteratively. As the first step, trial sizes are selected to obtain reasonable fluid velocities. Table 8.4 contains velocities that have been found to be satisfactory in service. The upper limits were established to avoid excessive turbulence, erosion, and noise. For seawater piping, a minimum velocity of 1 [m/s] is desirable to discourage the attachment of marine organisms.

The second step is to calculate resistance for the trial pipe sizes using design flows. The resistance is calculated for each flow path and each operating condition. The resistance is calculated for each flow path and each operating condition. The sum of the flow resistance (dynamic loss) plus the elevation change (static loss or gain) in each flow path plus the required pressure at the terminal point is compared with the pressure available at the source (see Annex B for the case of a centrifugal pump design). The trial sizes are adjusted and resistances recalculated until the source pressure is equal to or greater than the resistance for the worst-case condition. A final check should be made to ensure that the velocity in each pipe segment is satisfactory.

Pipe flow resistance depends on the flow rate, pipe dimensions and roughness, and the properties of the fluid. The tools of analysis are derived from the momentum relation, the continuity equation, a friction factor, the general energy equation, and the equation of state. The first three of these may be combined to form the following differential equation, which describes the condition of fluid in motion:

$$\frac{dp}{\gamma} + d\left(\frac{V^2}{2g}\right) + dz + \frac{\tau}{\gamma R} dL = 0 \tag{8.1}$$

, where:

p = fluid pressure, [kg/m^2];

γ = fluid density, [kg/m^3];

V = fluid velocity, [m/s];

g = acceleration of gravity, [m/s^2];

z = elevation of fluid, [m];

τ = fluid frictional shear stress, [kg/m^2];

R = mean hydraulic radius of flow channel (area/wetted perimeter), [m];

L = pipe length, [m].

If the flow is horizontal or the fluid is a gas, the third term can be dropped. Additionally, if the fluid is a liquid and there are no significant changes in flow area, the second term can be dropped. The remaining terms can be integrated to obtain the following expression for the pressure loss, Δp, over a length of pipe, ΔL:

$$\Delta p = \frac{\tau}{R}\Delta L \tag{8.2}$$

The fluid frictional shear stress at the pipe wall is defined as:

$$\tau = f\frac{\gamma}{g}\frac{V^2}{8} \tag{8.3}$$

, where f is a dimensionless friction factor. R is defined as one-fourth the pipe diameter, d, for a circular pipe flowing full; therefore, the head loss, h_L, over a length of pipe can be determined from equation (8.2) as:

$$h_L = \frac{\Delta p}{\gamma} = f\frac{L}{d}\frac{V^2}{2g} \tag{8.4}$$

For laminar flow, the friction factor is a function of Reynolds number (i.e., of pipe diameter and fluid velocity, density, and viscosity). For turbulent flow, the friction factor is also a function of roughness of the pipe wall. Empirical values such as those of Moody are used to determine the friction factor for new pipes of various materials. Increases in pipe growth or scaling from corrosion should be taken into account by use of appropriate roughness values.

Valves and fittings behave differently than straight pipe in that their flow resistance is primarily caused by turbulence, changes in direction, and changes in velocity of the fluid rather than frictional shear stress. Empirical studies show that the resistance of a valve or fitting can be expressed as a resistance coefficient, or "K factor", representing the number "velocity heads" lost through the component, that is:

$$h_L = K\left(\frac{V^2}{2g}\right) \tag{8.5}$$

The K factor is essentially independent of friction factor and Reynolds number. Values of K for common valves and fittings are given in Table B.1 of Annex B.

Tab. 8.4 – Design fluid velocities for piping systems.

Service	Fluid Velocity, fps	
	Nominal[a]	Limit
Condensate pump suction	$\sqrt{d}$	3
Condensate pump discharge	$3\sqrt{d}$	8
Condensate drains	$0.3\sqrt{d}$	1
Hot-water suction	$\sqrt{d}$	3
Hot-water discharge	$3\sqrt{d}$	8
Feedwater suction	$1.3\sqrt{d}$	4
Feedwater discharge	$4\sqrt{d}$	10
Cold freshwater suction	$3\sqrt{d}$	15
Cold freshwater discharge	$5\sqrt{d}$	20
Lube-oil service pump suction	$\sqrt{d}$	4
Lube-oil discharge	$2\sqrt{d}$	6
Heavy-fuel service suction	$\sqrt{d}$	4
Heavy-fuel service discharge	$1.5\sqrt{d}$	6
Heavy-fuel transfer suction	$\sqrt{d}$	6
Heavy-fuel transfer discharge	$2\sqrt{d}$	15
Distillate-fuel suction	$2\sqrt{d}$	7
Distillate-fuel discharge	$5\sqrt{d}$	12
Hydraulic-oil suction	$1.5\sqrt{d}$	8
Hydraulic-oil discharge	$8\sqrt{d}$	20
Seawater suction	$3\sqrt{d}$	12[b,c]
Seawater discharge	$5\sqrt{d}$	12[b,c]
Steam, high pressure	$50\sqrt{d}$	200
Steam exhaust, 215 psig	$75\sqrt{d}$	250
Steam exhaust, high vacuum	$75\sqrt{d}$	330

[a] d is the pipe internal diameter in inches.

[b] 9 fps for galvanized steel pipe.

[c] Seawater velocity in titanium and GRP piping may exceed these limits without detrimental erosion; however, friction losses, turbulence, and noise may still be limiting factors.

While the above can be used to determine pipe sizes, it cannot necessarily be used to predict actual flows or operating pressures in the system. However, such predictions may be necessary when parallel paths must be balanced (such as in a sprinkling grid), when operating pressures or velocities must be known accurately to determine control settings, when pipe sizes must be optimized to minimize weight, or when operating parameters for other than the design conditions must be known. For these situation, a flow network analysis such as the Hardy Cross method for balancing pipe networks can be used (see Annex C). Using this method, preliminary pipes sizes are estimated first, as before, and then calculations are made for iteratively assumed flows in each path until the calculated resistance exactly matches the pressure available to cause flow, thus corresponding to the actual flow in the path. When performing a flow network analysis, valve and fittings losses should be represented as K factors rather than as equivalent lengths to improve accuracy, because equivalent lengths vary with flow rate while K factors are independent of flow rate.

When more than one pipe size will satisfy these conditions, additional factors such as weight, space, and ease of fabrication may be considered, which usually results in the selection of the smallest suitable sizes.

Ideally, pipe sizes and pressure sources (such as pumps or compressors) should be selected simultaneously, permitting a balance to be achieved between the installation cost and the operating cost of the system. The result would be an optimum design that does not have oversized pipes (requiring excessive weight and space) or undersized pipes (resulting in excessive driver power). In practice, the ratings of pressure sources are often established so that their cost and space requirements can be determined and adequate lead time for manufacture can be provided well before the pipe sizes are selected. It is then the responsibility of the piping engineer to select pipe sizes that are compatible with the design characteristics previously selected.

A suitable margin should be added to the calculated system resistance when selecting source pressures and pipe sizes. The size of the margin should consider deterioration of the pressure source over its expected life, increases in piping resistance due to biological fouling or scaling from corrosion, and expected growth in system demand.

Pipe sizes should ensure rated flow to each component during all operating conditions wherever possible. Orifices or throttle valves should be used only where necessary to regulate flow, or to correct unavoidable unbalances where a main serves two or more components through parallel piping circuits. Pressure losses through piping and components in parallel paths should be such that it is not necessary to install a restriction in the path to a component requiring the greater flow (such as a main condenser) to ensure adequate flow in the path to a component requiring the lesser flow (such as lubricating-oil cooler).

For a system containing a pump, pipe sizes must be selected with consideration to both the pump total head (defined as the rated pressure differential between the pump suction and discharge connections) and the required pump section head. The total system pressure loss including the pump suction piping loss must not exceed the pump total head. In addition, the total pressure loss in the pump suction piping must not reduce the net positive suction head available at the pump suction below the net suction head required by the pump. This is of particular concern when the fluid has a high vapor pressure (e.g., feedwater) or is highly viscous (e.g., lubricating oil), or when the pump is located above the fluid source. The total pressure loss includes both the flow resistance and the net static pressure change due to elevation. Annex B, contains further details concerning these considerations.

Low ambient temperatures are frequently encountered when starting and operating shipboard systems, which result in significantly higher resistances due to an increase in fluid viscosity. Cold start-up conditions often determine the worst-case resistance. Consideration of low temperatures is particularly important in the design of fuel, lubricating-oil, and hydraulic systems.

To prevent ingress of air in closed-circuit piping, such as chilled-water systems and freshwater cooling systems, particular attention should be paid to maintaining a positive gauge pressure throughout the system under all operating conditions, especially when the system has a high vertical loop.

Systems providing so-called “hotel services”, i.e., hot and cold potable water and waste and soil drains, are subjected to peak loading at various times of the day, as well as unequal loads in various parts of the systems. Establishing the appropriate design flow for segments of piping in these systems, therefore either a probabilistic or empirical approach should be adopted.

Since the waterline varies with the loading condition of the ship, analyses for sea-connected systems should be based on the ship displacement representing the worst-case condition. For example, in the case of a fire main system discharging to fireplugs in the superstructure, the lightest load condition is the worst case because it places the fireplugs at their greatest elevation above the waterline.

For most types of piping, pipe sizes are identified using the term "nominal pipe size" (NPS) or simply "nominal diameter" (DN). The relations between DN and the pipe diameter and pipe wall thicknesses are usually well defined by the Classification Society rules or standard DIN 2441, as shown by Table 8.5.

Tab. 8.5 – Standard dimensions for pipes, according to DIN 2441.

DN [cm]	**Pipe external diameter [cm]**	**Pipe wall thicknesses [cm]**
15	21.3	3.25
20	26.9	3.25
25	33.7	4.05
40	48.3	4.05
50	60.3	4.50
65	76.1	4.50

d) Pipe wall thickness

The pipe wall thickness must be sufficient to withstand internal and external design pressures, and external loads imposed during assembly and operation.

The design pressure and temperature use to establish the pipe wall thickness should be the highest (or most severe) the piping is expected to experience in service. These values are also used in selecting the pressure rating of the valves and other pressure-containing components in the system. Different values may be chosen for different parts of the system; for example, pump suction piping is usually designed for a lower pressure than its discharge piping. Improper operation and component failure must be considered in establishing design conditions; thus, the relief-valve setting, rather than a pressure regulating valve-setting, should be used as the design pressure; and stop valves or check valves should not be considered boundaries for purposes of establishing design pressure. For open-ended piping, such as escape piping, that is subjected to high-flows, the maximum back pressure at upstream end should be used as the design pressure.

The minimum thickness to withstand design pressure depends on the pipe size and allowable stress of the material at the design temperature. The internal pressure usually determines this thickness. The following factors must be considered in addition to the design pressure and temperature when selecting the standard thickness to order:

> d.1) Thickness must be such that fabrication and assembly procedures, such as threading and bending, will not thin the pipe below the minimum wall thickness under any circumstances;
>
> d.2) For piping that is subjected to corrosion or erosion, particularly in seawater, an allowance based on material and expected life of the piping should be added to the minimum thickness (a thickness increase of about 10%);

d.3) For open-ended and low-pressure piping, the ordered thickness should provide sufficient mechanical strength to prevent damage by the crew or cargo, or operational damage after installation.

e) Flexibility and support

All piping must have sufficient flexibility to absorb dimensional changes resulting from thermal expansion and contraction, and motion resulting from flexing the hull structure, resilient equipment mounts, and shock excursions. This flexibility must be provided to prevent:

e.1) Pipe overstress in compression, tension, or torsion;

e.2) Overload of piping supports;

e.3) Excessive bending moment at joints;

e.4) Excessive design loads on equipments to which the piping is connected.

The necessary flexibility must be provided without exceeding the motion tolerance of supports or allowing piping to strike adjacent structure.

The flexibility of piping depends on its size, wall thickness, and material; the number and location of changes in direction; and the type and location of supports. The amount of movement that must be absorbed by the piping depends on the operating temperature range, the structure flexibility of the ship, the movement of piping attachment points (e.g., resiliently mounted equipment), and the shock inputs. Flexibility calculations are required whenever reasonable doubts exists that adequate flexibility has been provided. Reasonable doubt of flexibility of a two-anchor segment of ferrous piping of uniform size may be considered to exist when:

$$\frac{d.y}{(U-L)^2} \leq 4.32 \tag{8.6}$$

, where:

d = pipe nominal diameter, in [cm];

y = resultant movement to be absorbed by the, in [cm];

U = straight-line distance between anchors, in [cm];

d = developed length of pipe, in [cm];

For high-temperature systems, flexibility is primarily provided by designing bends, elbows, loops, and offsets in to the piping run. The response to thermal expansion of piping containing a U-shaped expansion bend is illustrated in Figure 8.3. The left-hand sketch shows the pipe anchored only at point A, allowing free expansion. When the pipe is heated, expansion causes point B to be displaced to point B'; however, the action of this force would result in the pipe having an angular deflection at this point and a restraining moment must be added. The resulting expansion stresses in this illustration are bending stresses. The deeper the U-bend between anchor points, the lower the stresses will be for a given temperature range. Expansions bends are frequently installed in three-dimensions as illustrated in Figure 8.4.

Flexibility is greatly increased in three directions, and only one leg of the three legs is in torsion.

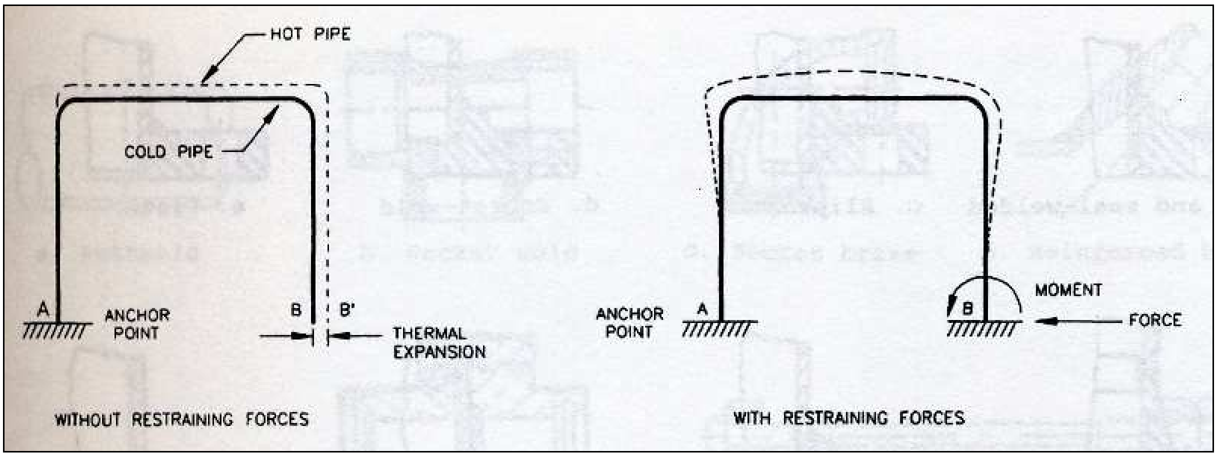


Fig. 8.3 – U-shaped expansion bend.

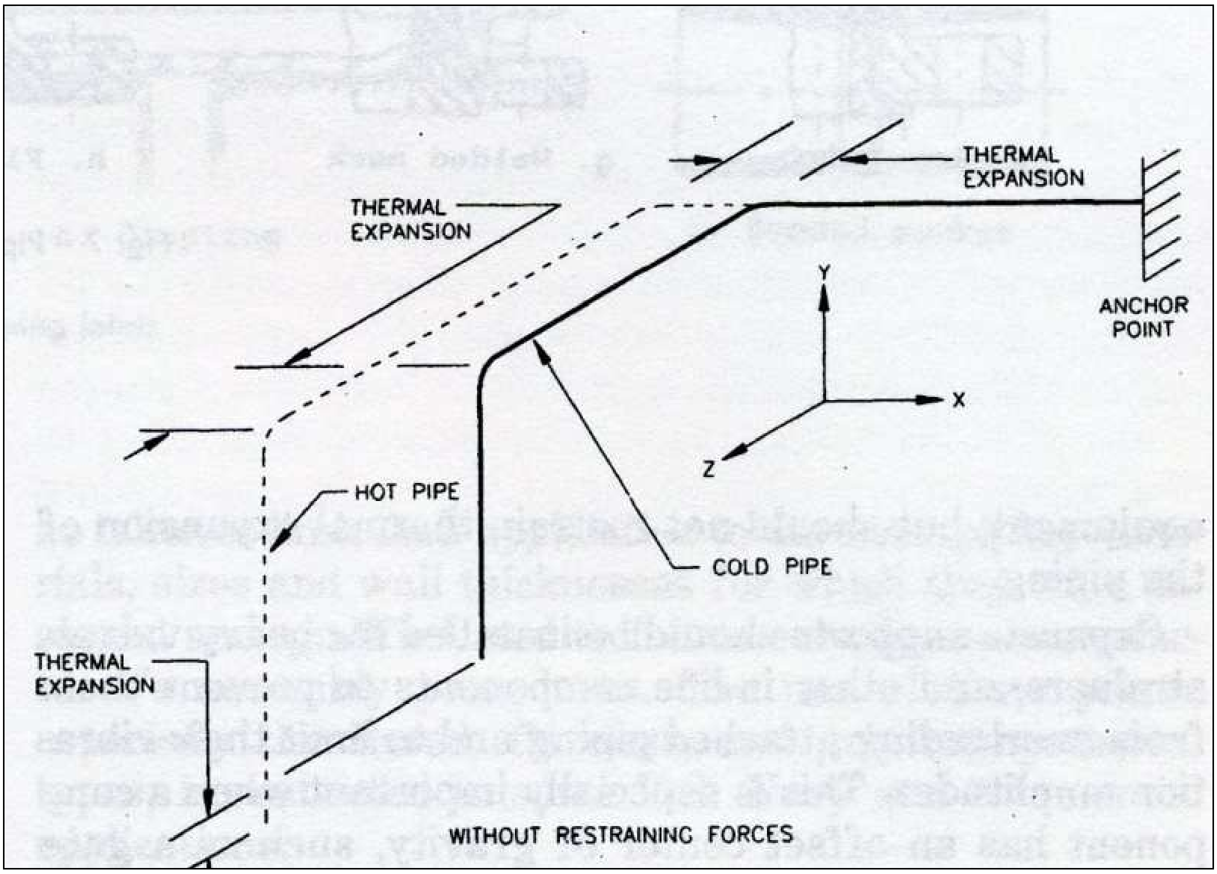


Fig. 8.4 – 3D expansion bend.

Expansion joints may also be used to provide flexibility. Sliding and elbow types of expansion joints absorb linear motion, while ball, swivel, and rotary types absorb angular motion.

The motion of resiliently mounted equipment is often accommodated by installing flexible hoses at the equipment, such as air compressors, the connected instrument piping should be provided with suitable loops or bends to prevent fatigue failures.

Pipe supports must be sufficient to carry the weight of the piping and the contained fluid, including the hydrostatic test fluid, and inertial loads resulting from vibration, ship motion, and shock. Pipe supports should prevent the transmission of excessive loads to connected equipment, but should not restrain thermal expansion of the piping.

Separate supports must be installed for heavy valves, strainers, and other in-line components to prevent them from overloading attached piping and to limit their vibration amplitudes. Valve bonnet bolts should not be used for attaching supports unless the bolts have been designed strong enough for the loads. During ship trials, additional supports may be found necessary to eliminate resonant conditions.

Extra support is usually required in the vicinity of large relief valves to absorb the reaction forces that occur when relief valves lift.

f) Joints

Shipboard piping is exposed to constant vibration and flexing; therefore, highly reliable joints are required. Many types of joints do not have the strength and durability required to operate in the shipboard environment for a long period without leaking. Some of the satisfactory joints include: bolted flange, butt weld, socket weld, brazed socket, reinforced branch connection, threaded, union, coupling, mechanically attached fitting, and bonded socket (for plastic and composite materials).

The selection of joints for a given piping system is based on many factors, including: pressure, temperature, cost, safety, ambient conditions, pipe size, pipe material, relative ease of assembly in the shop or on the ship, ease of inspection and quality assurance, availability of components with matching connections, skill level required for installers, and restrictions imposed by regulatory bodies, classification societies, and owner requirements. Most systems contain several different types of joints.

The flanged joints shown by Figure 8.5 are suitable for the full range of pressures and temperatures of shipboard systems. Gaskets suitable for the pressure, temperature, and flange mating surfaces must be selected. The bolts must provide adequate strength for the joint size and pressure, and the bolting material must be suitable for the ambient conditions (e.g., seawater corrosion, high temperature).

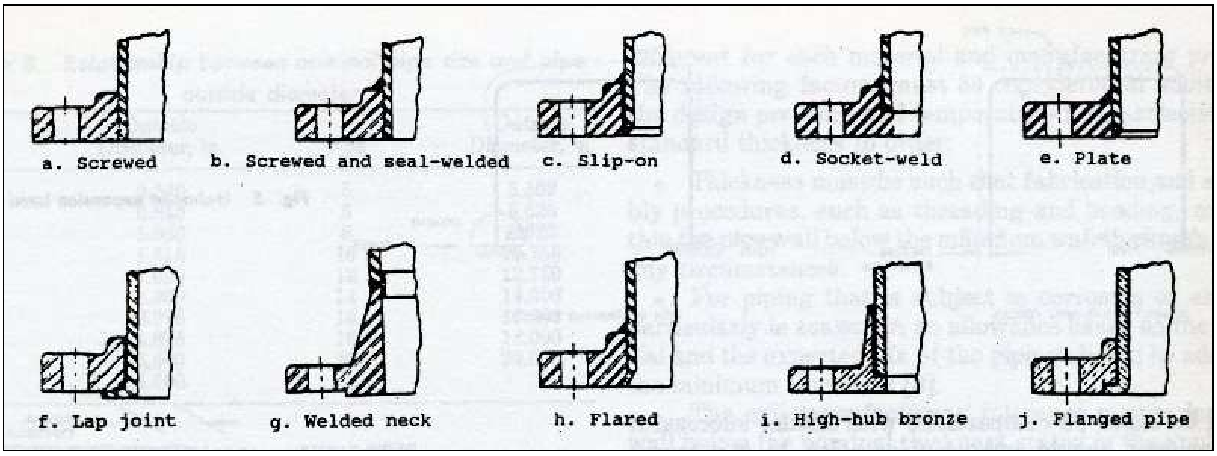


Fig. 8.5 – Typical piping flanges.

Welded joints (see Figure 8.6 (a) and (b)) are also suitable for all shipboard pressures and temperatures.

Brazed joints (see Figure 8.6 (c)) have upper temperature limits that depend on the pipe material and the brazing metal used.

Reinforced branch connections (see Figure 8.6 (d)) provide a method of attaching branches without using a fitting, thus reducing the number of joints per branch from three to two, and making easier the installation of anew branch on an existing pipe. These connections are designed to reduce stress concentration that exists at the junction of the two pipes in an unreinforced connection. The connections are designed for either welding or brazing.

Threaded piping joints, of the straight or tapered type (see Figure 8.6 (e) and (f)), are convenient to assemble and disassemble. However, compared with other joint types, they are more prone to leakage and crevice corrosion at the threads, and have less mechanical strength. Union joints (see Figure 8.6 (g)) are designed to overcome the weaknesses of threaded joints by providing greater mechanical strength and allowing use of an O-ring if necessary to isolate the threads from the system fluid, while still providing easy assembly and takedown.

Couplings are manufactured in many configurations (see Figure 8.6 (h)) and provide an inexpensive, simple method of assembly without hot work. Some types of couplings that are attached directly to the pipe are not considered secure against separation due to vibration, thermal movement, and flexing of the ship. Some types require a packing gland or other seal to prevent leakage.

Bonded socket joints (see Figure 8.6 (i)) are used with GRP pipe and are assembled with adhesive.

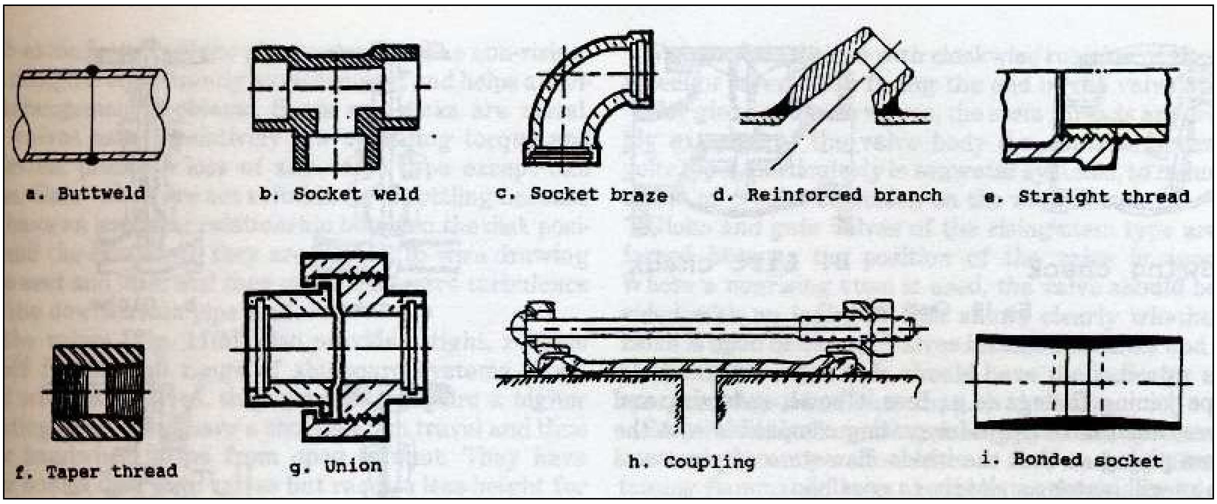


Fig. 8.6 – Typical piping joints.

