CHAPTER 8

COOLING SYSTEMS

8-1. Cooling system design features

This chapter presents an overview of diesel engine cooling systems. Diesel engines are heat-generating sources cooled by circulating a water-based coolant through a water jacket which is part of the equipment. The coolant is circulated through piping to a device to remove the heat added to the coolant by the engine and then back to the engine. Typical components associated with the cooling loop serving an engine are pumps, air separators, coolant expansion (or surge) tanks, temperature control valves, temperature switches, temperature and pressure indicators, and the coolant heat removal device.

a. General. Cooling systems are either closed or open. In closed systems, the system is designed to prevent significant losses from the system so the same coolant is used over and over. The quality of the coolant is easier and less costly to maintain in a closed system. Open systems either waste a coolant (use once and discharge to a drain) or re-circulate the coolant through systems that cool the coolant by evaporation, resulting in a buildup of impurities in the coolant stream. See figures 8-1, -2, and -3.

(1) Because of the need to carefully control coolant chemistry to prevent fouling of heat transfer surfaces and the need to closely control engine temperatures, closed cooling systems are generally used to cool diesel engines. The closed engine cooling system may also provide cooling for other components supporting the operation of the diesel engine, such as the lube oil cooler and the combustion air after-cooler on turbo-charged engines. Depending on the cooling needs of each device associated with the engine, all the devices may be cooled by a single-loop system, or multiple loops may be required.

(2) In an open system, water is re-circulated through an air contact cooling system, such as a cooling tower, cooling pond, or spray pond. Because of maintenance concerns relating to water quality, open cooling systems are generally not used on land-based diesel engines (or similar equipment), except as short-term emergency backup to a closed system.

(a) Although open cooling systems are usually not used to provide direct cooling to devices like diesel engines, re-circulating cooling water systems using cooling towers, cooling ponds, and spray ponds may be an important part of the overall cooling system for a facility. A large facility may have a lot of equipment that is water-cooled. The quantity of water required by each water-cooled device may not be significant, but the total quantity of cooling water required adds up to a large water bill or cannot be provided by the resources available to the site. And even if resources are available, some blast-protected facilities must disconnect from outside resources when in the blast mode of operation.

(b) Common devices used to remove heat from cooling water and supply re-circulating systems are cooling ponds (or open reservoirs), spray ponds, and cooling towers. The primary heat transfer mechanism for these devices is evaporation. When water evaporates, most of the impurities in the water are left behind that increases the impurities in the re-circulating water. These impurities can form scale on heat exchanger heat transfer surfaces, the walls of water distribution and return piping, and cooling tower surfaces, and will require maintenance to be performed to remove (or at least significantly

