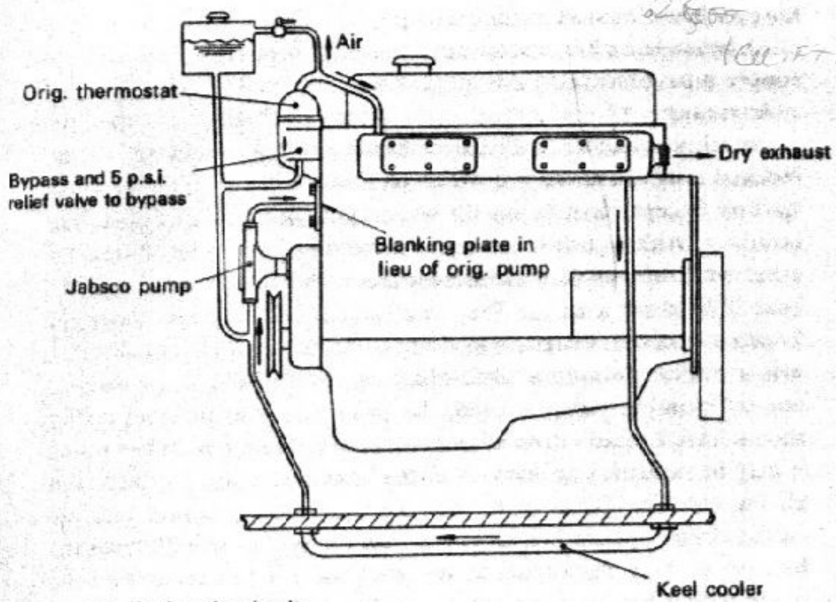
overcool the oil as it is to overcool the block. The engine oil will rapidly go black if both are overcooled. Often the best policy is to forget about oil cooling for the first season, fit an oil temperature gauge and see what happens.

There are many types of water-cooled oil coolers available through which the cooling seawater can be passed, to be attached to the block in a suitable place. Flexible high pressure rubber oil hoses will have to be used to connect the filter to the cooler and the block to the cooler. This is the only place in the lubricating system where the oil can be intercepted, and in this line the pressure will be around 50 p.s.i. The cooler must therefore be designed to withstand this pressure.

The lubricating oil may well be overcooled by such a system, which will be just as detrimental as overheating. It may be better, therefore, to pass the seawater through the oil cooler *after* it has been through the engine—it depends on the size of the cooler. A good method, where a heat exchanger or a keel cooler is employed, is to pass the fresh water, on the cool side of the circulation, through the oil cooler. This way the oil is quickly warmed to its correct temperature of around 180°F, and held there. It does entail a larger oil cooler because the temperature differences are less, and a larger heat exchanger to cope with the added heat picked up in the oil cooler. Also, the oil cooler must be fitted close to the heat exchanger to avoid overlong fresh water pipes, which will reduce the flow considerably if the original centrifugal pump is retained. It is possible to fit an oil cooler with large fresh water passages and connections directly beneath the heat exchanger, so that the colder fresh water drops down from the heat exchanger through the cooler and hence to the block. This ensures the minimum added resistance to flow.

Keel coolers

A method of cooling which has the advantages of the heat exchanger method without some of the complications is the keel cooler. It is a closed-circuit system with external copper tubes, usually arranged alongside the keel (14). Again a header tank must be fitted. A Jabsco pump is required to give a flow rate of about 1·5 gallons per minute per 10 HP. The HP figure to take is that of the full rated power of the engine. Because the pipework between the coolers and the engine is



14 Keel cooler circuit

necessarily long, the pipe diameter should be generous. The pump of necessity works in warm water; this temperature should not be more than 120° F if the impeller is to give its best service life. The maximum permissible temperature is 180° F.

The existing thermostat and aluminium housing can be retained, and a bypass and 5 p.s.i. relief valve must be incorporated. The header tank need not take part in the circuit itself—indeed it is better that way, as the quantity of water involved is less and the warm-up time correspondingly shorter.

