7 COOLING SYSTEM

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7.1 COOLING SYSTEM DESCRIPTION

The MBE 4000 cooling system is comprised of two separate systems; the jacket water cooling system and the Charge Air Cooling (CAC) system. Although these systems are separate, they usually share the same space which makes each system's performance dependent upon the other.

A well designed cooling system is a requirement for satisfactory engine performance and reliability. Thorough knowledge of the application, duty cycle, and environmental conditions is essential in designing and packaging the total cooling system. A properly designed system should still be able to perform within specifications after normal system degradation occurs.

The jacket water cooling system consists of a heat-exchanger or radiator, centrifugal type water pump, oil cooler, thermostats, and cooling fan. The water pump is used to pressurize and circulate the engine coolant. The engine coolant is drawn from the lower portion of the radiator through the water pump and is forced through the oil cooler and into the cylinder block. The heat generated by the engine is transferred from the cylinder and oil to the coolant. The heat in the coolant is then transferred to the air by the cooling fan when it enters the radiator.

Two full blocking-type thermostats are used in the water outlet passage to control the flow of coolant, providing fast engine warm-up and regulating coolant temperature.

The CAC system consists of the air inlet piping, the turbocharger, the cooling fan and the intake manifold. Ambient air is drawn in through the air cleaner and piping to the exhaust driven turbocharger. The turbo compresses the air which increases its temperature by about 300°F (150°C). The charge air is then cooled by the air from the cooling fan as it passes through the CAC to the intake manifold.

7.2 JACKET WATER COOLING SYSTEM

When the engine is at normal operating temperature, the coolant passes from the cylinder block up through the cylinder head, through the thermostat housing and into the upper portion of the radiator. The coolant then passes through a series of tubes where the coolant temperature is lowered by the air flow created by the fan.

Upon starting a cold engine or when the coolant is below operating temperature, the closed thermostats direct coolant flow from the thermostat housing through the bypass to the water pump. Coolant is recirculated through the engine to aid engine warm-up. When the thermostat opening temperature is reached, coolant flow is divided between the radiator inlet and the bypass. When the thermostats are completely open, all of the coolant flow is to the radiator inlet.

The function of the engine coolant is to absorb the heat developed as a result of the combustion process in the cylinders and from component parts such as the valves and pistons which are surrounded by water jackets. In addition, the heat absorbed by the oil is also removed by the engine coolant in the oil-to-water oil cooler.

The following illustrations show the coolant flow within the cooling system, when the thermostats are closed (see Figure 7-1) and open (see Figure 7-2).