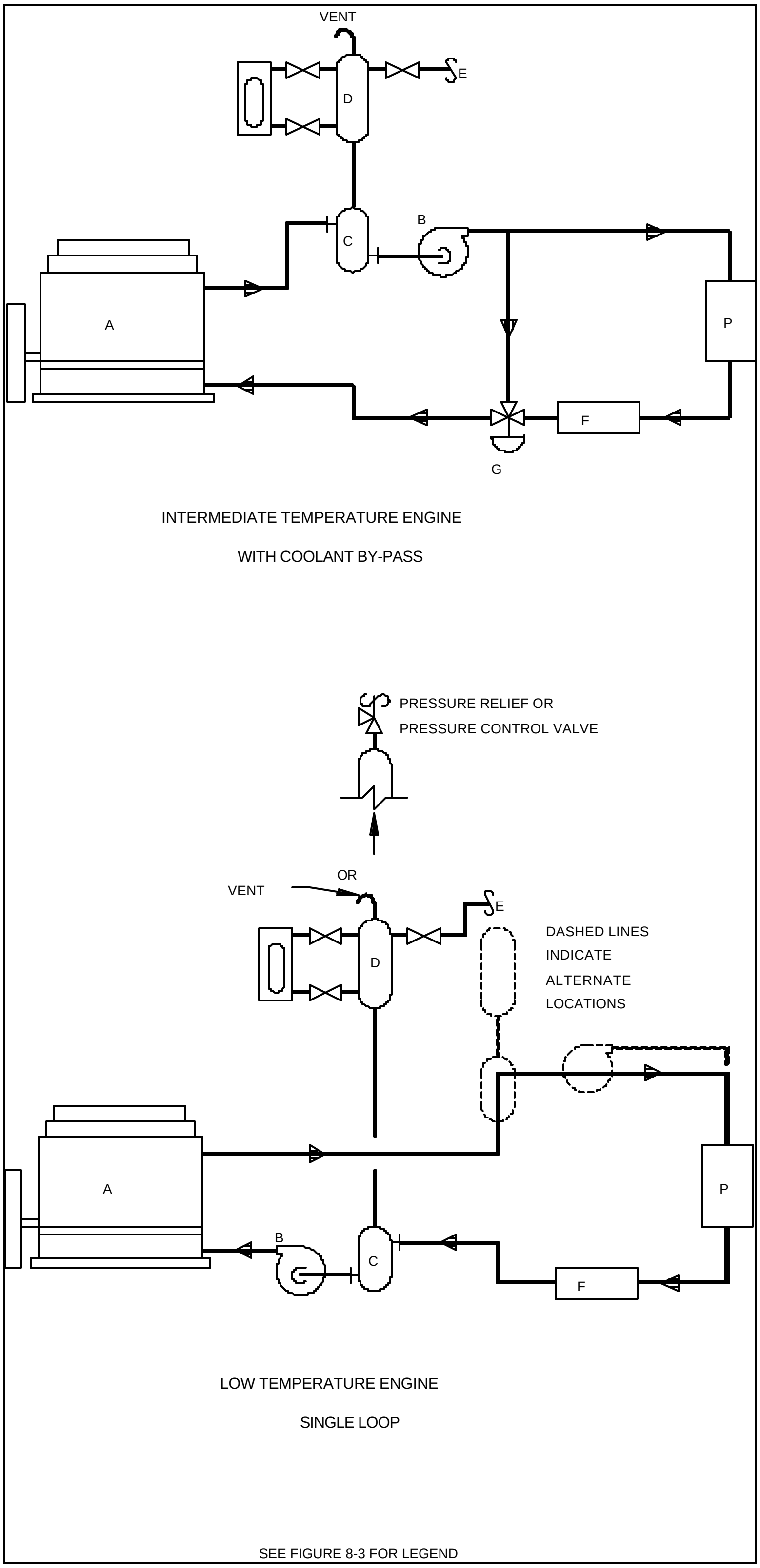


Figure 8-1. Examples of engine cooling systems(1)

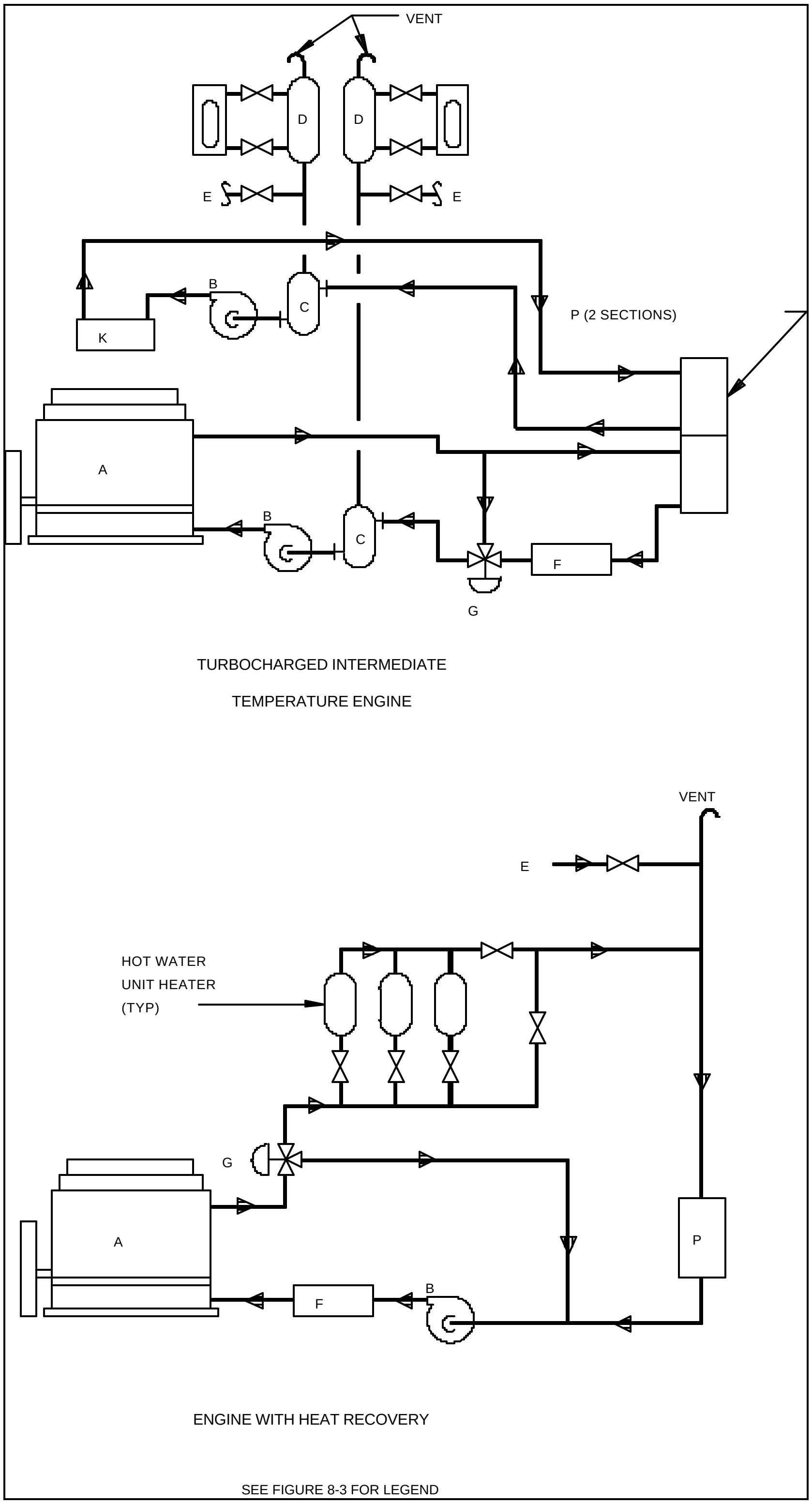
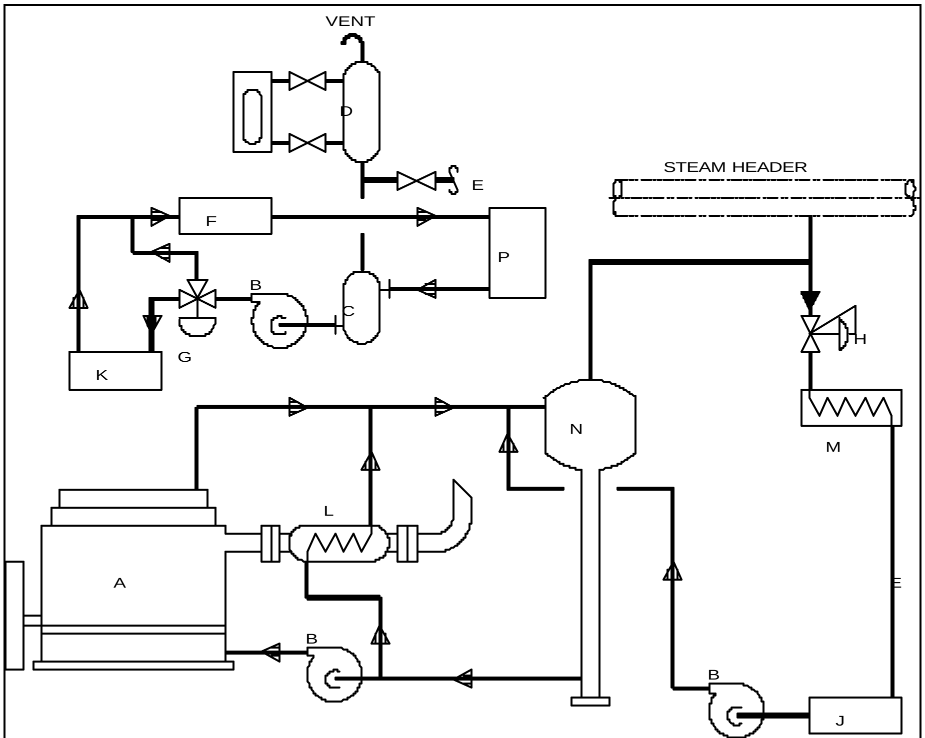