The category of mechanically attached fittings, which are illustrated in Figure 8.7, includes a number of devices that provide a firm attachment of the fitting to the pipe without welding, brazing, or threading the pipe. These fittings use various techniques including swaging, shape-memory alloys, flares, and ferrules that bite into or grip the pipe.

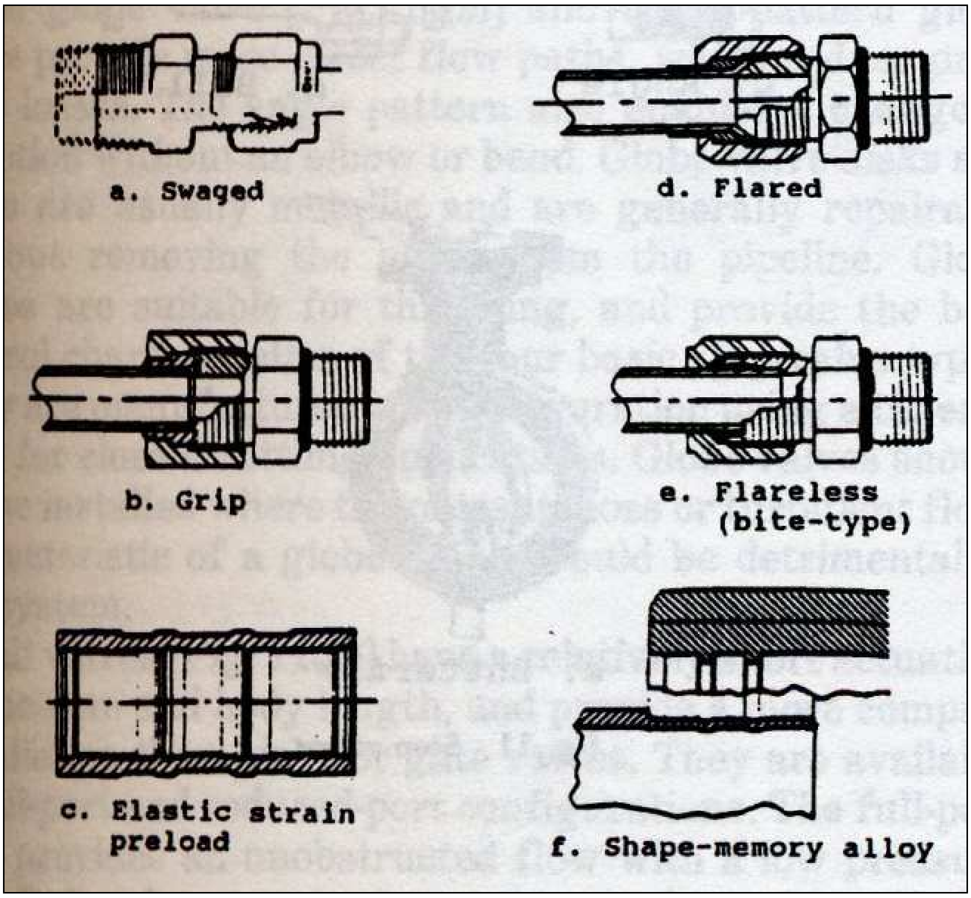


Fig. 8.7 – Typical piping mechanically attached fittings.

More recently, some European manufacturers developed other solutions for piping connections, much easy to install, such as this one illustrated in Figure 8.6 by a company designated Straub^{TD}.

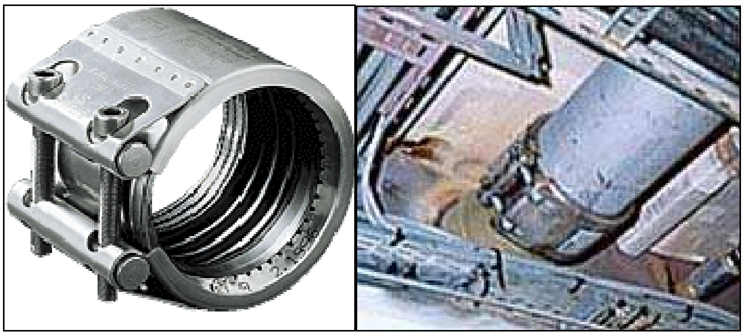


Fig. 8.8 – Straub type piping joint.

Joints that have a high resistance to fire, such as welded, union, and flanged joints, should be used for fire extinguishing systems and systems containing flammable fluids.

To increase system reliability, the number of joints should e minimized by using pipe bends in place of elbows wherever practicable. Welded or brazed joints are preferable to other types, particularly in areas inaccessible for inspection and maintenance.

Relief, pressure-reducing, and control valves that require occasional removal for maintenance should have flanged or union ends.

Flanged and union joints should be located where they will be least affected by pipe bending due to thermal expansion, ship flexing, or other causes. Generally, this will require such joints to be located away from bends, elbows, and offsets.

Appropriate measures for quality assurance must be applied to all joints. Welded joints require nondestructive inspection and testing to varying degrees depending on the application. Applicable inspection techniques include visual, dye penetrant, magnetic particle, and radiography.

The integrity of joints must be checked after assembly by a hydrostatic test. An air test is sometimes substituted for a hydrostatic test when necessary to avoid system contamination by liquid.

g) Valves, cocks and valve actuators

Cocks and valves are designed to control or interrupt the flow. This is done in cocks by rotating the plug, and in valves by lowering, raising or rotating a disc in relation to a seating surface or by controlling the movement of a ball. These fittings have bodies furnished with flanged or screwed ends (or ends prepared by welding) for connection to the joining pipes.

g.1) Cocks

A cock may be straight-through, right-angled or open-bottomed as required by its situation in a pipe system. Its plug may be tapered or parallel with tightness achieved by lapping in or by resilient packing material (see Figure 8.9).

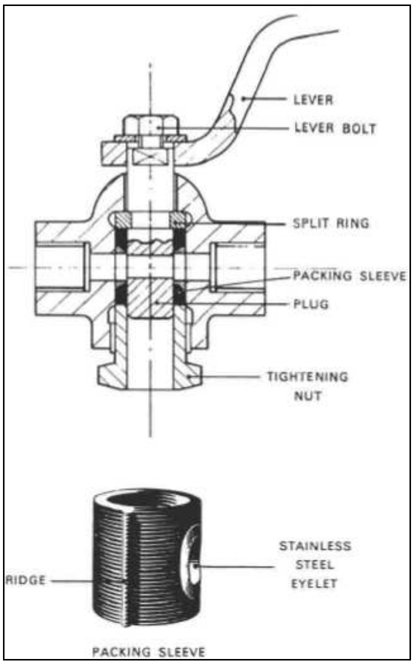


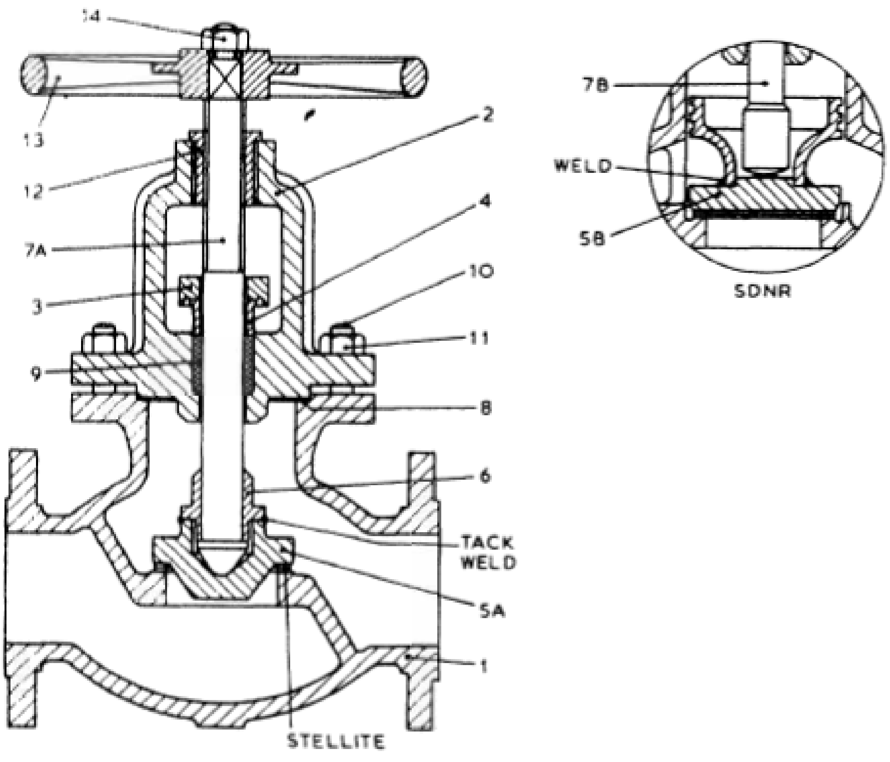
Fig. 8.9 – Sleeve-packed cock.

In machinery spaces, the short sounding pipes for fuel or lubricating oil tanks, must be fitted with cocks having parallel as opposed to tapered plugs. This, together with the requirement for weighted handles which will automatically close the cock when released, is for safety. Tapered plugs, when tightened to hold the cock open for sounding and then forgotten, have contributed to fires when tanks have overflowed.

g.2) Globe valves

The globe valves (see Figure 8.10) has a bulbous body, housing a valve seat and screw down plug or disc arranged at right angles to the axis of the pipe. For the valve shown, both seat and disc faces are stellited and almost indestructible. Alternatively, the seat may renewable or screwed into the valve chest or given a light interference fit and secured by grub screw. The seats may be flat or more commonly mitered. The spindle or stem may have a "V" or square thread, below or above the stuffing box. If the latter it will work in a removable or an integral bridge (bonnet).

The spindle may be held in the valve disc by a nut as shown or the button may locate in a simple horseshoe. Leakage along the valve spindle is prevented by a stuffing box, packed with a suitable material and a gland. If there is a change of direction, as in a bilge suction, the valve is referred to as an angle valve. Flow is from below the valve seat, so that the gland is not subjected to higher hydrostatic pressure when the valve is closed. The disc must be guided by wings or a stem on the underside for location, or by a piston as shown.



1. Body
2. Bonnet
3. Gland flange
4. Gland
5A Disc – stop type
5B Disc – piston SDNR
6. Disc stem nut
7A Stem – stop type
7B Stem – piston SDNR
8. Bonnet gasket
9. Gland packing
10. Bonnet studs
11. Bonnet stud nuts
12. Yoke bush
13. Handwheel
14. Handwheel nut

Fig. 8.10 – Globe valve of the screw-down non-return (SDNR) type.

The type of valve with the disc attached to the spindle is of the screw lift type. When the disc is not attached to the spindle (inset Figure 8.10) it is a screw-down non-return valve, as used for bilge systems, to prevent back flooding. They are also used as feed check and boiler stop valves. The disc requires guide vanes or a stem to keep it concentric with the seat when open. The greatest lift required is one-quarter of the bore; guides must be of a greater length than the lift.

A free-lifting non-return valve (Figure 8.11) is fitted in the compartment served by a bilge suction line, when the pipe is nearer to the ship side than one fifth of the ship's breadth. Such valves are intended to prevent flooding of the compartment in the event of collision damage.

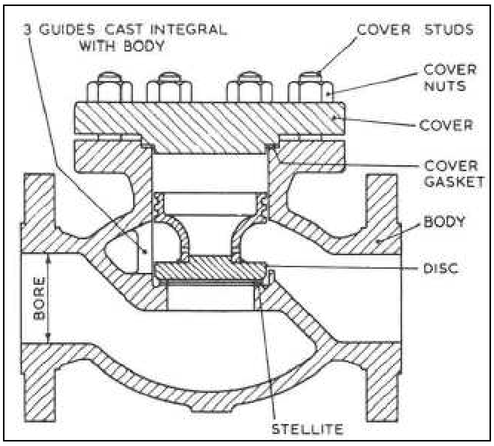


Fig. 8.11 – Non-return valve.

g.3) Gate valves

Unlike the globe valves, gate valves (see Figure 8.12) give full bore flow without change of direction. The valve disc known appropriately as a gate, is moved at right angles into the flow by a screwed spindle working in a nut. It rests when closed, between circular opening furnished with seats. Valves and seats may be tapered or parallel on their facing sides.

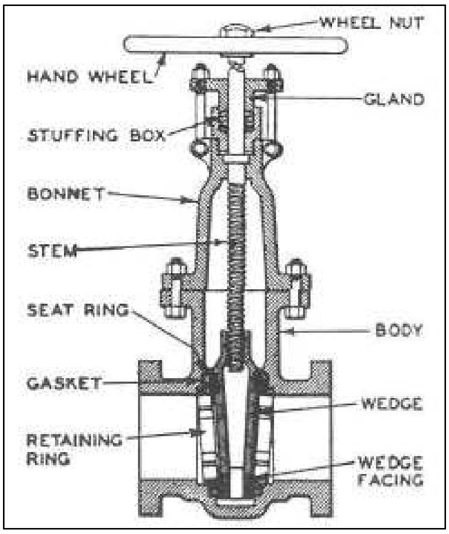


Fig. 8.12 – Gate valve.

Such a valve is not suitable to partially open operation since wire-drawing of the seat will occur. The bonnet of these valves are frequently of cast iron and care should be taken when overhauling. To ensure tightness, some parallel gates are fitted with twin discs, dimensioned similarly to the chest seats but pressed against the seats by a spring when closed.

Where change of direction is required, a full bore angle valve (see Figure 8.13) may be used.

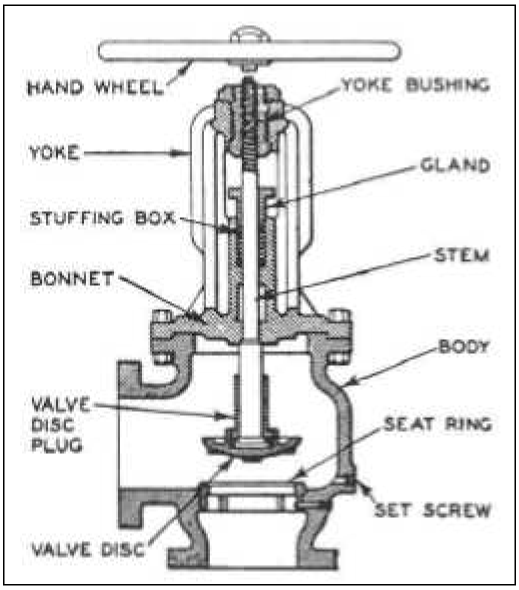


Fig. 8.13 – Full bore angle valve.

g.4) Butterfly valves

A butterfly valve (see Figure 8.14) consists basically of a disc pivoted across the bore of a ring body having the same radial dimensions as the pipe in which it is fitted. The full bore is straight through flow arrangement of this type of valve, especially if combined with a carefully streamlined disc profile, gives excellent flow characteristics and low pressure drop. The valve is quick-acting if required, as only a quarter of turn of the spindle is required to move the valve from the fully open to the fully closed position. Sizes range from 6 [mm] to over 1000 [mm] bore.

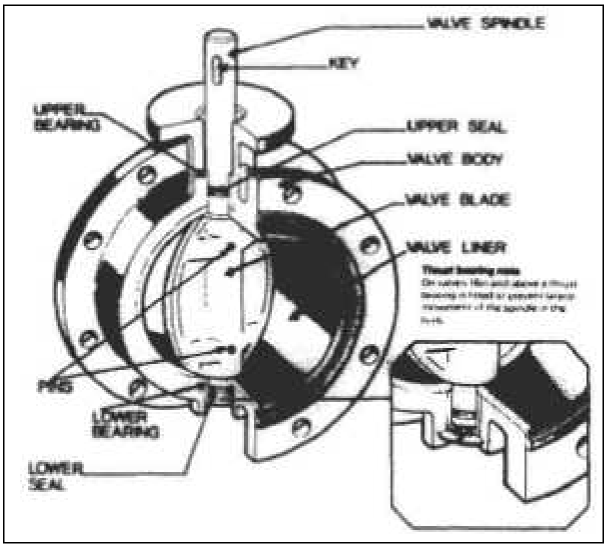


Fig. 8.14 – Butterfly valve.

For fine control of cooling water temperature an special type of ganged butterfly valve may be used to bypass coolers. Known as a diverter valve it consists of a “Y” or “T” casting with butterfly valves in two of the legs (see Figure 8.15). A pneumatic actuator working from a signal provided by temperature sensor opens one valve while closing the other. This gives precise control of the flow rate in the main branch lines. In the event of a temperature controller failure, a built-in return spring opens or closes the main and branch lines (as appropriate to the system of operation) to provide maximum cooling flow. Manual control is available for emergencies.

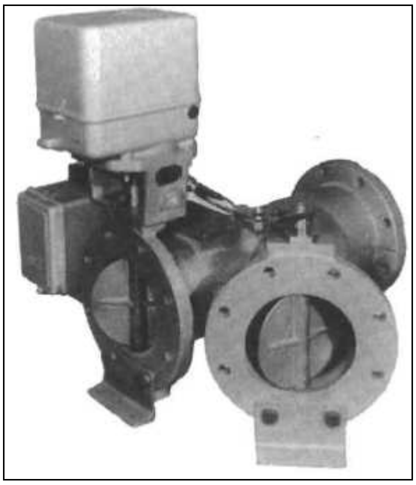


Fig. 8.15 – Diverter valve.

g.5) Flap valves

Scupper pipes from accommodation spaces are fitted with non-return valves. The scuppers from spaces below the bulkhead deck, are required to be fitted with non-return valves which can be positively closed from above the bulkhead deck or, if this is not practical, with two non-return valves. A common type of non-return valve (see Figure 8.16) has a hinged flap which is pushed open by outward flow and closed by its own weight. The flap prevents inward passage of seawater.

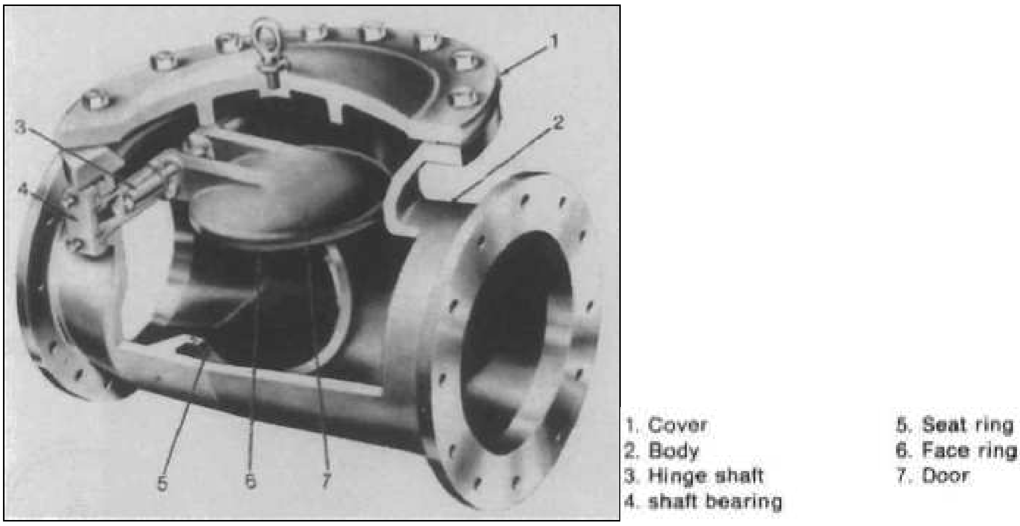


Fig. 8.16 – Flap check valve.

g.6) Change-over valve chests

Dual purpose tanks such as those for either oil or water ballast require exclusive connections to separate systems. Special valve chests (see Figure 8.17) with interchangeable blanks and connecting passages are installed for this duty.

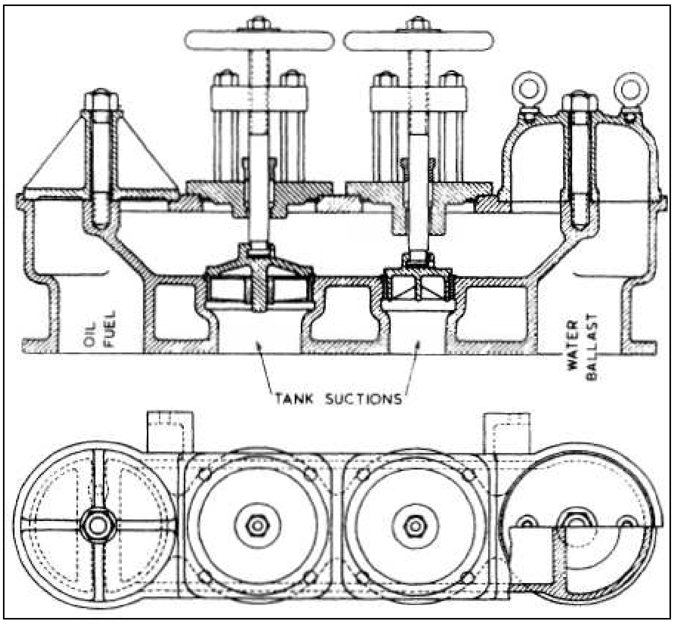


Fig. 8.17 – 2-valve change-over chest.

g.7) Valve actuators

A variety of valve actuators to control the opening and closing of globe, gate and butterfly valves are available. In some types an electric motor, fitted with limit switches is used to turn a threaded stem through a yoke, purely substituting the action of a handwheel. Most remotely operated valve have pneumatic or hydraulic actuators. These give linear motion to a piston which for a globe or gate valve moves the valve stem axially up or down. The globe valve disc may be given a slight turn on landing to clean the seat. The piston actuator for a butterfly valve rotates the valve disc through 90º directly or through a scroll arrangement (see Figure 8.18).

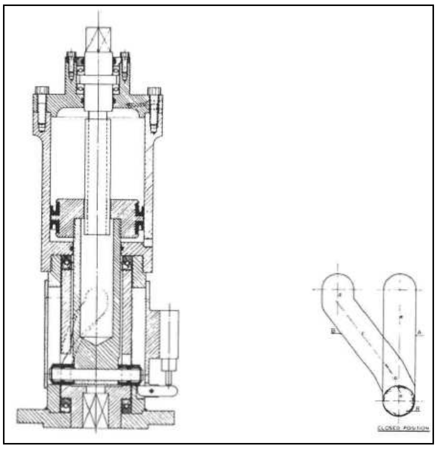


Fig. 8.18 – Pneumatic butterfly valve actuator.

g.8) Relief valves

Excess pressure is eased by a relief valve (see Figure 8.19). This consists of a disc held closed by a spring loaded stem. The compression on the spring can be adjusted so that the valve opens at the desired pressure. Under normal conditions a relief valve should operate consistently within reasonable limits of its set pressure. Incorrect function may be due to the setting, valve seat deposit or damage. Therefore, relief valve seats should be checked whenever the pump is overhauled.

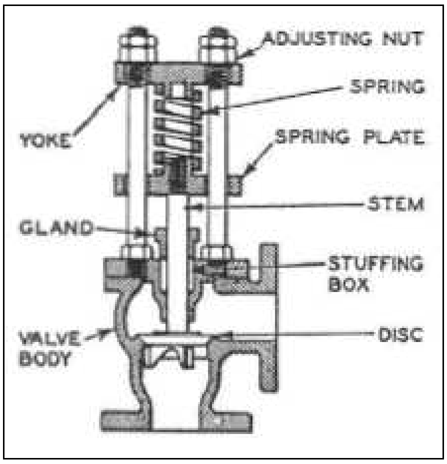
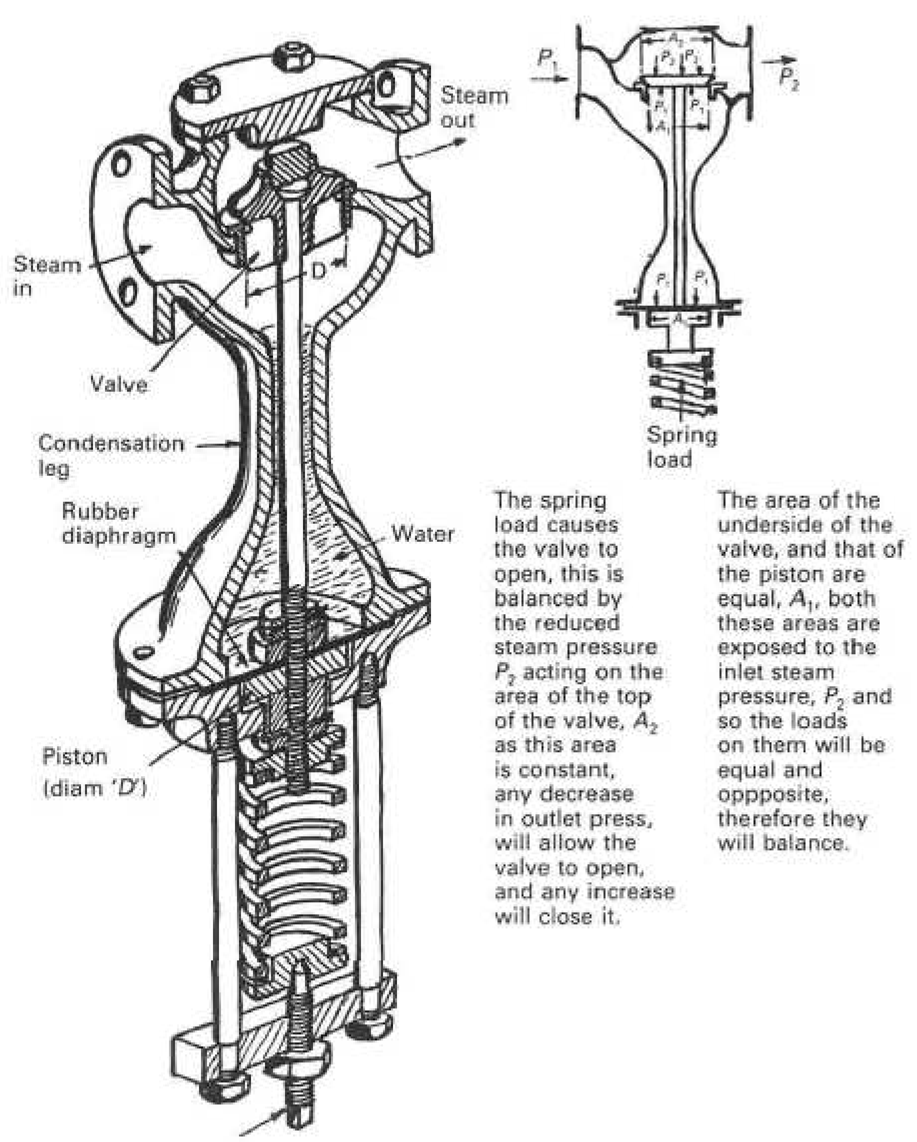


Fig. 8.19 – Relief valve.

g.9) Pressure reducing valves

If it is necessary to provide steam or air at a pressure less than that of the boiler or compressed air reservoir pressure, a reducing valve is fitted. This will maintain the downstream pressure within defined limits over a range of flow, despite any changes in supply pressure.