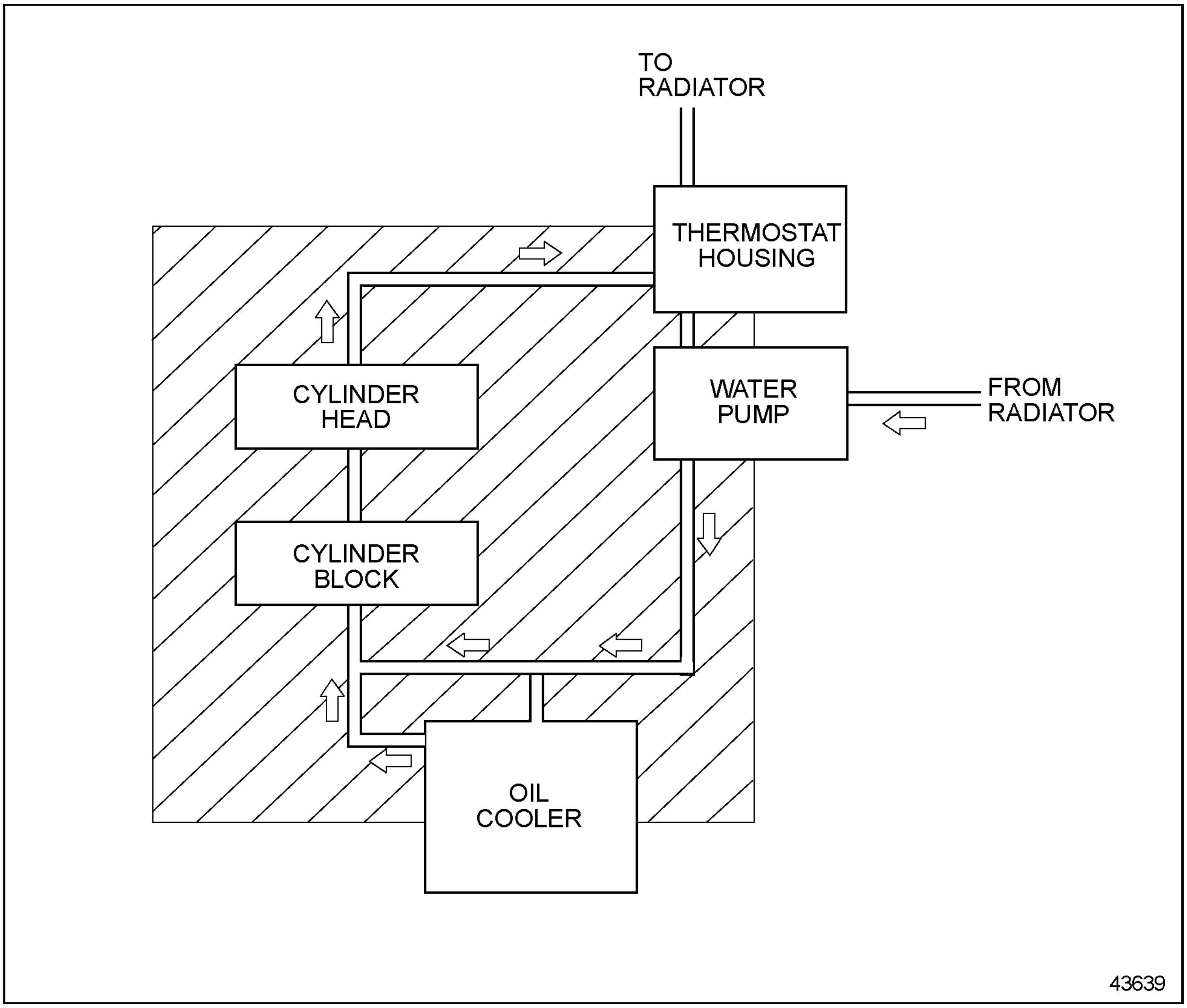


Figure 7-1 Thermostats Closed

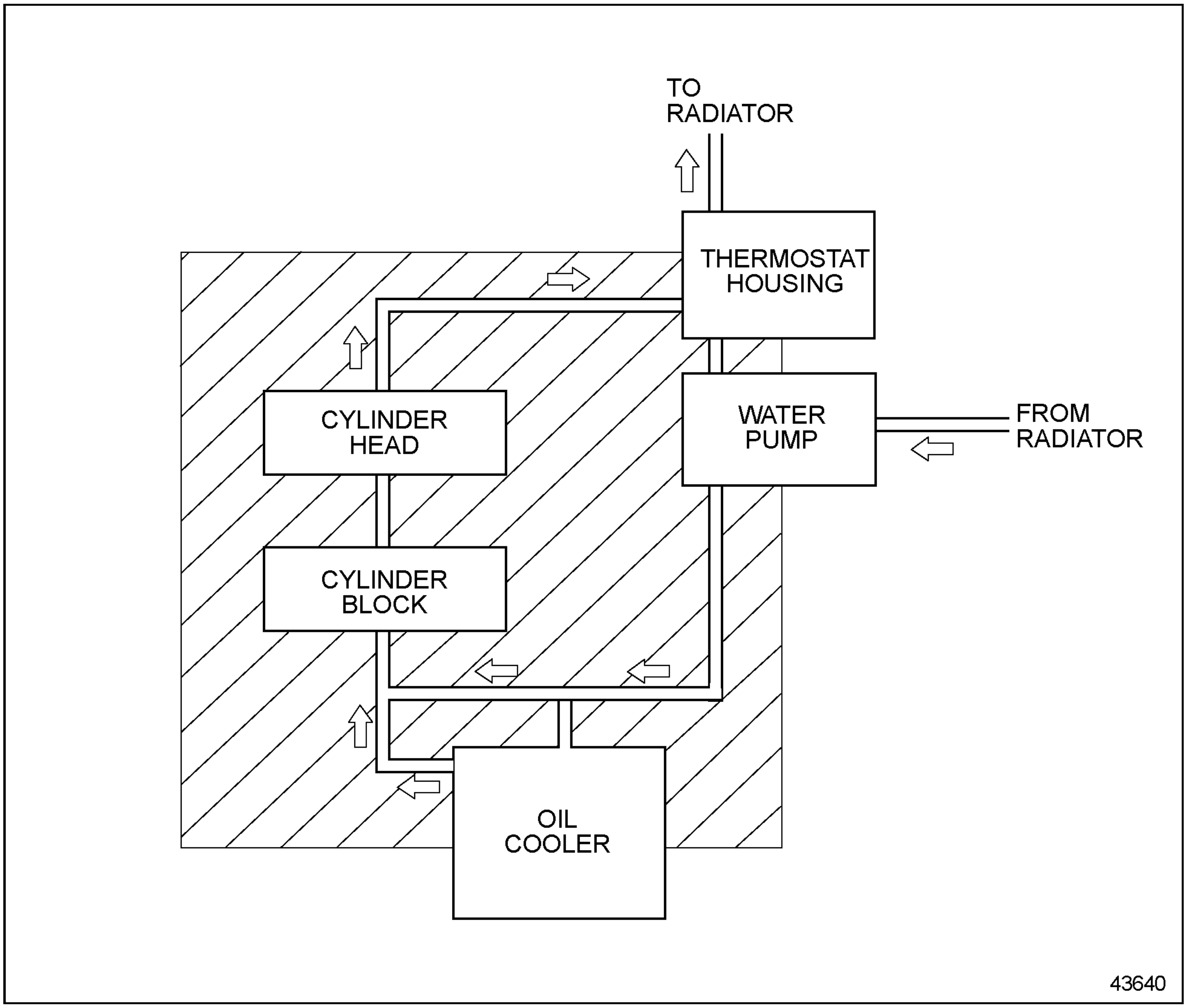


Figure 7-2 Thermostats Open

A pressurized cooling system permits higher temperature operation than a non-pressurized system. It is essential that the cooling system is kept clean and leak-free, that the filler cap and pressure relief mechanisms are properly installed and operate correctly, and that the coolant level is properly maintained.

As the engine temperature increases, the coolant and air in the system starts to expand and build pressure. The valve in the radiator pressure cap unseats and allows the trapped air to flow out the overflow tube. See Figure 7-3.