Figure 8-2. Examples of engine cooling systems(2)



HIGH TEMPERATURE ENGINE

WITH EXHAUST HEAT RECOVERY

LEGEND

A ENGINE	H BACK PRESSURE VALVE
B PUMP	J CONDENSATE RECEIVER
C AIR SEPARATOR	K AFTERCOOLER (OR TURBOCHARGEED ENGINE)
D EXPANSION TANK W/LEVEL GAUGE	L EXHAUST SILENCER WITH HEAT RECOVERY
E MAKE-UP COOLANT CONNECTION	M STEAM CONDENSER
F LUBE OIL COOLER	N FLASH TANK
G TEMPERATURE CONTROL VALVE	P COOLANT COOLING DEVICE/SYSTEM

Figure 8-3. Examples of engine cooling systems(3)

reduce) the built-up scale. Chemical treatment of and blowdown from open re-circulating water systems are tools for reducing the build up of contaminants.

b. Typical primary service diesel engine cooling system. A typical engine cooling system for a large stationary, primary service, turbo-charged diesel engine is shown on figure 8-4. The cooling system consists of three cooling loops: a loop for the engine, a loop for the lube oil cooler, and a loop for the combustion air after-cooler. Heat is removed from the closed engine cooling system in the jacket water heat exchanger that is a liquid-to-liquid heat exchanger. The cooling water supply for the jacket water heat exchanger is a closed re-circulating cooling water system using a cooling tower. The cooling water supply for the after-cooler is also from the cooling tower system, while the cooling water supply for the lube oil cooler is from an industrial water re-circulating system that uses an open cooling reservoir.