The very mimimum exposed area of the keel coolers (assuming copper pipe) is in the order of 15–20 square inches per HP (and the horsepower figure to take is the rated maximum of the engine); 30 square inches per HP is safer especially for warmer inland waters or canals, where speeds are low, both factors producing less cooling effect. In tropical waters, where water temperatures are high and fouling is rapid, doubling or quadrupling these figures may be necessary.

The surface area of a tube is found by the formula $3{\cdot}14 \times d \times L$, where d is the diameter and L the length in inches. Thus a 40 HP diesel would require 21·5 feet of one-inch tube at 20 sq. ins. per HP. This could be arranged as a parallel bank of three tubes each 7 feet long. Galvanised steel water barrel pipe has been used but allowance must be made for the poorer heat exchange properties compared to copper pipe.

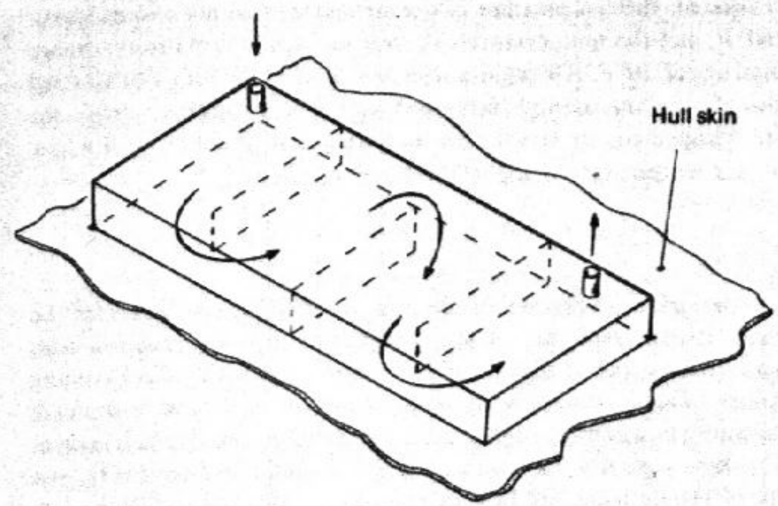
Advantages of the system over a heat exchanger are that the pipework is simpler and there is no seacock to fit or to get blocked with weed. It is difficult to drain a keel cooler system if the boat is kept afloat during the winter, but antifreeze can, of course, be added. Although it is attractive from the weed point of view for canal work, the coolers themselves are very liable to damage if the boat is used on a canal. They can, of course, be fitted under the transom where they are less likely to be damaged. To avoid airlocks, which can be a nuisance when filling up, particularly if the original non-self-priming pump is used, the pipes down to the keel cooler should have a steady drop without an intermediate rise. When filling it may be necessary to slacken off the hose connections to bleed out all the air. The filling pipe from the header tank should join the closed-circuit system low down, so that the system will fill from the bottom, pushing the air out as the level rises. A bypass around the pump with a tap incorporated can be fitted for filling, or the engine can be started up and run while filling through the header tank. A vent pipe for the air can be permanently fitted, running from the uppermost part of the system to the top of the header tank. If the lubricating oil is to be cooled, the fresh water on its way up from the keel cooler can pass through a large coil in the sump, or through an oil cooler. A large oil cooler is necessary as the temperature differences are smaller.

If the level in the header tank is arranged to be several inches above or below the external waterline, then any leakage in the keel coolers themselves can be detected by the level falling or rising. A pressure cap of around 7 p.s.i. in the header tank will reduce evaporation and allow a high running temperature. Although a keel cooling system has the advantages of a heat exchanger system while being simpler in layout, there is the snag that exhaust injection is not possible.

Tank Cooling

On a metal hull one can use the bottom plating as the heat exchanger surface. A tank is welded in place through which the engine cooling water is passed; the circuit is similar to that for keel cooling.

To get the best heat exchange for the smallest tank the water needs to be encouraged to flow over the bottom surface. The tank should be baffled (14A) and shallow. Aluminium is a good conductor of heat and it keeps its surface reasonably clean and so the surface area required need not be as much as on a steel boat, but even so a tank is not so efficient as keel cooling pipes. So a figure of 30 sq. ins. per HP (the figure of HP being taken as the engine's maximum rating) should be considered a minimum for temperate salt waters. With a steel tank on inland waters allowance has to be made for rust affecting the transfer of heat, so 40 sq. ins. per HP is not unreasonable. Always allow as large a tank as practicable. A box keel makes a good cooling tank, being more efficient than a rectangular tank.