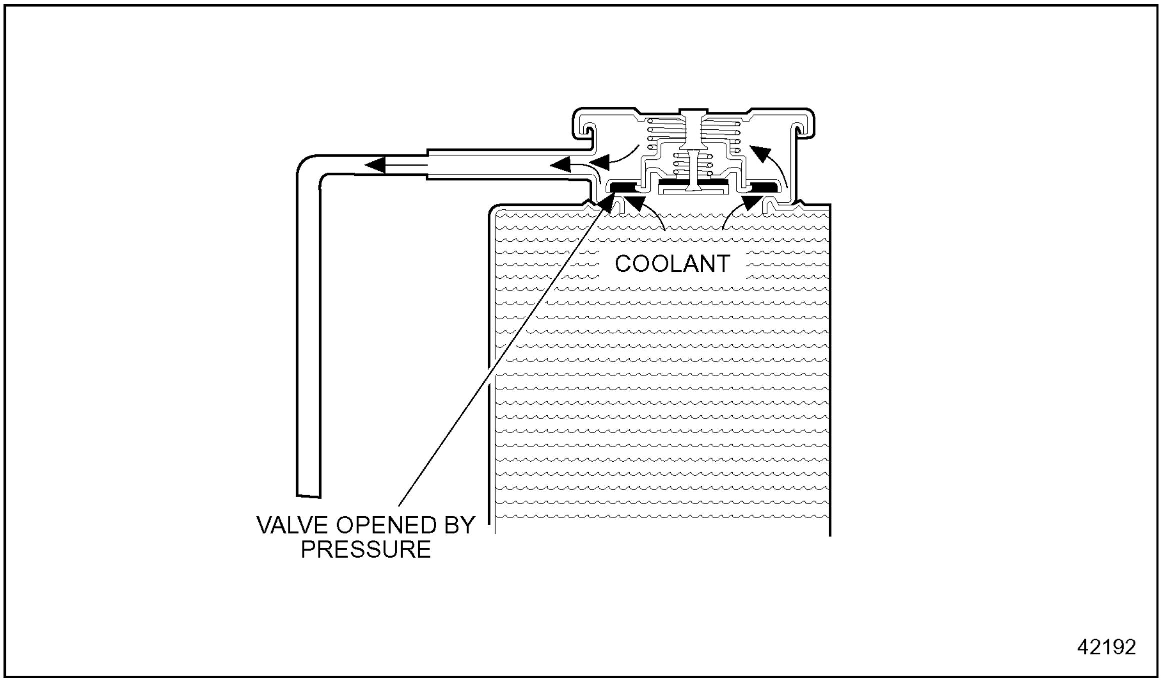
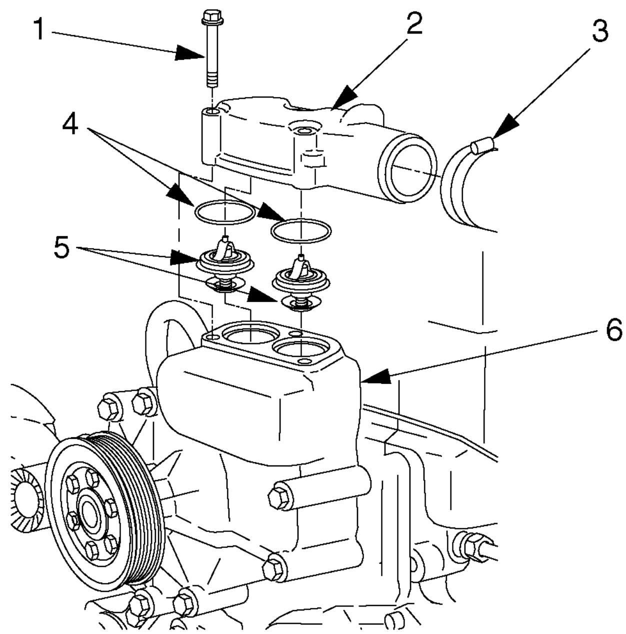


Figure 7-3 Coolant Expansion

When the engine starts to cool down, the air and coolant contract, causing a void and creating a vacuum in the system. The vacuum unseats another valve in the radiator pressure cap, allowing the coolant to flow back into the radiator.

7.3 THERMOSTAT

The temperature of the engine coolant is controlled by two blocking-type thermostats located in a housing on the front of the cylinder head. See Figure 7-4.



1. Mounting Bolt
2. Thermostat Housing
3. Upper Coolant Tube
4. O-ring
5. Thermostat
8. Coolant Pump Housing

Figure 7-4 Thermostat and Related Parts

In addition to a rubber seal that is part of the thermostat, there is a lip-type seal for each thermostat that is installed in a bore in the thermostat housing.

At coolant temperatures below the operating range the thermostat valves remain closed and block the flow of coolant from the engine to the radiator.

During this period, all of the coolant in the system is recirculated through the engine and is directed back to the suction side of the water pump via an internal bypass tube. As the coolant temperature rises above the start–to–open temperature, the thermostat valves begin to open, restricting the bypass system, and allowing a portion of the coolant to circulate through the radiator. When the coolant temperature reaches an approximate fully open temperature, the thermostat valves are fully open, the bypass system is blocked off, and the coolant is directed through the radiator. Thermostat closing and opening temperatures are listed in the "Technical Data" section of this manual (refer to section 14).

Properly operating thermostats are essential for efficient operation of the engine.

7.3.1 ENGINE VENTING

A single engine vent locaton is provided at the top of the EGR cooler. Vent lines from each cylinder head are tied together with the EGR cooler vent. This is intended to be used to release trapped air to the surge tank. This vent line should go to the top of the cooling system surge tank, above the water line. The vent line must include a restriction of 4.5 mm diameter.

7.4 WATER PUMP

The centrifugal-type water pump circulates the engine coolant through the coolant system.

The pump is mounted on the front of the engine block and is belt driven by the crankshaft pulley.

7.5 TYPES OF COOLING SYSTEMS

Radiator cooling systems can be classified into two broad categories: rapid warm-up and conventional. Only rapid warm-up systems are acceptable on the MBE 4000.

7.5.1 RAPID WARM-UP COOLING SYSTEM

The rapid warm-up cooling system eliminates coolant flow through the radiator core during closed thermostat operation.

This reduces warm-up time and maintains coolant temperature near the thermostat start to open value. Having the deaeration tank (internal or remote) separated from the radiator core will accomplish this. External vent and fill lines as well as internal standpipe(s) (radiator core air vent) are required in the deaeration tank. Proper size and location of these components are critical to having a balanced system. The fill line coolant return flow capabilities *must* exceed the flow into the tank under all operating modes. Positive water pump inlet pressure must be maintained in all operating conditions. The rapid warm-up cooling system has also been called positemp, continuous deaeration, or improved deaeration.

Another advantage of this system is its ability to place a positive head on the water pump, thus reducing the possibility of cavitation (see Figure 7-5 and Figure 7-6).