In the reducing valve shown in Figure 8.20 the higher inlet pressure (p_1) acts an upward direction on the main valve and in a downward direction on the controlling flexible diaphragm and the piston beneath it. These two parts are in a state of balance. The large spring pushes against the spindle, tending to open the valve against the reduced steam pressure (p_2) acting on the area A_2 at the top of the valve. Any decrease in pressure on the outlet side, will allow the valve to be pushed open by the spring. Any increase will close it. It is important that this type of valve is installed in the vertical position.



The spring load causes the valve to open, this is balanced by the reduced steam pressure P_2 acting on the area of the top of the valve, A_2 as this area is constant, any decrease in outlet press, will allow the valve to open, and any increase will close it.

The area of the underside of the valve, and that of the piston are equal, A_1, both these areas are exposed to the inlet steam pressure, P_2 and so the loads on them will be equal and oppposite, therefore they will balance.

Fig. 8.20 – Pressure reducing valve.

g.10) Quick closing valves

Fuel oil service and some other tanks must be fitted with valves that can be closed rapidly and remotely in the event of an emergency such as fire. Wire operated valves (see Figure 8.21) are commonly fitted, with wire pull levers located externally to the machinery space. An alternative to this type of valve is the one shown in Figure 8.22 which is hydraulically operated.

Quick-closing valves are examined and tested when installed and then periodically when the tank is not in use, to ensure that the mechanism functions correctly. Wires are sometimes found to be slack or hydraulic system empty.

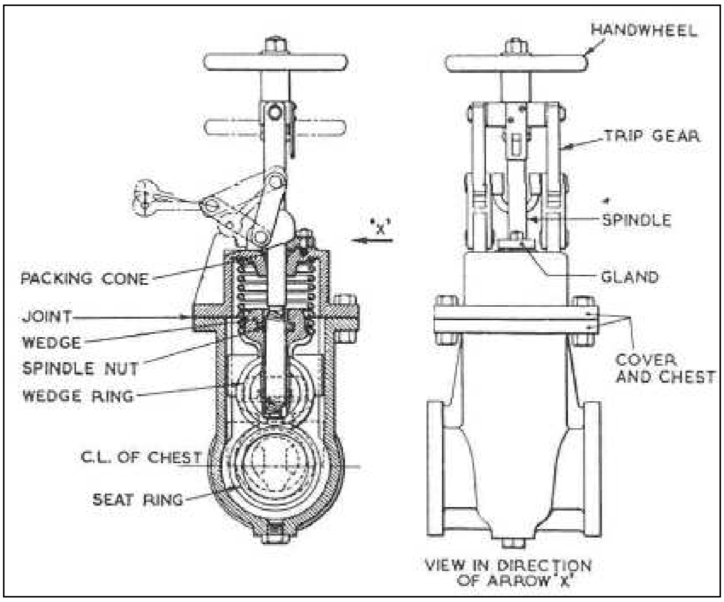


Fig. 8.21 – Quick-closing valve – mechanically operated.

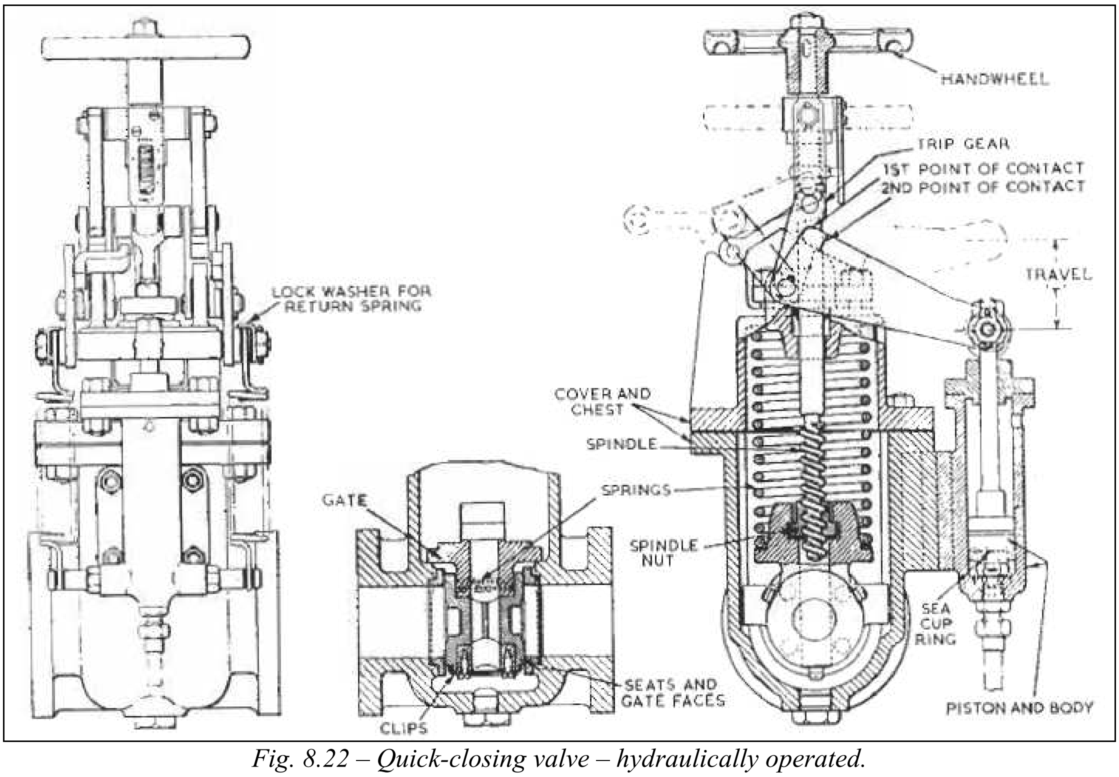


Fig. 8.22 – Quick-closing valve – hydraulically operated.

h) Orifices

An orifice plate (see Figure 8.23) is installed to introduce a specific additional pressure loss into a flow path. An orifice is a passive device that cannot respond to changes in system conditions, but is sized for a single condition of inlet pressure, outlet pressure, flow rate, fluid density, and fluid viscosity. An orifice is useful for balancing the pressure losses, hence, the flow, in parallel flow paths, and for limiting flow in a given path. An orificer cannot be used as a pressure reducer, because the downstream piping will be exposed to full upstream pressure whenever flow is stopped, such as upon a closure of a downstream valve.

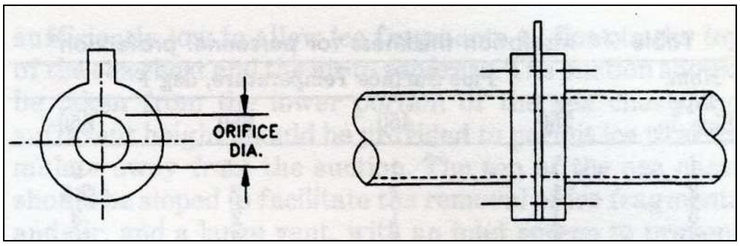


Fig. 8.23 – Orifice plate.

Multiple orifices should be used when necessary to avoid cavitation, which causes turbulence and noise.

i) Insulation and color code for identification of pipelines

Insulation is required on high temperature piping to limit the surface temperature for personnel protection, reduce the heat loss from the system, or prevent objectionable heat gain in enclosed spaces. Part or all of the piping in systems such as steam, engine exhaust gas, fuel service and hot potable-water systems requires insulation. Pipes that infrequently operates at temperatures above 52ºC, such as steam escape piping, does not require insulation unless it poses a personnel hazard.

Insulation is required on chilled water and refrigerant piping operating at temperatures below 4.4ºC to reduce the heat gain by the operating fluid.

To prevent condensation, anti-sweat insulation is normally installed on piping systems, such as fire main and seawater cooling that normally contain fluid at a temperature below the ambient dew point.

Insulation should be installed on freshwater or seawater piping that is in the weather, cannot practicably be drained in cold ambient temperature, and is subjected to intermittent stagnant or low-flow conditions that could allow freezing of the fluid.

The material most often used for high-temperature insulation are fiber-glass, mineral fiber, and calcium silicate. For low-temperature insulation, the most common materials are fiberglass, cellular glass, and foamed plastics.

Lagging should be installed over insulation to protect it from damage. Lagging materials include sheets of galvanized steel, corrosion-resistant steel, aluminum, cloth, and fiberglass.

For ease identification of pipes, these are usually painted or appended with stripes of different colors, depending on the standard adopted. As shown in Figure 8.24, these colored stripes identify the type of fluid and the system to which the pipe belongs.

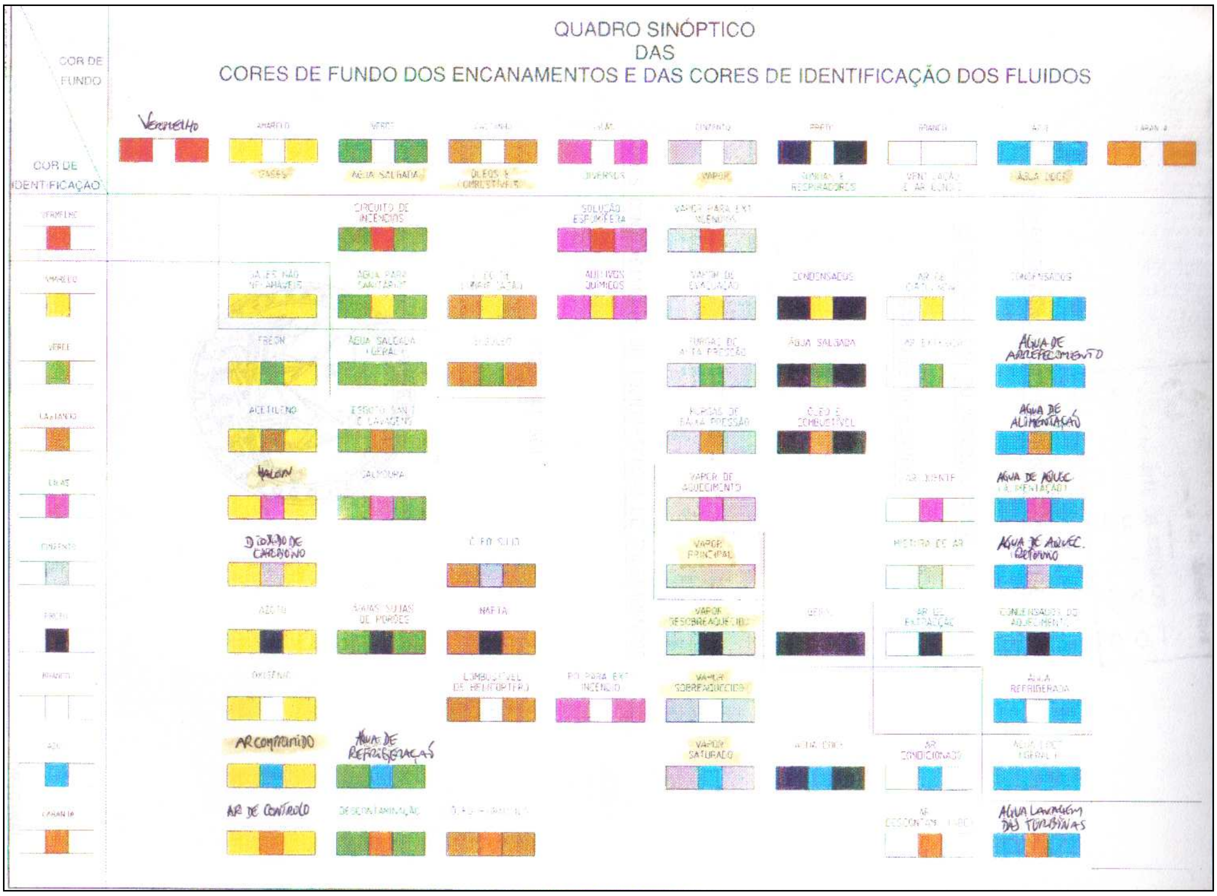


Fig. 8.24 – Pipe color identification according to Portuguese navy standard PTESMAT 501.

Insulation should not be installed on piping joints until after the system has been hydrostatically tested.

j) Sea connections

Sea chests are generally constructed of pipe or plating of material similar to the hull and welded to the shell plating (see Figure 8.25). In way of the double bottom, a sea chest is formed by a trunk extending between the shell plating and the inner bottom plating, with the seawater piping connected to the inner bottom plating. The design must provide adequate structural reinforcement to compensate for the size, shape, and location of the opening in the hull.

Sea chests should be clear of bilge keels and other hull projections, and should not interfere with docking blocks. They should be located where they will not be prone to pick up fluid from overboard discharge connections.

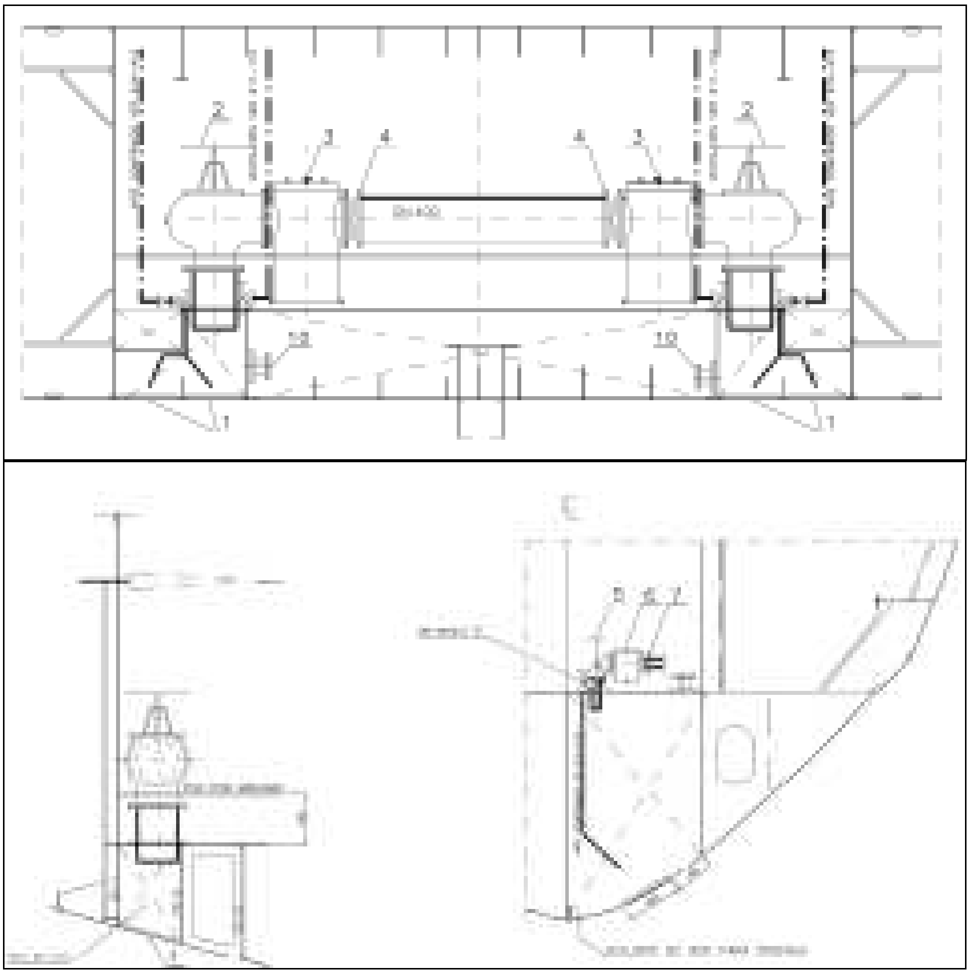


Fig. 8.25 – Sea chests.

Sea chests should be located to avoid high entrance losses and negative pressures induced by flow along the hull with the ship underway. Locations that may emerge during roll, pitch, or light-ship conditions, or allow ingestion of entrained air along the submerged hull, should be avoided.

Sea chests that will be used in shallow water should be located to avoid picking up debris or dirt from the bottom of the waterway. If a single location that will avoid both air ingestion and debris intake is not feasible, both high and low suction sea chests should be installed. If the vessel is of the oil spill recovery or military landing craft types and both sea chests might get clogged either with crude or mud, then an internal refrigeration close-circuit fed by a ballast tank should be provided for short time operations.

Each sea chest must have a strainer made of bars or perforated plate installed at the junction with the shell plating. The clear area through the strainer plate should be 1.5 to 2 times the total area of all the suction piping connected to the sea chest. Where practicable, the strainer openings should be no larger than the smallest flow passage in the connected systems. Where this is not practicable, a separate strainer is required in the system piping (see Figure 8.y).

Sea chests should be provided with a means of clearing debris from the strainer. Steam can be used where readily available; otherwise, compressed air can be used.

Overboard discharges consist of pipes attached directly to the shell plating. They should be located to avoid flow lines leading to suction sea chests, underwater logs, and sonar transducers. If installed above the waterline, they should not be located in way of boat-handling areas or accommodation ladders.

A sea valve should be installed in each pipe connected to a suction sea chest or overboard discharge. Where more than one pump is connected to a sea chest or overboard discharge, an additional valve should be installed in each branch to permit the isolation of each pump. Where a pump is located in a compartment other than that in which the sea chest or overboard discharge is located, an additional valve should be installed in the compartment in which the pump is installed. Sea valves should be installed as close as possible to the sea chest or shell plating, and any intervening joints should be welded.

Sea valves may be of the gate type, angle, or butterfly type (not allowed in military vessels); gate valves are preferred. Sea valves of the gate type should have stems of one-piece construction and the stem should not be attached to disc by pins. Sea valves in spaces not normally manned should have a remote control from the deck above.

The number of sea chests and overboard discharges installed should be the minimum consistent with proper operation of the connected systems. At least two sea chests should be installed for main propulsion cooling, generator cooling, and other vital systems to ensure a continuous supply in the event one become clogged. They should be separated as far as practicable.

Sea chests for the ships that will operate in ice require special consideration. Broken ice must be prevented from clogging the seawater cooling system inlet piping and strainers.

k) Watertight bulkheads

Pipes are carried through watertight bulkheads with the use of special fittings (see Figure 8.26) to avoid impairment of their integrity. The large flange of the fitting covers the necessary clearance in the bulkhead.

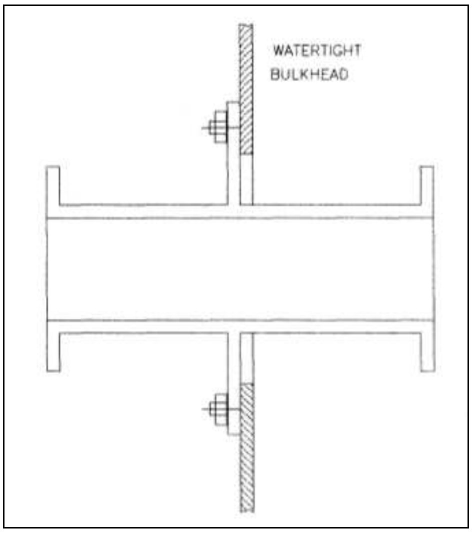


Fig. 8.26 – Bulkhead piece for use when a pipe passes through a watertight bulkhead.

8.2. Machinery plant support systems

8.2.1. General

Diesel, gas and steam turbine machinery plants require piping systems for fuel, lubricating oil, compressed air, cooling water, and other services. System configurations vary to suit each type of plant. Each type of plant also requires unique systems for its operation. As examples, steam plants require piping for steam, condensate, feedwater, and other services; diesel plants require freshwater cooling and, often waste-heat systems; and gas turbine plants have a bleed-air system.

This section describes many of these systems for diesel plants, providing greater detail for systems not covered on chapter 2. Moreover, as a framework for discussion, this section is generally oriented to a single-screw commercial ship**.**

8.2.2. Diesel plant piping systems

a) Seawater cooling system

The number and type of seawater heat exchangers for a diesel engine depend on the type and design of the diesel engine.

Seawater systems include cooling services in the engine room and such ship-service systems as ballast and fire main, as illustrated by Figure 8.27. Water enters the system through high and low sea chests on opposite sides of the ship. Each sea chest is fitted with sea valves, vents, valves, for steam or air blow-out, and gratings mounted flush with the hull. On tankers the high sea suction should be on opposite side of the ship from the pump room ballast discharge, since both are likely to be used in port. Where operation in freezing water is frequent, the sea chests may be fitted with pipe connections to introduce hot water from overboard discharge or from separate steam heater, or for direct steam injection. The low sea suction is used at sea where it is more likely to remain immersed as the ship rolls and pitches. The sea chests are connected by a large-diameter cross connection. Suction strainers are installed adjacent to each of the sea chests. Seawater pumps take suction from the cross connection.

The main seawater cooling system will normally include two full-size pumps. Pumps in seawater service tend to be high-maintenance items and pumps of similar capacity should be identical, simplifying spare parts requirements in service. In the systems of Figure 8.27, the required ballast pump capacity was sufficiently close to that of the main engine cooling pump to enable three identical pumps to be fitted, with one ballast pump designated as stand-by for the main engine cooling pump. On tankers, the main sweater cooling may also serve a condenser for the cargo and ballast pump turbines, or a separate circulating system may be fitted.

Seawater is typically provided to separate heat exchangers for propulsion engine lubricating oil and jacket water. These are usually installed in series, with the jacket-water cooler receiving the higher-temperature seawater. For the larger low-and medium-speed engines, additional seawater heat exchangers may be installed for cooling pistons, fuel injectors, combustion air, reduction gear lubricating oil, and other services. Machinery plants using controllable-pitch propellers may also required seawater cooling for hydraulic oil cooler.

The heated seawater leaving most of the auxiliaries is usually combined with seawater leaving the main engine coolers, upstream of a thermostatically controlled three-way re-circulating valve, which can return some of the heated water to the suction cross section, and discharge the rest overboard. This recirculation enables the seawater used for cooling to be maintained above 20ºC, even under very cold ambient temperature. For the system to operate in port with the main engine secured, the thermostat must sense the seawater temperature in the auxiliary cooling system.

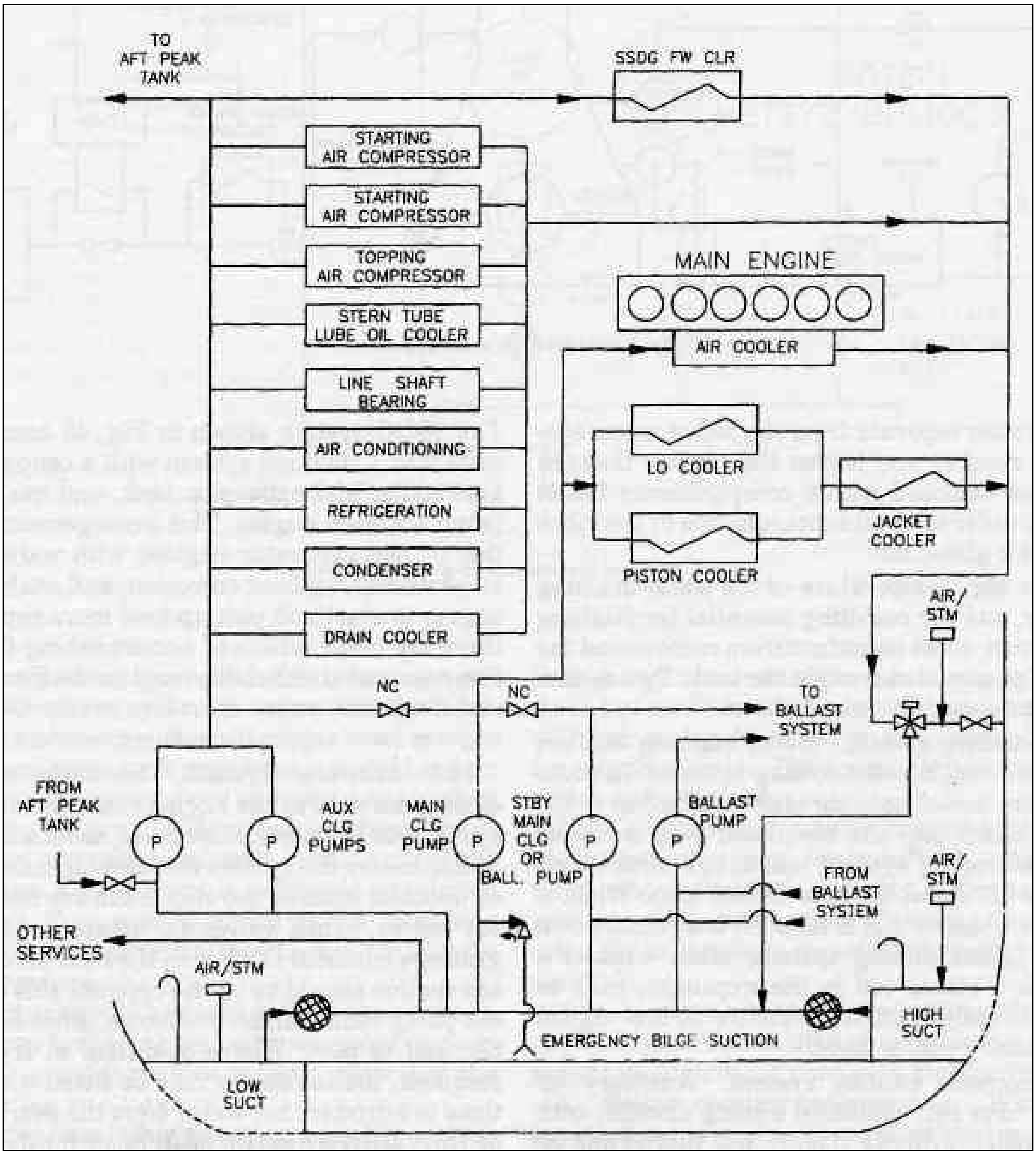


Fig. 8.27 – Seawater system.