14A Tank cooling, showing the principle of a shallow allwelded tank with baffles.

Engine enclosures

To successfully enclose the engine and apply noise reduction techniques the block, exhaust manifold, and perhaps the engine oil and gear box oil must be adequately cooled. Even so, the body of the engine will be quite hot and radiate heat. In an enclosed space the air temperature will soon rise. Apart from this, an engine consumes a large quantity of air per minute. A 1 litre engine running at 3,000 r.p.m. consumes about 50 cu. ft per minute. Air will flow through natural ventilators at a speed of about 100 ft per minute, so an inlet area of at least half a square foot (50 divided by 100) must be provided in this example. Air consumption is proportional to the engine cylinder capacity and also to the r.p.m.

An electric fan is the best solution, especially if noise reduction techniques are going to be employed, because the smaller duct can be effectively silenced. In the case of a diesel the fan should blow air in. For a petrol engine the fan should extract air from low down; this ensures that petrol vapour is extracted overboard, but it does mean that the inlet to the enclosure must be made larger than is the case when air is blown in.

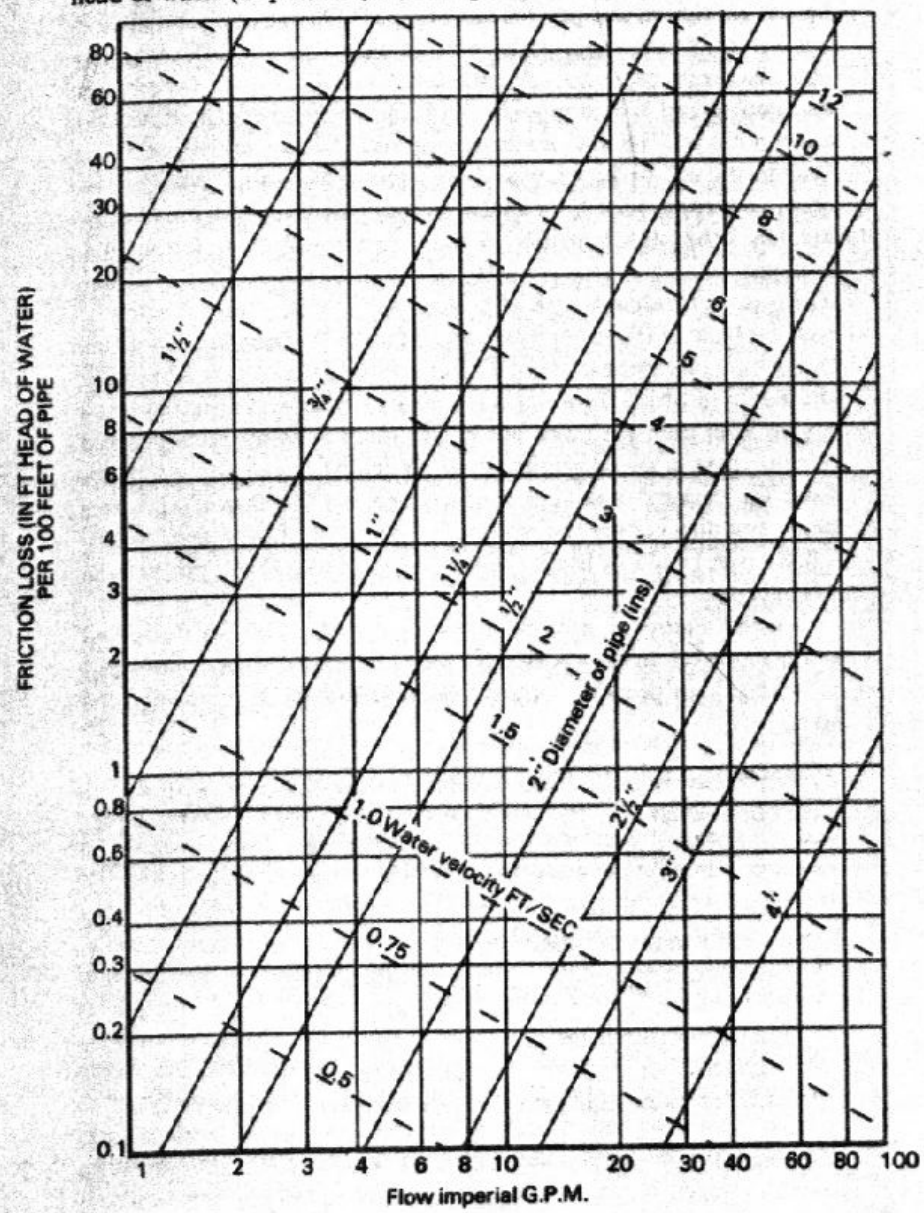
Whether the compartment is naturally ventilated or force ventilated, the temperature of the air inside must not exceed about 160° F, and the temperature rise over ambient should not be more than about 36° F. All engines lose power when sucking hot air (and also if working at high altitudes) and this is another reason for providing adequate ventilation. Batteries should not be sited where the air temperature is higher than about 120° F.