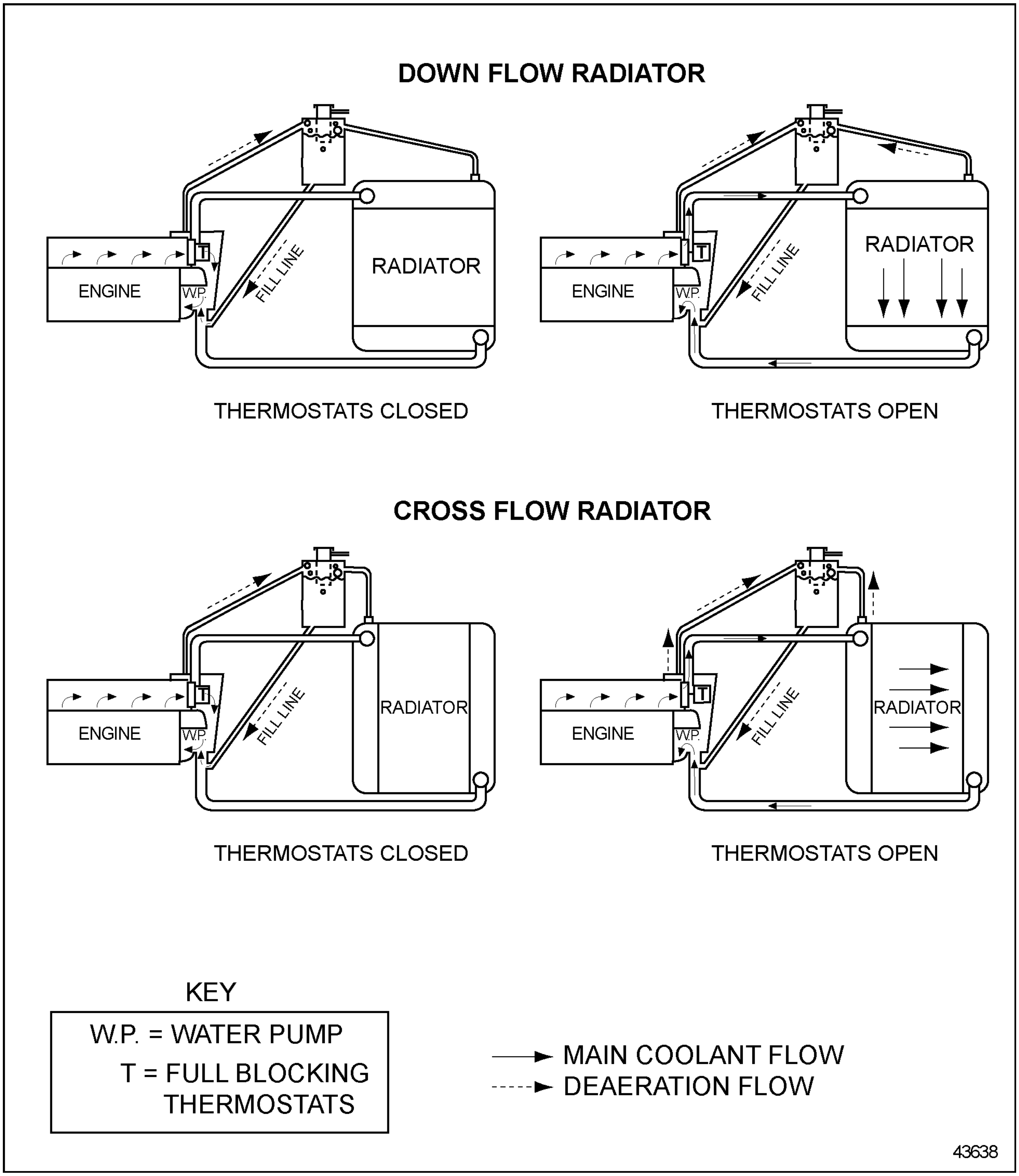


Figure 7-5 Rapid Warm-up Cooling System - Remote Tank, Cross Flow and Down Flow Radiators