(1) Hot coolant from the engine is piped to a temperature control valve (thermostat). The temperature control valve modulates the coolant flow between a branch that flows through the jacket water heat exchanger and a branch that bypasses the heat exchanger. After cooling, the total coolant stream enters an air separator unit. (Many cooling systems do not use an air separator unit.) The air separator is designed to separate gas bubbles from the coolant stream so the bubbles can be vented from the system. The coolant is then piped to the inlet of an engine-driven coolant pump that circulates water through the engine cooling water jacket. The expansion tank which, in the example system, is connected into the system through the air separator unit serves three equally important functions. The expansion tank provides space for coolant expansion, provides space for entrained gases to be removed from the system, and provides a static head which controls coolant flashing to steam in the system operating near the boiling point and prevents cavitation in the coolant circulating pump.

(2) The typical engine cooling system is equipped with a "keep warm" system. The keep warm system operates when the engine is not operating, but is in the standby ready to start mode. The keep warm system uses an electric motor-driven circulating pump to circulate jacket cooling water through a heater unit (usually an electric immersion heater) and then into the engine water jacket. The immersion heater heats the coolant to a temperature near the design coolant temperature for the engine. This minimizes startup wear on the engine and prolongs engine life. Maintaining the coolant, and hence the engine, near operating temperature also helps ensure that the engine will start.

(3) In the typical primary service diesel engine cooling system, the cooling water supply to the jacket water heat exchanger and lube oil cooler is either on or off. Temperature regulation of the engine coolant and lube oil temperatures is by bypass temperature control valves within the engine and lube oil cooling systems. The after-cooler cooling water supply also contains an on-off valve, but the temperature of the combustion air is regulated by a bypass valve in the cooling water piping at the after-cooler. When the engine receives a start signal, the engine controls open the on-off valves in the cooling waterlines. When the flow switches in the discharge lines indicate that cooling water flow has been established, the engine is allowed to start.

(4) In the typical primary service diesel engine cooling system, a number of pressure and temperature indicators are shown throughout the system. Readouts from these devices are important measures of how the system is operating. The readout units of these devices are usually mounted on the local control panel mounted at the diesel engine. The two main control devices for the engine cooling system are the two temperature indicators with output switches that either alarm on high engine coolant temperature or shut down the engine because of high engine coolant temperature. The alarm set point is usually set lower than the shutdown set point to permit the operator to investigate and correct the problem or start a standby engine before a high-temperature shutdown occurs.