Local instrumentation includes pressure gages at pump suctions and discharges, and thermometers before and after each cooler. Duplicate pumps are arranged for automatic starting of the standby pump. Alarms are fitted for low pump discharge pressure.

In some ships, connections are provided to ballast tanks to permit closed-circuit cooling sufficient for in-port use, in order to minimize the use of fouled or silted harbor water. In cold-water trades, similar connections to the forward peak tank may be used at sea, for main and auxiliary cooling. Connections to the aft peak tank may be provided from the auxiliary cooling water system to enable limited cooling services to be maintained while in dry dock, but, in any case, hose connections are provided in the piping to allow use of water from shore.

A set of cross connections between various seawater pumps is fitted to allow continuous operation under emergency conditions.

Cooling water for refrigerating machinery is often on a higher flat in the engine room.

Generator engines usually require only one sweater heat exchanger. A separate pump may be provided for each generator engine, with a standby supply from another source (e.g., an emergency supply from the fire main via a pressure-reducing valve). Seawater cooling pumps for diesel engines may be driven by power-take-offs directly from the engine. This reduces the number of electric motors, and reduces dependence of the engine on electric power. The use of engine-attached seawater pumps is not recommended if the pump cannot be arranged and designed to ensure that it will be primed automatically soon after the engine is started. For main propulsion engines, motor-driven pumps are also needed to provide an alternate supply to the main engine as required by regulatory bodies. Hence, a cross-connection to a ballast, fire, or other seawater pump of appropriate capacity is sometimes installed for this purpose.

Corrosion is troublesome in seawater systems. Therefore, piping is normally of copper-nickel, or of steel that is internally coated with an inert material such as polyethylene. Galvanized piping is unlikely to last long enough to be cost-effective.

Marine growth is also troublesome in seawater systems. Systems are often fitted with connections for the continuous injection of chemical poisons.

b) Lubricating-oil system

Diesel engine lubricating-oil service systems may be supplied by attached or motor-driven pumps, which circulate oil through filters and coolers to the engine. Sumps are integral with smaller, higher-speed engines. On larger engines, an independent sump is installed; gravity drainage or a scavenging pump returns oil from the engine cranckcase to the sump tank. If an attached pump is installed, a means of priming with a hand- or motor-operated pump is usually necessary to lubricate the engine before start-up.

Motorship lubricating-oil systems are complex because of the number of grades of oil required. A geared, medium-speed diesel plant may require different grades of oil for the main and auxiliary engines, and other grades for gearing and miscellaneous uses. A lubricating-oil system for a low-speed diesel plant involves at least two grades of oil for the main engine (one for circulating system and other for the cylinders) and a third for the auxiliary engines.

b.1) Main engine lubricating-oil circulating system

A typical circulating oil-system for a low-speed engine is illustrated by Figure 8.28. Oil draining from bearings and cooling passages to the bottom of the cranckcase passes into an independent sump that is built into the double-bottom below the engine, from which it is drawn by the lubricating-oil circulating pump for redistribution via a filter and a cooler.

The lubricating-oil circulating pumps are most often positive-displacement rotary pumps, and in larger plants are fitted in duplicate; however, as an alternative to the positive-displacement pumps, deep-well centrifugal pumps have also been used. Both pumps are motor-driven in installations with low-speed diesels, but higher-speed engines are often fitted with one engine-driven pump, relaying on a second motor-driven pump for standby service. Each pump has a coarse suction strainer for its own protection.

A full-flow filter is provided in the pump discharge line. It may be of the duplex, basket type, but better filtration is usually provided by a disposable-element or self-cleaning simplex unit, with as similar filter in bypass. Filtered oil is distributed to engine bearings, for governing and control services, to valve gear, and, on trunk-piston engines as well as some crossahead engines, for piston cooling. Some of these services may require high-pressure oil, which can be obtained by fitting booster pumps in the line, or by providing a second, higher-pressure circulating system.

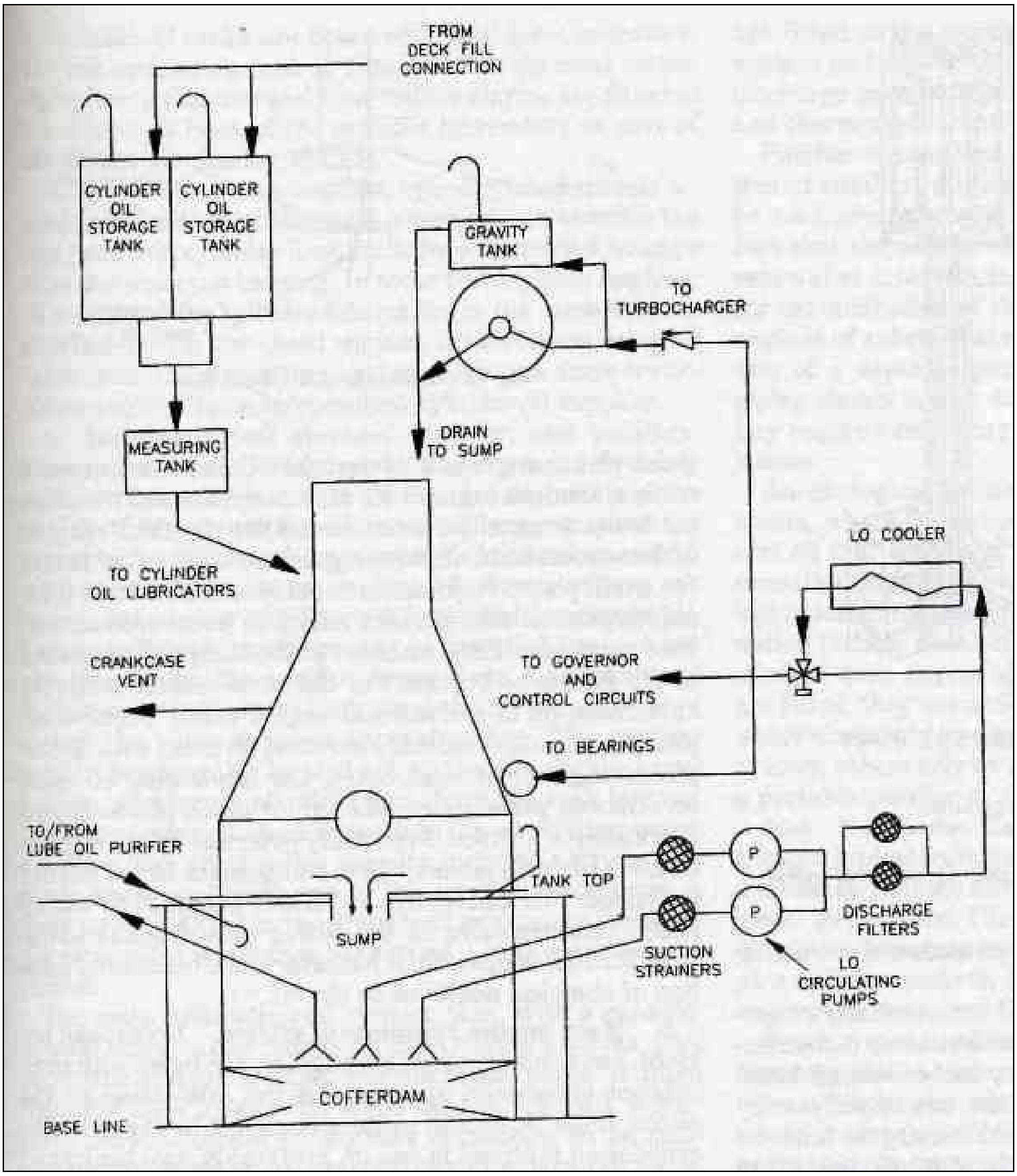


Fig. 8.28 – Main engine lubricating-oil system.

b.2) Lubricating-oil storage, transfer, and purification system

Smaller high-speed engines may rely solely on filtration and occasional oil changes to maintain the quality of the circulating oil, but most larger engines are arranged for continuous bypass purification using centrifugal purifiers, as shown in Figure 8.28. Two purifiers are shown, but one is a standby unit. In multiple-engine installations, individual purifiers may be installed for each engine.

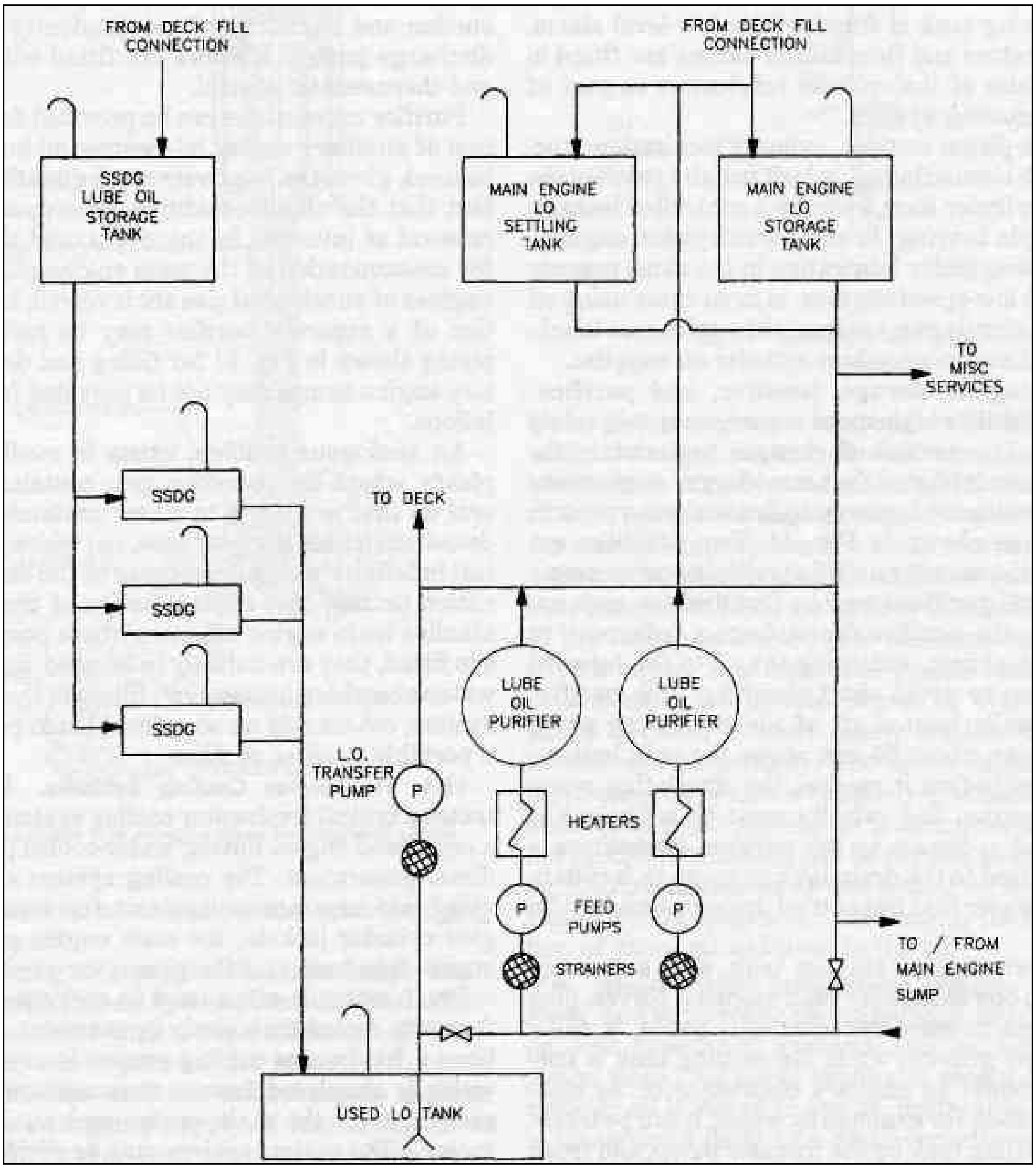


Fig. 8.29 – Lubricating-oil storage and treatment system.

Normally, the purifier draws from a bellmouth at the aft end of the sump to avoid short-circuiting. The purifier suction is generally located aft of the circulating pump, and lower, about 50 [mm] above the tank bottom, to remove water before it reaches the circulating pump suctions. The suction line velocity must be sufficient to carry water and sediment to the purifier. Sometimes a hand pump is fitted to the drain tank or sump to facilitate the removal of water that has settled during extended idle periods.

The main lubricating-oil storage tank, with capacity at least equal to one charge for each engine it serves, plus sufficient margin to meet miscellaneous needs, is filled from the deck by gravity, while the settling tank is normally empty. Should an engine's circulating oil be massively contaminated, for example by water, it can be transferred to the settling tank by the transfer pump, and fresh oil can be transferred from the storage tank.

Lubricating-oil purifiers with their attached pumps, must be located low in the ship to minimize the suction lift required from the main engine sump. Each purifier is sized to circulate the main engine drain tank three to five times per day. Purifiers are usually fully automatic in their operation, once started, and are programmed to shut down and alarm when malfunctions, such as water at the oil outlet, oil at the water outlet, or excessive vibration are sensed. Self-cleaning units cycle through sludge-ejection sequences automatically at present intervals.

c) Fuel service system

Diesel engine fuel service systems are designed to handle different grades of fuel depending on the design of the engine. High-speed engines generally operate on distillate fuel only; medium and slow-speed engines generally use blend of distillate and residual fuel, which is commonly known as “heavy fuel”.

While clean distillate fuels are sometimes considered suitable for combustion in diesel engines without any treatment other than settling and filtering, it is nevertheless advisable to centrifuge even distillate fuel. In normal operation fuel passes to the day tanks, from which the engine is supplied, only via the purifiers. At least two purifiers should be provided for continuous operation, either in series or in parallel. The rated capacity of each purifier should include sufficient margin above the main engine consumption at maximum continuous rating (MCR) to allow for maintenance.

Heavy fuels must be heated close to 100ºC to facilitate purification, and this hot oil input to the day tank could force the day-tank bulk temperature to rise above the flash point. For this reason some installations are fitted with a cooler in the heavy fuel purifier discharge line. To limit the cooling of heavy fuel between heaters and the engine, and to ensure a constant pressure at the injection pumps, a flow rate equal to two or three times engine consumption at MCR is maintained. The unconsumed fuel is recirculated back to the mixing tank.

In some tanks there is no mixing tank and recirculated fuel returns directly to daily tank; however, this return of hot oil can lead to an objectionably high day-tank temperature. When the mixing tank is at atmospheric temperature, it is supplied by gravity from the day tank, and its bottom is therefore lower than the bottom of the day tank, as shown in Figure 8.30, while its top must be higher than the top of the day tank to permit the venting of light fractions.

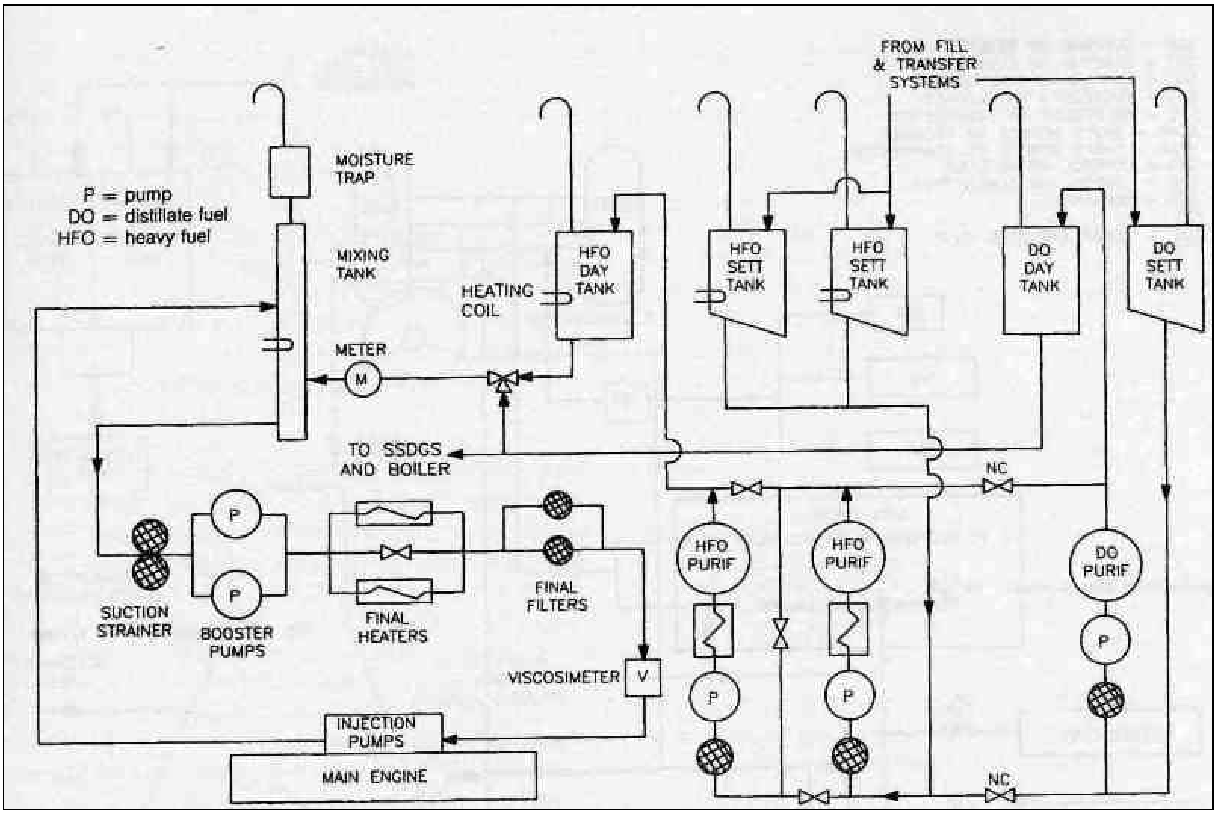


Fig. 8.30 – Fuel treatment and service system.

d) Freshwater and waste-heat systems

The freshwater cooling pumps circulate fresh water in a closed circuit through the engine water jacket and a freshwater/seawater heat exchanger.

Figure 8.31 shows a typical freshwater cooling system for a plant with a crosshead engine having water-cooled pistons and three diesel generators. The cooling system shown can be divided into separate subsystems for cooling the main engine cylinder jackets, the main engine pistons, the main engine injectors, and the generator engines.

Fresh water is often used to cool equipment that was formerly cooled exclusively by seawater. The benefit of a freshwater cooling system is in reduced maintenance, since only the central cooler is exposed to seawater. The added acquisition cost of a critical cooling system may be partly offset by the reduced use of corrosion resistance materials.

Local instrumentation in each system includes pressure gages at pump suctions and discharges, thermometers before and after heat exchangers, and gage glasses at expansion and drain tanks. Temperature control is usually achieved automatically by means of a three-way thermostatic valves.

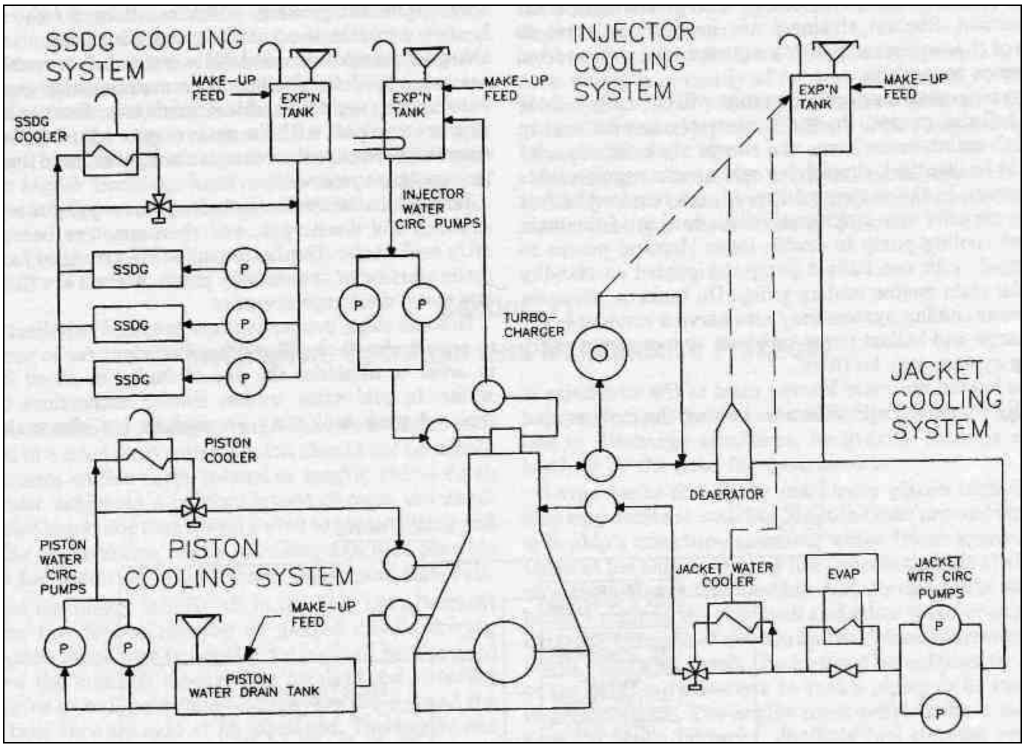


Fig. 8.31 – Freshwater cooling system.

e) Compressed-air systems

A typical compressed-air system is shown in Figure 8.32. The system can be divided into three segments that provide air for the main and auxiliary engine starting, air for instrumentation and control, and air for miscellaneous ship’s services.

Because of the maneuverability of a ship is dependent on the availability of starting air, the minimum number and size of the starting air receivers must comply with regulations. Typically, sufficient air must be available to enable at least six consecutive starts of a non-reversing engine, or twelve of a direct-reversing engine. This volume of air must be available without recharging, and be stored in at least two receivers. The main starting air receivers are normally charged with two compressors at about 30 [bar]. Starting air compressors are usually started in sequence as the receiver pressure falls. Where the starting load of large starting air compressors is a concern, they may be arranged to start automatically and then cycle on their discharge pressure unloaders. Automatic drain traps are fitted at moisture separators and at receivers.