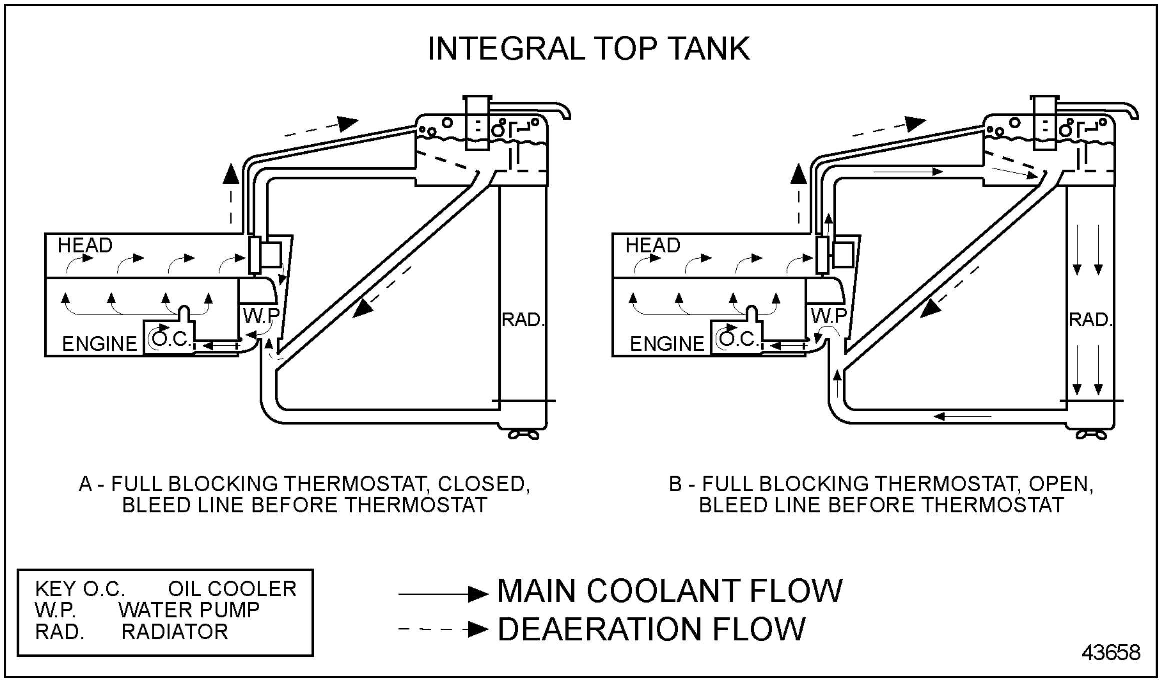


Figure 7-6 Rapid Warm-up with Integral Top Tank

7.5.2 CONVENTIONAL COOLING SYSTEM

The conventional cooling system is filled directly through the radiator core. It has low coolant flow through the core during closed thermostat operation from small air bleeds located in the thermostat or in the thermostat housing. This type of system may experience slow warm-up or inability to maintain minimum operating temperatures during cold ambient operations. Detroit Diesel will not approve a conventional cooling system for the MBE 4000.

7.5.3 AUXILIARY AIR-COOLED COOLER CORES

Heat exchangers in addition to jacket water and charge air cooler radiators are quite often part of the total cooling system. Heat exchangers such as air-to-oil, air-to-air, oil-to-air, or others are to be used and mounted either in front of the radiator or behind it. If auxiliary coolers are used, greater restriction of air flow and increased heat load must be consideredk.

NOTE:
Provide access to the areas between the cores for cleaning purposes.

7.5.4 COOLANT HEATERS

Cold weather operation often requires the use of coolant heaters. Information on coolant heaters can be obtained from DDC Application Engineering.

7.6 AIR-TO-AIR CHARGE COOLING

An air-to-air charge air cooler is mounted ahead of or beside the engine coolant radiator. The pressurized intake charge is routed from the discharge side of the turbocharger, through the CAC, and then to the intake manifold. This effectively reduces the temperature of the compressed air leaving the turbocharger, permitting a denser charge of air to be delivered to the engine. Cooling is accomplished by outside air directed past the cooling fins and core tubes of the CAC.

The intake air charge is routed to the cylinders by an intake manifold which directs the air to ports in the cylinder head, through two intake valves per cylinder, and into the cylinder. At the beginning of the compression stroke, each cylinder is filled with clean, fresh air which provides for efficient combustion.

7.6.1 CHARGE AIR COOLER

A CAC is normally mounted ahead of the cooling system radiator. The compressed air leaving the turbocharger is directed through the charge air cooler before it goes to the air inlet side of the intake manifold. See Figure 7-7 that shows a typical arrangement with a CAC placed in front of the radiator with a suction fan. With a blower fan, the CAC would be between the radiator and the engine.

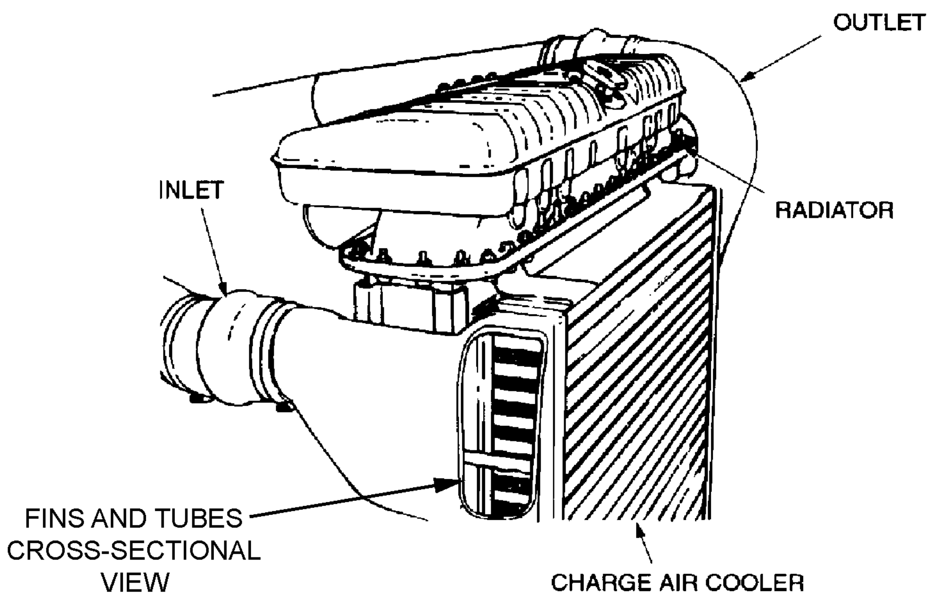


Figure 7-7 Typical Charge Air Cooler

The CAC is used to reduce the compressed air temperature leaving the turbocharger before it reaches the intake manifold. This permits a more dense charge of air to be delivered to the engine.

Cooling is accomplished by incoming air flowing past the tubes and fins of the intercooler. The compressed intake charge flowing inside the CAC core transfers the heat to the tubes and fins where it is picked up by the incoming outside air. Powder coated, painted, untreated mild steel is unacceptable for piping.

Aluminum, aluminized steel, stainless steel or fiber reinforced plastic piping is used to transfer the air from the turbocharger outlet to the CAC, and from there to the intake manifold.

Flexible rubber couplings and hose clamps are used to secure the duct work to the turbocharger, the CAC inlet and outlet, and the intake manifold.

7.7 COOLING SYSTEM PERFORMANCE REQUIREMENTS

Engine heat transferred to the coolant *must* be dissipated at a sufficient rate so engine coolant temperature does not exceed established safe limits under all operating conditions. The typical maximum engine coolant temperature is 221°F (105°C) for on-highway engines as listed in Table 7-1. Specific requirements are is listed in the “Technical Data” section of this manual (refer to section 14).

Engine	Maximum Engine Coolant Temperature
On-highway	105°C (221°F)

Table 7-1 Maximum Engine Coolant Out Temperature

The maximum ambient temperature at which these requirements are met is referred to as ambient capability. Operating with antifreeze, at high elevation, or other severe environmental conditions will require increasing the cooling capability of the system so the maximum allowable engine coolant temperature is not exceeded.