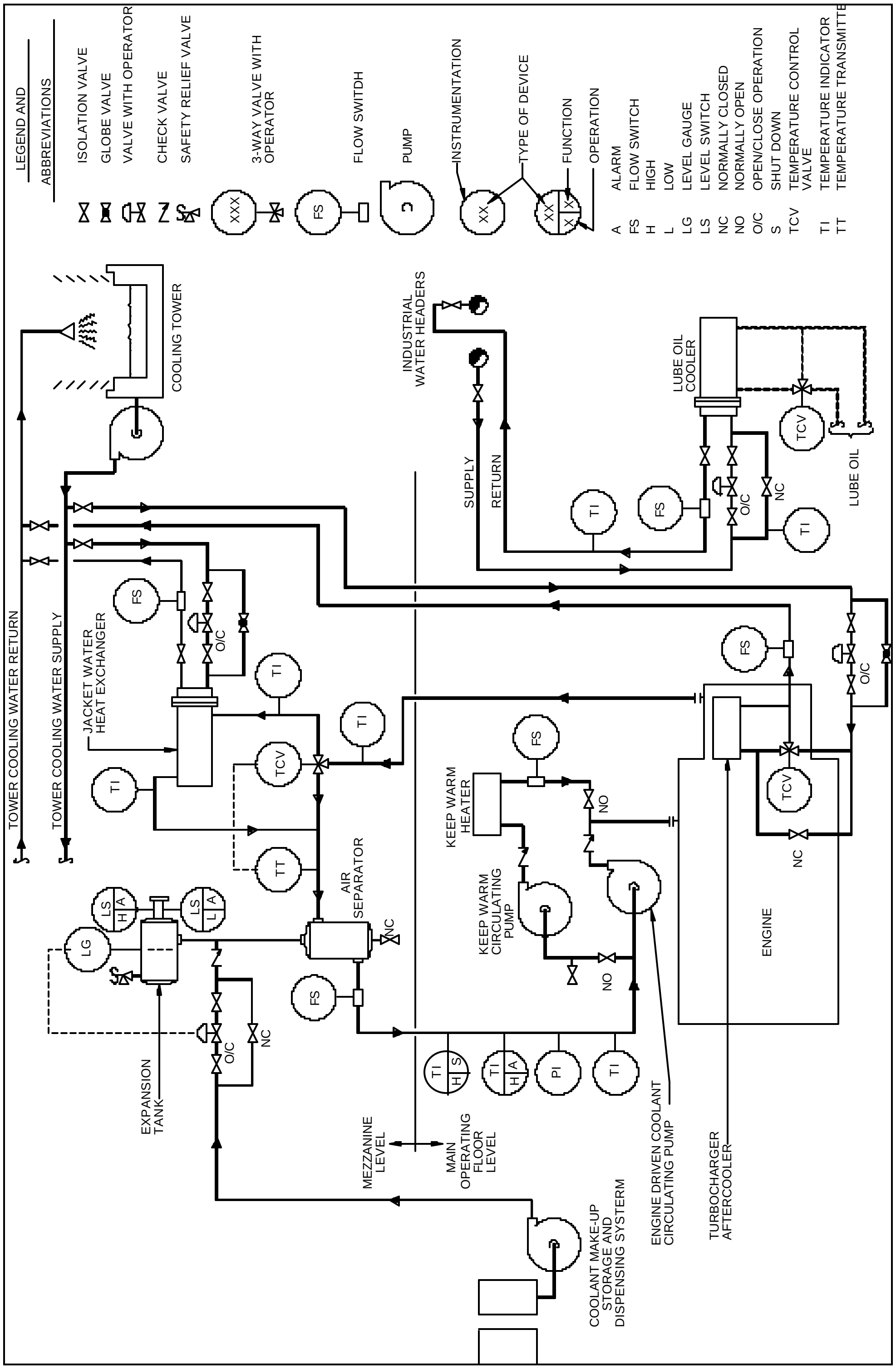


Figure 8-4. Typical primary service diesel engine cooling system

c. Typical radiator diesel engine cooling system. A typical stand-alone engine cooling system for a turbo-charged diesel engine is shown on figure 8-5. The cooling system consists of two cooling loops: a loop for the engine, and a loop for the lube oil cooler and combustion air after-cooler. Heat is removed from the closed engine cooling system in the jacket water radiator and the lube oil/after-cooler radiator which are liquid-to-air heat exchangers. The use of radiators with fan motors powered from the engine electrical system makes the engine cooling system independent of other facility systems and is typical of cooling systems for emergency service diesel engines. However, radiator cooling systems are also used in many primary service diesel engine installations where the radiator fan motors may be powered by the engine electrical systems or driven by an electric motor powered from the facility electrical distribution system.

d. Coolant makeup storage and dispensing systems. Most facilities with diesel engines have a coolant makeup storage and dispensing system. In large facilities, one system can usually serve all of the engines. At a minimum, the system will consist of a tank for preparing and storing large quantities of engine coolant with a pump and distribution piping to dispensing points near the makeup coolant fill points on equipment. Most systems are directly connected to the makeup coolant fill points. Most systems also include storage so that coolant drained from an engine during maintenance can be reused. In some systems with used coolant storage, there is either a separate coolant drain pump or the coolant distribution and drain piping is connected into a manifold that allows the makeup coolant dispensing pump to serve as both a dispensing and drain pump.

e. Coolant quality. Water treatment is critical to the operation of the engine cooling systems. It is important that a coolant quality monitoring and treatment program for a facility be developed and followed. Because of the wide variation in water supplies available and the likelihood of seasonal variations within a single source, no single coolant treatment program will work at every facility. Each facility requires a program tailored to the equipment used in the facility and the quality of the available water supply. A minimum water treatment program must provide for control of coolant quality parameters as follows.

(1) In outdoor installations, engine operations that may be shut down in cold weather must be protected against freezing.

(2) Only water with a hardness value of 0 (zero) should be used to make engine coolant.

(3) The pH value of the coolant solution should be between 8.0 and 9.5.

(4) The total solids concentration of the coolant should not exceed 3,500 parts per million.

(5) The oxygen content of the coolant should be maintained at a value of 0 (zero) by the addition of oxygen scavenging compounds, or the metal surfaces of the engine need to be protected against corrosion by the addition of corrosion inhibiting compounds.

f. Typical cooling tower system. A typical cooling tower (evaporative cooler, spray cooler, etc.) is shown on figure 8-6. Tower re-circulating cooling water flows from the pan section through a strainer built into the pan section into the spray (tower circulating) pump. The spray pump provides water to the spray header (or as a circulating pump discharges water into an open channel water distribution header). The downward flow of water in the cooling tower flows over the outside surface of the cooling coil. The evaporation of tower cooling water absorbs heat transferred through the cooling coil tube wall from the facility re-circulating cooling water stream.