Pipe size

It is important to choose an adequate internal pipe diameter for the water circuit, especially if long lengths of pipe are involved with many bends and connections for example as with a keel cooling system. If the pipe bore is too small, the resistance to the flow causes the pump to work at a high pressure (or head of water) which in turn, with Jabsco pumps, means that the flow is less. Not only this but the life of the impeller will be much reduced. For instance the ½ inch Jabsco, suitable for the BL 1·5 litre heat exchanger cooled diesel, gives 8·4 gallons per minute at 1,500 r.p.m. against a 10 feet head of water. This reduces to 7·7 g.p.m. against 20 feet and 7·1 against 30 feet. For this engine one wants about 6 g.p.m. From the table below, ¾ inch pipe is just about adequate leading to a velocity of just over 4 ft/sec within the pipe, a level at which copper pipe will have a long life. Faster velocities can erode copper pipe very quickly. Aluminium brass pipe can withstand 8 ft/sec, copper nickel pipe 15 ft/sec. Faster velocities imply higher pressures and smaller bore piping.

If 4 ft/sec is adhered to, the pipe size can be chosen simply from the

table below knowing the flow rate required. If a long piping system is envisaged such as in keel cooling, then a check should be made on the head of water (or pressure) that the pump will have to work against.



14B Friction losses in pipes

To do this, add up the total length of pipe that the water must pass through on its circulation and then add the equivalent length of pipe due to bends and restrictions according to the table below. From the figures of friction loss per 100 feet of pipe (14B) one can find the head against which the pump must work, a figure to use with the pump manufacturers catalogue. As an example suppose a BL 1·5 diesel is keel cooled and ¾ inch pipe chosen from engine to cooler. If the keel coolers are of 1 inch pipe arranged in parallel (say a bank of 3) the flow inside will be very low and the friction loss small enough to be ignored. Suppose the ¾ inch pipe length amounts to 20 feet and there are ten bends (each worth 25 diameters = 1½ feet) ten sudden enlargements or contractions (each worth 20 diameters = 1¼ feet). The total equivalent length of pipe is therefore 20 + 15 + 12½ = 47½ feet. So from (14B) at 4½ ft/sec and 6 g.p.m. the head against which the pump must work is about 11 feet. (In the general case add to this the height to which the water is pumped if the water is discharged at a higher level than sea level; but in this case, of course, being closed circuit, there is no additional head). Then one can choose a pump from the makers' catalogue that will achieve this flow against this head, and also choose the required pump r.p.m. Low speeds (below 2,000 r.p.m.) and low heads (below 10 feet of water) will prolong the impeller life.

A small change in pipe bore has a large effect on the flows and heads involved. In the above example ½ inch bore piping would lead to a very high pressure. Always be generous when choosing pipe sizes.

4 ft/sec water velocity (recommended speed) for copper pipe

Pipe bore inches	½	¾	1	1¼	1½
Flow achieved g.p.m.	2·4	5·2	9·1	14·6	21

Head loss due to bends etc

Equivalent lengths of pipe:

Square elbow	60 diameters
90° bend	25 diameters
Sudden enlargement or contraction	20 diameters
Strainer twice pipe area	15 diameters