7.7.1 SYSTEM FILL

The cooling system *must* have sufficient venting (air bleeding) to permit filling at a minimum continuous rate of 8 L/min (2 gal/min) and on an interrupted basis using a 10 liter (2-3 gallon) bucket. Upon first indication of a full system, the amount of coolant needed to complete the fill *must not* exceed the satisfactory drawdown amount. This is also a requirement for interrupted fill. Refer to section 7.7.5 for drawdown capacity information.

7.7.2 SYSTEM DRAIN

Sufficient drains, strategically located, *must* be provided so the cooling system can be drained to:

- ☐ Prevent freeze problems during cold weather storage
- ☐ Remove all contaminated coolant during system cleaning
- ☐ Minimize refill problems due to trapped air or water pockets

7.7.3 DEAERATION

The cooling system *must* be capable of expelling all entrapped air within 10 minutes varrying engine speed between idle and rated speed after an initial fill with blocked open thermostats. The water pump *must not* become air bound.

NOTICE:
An air bound pump cannot adequately circulate coolant. This can lead to overheating and severe engine damage.

7.7.4 SYSTEM COOLANT CAPACITY

Total cooling system coolant capacity *must* be known in order to determine the expansion and deaeration volumes required in the top tank. See Figure 7-8.

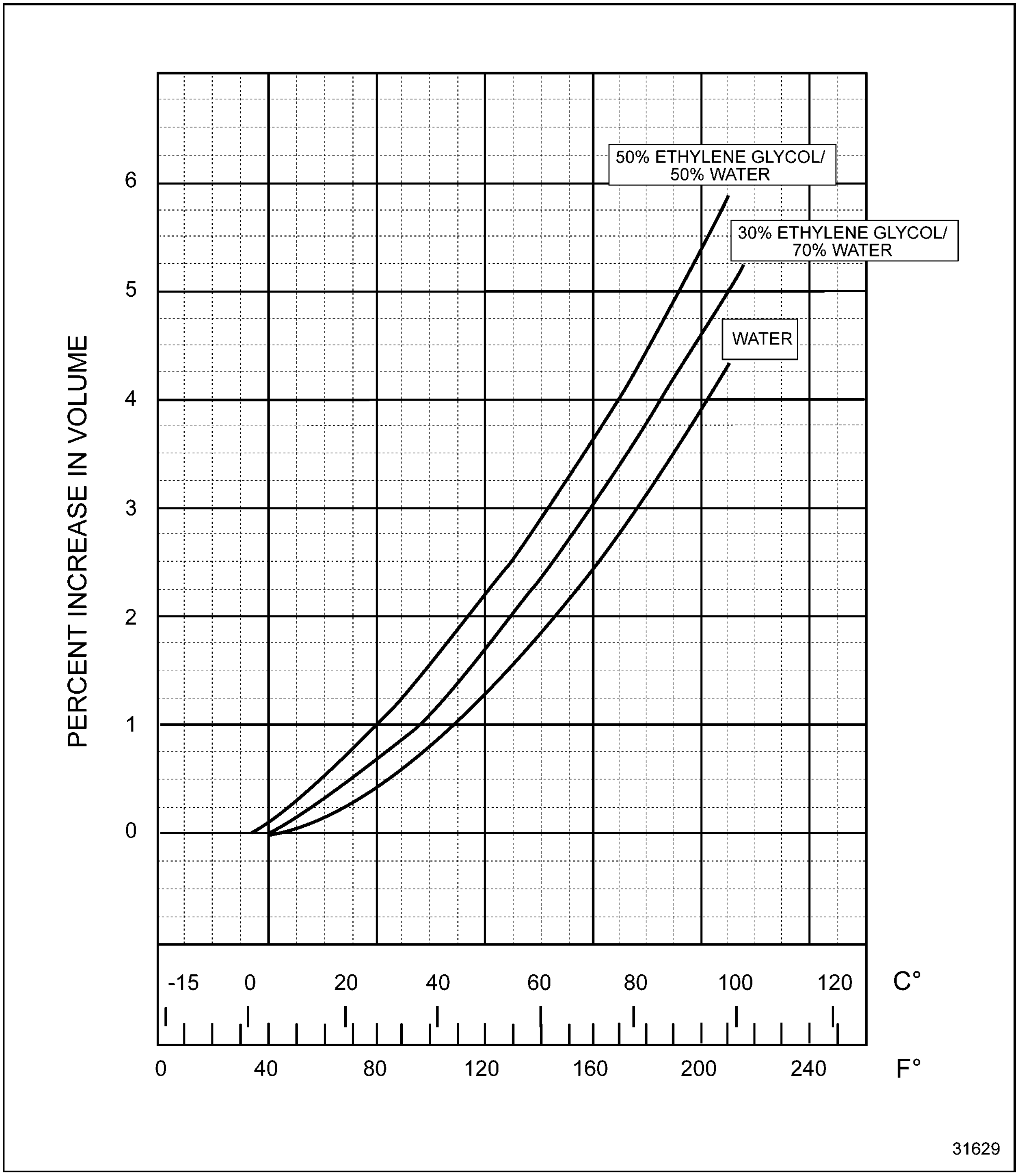


Figure 7-8 Percent Increases in Volume for Water and Antifreeze Solution

The total capacity *must* include the basic engine, radiator, heater circuit, plumbing, etc. A minimum 6% expansion volume *must* be provided in the top tank along with a 2% deaeration volume and sufficient reserve volume to meet drawdown capacity. This volume *must* be provided, with or without a coolant recovery system.

Basic engine coolant capacity is listed in the “Technical Data” section of this manual (refer to section 14).