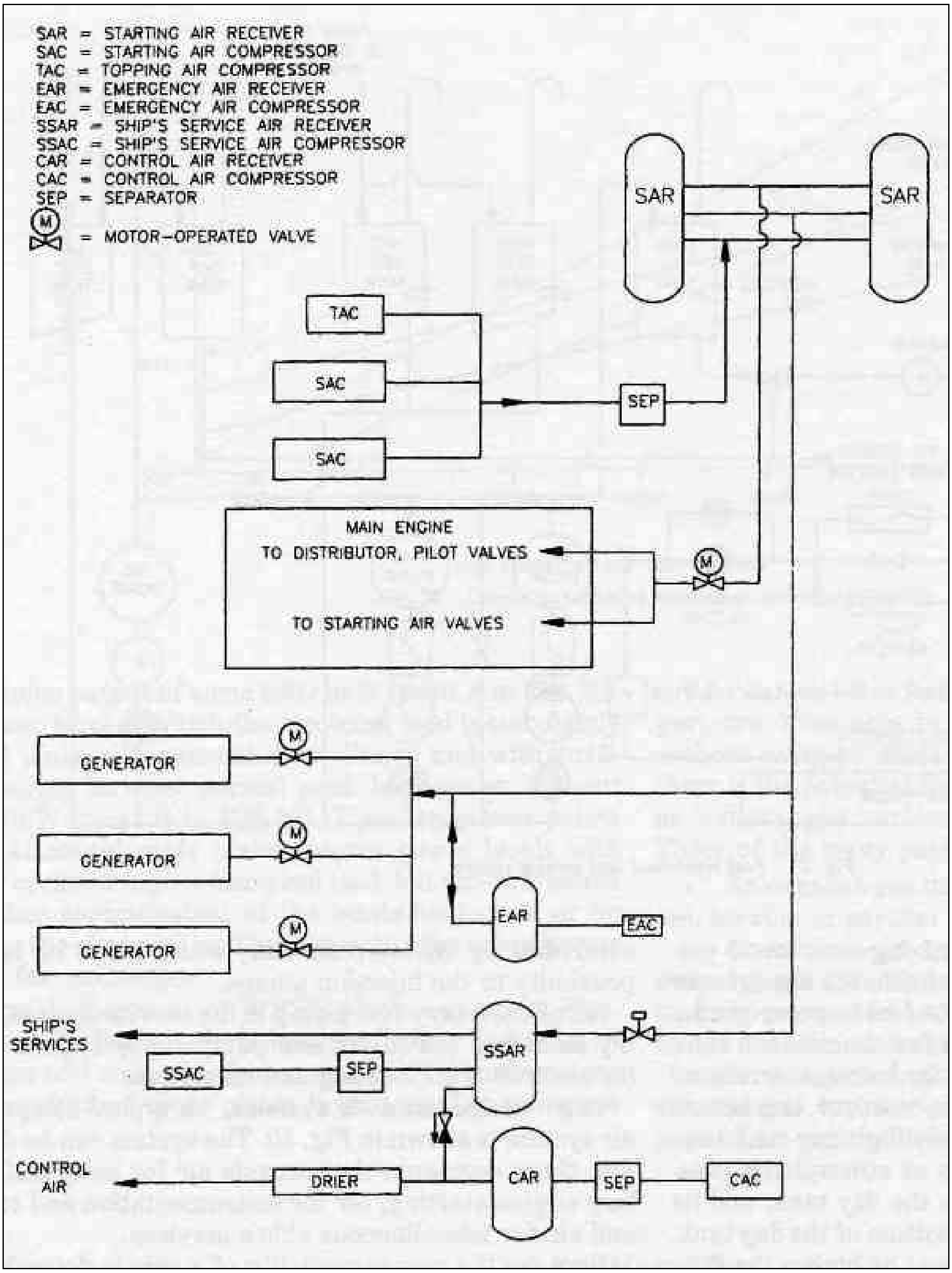


Fig. 8.32 – Compressed-air system.

8.3. *Ship service systems*

8.3.1. *Fuel fill and transfer system*

Fuel fill and transfer systems receive and store fuel, deliver it to service tanks for the machinery plant, transfer fuel between storage tanks, and sometimes, if necessary, offload fuel. Some naval vessels have an additional requirement to deliver fuel to ships alongside. Fuel filling and transfer systems are illustrated by Figure 8.33.

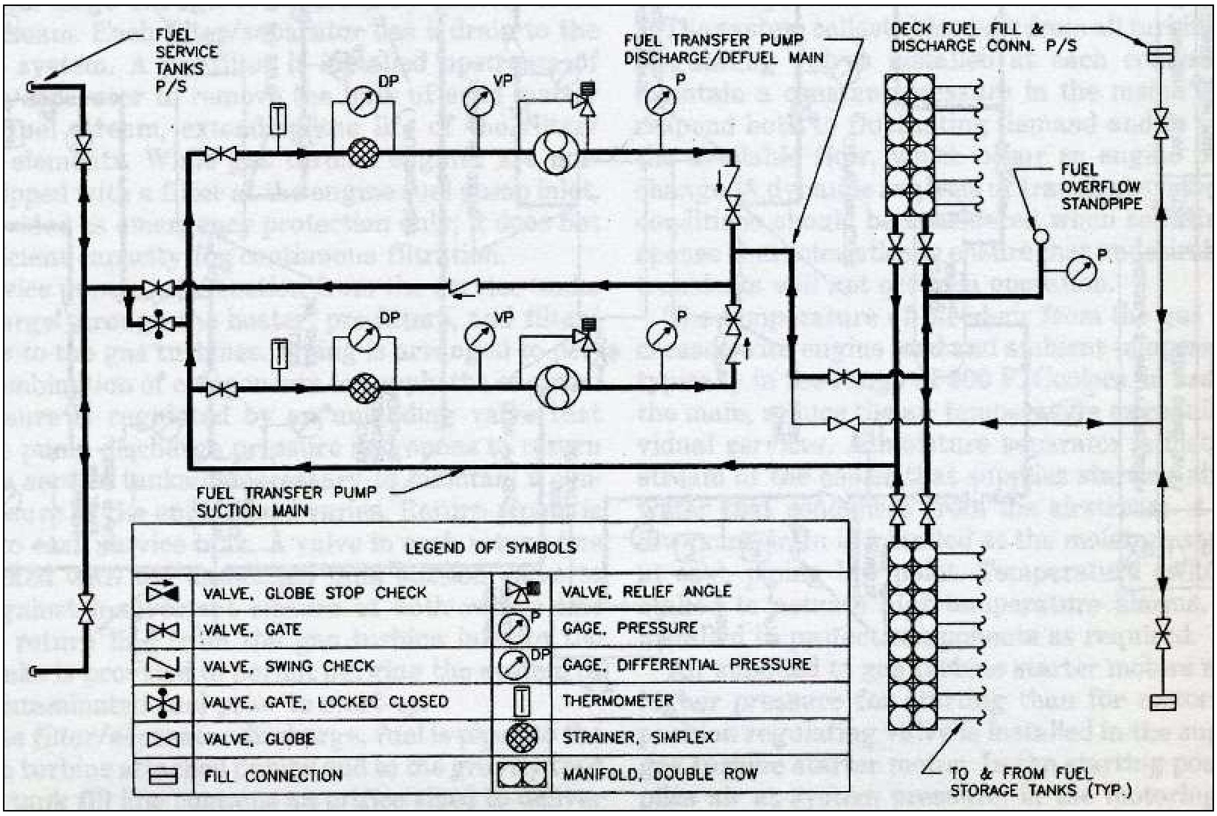


Fig. 8.33 – Fuel fill and transfer system.

The filling system has a port and starboard weather-deck hose connections that are joined to a filling main. Branches from the main lead to one or more manifolds, from which a tailpipe extends to each fuel storage tank. The tailpipes must run low in the ship since they are used to transfer pump suction as well as filling.

Since the highest system flow usually occurs during filling, the filling rate will usually determine storage tank tailpipe sizes. However, tailpipe sizes should also be checked for adequate pump-suction pressure during transfer operations. Piping should permit filling with a specified deck pressure at the design filling rate, considering fuel viscosity at the design ambient temperature. The design filling rate should be the lesser between the sufficient to take aboard about half the ship fuel capacity in no more than one watch (4 to 8 hours) and that corresponding to a maximum speed of 0.2 [m/s] inside the pipe in order to prevent erosion. Naval vessels are equipped for refueling at sea at much higher rates.

Two fuel-transfer pumps should be provided. Each transfer pump should be sized to fill the largest service tank at a rate sufficient to allow adequate time for settling and sampling before putting the tank on line.

In selecting the transfer pump capacity, consideration may also be given to providing the capability to offload about half the ship fuel capacity during daylight hours in preparations for repairs or drydocking. The capability to transfer fuel for trim correction may also be an important factor. Both transfer pumps may be considered in use for offloading and trim correction.

Transfer piping is arranged so that the pumps can transfer fuel from storage tanks to service tanks, and from storage tanks and service tanks to the deck connections for offloading. Piping should also be provided to transfer fuel between storage tanks for consolidation prior to refueling and to adjust the trim of the ship.

On ships using heavy or residual fuel, storage tanks should be provided with heating coils to raise the fuel to the pumping temperature.

On ships having diesel or gas turbine machinery plants, fuel transfer systems are also used for fuel purification. Centrifugal purifiers should be provided to remove water sediment from the fuel prior to delivery to the service tanks. A heater is installed upstream of each purifier to provide the correct fuel temperature (hence viscosity) to the purifier. The purifiers and heaters are connected in series with the transfer pumps. The transfer system is also connected to the low suction of each fuel service tank so that contaminated fuel can be drawn from the tank and circulated through the purifiers back to the tank.

Since regulatory body requirements prohibit routine ballasting of fuel tanks, the fuel, bilge, and ballast systems should normally not be interconnected. However, some ships must be able to ballast fuel-storage tanks with seawater to improve in an emergency. In such cases, cross-connections between fuel-storage tank tailpipe manifolds, the ballast system (for filling), and the bilge system (for emptying) are necessary.

8.3.2. Bilge and ballast systems

Bilge and ballast systems, while having two distinct functions, are interconnected so that the same pumps (commercial practice) or eductors (military practice) commonly serve both functions, and piping is arranged so that each system can operate independently. Typical bilge and ballast systems are illustrated by Figure 8.34.

Bilge systems are provided primarily for the safety of the ship, and are subjected to extensive regulatory-body requirements. A bilge pumping system is provided on all ships to permit emergency dewatering of all watertight compartments, except for ballast, oil, and water tanks that have independent means for filling and emptying. The system also provides drainage for spaces such as anchor-chain lockers where water may accumulate during normal operation of the ship and cannot be drained by gravity. The bilge system should be capable of draining all tank tops, watertight flats, and insulated holds. Separate hand pumps or fireman-actuated eductors are normally installed for isolated areas such as chain lockers and deck over peak tanks. Where drainage from a particular compartment is considered undesirable, it may be omitted provided the safety of the ship is not affected.

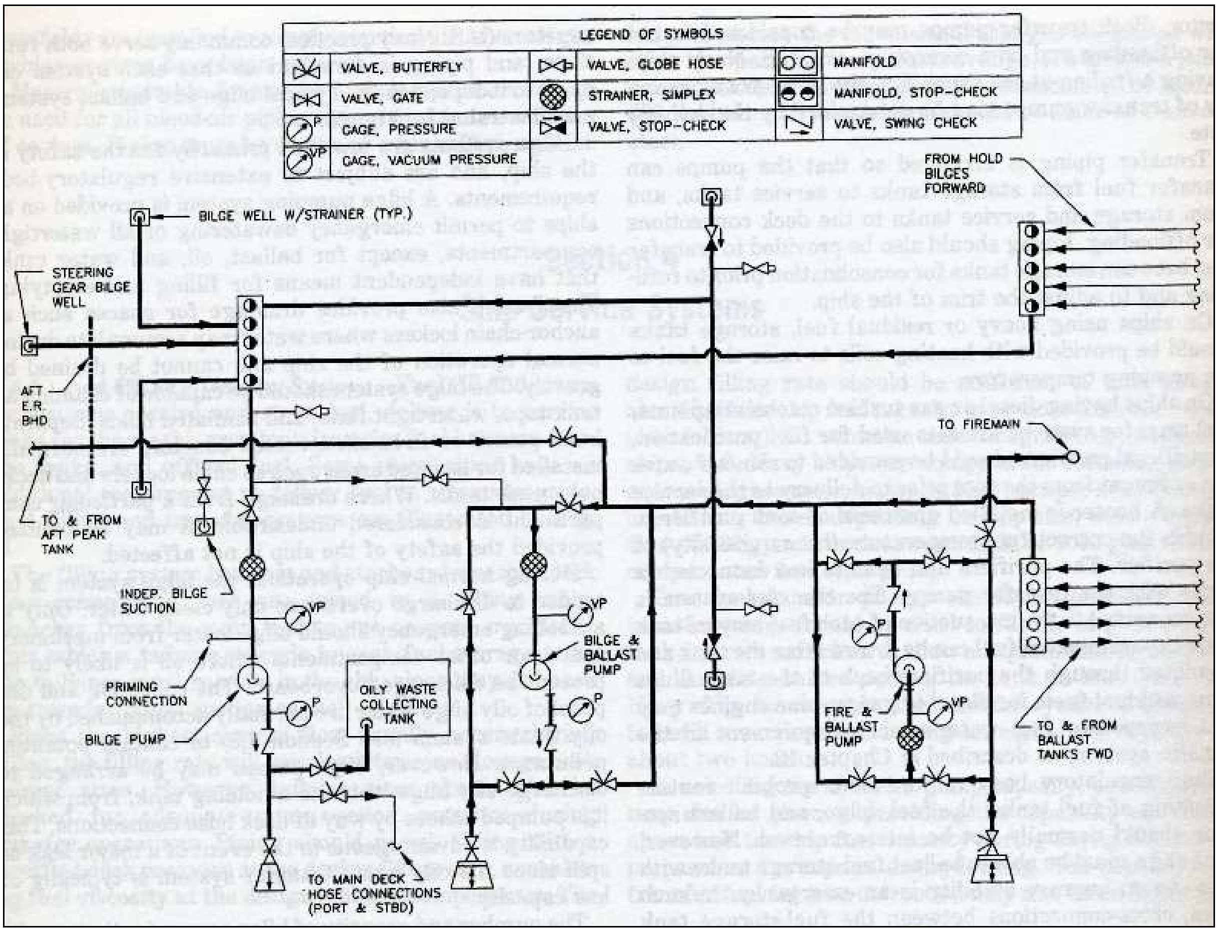


Fig. 8.34 – Bilge and ballast systems.

During normal ship operation, the bilge system is intended to discharge overboard only clean water. Only in a flooding emergency should bilge water from machinery spaces or other compartments where oil is likely to be present be discharged overboard. The collection and disposal of oily bilge water are normally accomplished by oil-waste system (see section 6.4) to contain potential pollutants. However, bilge pumps may be arranged to discharge oily bilge water to a holding tank, from which it is pumped ashore by way of deck hose connections. This capability is advantageous in the event of a major leak or spill since the oily-waste transfer system is typically of low capacity.

The number and capacity of bilge pumps (or their equivalents) are determined in accordance with regulatory-body requirements depending on ship size, type, and service. At least two bilge pumps must be provided on all ships. Although bilge pumps may also serve other systems, such as ballast, fire, or seawater cooling, at least one pump must always be available for pumping bilges.

The minimum size of suction headers and tailpipes is established in accordance with regulatory-body requirements. However, pressure-loss calculations should be performed to confirm that pump suction lift requirements are satisfied.

Since bilge pumps are usually of the centrifugal type and the level of liquid is below the pump, a priming capacity should be provided by using self-priming pumps, installing a vacuum priming system. Bilge pumps normally discharge directly overboard when used for space drainage.

8.3.3. Oily-waste system

An oily-waste system consolidates and disposes oily waste and waste oil that is collected in machinery spaces. The term “oily waste” refers to waste liquid that is mostly water, while “waste oil” denotes liquid that is mostly oil. Such wastes cannot be discharged overboard because of pollution abatement regulations. An oily-waste system is usually kept separate from a bilge system to avoid contamination of bilge-system piping with oil that could subsequently be discharged overboard. In addition, the bilge system pumps and piping are deigned for the high flow rates needed in an emergency and so cannot be used efficiently for handling small quantities of waste liquids.

Drip pans, funnel drains, and gravity-drain piping should be provided wherever practicable to collect oily waste and waste oil at the source and convey it to a collecting tank. Oil-free water should be piped directly overboard or to waste-water tanks to reduce the volume of bilge waste. Liquid that accumulates in bilges in spite of these measures is collected in drain wells.

A typical oily-waste system is shown in Figure 8.35. The oily-waste system takes suction on the drain wells and discharges to an oily-waste collecting tank. In military vessels, this is usually accomplished by an oily-waste transfer pump taking suction on a main, which has branches to each drain well. A separate pump is normally provided in each machinery space. Commercially, a float-operated automatic sump pump discharging to an oily-waste collecting tank is usually provided in each drain well; this arrangement is desirable with unattended machinery spaces.

The contents of the oily-waste collecting tank are processed by an oil-water separator, which normally produces an effluent that is suitable to overboard discharge. An oil-content monitor is provided to continuously measure the oil content of the effluent. If the set limit on oil content is exceeded, the effluent is automatically recirculated to the collecting tank, or the separator is stopped. Oil is discharged via separate piping to the waste-oil tank.

Piping is provided to discharge oily waste and waste oil to shore collection facilities via port and starboard hose connections on the weather deck. The oily-waste transfer pump or the oil-water separator pump, as applicable, is arranged for this purpose. In either case, the pump head must be sufficient to provide adequate pressure (approximately 10 [psi]) at the hose connection for discharge to shore. The deck flanges are required to be of standard design to ensure compatibility with all port facilities. Piping may also be provided for discharging waste oil to the incinerator or the boilers on commercial ships so equipped.

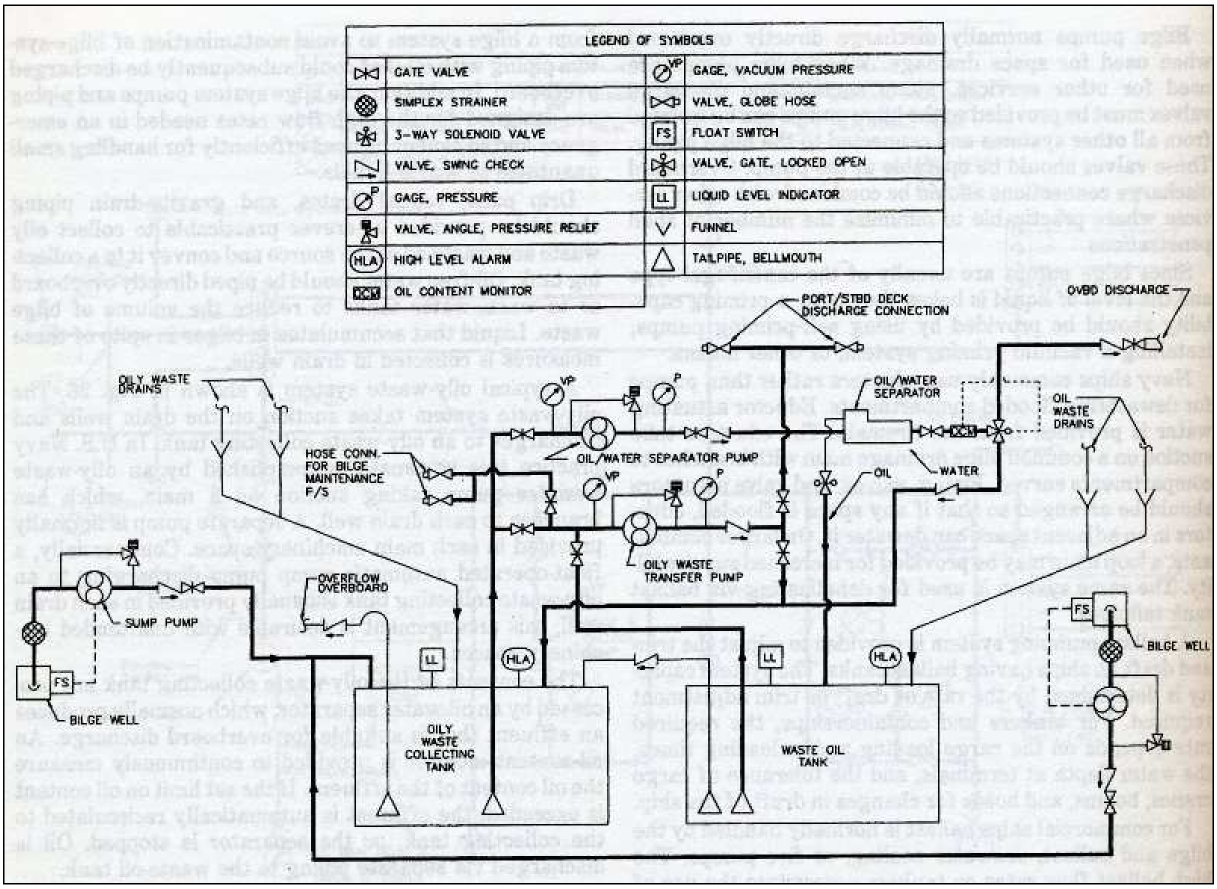


Fig. 8.35 – Oily-waste system.

8.3.4. Freshwater service system

A freshwater service systems supply shipboard hotel services and various other demands depending on the type of ship.

Fresh water may be carried aboard in sufficient quantity to support all services for the design duration of a voyage and replenishment from port facilities, or it may be produced from seawater by onboard distillation or reverse-osmosis units (see section 8.4). Ships designed for ocean service, or for coastwise service with large compliment of crew or passengers, should generally be provided with one or more water production units. For commercial applications, a single unit may be provided if the potable-water storage tank volume is sufficient to meet emergency needs and the unit installed is a highly reliable design.

Potable water is fresh water that is obtained from shore or a water production plant, stored in onboard tank, treated to make it safe for human use, and distributed throughout the ship sinks, lavatories, showers, galleys, laundries, drinking fountains, etc. On commercial ships, a separate wash-water system is sometimes provided for services that do not require water of potable quality, including lavatories, showers, and laundries. This reduces the amount of water to be treated and the quantity of piping that must designed to meet the health regulations. However, a single system is normally provided to simplify tankage and piping.

A potable-water system must be designed to prevent contamination by substances harmful to human health. A typical freshwater service system of a small compliment vessel is shown in Figure 8.36. Piping is provided to fill the potable-water storage tank from a deck-hose connection when in port. Two potable-water pumps should be provided to feed a compression tank, with one a standby. The tank is partially filled with pressurized air, and acts as an accumulator. When water usage reduces the tank air pressure, a pressure switch starts to pump to refill the tank; the pump is stopped when the pressure is restored to normal.

A vacuum priming system should be provided for the potable-water pumps if the storage tanks are not located so that the pumps will always have positive submergence.

Water heaters are installed to supply hot potable water to showers, lavatories, sinks, laundry, galley, and other services. Water heaters can operate with electricity, or diesel engine jacket water. When water heaters are operated with waste heat, an electric heater should be provided for use in port when the engines are secured. Water heaters should be of sufficient capacity to meet peak demand when usage is high, such as the change of the watch and during meal preparation periods. The heating source should be controlled by a thermostatically operated switch or valve to limit the water temperature and should have a relief valve that discharges to a drain in a manner which will not endanger personnel.

If possible the heater should be provided with a recirculating loop to maintain hot water near each user, thus reducing potable-water wastage. Each segment of distribution piping should be sized for the peak load in the segment based on the rated flow of the fixture.

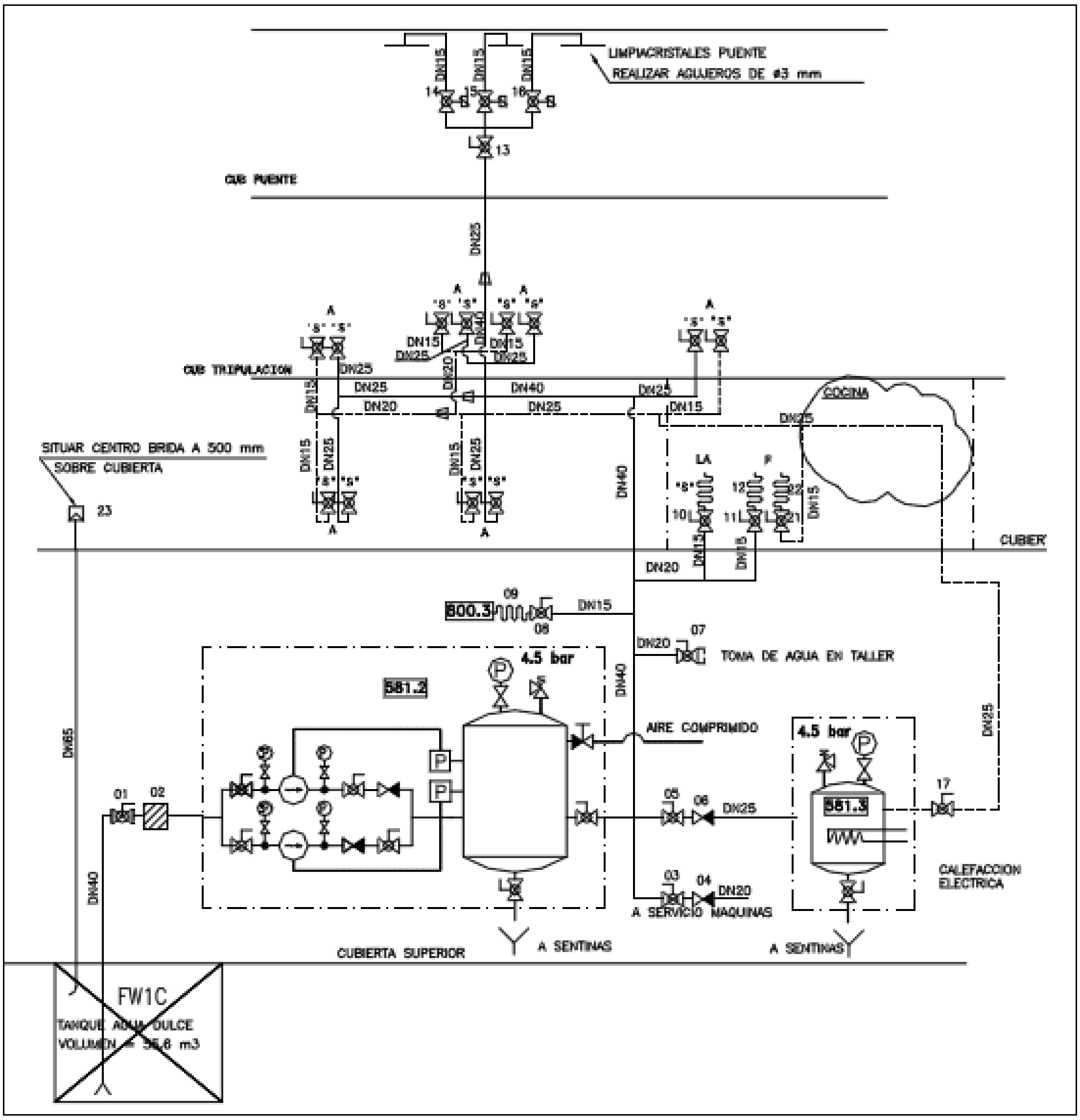


Fig. 8.36 – Freshwater service system.