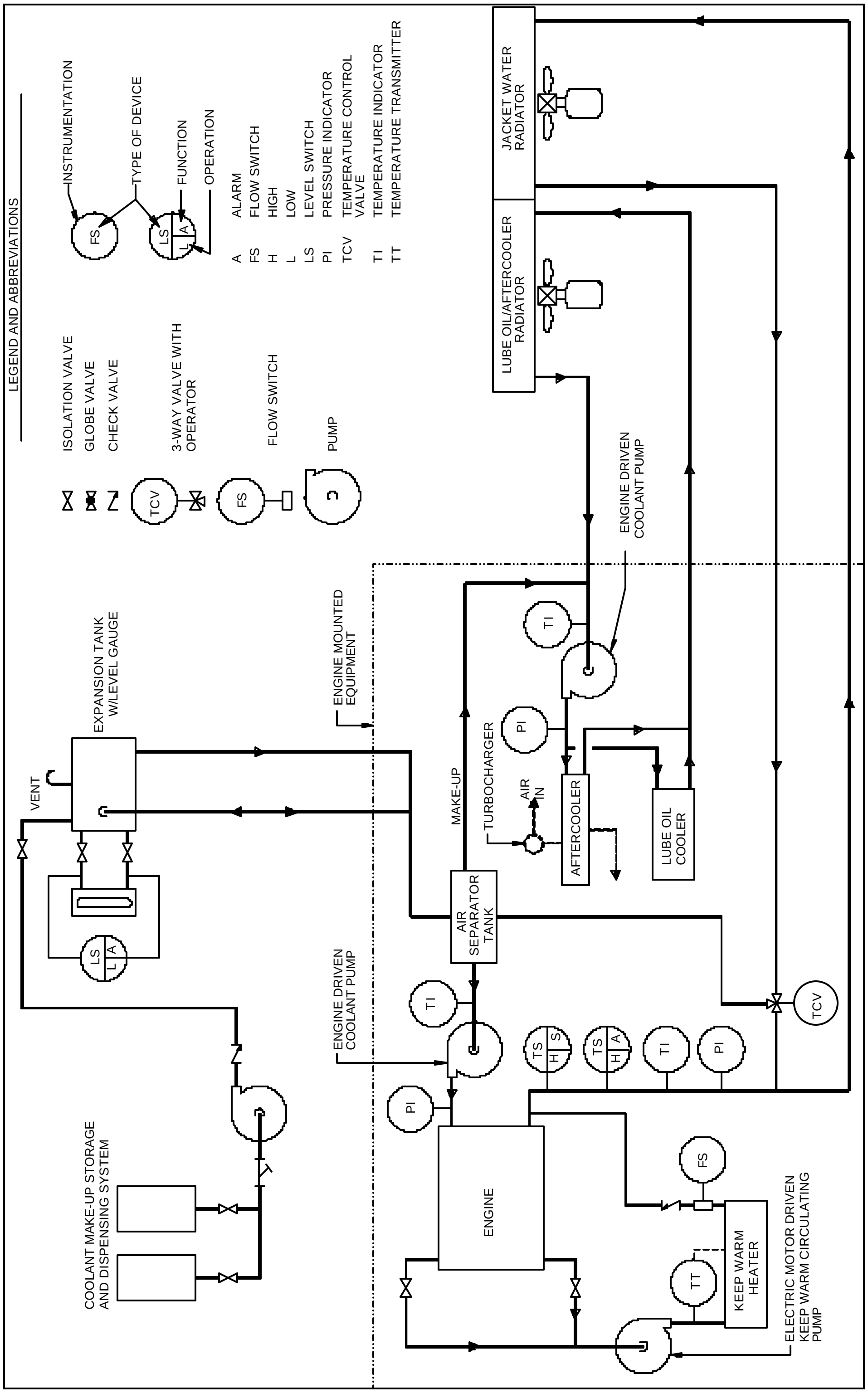


Figure 8-5. Typical radiator diesel engine cooling system

(1) As water evaporates, impurities are left behind. The quality of the tower cooling water may be controlled by discharging (blowing down) a portion of the tower water and adding fresh water and chemical treatment. Most towers have a blowdown valve located in the discharge piping of the spray pump. While some large towers may have water quality sensing equipment that controls the operation of the blowdown valve, most towers have a manual valve. A manual blowdown valve is usually adjusted to discharge water at a rate equal to the evaporation rate when the tower is operating at design conditions. Water is added to the pan section to maintain a constant level through a makeup water control valve. Most towers utilize float-operated makeup water control valves.

(2) Most cooling tower designs use fans to circulate air through the cooling tower. On many cooling tower units, the fans are integral with the unit. However, it is not uncommon for the fan to be a separate installation connected to the cooling tower by a duct system. Several cooling tower fan arrangements are shown on the left side of figure 8-6. The temperature of the facility re-circulating cooling water discharged from the cooling tower can be controlled by controlling the flow of air through the cooling tower. Reducing airflow increases temperature. The flow control damper may be part of the tower as shown on figure 8-6 or may be installed at the inlet or discharge of the fan. Most towers are equipped with mist eliminators. Mist eliminators reduce the amount of water droplets carried out of the cooling tower.

(3) In facilities with variable facility re-circulating cooling water demands, several cooling tower units may be manifolded in parallel. As the cooling load decreases, cooling tower units may be taken out of service so that the facility re-circulating cooling water temperature can be maintained at the proper value. In multiple cooling tower installations, valves are usually installed so that the tower is completely isolated from the facility re-circulating system. These valves may be remote-operated as shown on figure 8-6. Multiple cooling tower installations with all of the towers discharging into a common air discharge duct may also isolate the air side of the tower with an isolation damper. The isolation damper may be in addition to the airflow control damper. The isolation damper prevents moist air from other units from backflowing into the facility through an out of service unit. The isolation damper also allows personnel entry into out of service units to perform maintenance activities.