7.7.5 DRAWDOWN CAPACITY

Drawdown capacity is the amount of coolant which can be removed from the system before aereation or flow loss occurs. The drawdown capacity for MBE 4000 engines is 10% of the total cooling capacity. System design *must* permit reasonable loss of coolant from the hot full level before aeration of the coolant begins. Additional coolant capacity may be necessary if aeration begins before this point. Perform drawdown tests at the maximum tilt angle.

7.7.6 CORE CONSTRUCTION

Tube and plate fin design is preferred because of lower restriction to both air and coolant flow. Tube and plate fin designs are easier to clean than louvered serpentine types and generally of more rugged construction making it more suitable to operate in the diesel engine environment.

7.7.7 WATER PUMP INLET PRESSURE/MAXIMUM STATIC HEAD

When the engine is operating at maximum engine speed, fill cap removed, and thermostat fully opened, the water pump inlet pressure *must not* be lower than atmospheric pressure (suction) with a rapid warm-up cooling system

These requirements *must* be met to minimize water pump cavitation and corresponding loss in coolant flow. Keep restrictions to the water pump inlet such as radiator cores, heat exchanger, auxiliary coolers and the associated plumbing to a minimum.

7.7.8 COOLANT FLOW RATE/EXTERNAL PRESSURE DROP

The coolant flow rate through the engine and radiator *must* be within 90% of the rated flow listed in the “Technical Data” section of this manual (refer to section 14). Ensure that the flow is maintained when coolant is shunted away from the engine or radiator to supply cab heaters, air compressors, auxiliary coolers, wet exhaust systems, etc.

External pressure drop is defined as the sum of all components in the system. For example, a radiator with a 3 psi restriction plus a heat exchanger, with a 2 psi restriction mounted between the water pump and oil cooler gives a total pressure drop of 5 psi. This is within the typical MBE 4000 engine maximum allowable value. The current data is listed in the “Technical Data” section of this manual (refer to section 14).

7.7.9 MINIMUM COOLANT TEMPERATURE

The overall design should ensure minimum coolant temperature 71°C (160°F) be maintained under all ambient operating conditions; operating conditions are listed in the “Technical Data” section of this manual (refer to section 14). A cold running engine can result in poor engine performance, excessive white smoke, and reduced engine life.

7.7.10 SYSTEM PRESSURIZATION

MBE 4000 engines require a minimum 15 psi pressure cap. The specific requirements are listed in the “Technical Data” section of this manual (refer to section 14). The pressure caps raise the boiling point of the coolant which minimizes coolant or flow rate loss due to localized boiling and water pump cavitation. Higher rated pressure caps may be required for high altitude and severe ambient operation. Cooling system components *must* be able to withstand increased pressure.

7.7.11 COOLANTS

A proper glycol (ethylene, propylene) or extended life organic acid, water, Supplemental Coolant Additive (SCA) mixture meeting DDC requirements is required for year-round usage.

The coolant provides freeze and boil protection and reduces corrosion, sludge formation, and cavitation erosion. Antifreeze concentration should not exceed 67% for ethylene glycol (50% for propylene glycol). Detroit Diesel requires SCAs be added to all cooling systems at initial fill and be maintained at the proper concentration. Follow SCA manufacturers' recommendations. Refer to *Coolant Selections for Engine Cooling Systems* (7SE0298), available on the DDC extranet.

7.8 CHARGE AIR COOLING REQUIREMENTS

Sufficient cooling capability is required for optimum engine performance. Exceeding the system temperature and pressure design limits defined in this chapter can adversely affect fuel economy, power, emissions and durability.

7.8.1 COOLING CAPABILITY

The cooling capability of the air-to-air system must be sufficient to reduce the turbocharger compressor out air temperature to within 21°C (38°F) of ambient temperature on all MBE on-highway engines. Air inlet manifold temperature requirements are listed in the “Technical Data” section of this manual (refer to section 14).

7.8.2 MAXIMUM PRESSURE LOSS

The maximum allowable total static pressure drop across the MBE 4000 charge air system is 10.0 kPa (3 in. Hg). This includes the restriction of the charge air cooler and all the plumbing and accessories from the turbocharger compressor to the engine air inlet manifold.

7.8.3 CLEANLINESS

All new charge air cooling system components must be thoroughly clean and free of any casting slag, core sand, welding slag, etc. or anything that may break free during operation. These foreign particles can cause serious engine damage.

7.8.4 LEAKAGE

Leaks in the air-to-air cooling system can cause a loss in power, excessive smoke and high exhaust temperature due to a loss in boost pressure. Large leaks can possibly be found visually, while small heat exchanger leaks will have to be found using a pressure loss leak test.

The charge air cooler is considered acceptable if it can hold 25 psi (172 kPa) pressure with less than a 5 psi (34.5 kPa) loss in 15 seconds after turning off the hand valve.

7.9 END PRODUCT QUESTIONNAIRE

A Detroit Diesel End Product Questionnaire (EPQ) *must* be completed on new installations, engine repowers, and installation modifications. Copies of the Detroit Diesel long and short EPQ forms can be found in the appendix of this manual. The short form may be used for ten or less units per year.

7.10 COOLING SYSTEM DESIGN CONSIDERATIONS

Many factors *must* be considered when designing the overall cooling system. The design process can be broken down into two phases:

- ☐ Consideration of heat rejection requirements
- ☐ Consideration of specific component design

The following guidelines are presented as a systematic review of cooling system considerations in order to meet minimum standards.

7.10.1 COOLING SYSTEM REQUIREMENTS

The first cooling system consideration is to establish what coolant and air temperature values must be met for an application.

Engine Operating Temperature

Engine coolant temperature, under normal operating conditions, will range from 6°C (10°F) below to 8°C (15°F) above the start to open temperature of the thermostat. The temperature differential between the engine coolant in and out is typically 6°C (10°F) at maximum engine speed and load. The maximum allowable engine coolant temperature is listed in the "Technical Data" section of this manual (refer to section 14).

The engine coolant temperature rise and radiator coolant temperature drop values will be different whenever the engine and radiator flows are not the same (partial thermostat open operation). Placing auxiliary coolers between the engine and the radiator will cause the same effect. The maximum allowable coolant temperature represents the temperature above which engine damage or shortened engine life can occur.