8.3.5. Fire main systems

a) Fire main system

A fire main system supplies seawater at high pressure throughout the ship for sprinkling systems and hand-held hoses. Seawater is an essential shipboard extinguishing agent because it is in abundant supply, it can be applied as stream or spray to suit various fire-fighting situations, and it is a highly effective cooling agent, which can prevent re-flashing of combustible material, retard the spread of fire through ship structure, and protect fire-fighting personnel.

The common elements in all fire main designs are: centrifugal fire pumps operating at high pressure to provide effective hose stream reach, penetration, and spray formation; a piping system extending throughout the ship; and various means of applying seawater to a fire. Beyond these common elements, the design of fire main systems depends on the ship size, type, and service.

A typical fire main and foam system for a tanker is shown in Figure 8.37.

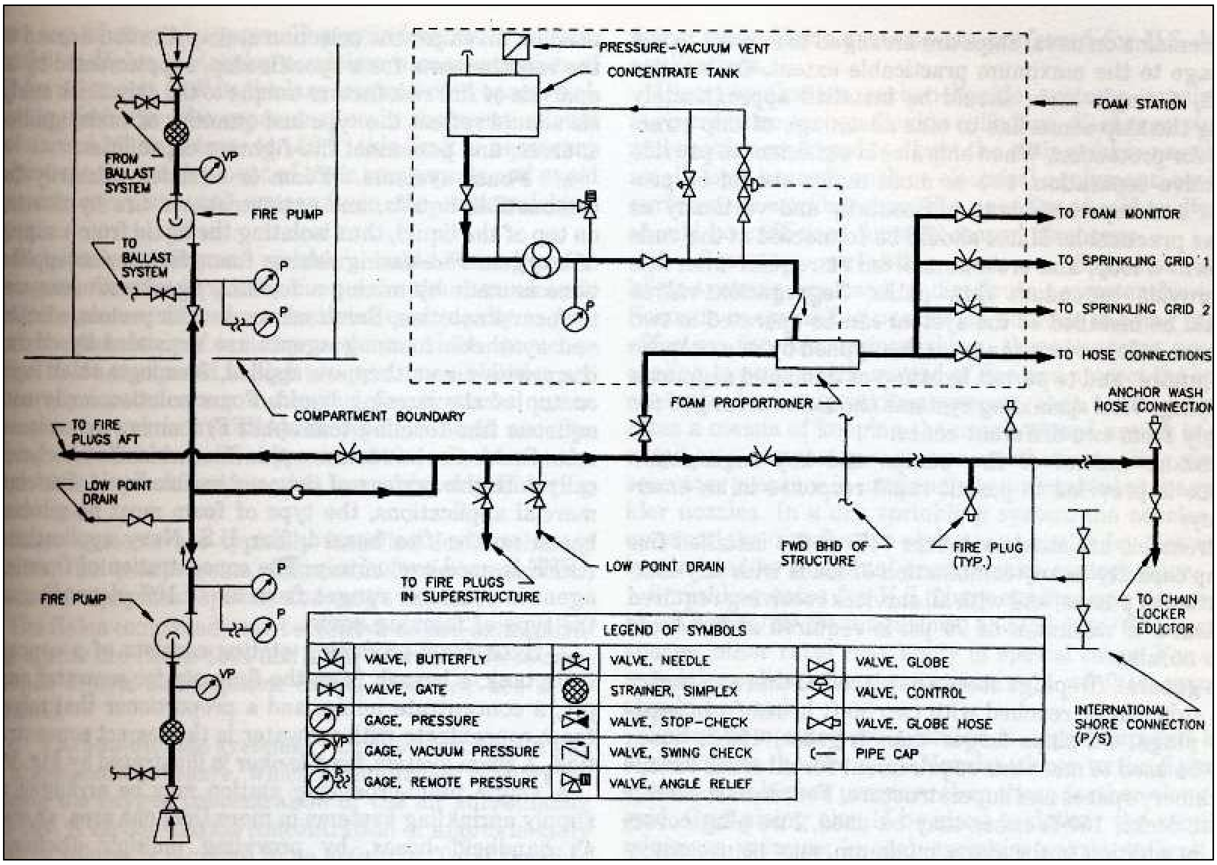


Fig. 8.37 – Fire main and foam system.

Fire main systems for commercial ships are designed to discourage uses other than for fire protection to ensure that the full capacity of the system will be available in an emergency, with minimal realignment of pumps and valves. Fire pumps may be used for other services, such as bilge, ballast, and seawater cooling, provided that at least one pump is kept immediately available for fire main service. Branches from the fire main for other than fire-protection purposes are generally not permitted, but piping that supplies another service is usually required to be connected at the pump, rather than to the fire main, and must have a local valve arranged to immediately isolate the other service. Exceptions may be made for low-demand services such as deck and anchor washing, provided the demand of these services is added to the required pump capacity. On tankers, connections for cargo-tank cleaning are frequently allowed without increasing the pump capacity on the basis that such use is obvious to the crew and can be immediately secured if necessary.

Fire pumps must not be connected to any oil piping. Connection to the bilge system is permitted for emergency dewatering.

At least two fire pumps should be installed. Pumps may be driven by electric motors or combustion engines. The pumps, sea chest, and sources power should be located in separate spaces to ensure that a fire in one space will not disrupt operation of both pumps.

The minimum required capacity of each pump depends on the ship size and service. In general, each fire pump must have a capacity sufficient to meet the greater of two criteria: either a minimum flow rate based on ship size, or the simultaneous supply of a minimum number of fire hoses operating at the required pressure. The minimum number of hoses and required hose nozzle size (DN40 or DN60) depends on ship type. The capacity of each pump must be sufficient to meet the hose stream requirements while simultaneously supplying sprinkling systems, such as the deck foam system on tankers.

The rated head of fire pumps must be sufficient to provide a minimum pressure of 3.5 [bar] for non-tankers, or 5 [bar] for tankers, at the most remote fire-hose nozzles with the required number of hoses operating simultaneously. Each fire pump discharges to a common fire main, which extends throughout the ship, with a branch to each service. The combined static and friction losses to the most remote fire hoses determine the required head. The fireplugs at the highest level of the superstructure usually constitute the worst case; however, on some ships the horizontal length of the fire main may be such that friction losses to the most distant fireplug will govern. The resultant fire pump head is usually in the range of 7 to 10 [bar].

The fire pump head needed to supply fireplugs high in the superstructure may result in excessive pressure at hoses in machinery spaces and other locations low in the ship. Excessive pressure makes hose nozzles difficult to handle and may make snaking hoses within the ship impossible. In such cases a pressure-reducing station should be provided for the lower fireplugs.

Fireplugs should be placed so that all parts of living quarters, storerooms, working spaces, and weather decks accessible to the crew while at sea can be reached with two effective spray patterns of water, with at least one spray pattern from a single 15 [m] hose. All portions of main machinery spaces should be within the reach of at least two spray patterns of water, each of which should be from a single 15 [m] hose from a separate plug.

Commercial ship fire mains are usually unpressurized (dry) when not in use, in order to reduce pump wear and avoid freezing of long runs of exposed piping, which exists on many designs, particularly on tankers and container vessels. The system may be kept continuously pressurized (wet) in some applications when rapid availability of fire main pressure at hose nozzles is required, such as on passenger vessels. The life of galvanized steel pipe is generally considered acceptable for dry systems; however, copper-nickel is preferred material for both dry and wet systems.

Fire main systems on military vessels are continuously pressurized (wet) systems because water must be available immediately for munitions sprinkling, and seawater must be continuously available outside of the machinery spaces for equipment cooling, sanitary flushing, ballasting, and operating educators for drainage and de-ballasting.

b) Fire-extinguishing systems

To supplement the fire main, fixed fire-extinguishing systems are installed for specific hazards. These include:

b.1) Carbon-dioxide for total flooding;

b.2) Halon for total flooding;

b.3) Foam sprinkling;

b.4) Seawater sprinkling;

b.5) Chemical suppression.

Not all of these systems are used in all the ships; the selection depends on the requirements for a specific ship, supplemented by an analysis of fire risk factors unique to the ship.

8.4. Introduction to the most common solutions utilized onboard to produce fresh water from seawater

The production onboard of fresh water from seawater is generally carried out by one of two processes: distillation followed by condensation or reverse-osmosis (RO). Both systems have advantages over the other, in particular with respect to the quality of water produced, the cost of providing boiler feed make-up, maintenance requirements, and running costs.

8.4.1. Distillation systems

The principal advantage of the distillation method is usually claimed to be high quality water produced at relatively low cost. Distillers can produce fresh water with total dissolved solids (TDS) of 4 [ppm], better than the World Health Organization (WHO) requirement of 500 [ppm] TDS, and average 300 [ppm] produced by RO systems.

This TDS level makes the product suitable for boiler and drinking water use although, because of the high removal of salts from the seawater during process, fresh water produced from desalination plants tends to contain high levels of CO_2 which causes corrosion in the piping system, and leads to the phenomena known as “red water”. A mineralizing filter to re-harden the product is usually recommended to overcome this; it also has the advantage of adding some mineral content to the water resulting in what some believe to be a more palatable drink.

An additional benefit with many distillation plants is their ability to run off waste heat such as jacket cooling water or exhaust gas boilers. On ships which are largely stationary, such as fish factory ships, or where waste heat is already in use for other purposes, such as accommodation heating on cruise ships, the steam needed may have to be provided by auxiliary boilers.

The capacity of the distillation plants ranges from 35 to 800 [m^3/day]. This capacity is achieved through the combination of a new separation technique and the basic principle of evaporation under vacuum in vertical tubes. As illustrated in Figure 8.38, the vapor forms a column around the center of the tube which presses the supply water against the tube surface, ensuring a continuous thin film of water on the tube surfaces and so eliminating dry spots where scale deposits might form.

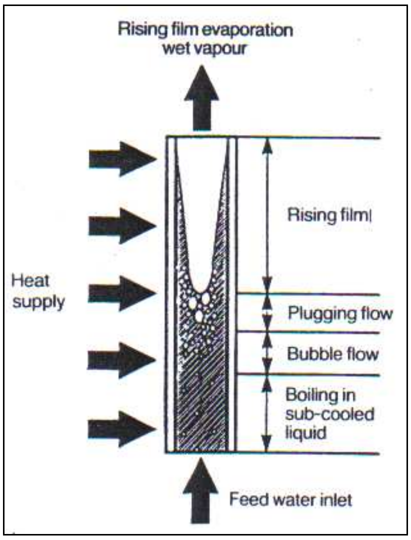


Fig. 8.38 – Rising film evaporation on a distillation system.

A controlled amount of seawater is fed into the bottom of each effect and into the tubes in the heat exchanger, where it is heated by the jacket cooling water or live saturated steam encompassing the tubes.

Some of the supply water is evaporated under vacuum – created by water ejectors connected to each effect – making it possible to lower the boiling temperature and minimizing the amount of energy necessary to evaporation. The vapor generated in the first effect passes a separation compartment where the remaining water droplets are separated from the vapor and extracted with the brine, and then flows through the vapor connection pipe to the heat exchanger in the second effect; the vapor is now used as heating medium for the second effect.

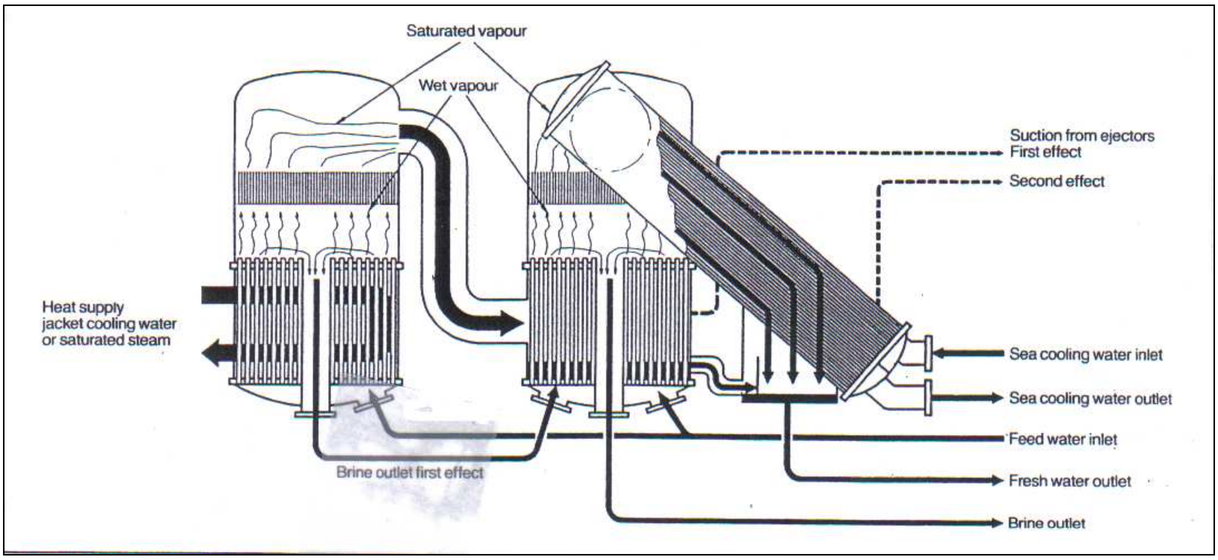


Fig. 8.39 – Evaporation followed by condensation on a distillation system.

Brine extracted from the first effect is mixed with seawater and brought to evaporation. Vapor used for heating of the second effect condenses on the outside of the heat exchanger tubes, and flows through the flash pipe in the bottom of the heat exchanger into the flash tank. Separated vapor is then condensed on the outside of the condenser tubes through which cooling water is flowing. The resulting condensate flows into the flash tank and is pumped into the fresh water tank.

8.4.2. Reverse-osmosis systems

Osmosis is a technique which plants use to absorb water from the soil and to transport the water up to the stem to all the parts of the plant. Dilute and more concentrated solutions are separated by a semi-permeable membrane, which acts like a very fine filter. The semi-permeable membrane allows water molecules to pass, but prevents the movement of salt or other dissolved chemical molecules.

If two saline solutions (or water and a saline solution) are separated only by a semi-permeable membrane, there will be a transfer of water through the membrane to the more concentrated saline solution. The passage of water will continue until a stable condition is reached, with the difference of liquid levels across the semi-permeable membrane being referred to as the osmotic pressure. The osmotic pressure varies with temperature and the concentration of the two solutions (see Figure 8.40 (a)).

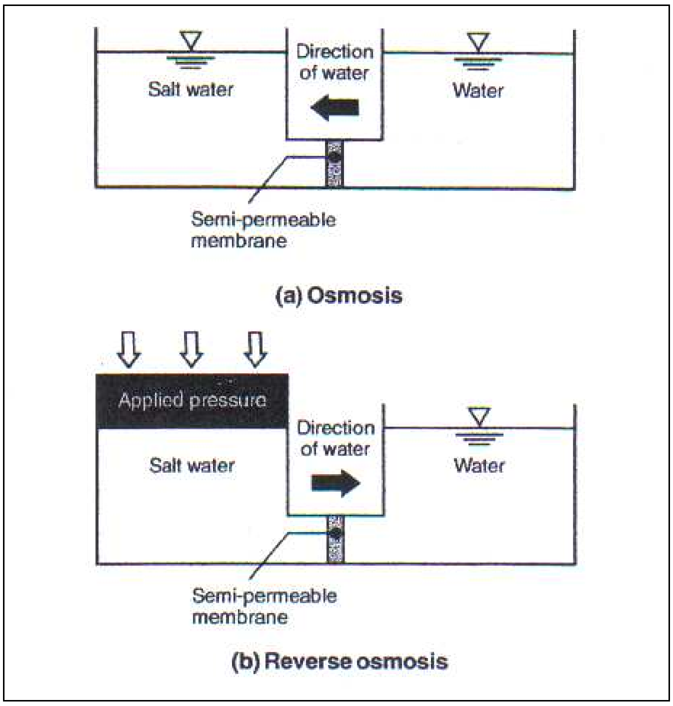


Fig. 8.40 – Direct and reverse osmosis principle.

By applying pressure (in excess of the osmotic pressure) to the salt-water solution, the process can be reversed, and water molecules from the salt-water solution can be forced through to the other side of the semi-permeable membrane (see Figure 8.31 (b)). The osmotic pressure to produce fresh water from seawater using RO plant is about 75 [bar]. Usually, RO plants use a carbon filter in the pre-treatment system (to protect highly loaded membranes), which needs replacement every ten years. In addition, a disinfection system should be provided to kill bacteria before water enters the potable-water distribution piping. The system may be of the type that injects an amount of chlorine or bromine in proportion to the quantity of water being produced.

For an RO system to produce the same quality of water as a distillation plant, a multistage plant would be needed which is not economical.

Although unnecessarily pure for drinking, distilled water is required for boiler feed water; steam turbines, for instance, require a TDS of between 1.5 and 2 [ppm].

RO can supply systems with capacities ranging from 2 to 500 [m^3/day] at a quality below the WHO level: these units can also go down to 1 [ppm] TDS, but at extra cost.

Assuming seawater enters onboard at 25ºC, the typical amount of energy necessary to produce fresh water using RO plant are between 10 to 15 [kWh/m^3 of water produced]. If a distillation plant is used then amount of energy necessary is about 2 to 3 times larger. Therefore, when waste heat is not readily available, RO systems are the most cost effective means of providing fresh water onboard.

8.5. Refrigeration, Heating, Ventilation, and Air Conditioning

8.5.1. Introduction

Refrigeration is a process in which the temperature of a space or its contents is reduced to below that of their surroundings. Heating is simply the opposite of refrigeration. Air conditioning is the control of temperature and humidity in a space together with the circulation, filtering and refreshing of the air. Ventilation is the circulation and refreshing of the air in a space without necessarily a change of temperature. With the exception of special processes, such as fish freezing, air is normally employed as the heat transfer medium. As a result fans and ducting are used for refrigeration, air conditioning and ventilation. The three processes are thus interlinked and all involve the provision of a suitable climate for men, machinery and cargo.

8.5.2. Refrigeration

Refrigeration of cargo spaces and storerooms employs a system of components to remove heat from the space being cooled. This heat is transferred to another body at a lower temperature. The cooling of air for air conditioning entails a similar process.

The transfer of heat takes place in a simple system: firstly, in the evaporator where the lower temperature of the refrigerant cools the body of the space being cooled; and secondly, in the condenser where the refrigerant is cooled by air or water. The usual system employed for marine refrigeration plants is the vapor compression cycle, for which the basic diagram is shown in Figure 8.30.

The pressure of the refrigerant gas is increased in the compressor and it thereby becomes hot. This hot, high-pressure gas is passed through into a condenser. Depending on the particular application, the refrigerant gas will be cooled either by air or water, and because it is still at a high pressure it will condense. The liquid refrigerant is then distributed through a pipe network until it reaches a control valve alongside an evaporator where the cooling is required. This regulating valve meters the flow of liquid refrigerant into the evaporator, which is at a lower pressure. Air from the cooled space or air conditioning system is passed over the evaporator and boils off the liquid refrigerant, at the same time cooling the air.

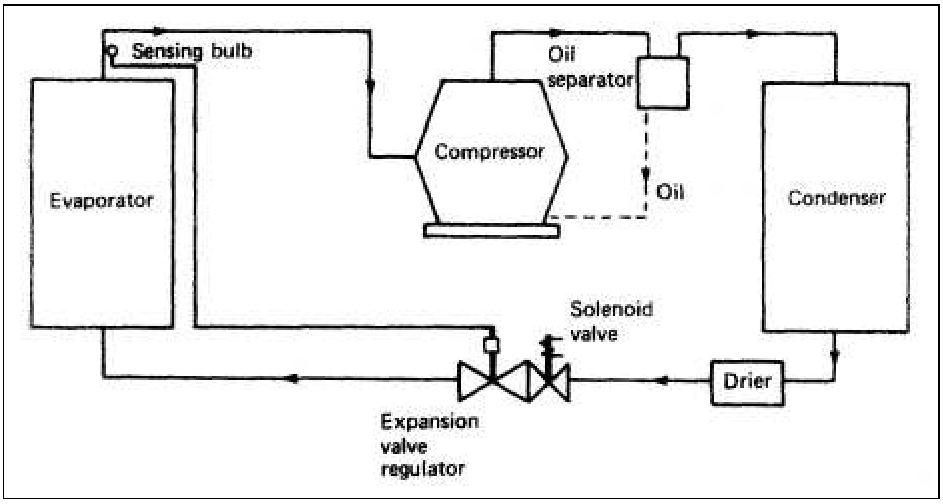


Fig. 8.41 – Vapor compression cycle.

The design of the system and evaporator should be such that all the liquid refrigerant is boiled off and the gas slightly superheated before it returns to the compressor at a low pressure to be recompressed.

Thus it will be seen that heat that is transferred from the air to the evaporator is then pumped round the system until it reaches the condenser where it is transferred or rejected to the ambient air or water. It should be noted that where an air-cooled condenser is employed in very small plants, such as provision storerooms, adequate ventilation is required to help remove the heat being rejected by the condenser. Also, in the case of water-cooled condensers, fresh water or sea water may be employed. Fresh water is usual when a central fresh-water/sea-water heat exchanger is employed for all engine room requirements. Where this is the case, because of the higher cooling-water temperature to the condenser, delivery temperatures from condensers will be higher than that on a sea water cooling system.

Refrigerants:

Generally speaking these are sub-divided into primary and secondary refrigerants.

a) Primary refrigerants

This is the refrigerant employed in the compressor, condenser and evaporator system and certain properties are essential requirements. For example it will boil off or evaporate at a low temperature and reasonable pressure and it will condense at a temperature near normal sea water temperature at a reasonable pressure. The refrigerant must also be free from toxic, explosive, flammable and corrosive properties where possible. Some refrigerants have critical temperatures above which the refrigerant gas will not condense. This was one of the disadvantages of carbon dioxide, which was used for many years on ships. Ships operating in areas with very high sea-water temperatures had difficulty in liquefying the carbon dioxide without some additional sub-cooling system. A further disadvantage of carbon dioxide was the very high pressure at which the system operated, resulting in large and heavy machinery.

Between the carbon dioxide era and the present refrigerants, methyl chloride and ammonia were used. Due to its explosive properties, methyl chloride is now banned for shipboard use. Ammonia is still employed, but requires special ventilation.

The modern refrigerants are fluorinated hydrocarbon compounds of various formulae, with the exception of Refrigerant 502, which is an azeotropic (fixed boiling point) mixture of Refrigerant 22 and Refrigerant 115. These are usually referred to as “Freons” with a number related to their particular formula.

Most modern refrigerants are chlorofluorocarbons (CFCs) which have a damaging effect on the ozone layer, in addition to accumulating in the atmosphere and causing global warming. The Montreal Protocol, signed in 1987 and reviewed in 1990 and 1992, regulates the manufacture and use of CFC gases. The phasing-out of existing CFCs is likely to form part of a new Annex to MARPOL 73/78 and alternatives are being sought for shipboard use.

b) Secondary refrigerants

Both large air conditioning and cargo cooling systems may employ a secondary refrigerant. In this case the primary refrigerant evaporator will be circulated with the secondary refrigerant, which is then passed to the space to be cooled. Secondary refrigerants are employed where the installation is large and complex to avoid the circulation of expensive primary refrigerants in large quantities. These primary refrigerants can be very searching, that is they can escape through minute clearances, so it is essential to keep the number of possible leakage points to a minimum.

In the case of air conditioning plants, fresh water is the normal secondary refrigerant, which may or may not have a glycol solution added. The more common secondary refrigerant on large cargo installations is a calcium chloride brine to which is added inhibitors to prevent corrosion.

System components:

a) Compressor

There are three types of compressor in use at sea: centrifugal, reciprocating, and screw.

Centrifugal compressors are used with Refrigerants 11 or 12 and are limited in their application to large air conditioning installations. They are similar in appearance to horizontal centrifugal pumps and may have one or more stages.

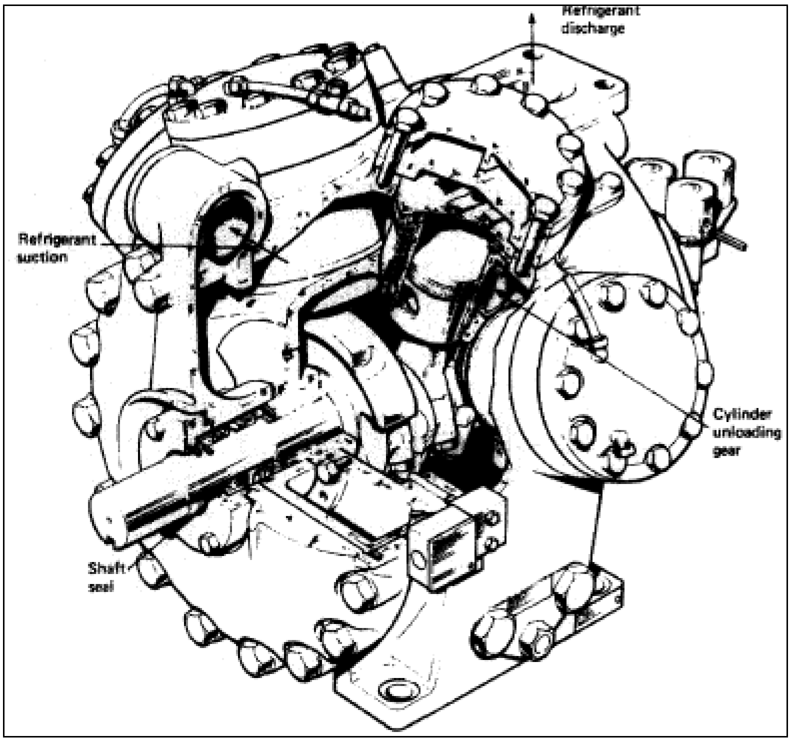


Fig. 8.42 – Reciprocating compressor.