8-2. Cooling system major components

Cooling systems are generally comprised of the following major components.

a. Heat exchangers. Diesel engine installations utilize heat exchangers to control the temperature of engine coolant, lube oil, fuel oil, and combustion air. Temperature is controlled by heat transfer through a tube wall or plate surface to another fluid (gas or liquid). Control of the above temperatures maintains the engine temperature. The most common type of heat exchanger used in the diesel engine cooling system is a tubular heat exchanger. Engine coolant heat exchangers are usually air-cooled or water-cooled. Air-cooled units are referred to as radiators. A radiator consists of an inlet box and a discharge box connected by many small diameter tubes arranged so that air flows through the tube bundle around the outside of the tubes. The tubes usually have fins on the outside surfaces to enhance the heat transfer between the tube surface and the cooling air. Radiator units are usually equipped with a thermostatically controlled fan that moves air through the tube bundle.

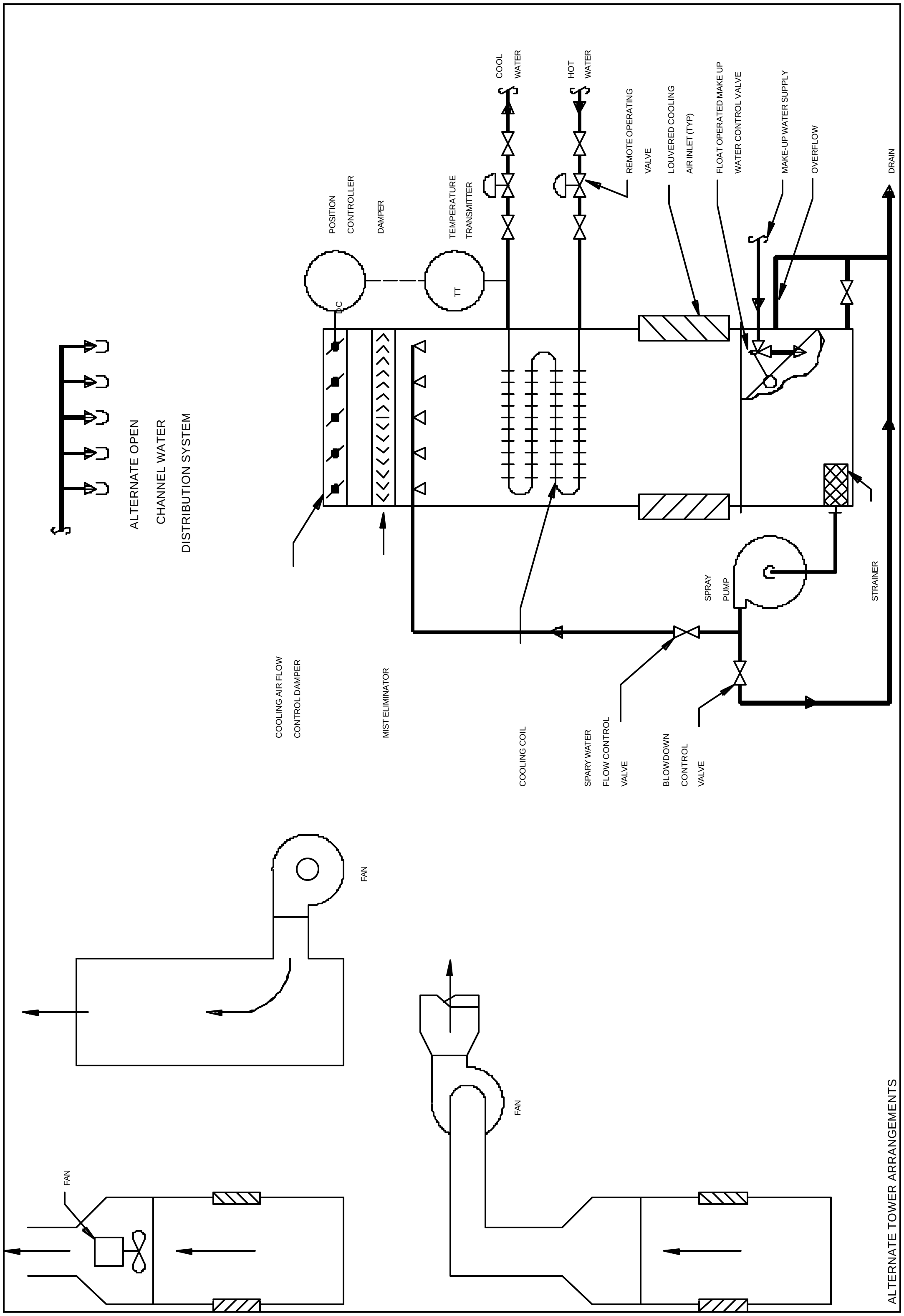


Figure 8-6. Typical evaporative cooling tower

b. Air separators. Some diesel engine cooling systems use air separators to remove air (gas) bubbles that have become entrained in the cooling fluid. Some air separators are just a tank constructed so the coolant inlet is not in a direct line with the coolant outlet. The surface area of the tank is large compared to the coolant piping. The slowing of the coolant stream and change in direction allows gas bubbles to rise to the surface of the tank or into the coolant expansion tank to be vented. A very common air separator is a mechanical separator with a tangential entry that causes the coolant stream to spin from an upper entry to a lower discharge. The resulting turbulence enhances gas separation. Tangential entry mechanical separators generally require less space than tank type separators, but require that the circulating pump is capable of producing higher differential pressures.