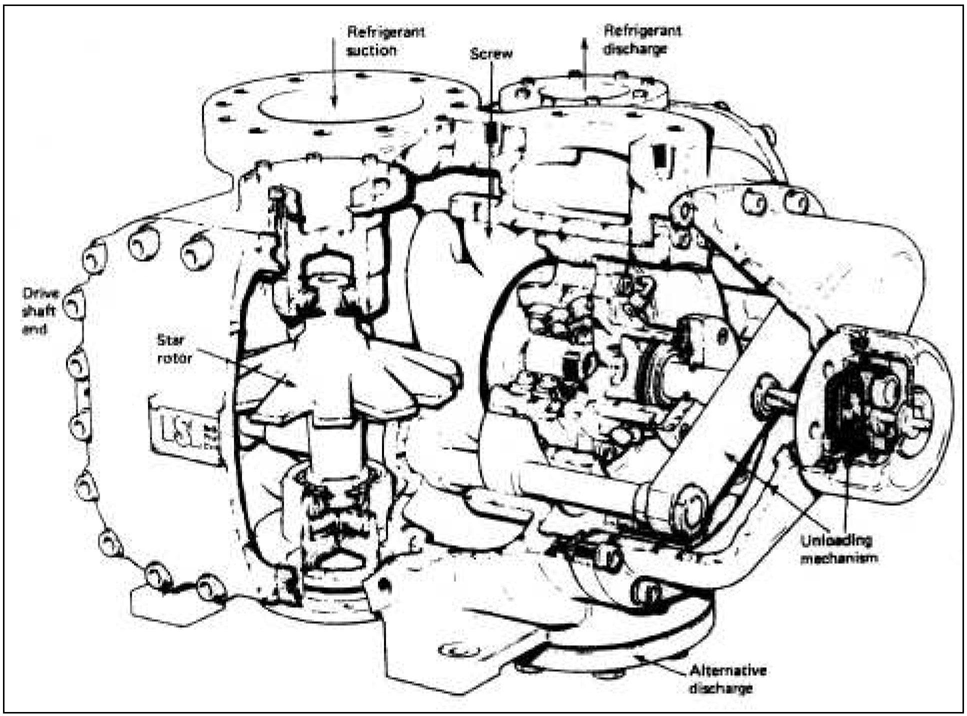


Fig. 8.43 – Single-screw compressor.

Reciprocating compressors cover the whole spectrum of refrigeration requirements at sea, from air conditioning to low temperature cargo installations. They are normally of a compact design and may be of an in-line, V or W configuration. Figure 8.42 shows a 4-cylinder W configuration. The construction arrangement can be seen and the principle of operation is similar in many respects to an air compressor,

For low-temperature applications the machine may be arranged as a two-stage compressor and some machines are made so that they can be changed from single to two stage, depending on cargo requirements. As the crankcase is subject to refrigerant pressure, the drive shaft seal is required to prevent a flow of refrigerant out of the compressor or ingress of air. In semi-hermetic or hermetic machines this problem is obviated as the motor and compressor are in one casing.

Screw compressors have replaced reciprocating compressors in large installations for two reasons. Firstly, fewer and more compact machines are used; secondly, a reduced number of working parts results in greater reliability with reduced maintenance requirements. There are two types of screw compressor; one employs two rotors side by side and the other, which is a more modern development, is a single rotor with two star wheels, one on either side. As the star wheels compress the gas in opposite directions, the thrust on this type of rotor is balanced. Such a compressor in shown in Figure 8.43. The principle of operation for both types is similar to a screw-type positive displacement pump.

To achieve a seal between the rotors, oil is injected into the compressor: to prevent this being carried into the system, the oil separator is larger and more complex than the normal delivery oil separator associated with a reciprocating compressor. Also, because some of the heat of compression is transferred to the oil, a larger oil cooler has to be fitted, which may be either water or refrigerant cooled.

Since AC motor driven compressors are usually single speed, some form of cylinder unloading gear is necessary to reduce the compressor capacity. This unloading gear usually comprises a means of holding the suction valves open.

b) Condensers

Condensers are generally water cooled, as mentioned previously, and are of the shell and tube type. A typical modern unit is shown in Figure 8.44 in which it will be seen that the refrigerant passes over the tubes and the cooling water is passed through the tubes. In the case of sea water cooled condensers it is usual to have a two-pass arrangement through the tubes. The sea water side maintenance mentioned for coolers applies also to this condenser.

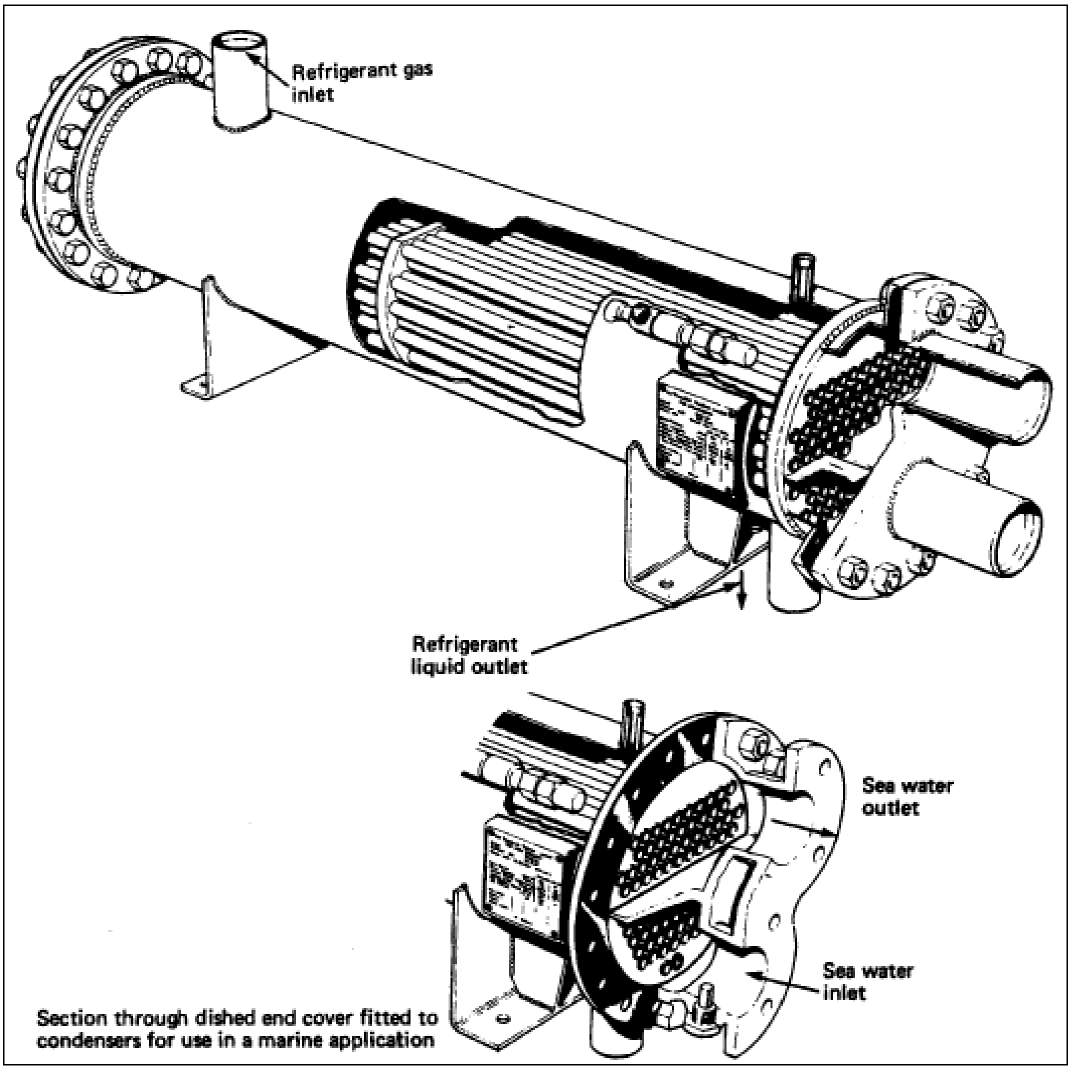


Fig. 8.44 – Condenser.

Where condensers are of 3 [m] and over in length between tube plates it is quite usual to have a double refrigerant liquid outlet so that the refrigerant drains away easily when the vessel is pitching or rolling.

c) Evaporators

Evaporators fall into two categories: refrigerant to air and refrigerant to secondary refrigerant types.

The most simple of the refrigerant to air type is in the form of a bank of tubes with an extended surface of gills or fins. In these the refrigerant is expanded in the tubes while the air is passed over the fins by circulating fans. This type of unit will be found in the domestic cold stores in which the fan and coil unit are one, and a larger version in direct expansion cargo or air conditioning systems where the fan or fans may be remote.

A more elaborate design is used for secondary refrigerant cooling which takes the form of a shell and tube vessel. Such a type is illustrated in Figure 8.45 and employs direct expansion. In this case the refrigerant passes through the tubes and the secondary refrigerant is passed over the tube bank. The refrigerant is sprayed into the tubes so as to ensure an even distribution through all the tubes. Any oil present is not sprayed and drains away. In this type of evaporator two features are employed to improve heat transfer efficiency. On the refrigerant side there is a centre tube with a spiral fin fitted around it (as illustrated) or the insert may be in the form of an aluminum star which has a spiral twist on it. Also, baffles are arranged on the brine side to deflect the brine across the tube bank.

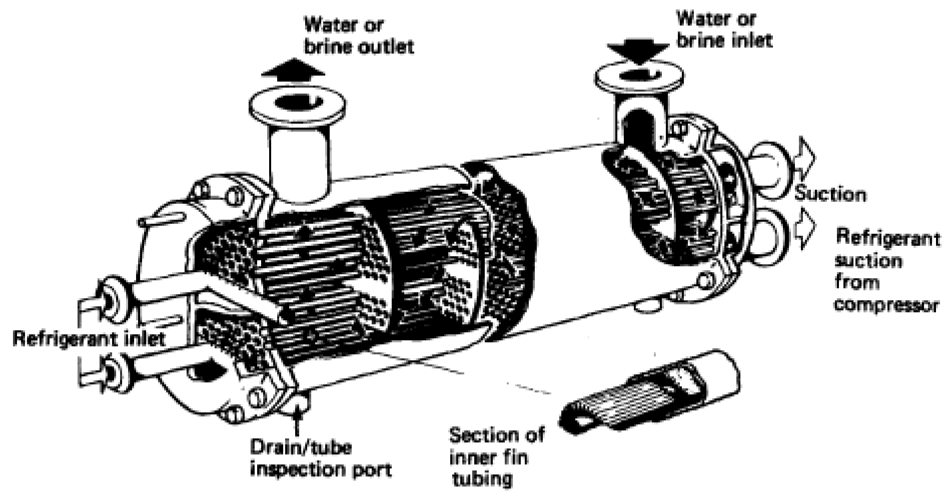


Fig. 8.45 – Evaporator.

d) Refrigerant flow control valves

It is usual to have a solenoid valve in the liquid line prior to the expansion valve or regulator. This shuts or opens as determined by the thermostat in the space or the secondary refrigerant being cooled. It may also be used to shut off various circuits in a cooler when the machine is operating on part-load conditions.

The expansion valve/regulator is a more complex piece of equipment which meters the flow of refrigerant from the high-pressure to the low-pressure side of the system. This may be of the thermostatic type, as shown in Figure 8.46. The bulb senses the temperature of the refrigerant at the outlet from the evaporator and opens or closes the valve accordingly. The design of the valve is critical and is related to the pressure difference between the delivery and expansion side. Therefore, it is essential that the delivery pressure is maintained at or near the maximum design pressure. Thus, if the vessel is operating in cold sea water temperatures it is necessary to re-circulate the cooling water to maintain the correct delivery pressure from the condenser. If this is not done, the valve will 'hunt' and refrigerant liquid may be returned to the compressor suction.

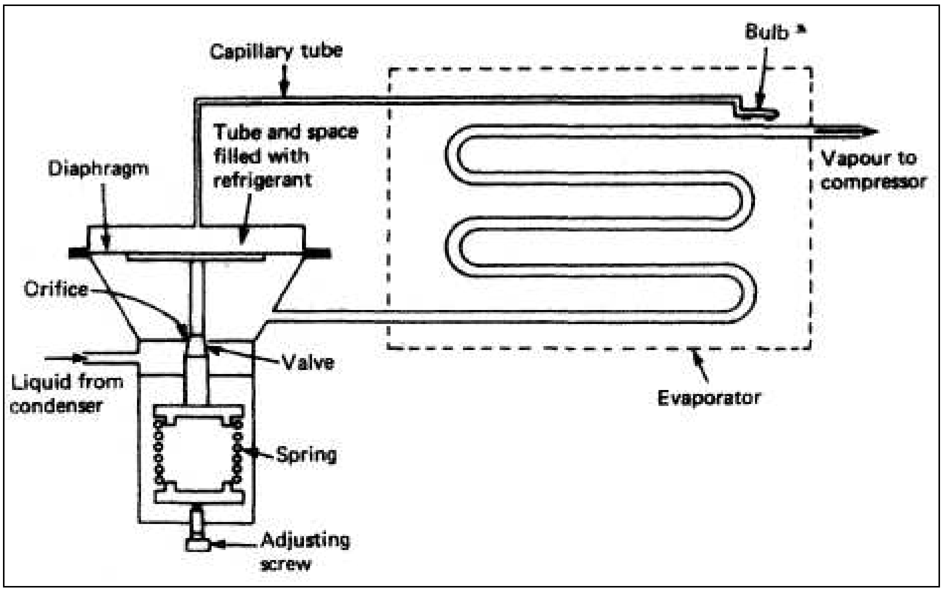


Fig. 8.46 – Thermostatic expansion valve.

e) Auxiliary fittings

Delivery oil separators are essential for screw compressors, but for other systems, depending on the design criteria and length of pipe run, they may or may not be fitted.

Refrigerant driers are essential with the Freon gases to remove water from the system, otherwise freezing of the water can take place in the expansion valve.

A liquid receiver may be fitted for two reasons. Firstly, to give a sufficient reserve of refrigerant in the system to cater for various operating conditions (this is known as a back-up receiver). Secondly, for storage of the refrigerant where it is required to pump over, i.e. store, the charge for maintenance purposes. In very small systems this pump over can sometimes be achieved in the condenser.

Cargo refrigeration:

Refrigerated cargo vessels usually require a system which provides for various spaces to be cooled to different temperatures. The arrangements adopted can be considered in three parts: the central primary refrigerating plant, the brine circulating system, and the air circulating system for cooling the cargo in the hold.

A central refrigerating plant is shown in Figure 8.47. The refrigerant flow through the chiller splits into four circuits, each with its own expansion valve. The four circuits are used to control the amount of evaporator surface, depending on the degree of condenser loading at the time, thus giving greater system flexibility. The large oil separator is a feature of screw compressor plants and the circuit for oil return is shown in the illustration.

Each primary refrigerant circuit has its own evaporator within the brine chiller (as shown in Figure 8.47) which results in totally independent gas systems. There will probably be three such systems on a cargo or container ship installation. Since they are totally independent each system can be set to control the outlet brine at different temperatures. Each brine temperature is identified by a color and will have its own circulating pump. The cold brine is supplied to the cargo space air cooler and the flow of this brine is controlled by the temperature of the air leaving the cooler.

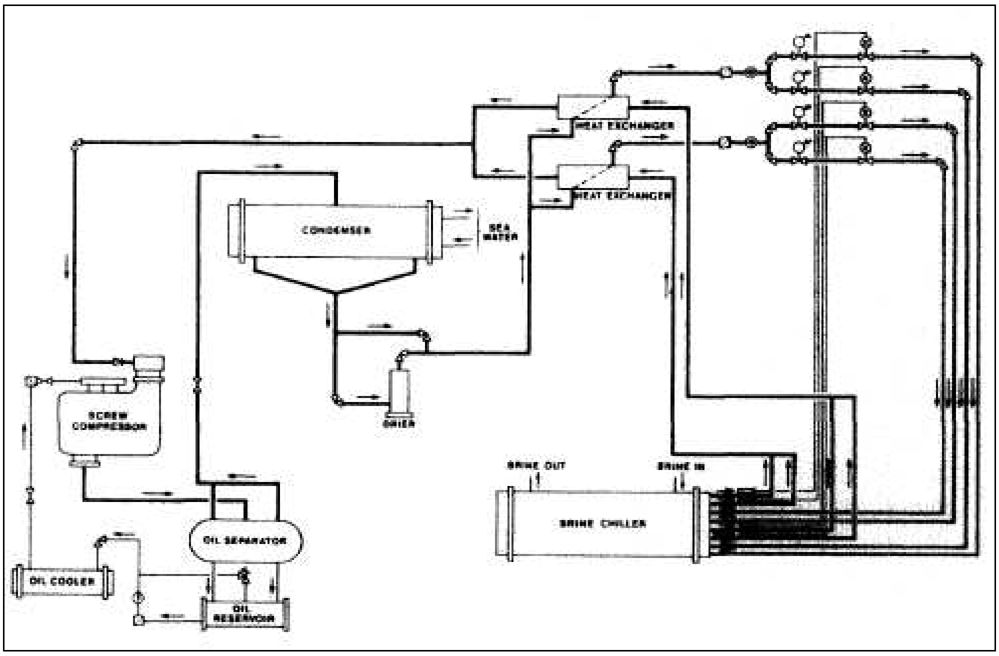


Fig. 8.47 – Central refrigerating plant.

The cooler in the cargo space is arranged for air circulation over it and then through the cargo before returning. An arrangement of fans and ducting direct the air to the cooler and below the cargo (Figure 8.48). The cargo is stacked on gratings which allow the passage of cooled air up through the cargo.

For small refrigerated cargo spaces or provision rooms a direct expansion primary refrigerant system may be used (Figure 8.49). The twin circuit arrangement for each cooler (evaporator) provides flexibility and duplication in the event of one system failing. The back pressure valve maintains a minimum constant pressure or temperature in the evaporator when working a space in high-temperature conditions to prevent under-cooling of the cargo. If one space is operating at a low-temperature condition at the same time the back pressure valve would be bypassed. The liquid cooler illustrated in the diagram is necessary where an abnormal high static head has to be overcome between the machinery and the coolers. In this vessel the liquid is sub-cooled to prevent it flashing off before reaching the thermostat expansion valve.

Containers which require refrigeration present particular problems. Where only a few are carried or the ship has no built-in arrangement for refrigerating containers, then clip-on or integral refrigeration plants would be provided. The clip-on or integral unit may be either air or water cooled. In the case of air cooled units adequate ventilation has to be supplied if they are fitted below decks. For water cooled units some sort of cooling water arrangement must be coupled up to each unit. Also an electrical supply is required for each type.

Vessels designed for specific refrigerated container trades have built-in ducting systems. These can be in two forms: a horizontal finger duct system in which up to 48 containers are fed from one cooler situated in the wings of the ship or, alternatively, a vertical duct system in which each stack of containers has its own duct and cooler. This type of system is employed for standard containers having two port holes in the wall opposite the loading doors. Air is delivered into the bottom opening and, after passing through a plenum, rises through a floor grating over the cargo and returns via another section of the plenum to the top port. The connection between the duct arid containers is made by couplings which are pneumatically controlled.

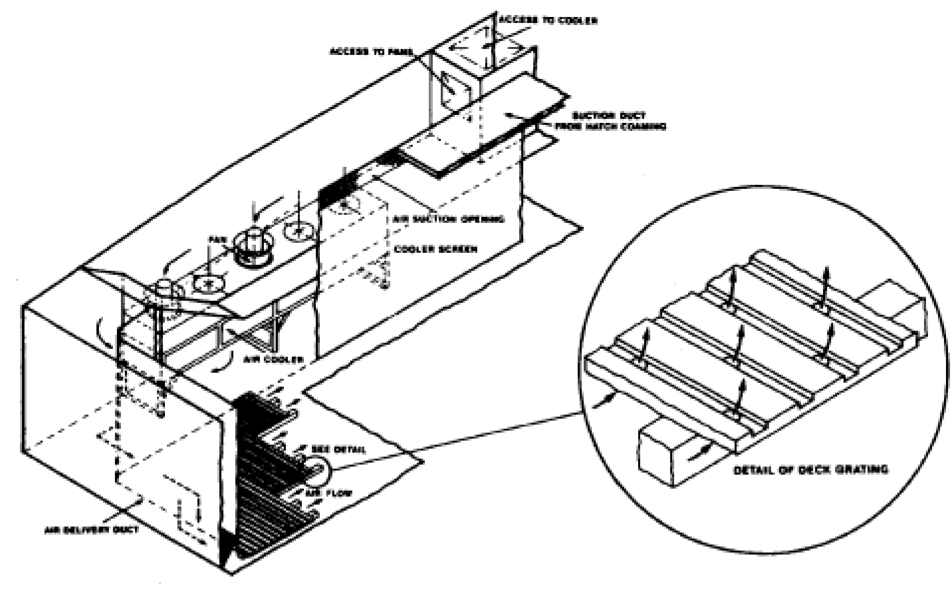


Fig. 8.48 – Cargo space arrangement.

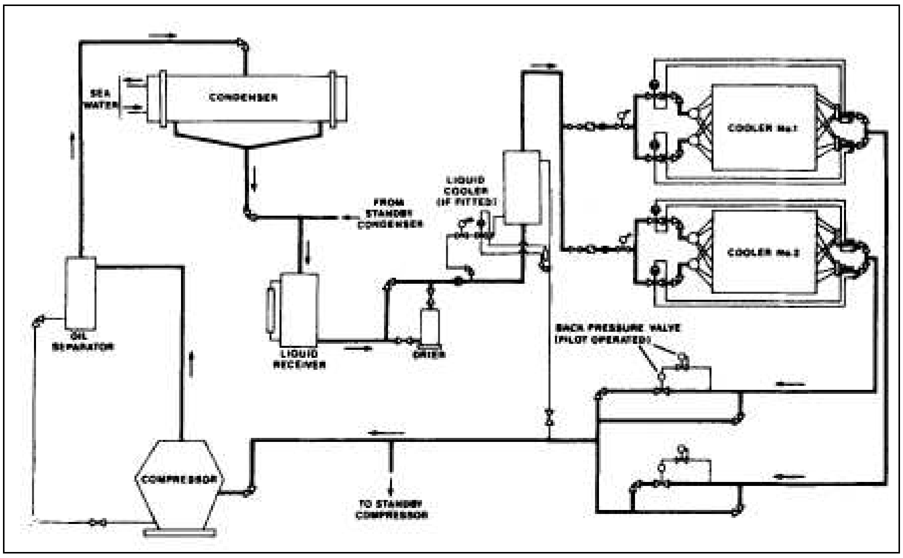


Fig. 8.49 – Direct expansion system.

8.5.3. *Air conditioning*

Ships travel the world and are therefore subject to various climatic conditions. The crew of the ship must be provided with reasonable conditions in which to work regardless of the weather. Temperature alone is not a sufficient measure of conditions acceptable to the human body. Relative humidity in conjunction with temperature more truly determines the environment for human comfort. Relative humidity, expressed as a percentage, is the ratio of the water vapor pressure in the air tested, to the saturated vapor pressure of air at the same temperature. The fact that less water can be absorbed as air is cooled and more can be absorbed when it is heated is the major consideration in air conditioning system design. Other factors are the nearness of heat sources, exposure to sunlight, sources of cold and the insulation provided around the space.

An air conditioning system aims to provide a comfortable working environment regardless of outside conditions. Satisfactory air treatment must involve a relatively 'closed' system where the air is circulated and returned. However, some air is 'consumed' by humans and some machinery so there is a requirement for renewal. Public rooms and accommodation will operate with a reduced percentage of air renewal since the conditioning cost of 100% renewal would be considerable.

Galleys and sanitary spaces, for instance, must have 100% renewal, but here the air quantities and treatment costs will be much smaller. Systems may however be designed for 100% renewal of air although not necessarily operated in this way. Noise and vibration from equipment used in the system should be kept to a minimum to avoid a different kind of discomfort. Three main types of marine air conditioning system are in general use, the single duct, the twin duct and the single duct with reheat.

The single-duct system is widely used on cargo ships (Figure 8.50).Several central units are used to distribute conditioned air to a number of cabins or spaces via a single pipe or duct. In warm climates a mixture of fresh and recirculated air is cooled and dehumidified (some water is removed) during its passage over the refrigeration unit. In cold climates the air mixture is warmed and humidified either by steam, hot water or electric heating elements. The temperature and humidity of the air is controlled automatically at the central unit. Within the conditioned space control is by variation of the volume flow of air.

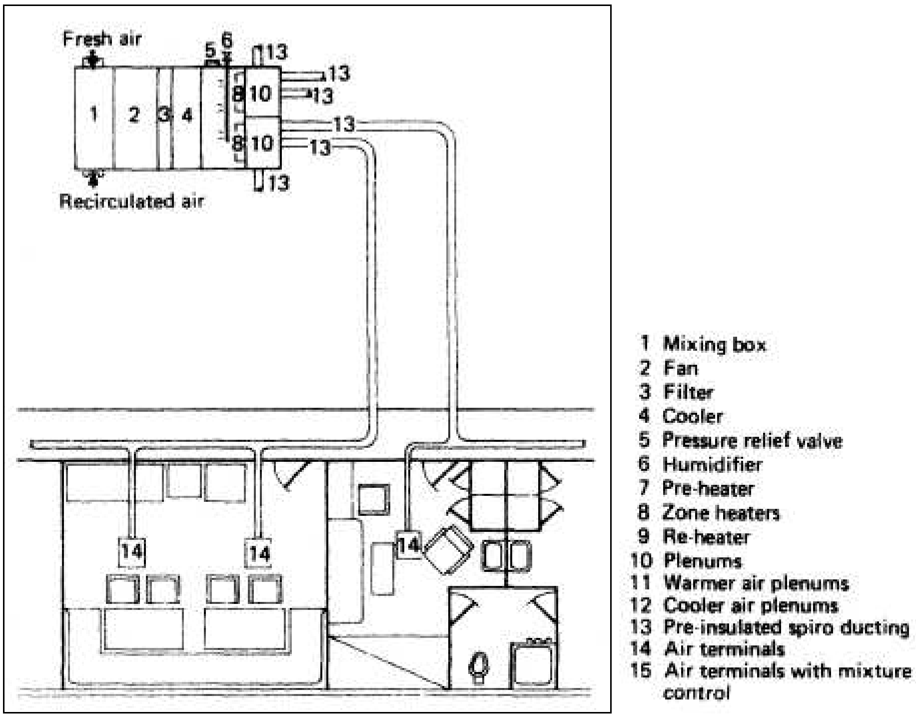


Fig. 8.50 – Single-duct system.

The twin-duct system provides increased flexibility and is mainly used on passenger ships (Figure 8.51). A central unit is used with cooled dehumidified air provided through one duct. The other duct is supplied with cooled air that has been reheated. Each treated space is provided with a supply from each duct which may be mixed as required at the outlet terminal. In cold climates the pre-heater will warm both supplies of air, resulting in a warm and a hot supply to each space. The 'single duct with reheat' system is used for vessels operating in mainly cool climates. The central unit will cool and dehumidify or preheat and humidify the air as required by outside conditions. In addition, before discharge into the treated space a local reheating unit will heat the air if required, depending upon the room thermostat setting.

The refrigeration system used in the central unit is shown in Figure 8.52. A direct-expansion system is shown using a reciprocating compressor, sea water cooled condenser and a thermostatically controlled regulating valve. The air to be cooled passes over the evaporator or cooler. The cooling effect of the unit may need to be reduced if there is no great demand and the hot gas bypass system provides this facility.

Maintenance of the above systems will involve the usual checks on the running machinery and the cleaning of filters. Air filters in the central units are usually washable but may be disposable. The filters should be attended to as required, depending upon the location of the ship.

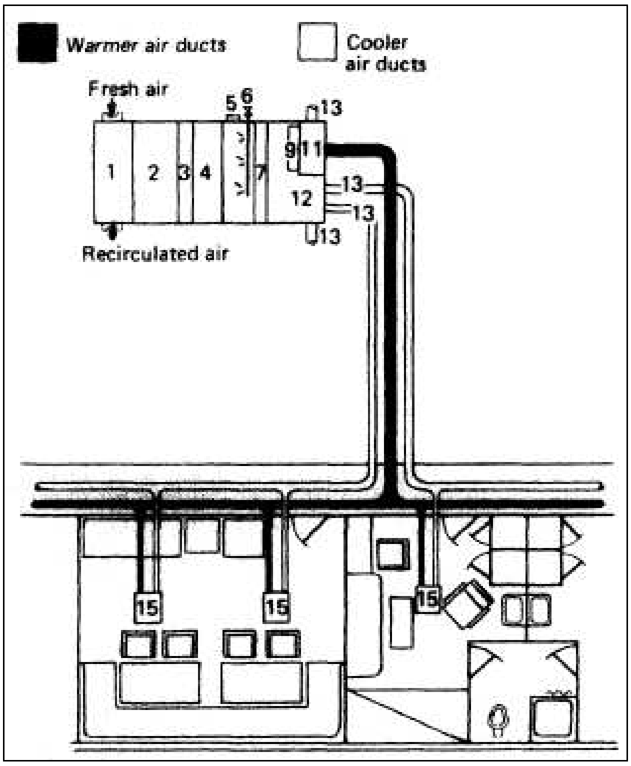


Fig. 8.51 – Twin-duct system.

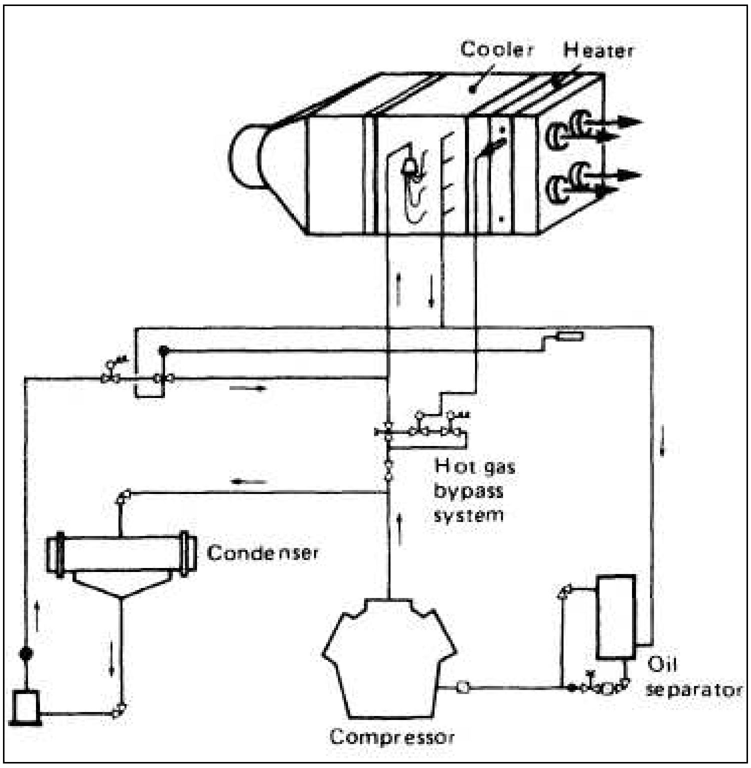


Fig. 8.52 – Direct-expansion refrigeration system for an air cooler.

8.5.4. Ventilation

Ventilation is the provision of a supply of fresh untreated air through a space. Natural ventilation occurs when changes in temperature or air density cause circulation in the space. Mechanical or forced ventilation uses fans for a positive movement of large quantities of air.

Natural ventilation is used for some small workshops and stores but is impractical for working areas where machinery is present or a number of people are employed.

Forced ventilation may be used in cargo spaces where the movement of air removes moisture or avoids condensation, removes odors or gases, etc. The machinery space presents another area which requires ventilation. As a result of its large size and the fact that large volumes of air are consumed a treatment plant would be extremely costly to run.

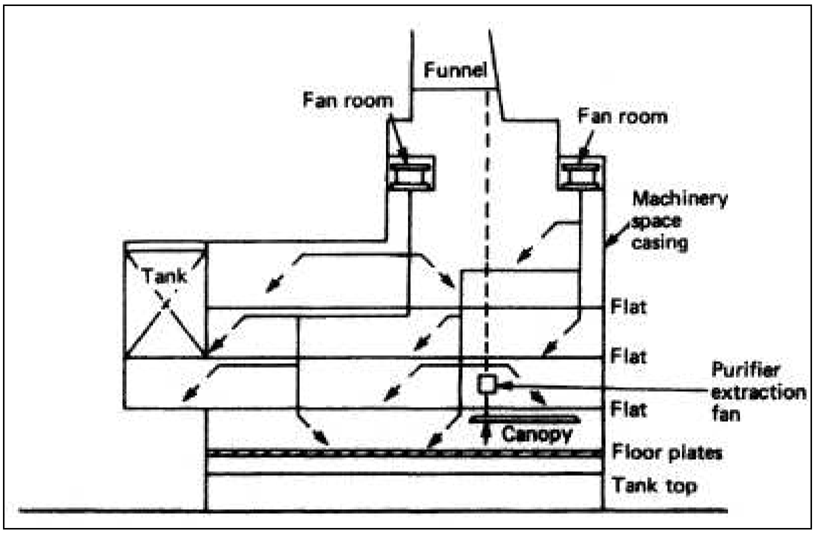


Fig. 8.53 – Machinery space ventilation - diagram.

Ventilation is therefore provided in sufficient quantities for machinery air consumption and also to effect cooling. The usual distribution arrangement is shown in Figure 8.53. Several axial-flow fans provide air through ducting to the various working platforms. The hot air rises in the centre and leaves through louvres or openings, usually in the funnel. The machinery control room, as a separate space, may well be arranged for air conditioning with an individual unit which draws air through trunking from the outside and exhausts back to the atmosphere.

8.5.5. Psychrometric Analysis

In order to determine all of the required supply air conditions and the cooling coil capacity for proper conditioning of the space, the following information is required:

a) Room sensible and latent heat gains;

b) Outside and inside design conditions for summer and winter seasons;

c) Either flow rate (in cubic meters per second) or dry bulb temperature of the supply air. One of these is selected and the other is then determined from the sensible heat equation. However, both must be in the range that is considered satisfactory for “good practice” (see ISO 7547 Air-conditioning and ventilation of accommodation spaces on board ships - Design conditions and basis of calculations).

Supply air temperatures are usually chosen so that the temperature difference between room and supply air is between 10-23° C. Factors such as type and location of air supply outlets will affect the temperature difference selected.

Moreover, the flow rate supply of air must neither be too little nor too great, to prevent discomfort from staleness or drafts.

To determine the required entering and leaving air conditions and the coil sensible, latent, and total loads it is advisable to sketch the coil process line on the psychometric chart and also a diagrammatic arrangement of the air mixing process as shown in Figures 8.54-55.

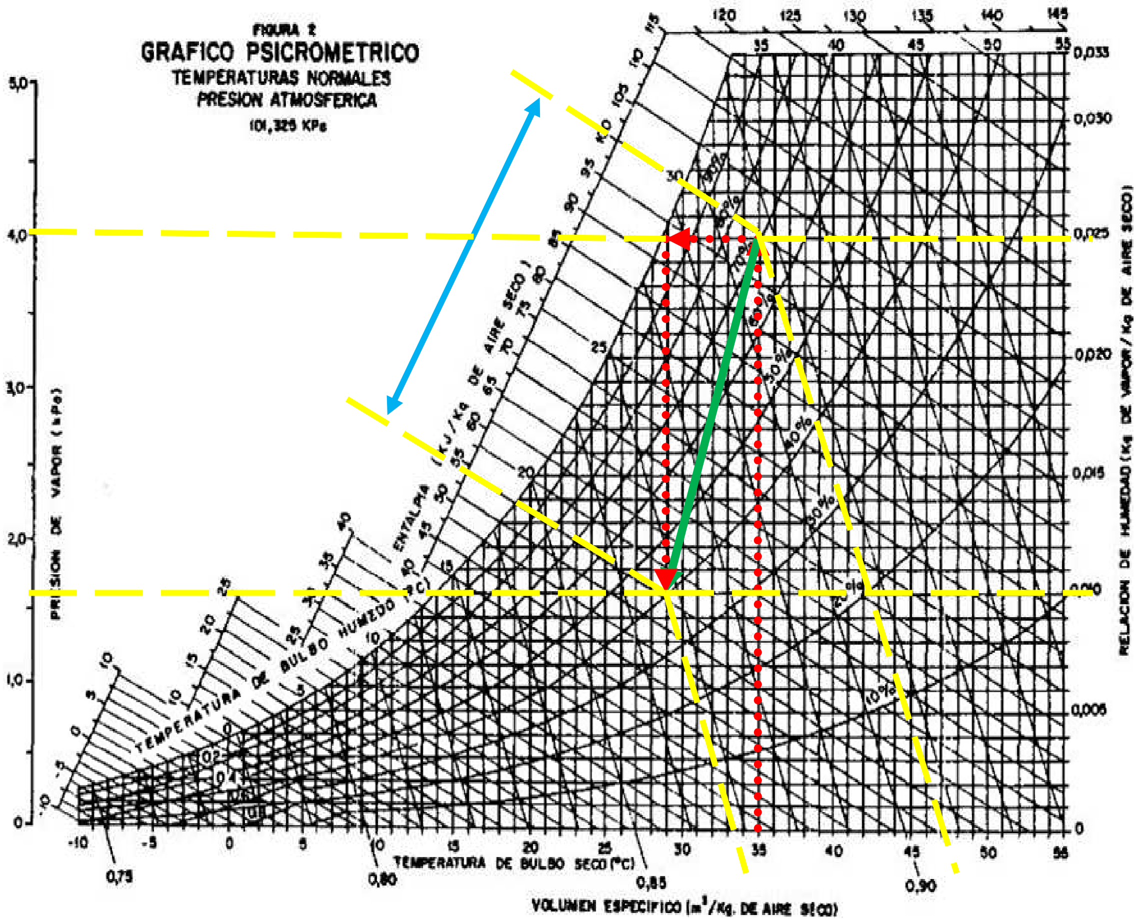


Fig. 8.54 – Sketch of a coil process line on psychrometric chart.

As illustrated in Figure 8.54, showing the air conditioning process on a psychrometric chart is very helpful in selecting equipment and in analyzing problems, since all these processes are shown by drawing a line from the initial air condition to its final condition. The air changes its properties along this line, and, as discussed below, most processes are represented by straight lines.

Sensible heat change process calculations (sensible heating or cooling)

Sensible heat change process is one where heat is added or removed from the air and the dry bulb (DB) temperature changes as result, but there is no change in water vapor content. The direction of the process must therefore be along a line of constant humidity ratio, as illustrated in Figure 8.54.a. Sensible heating (process 1-2) results in an increase in DB and enthalpy. Process 1-3, sensible cooling (heat removal) results in a decrease in DB and enthalpy.

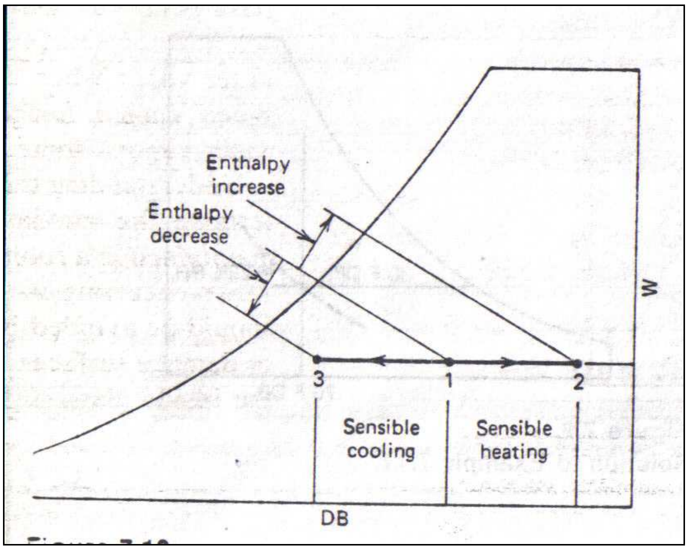


Fig. 8.54.a – Sensible heating and sensible cooling process lines on psychrometric chart.

The sensible heat equation applied to moist air is given by:

$$Q_S = 1.005 m_a \Delta t + 1.867 m_w \Delta t \tag{8.7}$$

, where:

m_a = mass flow rate of air, in [kg/s];

m_w = mass flow rate of water vapor, in [kg/s];

Δt = temperature change, in [ºC].

The first term in the above equation expresses the enthalpy change of the dry air and the second term expresses the enthalpy change of the water vapor. For approximate air conditioning calculations the second term is often small (1.5%) enough so that it can be neglected, and the sensible heat equation is simply written as:

$$Q_S = 1.005 m_a \Delta t \tag{8.8}$$

Latent heat change process calculations (humidifying and dehumidifying)

The process of adding water vapor to the air is called humidification, and removal of water vapor from the air is called dehumidification, as illustrated in Figure 8.54.b. Process 1-4, humidification, results in an increase in humidity ratio and enthalpy. In humidification the enthalpy of the air increases due to the enthalpy of water vapor added. This is why it is called a latent heat change. In dehumidification process 1-5, removal of water vapor results ina decrease in enthalpy. These processes - pure humidification and dehumidification without a sensible heat change – do not occur often in practical air conditioning processes. However, the concept is important to understand in analyzing conditions.

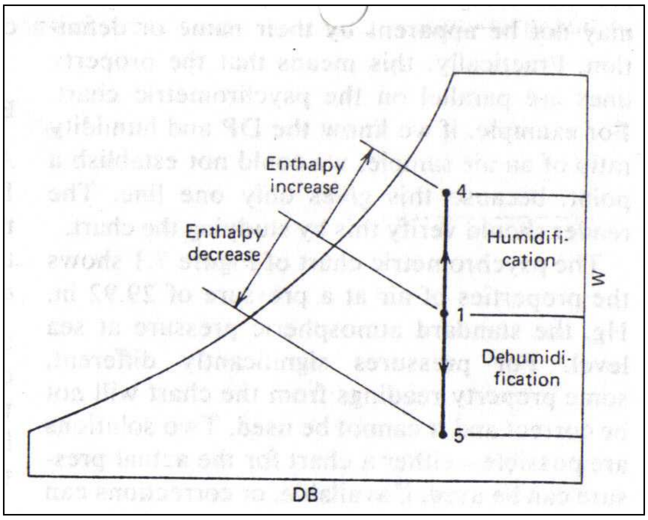


Fig. 8.54.b – Latent heat change process lines on psychrometric chart (humidification and dehumidification).

The amount of water vapor added or removed from air in a humidifying or dehumidifying process is given by:

$$m_w = m_a\left(w_2 - w_1\right) \tag{8.9}$$

, where:

w_1 = humidity of air on initial stage 1, in [kg w./kg d.a];

w_2 = humidity of air on final stage 2, in [kg w./kg d.a].

As with the sensible heating process, it is usually acceptable to assume air at standard conditions. If the air volume flow rate (vol_a) is expressed in [m^3/s], substituting in the equation above gives:

$$m_w = 1.2 vol_a\left(w_2 - w_1\right) \tag{8.10}$$

, or, if humidity ratio is given in [g w./kg d.a] we need to consider:

$$m_w = \frac{vol_a\left(w_2 - w_1\right)}{833} \tag{8.11}$$

As it is well known, the evaporation of water requires heat. The latent heat of vaporization of water at air conditioning temperatures is 2501 [kJ/kg], therefore the latent heat change is given by:

$$Q_L = m_w h_{fg} = \frac{2501}{833} vol_a\left(w_2 - w_1\right) = 3.0 vol_a\left(w_2 - w_1\right) \tag{8.12}$$

, where:

Q_L = latent heat change, in [kJ/h].

Combined sensible and latent process calculation

The following combined sensible and latent processes, illustrated in Figure 8.54.c, may occur in air conditioning:

a) Sensible heating and humidification (1-6);

b) Sensible heating and dehumidification (1-7);

c) Sensible cooling and humidification (1-8);

d) Sensible cooling and dehumidification (1-9).

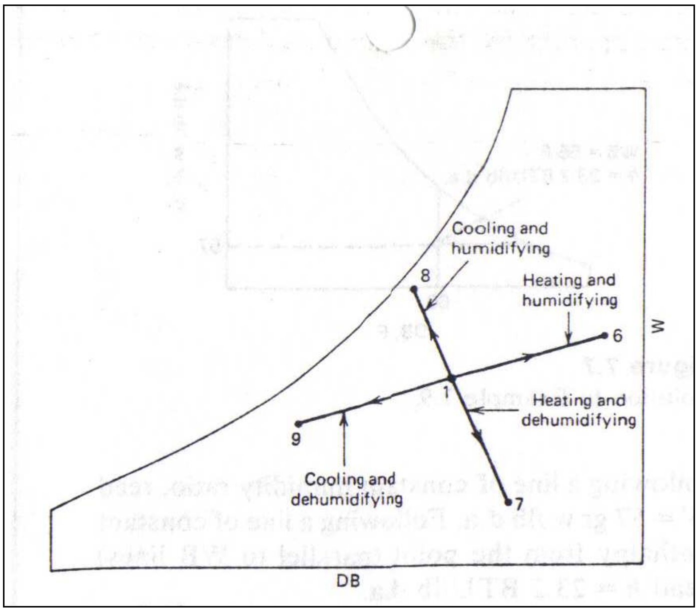


Fig. 8.54.c – Latent heat change process lines on psychrometric chart (humidification and dehumidification).

Note that, generally, DB, W, and enthalpy all change. For example, in the cooling and dehumidification process 1-9 both DB and W are decreased, and the enthalpy decreases due to both sensible and latent heat removal.

It is important to determine the amount of heat and water vapor to be added or removed in the conditioning equipment, and to determine the changes in properties. This can be done by using the sensible and latent heat equations, with the aid of the psychrometric chart.

Combined sensible and latent process calculation: The cooling and dehumidification process on summer

Air conditioning for human comfort usually requires a process where both sensible and latent heat are removed from air – that is, the air is cooled and dehumidified. The sensible heat removed and latent heat removed are found from equations (8.8) and (8.12), respectively. The sum $Q_T = Q_S + Q_L$ is the total heat removed from the process. An equation for total heat added or removed that is useful when solving problems on the psychrometric chart is:

$$Q_T = 1.2 vol_a (h_2 - h_1) \qquad (8.13)$$

, where:

Q_T = total heat change, in [kJ/h];.

h_1 = enthalpy of air on initial stage 1, in [kJ/kg];

h_2 = enthalpy of air on final stage 2, in [kJ/kg].

This equation applies to any process from any conditions 1 to 2.

It is advisable to solve psychrometric problems both by the complete equations and from psychrometric chart. This reduces the chances of errors, by comparing results.

Combined sensible and latent process calculation: The heating and humidification process on winter

The solution of any other combined sensible-latent process is handled in the same manner as the cooling-dehumidification process. Heating and humidification are typical of winter air conditioning systems. The other processes are encountered less often. However, some industrial air conditioning applications may require them. It should be noted that some combinations of processes may have sensible and latent heat in opposite directions. For instance, the heating and dehumidification process has sensible heat added and latent heat removed.

The air mixing process calculation

As illustrated in Figures 8.55.a and 8.55.b, the air mixing process is one where two streams of air are mixed to form a third stream. This process occurs frequently in air conditioning, particularly in mixing outside air with return air from the rooms. If the conditions of the two airstreams that are to be mixed are known, the conditions after mixing can be found according to the Conservation Energy Principle, i.e., the sensible heat content of the air before and after mixing is the same, and the Principle of Conservation of Mass, i.e., the water vapor content (humidity ratio) on the air before and after mixing is the same. That in mathematic terms is:

$$t_3 = \frac{m_1 . t_1 + m_2 . t_2}{m_3} \tag{8.14}$$

$$w_3 = \frac{m_1 . w_1 + m_2 . w_2}{m_3} \tag{8.15}$$

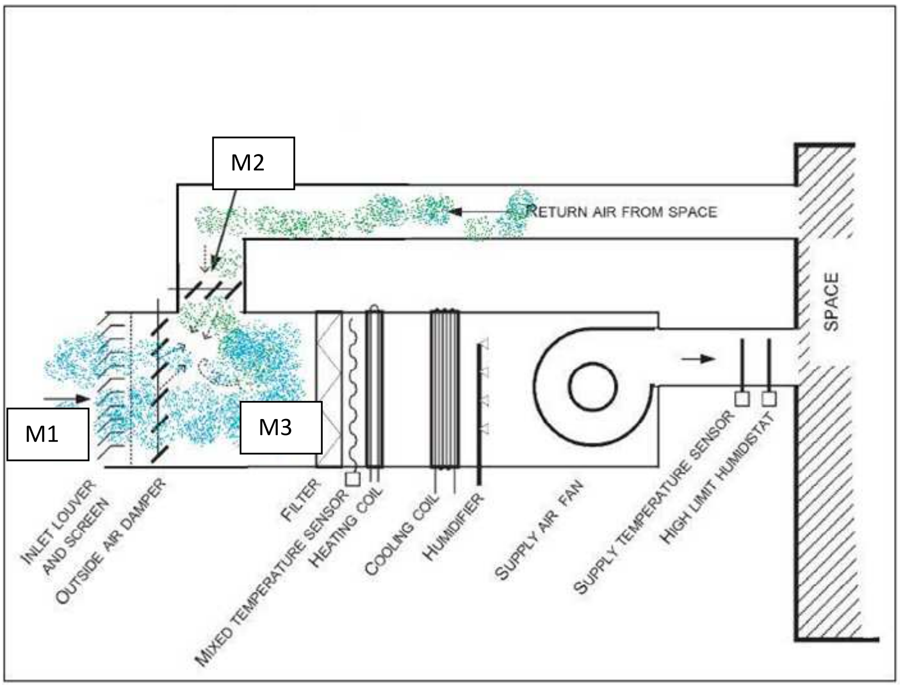


Fig. 8.55.a – Sketch of an air mixing process.

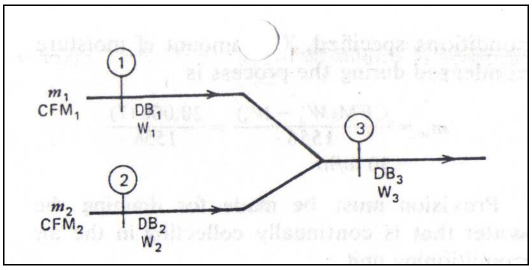


Fig. 8.55.b – Diagrammatic arrangement of an air mixing process.