c. Expansion tanks. When coolant is heated, it expands. If the cooling system was completely closed, the forces generated by expansion of the coolant could damage the engine. The expansion tank provides space for coolant expansion. The expansion tank also provides added coolant capacity to make up for small losses. The expansion tank is generally installed some distance above the engine to provide a static head to prevent coolant flashing to steam which might result in cavitation in coolant circulating pumps.

d. Pumps. Various types of pumps are utilized in cooling systems.

(1) The pumps that circulate coolant when the engine is operating are generally mounted on the engine and are gear-driven by the engine. The pumps are generally furnished by the engine manufacturer with the engine so the design of the pump may vary from manufacturer to manufacturer. The most common pump design is a single-stage, end suction, centrifugal pump. The pump housings are generally cast iron, and the pump impeller and shaft bearings are generally bronze.

(2) The keep warm circulating pump circulates engine coolant through a keep warm heater when the engine is not operating. The keep warm pump is typically a single-stage, end suction, centrifugal type driven by an electric motor. Pump housings are generally cast iron or carbon steel, and the pump impeller and shaft bearings are generally bronze. The pump is generally direct-connected to the electric motor.

(3) The type of pump used to circulate cooling water in facility recirculating cooling water systems varies with the design of the system. The pumps are generally driven by direct-connected electric motors. Common types of pumps that may be used are as follows.

(a) Centrifugal pumps, horizontal, are preferred for pumping from aboveground water supplies which continuously flood the pump suction. These pumps may also be used to pump from reservoirs below the pump if the net positive suction head capability of the pump is not exceeded. When drawing from reservoirs below the pump, it is common practice to install foot valves at the inlet to the suction piping, so the suction piping remains full when the pump is not in operation.

(b) Centrifugal pumps, vertical, may be used, but are not preferred, for pumping from pits, ponds, or reservoirs, or from horizontal tanks where the pump extends down into the fluid to be pumped from a platform above the fluid. These pumps may have multiple stages.

(c) Turbine pumps, vertical, are preferred for pumping from pits, ponds, reservoirs, or horizontal tanks where the pump extends down into the fluid to be pumped from a platform above the fluid.

(d) Positive displacement pumps are not generally used in facility re-circulating cooling water systems.

e. Keep warm heaters. Keep warm heaters are generally low density electric immersion units supplied as a package with thermostatic control units. The heaters are sized to keep engine coolant circulated by the keep warm pump at the design operating temperature of the keep warm system. The operating temperature of the keep warm system depends on the needs of the engine. Keep warm systems may provide temperatures as low as 70°F to temperatures just below the coolant temperature in an operating engine.

f. Engine coolant temperature control valves. Temperature control valves are used in engine cooling systems which use a coolant bypass to maintain either a constant coolant temperature at the engine coolant outlet or a constant coolant supply temperature. The most common engine coolant temperature control valve is a self-contained, factory-set, thermostatic element-operated, sealed, three-way valve unit. When installed to maintain a constant coolant outlet temperature, the unit is referred to as a diverting valve. When installed to maintain a constant coolant inlet temperature, the unit is referred to as a mixing valve. The valve is designed to maintain full coolant flow through the engine cooling system. A thermostatic element in one of the valve ports controls a sliding valve assembly that controls the flow through that port. In the closed position, all of the flow is from the inlet port and out the other port. As the thermostatic element moves the sliding valve off the valve seat, a portion of the flow is from the inlet and through the thermostatically controlled port. At full lift, all of the flow is through the thermostatic port. (Some valves operate the opposite of the preceding description.)

g. Engine instrumentation and controls. Typical instrumentation and controls used in engine cooling systems include the following.

(1) Pressure indicators are located throughout the engine cooling system with pressure ranges varying according to function.

(2) Level indicators are installed on all coolant expansion tanks for local indication.

(3) Level transmitters are installed where needed to provide a signal to a remote location or control room for engine coolant level indication.

(4) Level controllers usually provide control signals for high level alarm, transfer pump start and stop, and low level alarm.

(5) Temperature switches may be used to activate a high coolant temperature alarm. Temperature switches may also be used to shut the engine down when coolant temperatures reach the point where further operation may result in damage to the engine.

(6) A flow switch can be located in an overflow line out of the top of each day tank. When flow is detected by a flow switch, the fuel oil transfer pumps will deactivate.