7.10.2 ENGINE PERFORMANCE

Each engine rating has its own individual performance characteristics. The two areas of performance which have the greatest effect on cooling system design are heat rejection and water pump output. These values are is listed in the "Technical Data" section of this manual (refer to section 14).

Engine Heat Rejection

Heat is rejected from an engine into four areas; jacket water, charge air, exhaust and radiation. The jacket water and charge air heat must be dissipated in order to meet coolant and intake manifold rejection requirements. The exhaust heat and radiated heat must be considered because both often have an effect on air temperature which affects fan and heat exchanger performance Limiting ambient temperature may occur at engine speeds other than maximum.

Coolant Flow

The pump flow listed in the "Technical Data" section of this manual (refer to section 14) is derived from a laboratory engine operating under SAE J1995 conditions. Actual engine installations often have substantially different plumbing arrangements and employ different coolants. Refer to section 7.10.4.6 for information about water pump performance.

Heat Transfer Capabilities

Heat transfer capabilities *must* be adequate for the designated coolant, air temperatures, and flows. These capabilities should include reserve capacity to allow for cooling system deterioration.

7.10.3 ENVIRONMENTAL AND OPERATING CONDITIONS

Consider both environmental and operating modes of the installation when designing the cooling system. Reserve capacity and special selection of components are required for operation in the following extremes:

- ☐ Hot or cold ambient temperatures (refer to section 7.10.3.1)
- ☐ High altitude (refer to section 7.10.3.2)
- ☐ Space constraints (refer to section 7.10.3.3)
- ☐ Noise limits (refer to section 7.10.3.4)
- ☐ Tilt operation or installations (refer to section 7.10.3.5)
- ☐ Arid, damp, dusty, oily, windy conditions
- ☐ Long-term idle, full load, peak torque operation
- ☐ Long-term storage or standby operation
- ☐ Indoor/outdoor operation
- ☐ Serviceability limitations
- ☐ Infrequent maintenance intervals
- ☐ Severe shock or vibration
- ☐ System deterioration
- ☐ Multiple engine installations

The heat rejected to the coolant generally increases when engine performance is reduced due to external conditions. Engine performance is adversely affected by:

- ☐ High air restrictions
- ☐ High exhaust back pressure
- ☐ High air inlet temperature
- ☐ Altitude

Ambient Temperature

The ambient temperature in which an engine will be operated must be considered when designing the jacket water (JW) and CAC systems. The worst case cooling conditions are often at the highest expected ambient temperature.

Operating in extremely cold ambient, at light loads, or during extended idling will require conservation of heat energy. Coolant temperatures *must* be maintained near the thermostat opening value. This controls engine oil temperature at a satisfactory level for good engine performance and reliability. Cab heater performance is adversely affected if coolant temperatures are not maintained.

Altitude

As altitude increases air density decreases, and reduces engine and cooling system performance. A 1°C per 305 m (2°F per 1000 ft) decrease in the ambient capability is assigned as a general rule.

The reduced atmospheric pressure will lower the boiling point of the coolant. A higher rated pressure cap/relief valve may be required to suppress boiling.

Space Constraints

Cooling system design is often influenced by space constraints. Heat exchanger height, width, and depth can be dictated by the application. This, in turn, limits fan diameter and heat exchanger surface area.

Noise Limits

Noise limitations are another environmental concern which can effect the cooling system. Operating location and/or government regulations can limit noise generated by a cooling fan. Fan noise is directly related to fan speed which affects air flow (refer to section 7.13).

Tilt Operations or Installations

Cooling systems *must* perform satisfactorily at maximum tilt operation. This is especially critical for applications where the engine *must* operate for extended periods on steep grades.

7.10.4 SYSTEM COMPONENTS

Total heat rejected to the coolant and air must be determined to properly size the radiator , CAC, and fan arrangement so sufficient heat can be dissipated. This information is listed in the "Technical Data" section of this manual (refer to section 14).

Additional Heat Loads to Coolant

The following items will add an additional heat load to the engine coolant:

- ☐ Transmission coolers
- ☐ Torque converters
- ☐ Hydraulic oil coolers
- ☐ Air compressors
- ☐ Retarders
- ☐ Brake coolers
- ☐ Water cooled exhaust systems
- ☐ Exhaust gas coolers

The highest single source heat load to the coolant generally occurs during the no fuel braking mode in applications that use retarders. The amount of heat generated from a retarder is dependent upon its frequency and duration of application. The heat load source is from the retarder oil cooler, but engine friction heat also exists. The cooling system *must* be able to control maximum engine coolant temperature regardless of the mode of operation.

Additional Heat Loads to Air

The following factors or components will raise the temperature of the radiator inlet air or increase restriction to air flow when selecting a radiator and fan. The following are some of the common factors:

- ☐ Air-to-air coolers
- ☐ Oil-to-air coolers
- ☐ Hydraulic coolers
- ☐ Transmission coolers
- ☐ Recirculated radiator discharge air
- ☐ Engine radiated heat (blower fans)
- ☐ Air conditioning condenser
- ☐ Engine compartment configuration
- ☐ Fuel coolers

Coolant Type

The type of coolant chosen for a cooling system can have an effect on the system performance. Water pump output and heat transfer characteristics are different for water than for antifreeze because the fluids have different densities, viscosities and thermal conductivity. The heat exchanger manufacturer is the best source for determining what the difference in performance would be from one type of coolant to the next.

Plumbing

Consider the following requirements for all water connections made between the engine and the radiator, deaeration tank, heaters, filters, etc.:

- ☐ All connections *must* be as direct as possible, durable, and require minimal maintenance.
- ☐ Pipe and hose connections *must not* be necked down or be smaller than the engine inlet(s) and outlet(s). Fitting size *must* be considered so minimum hose inside diameter requirements are not exceeded.
- ☐ The number of connections *must* be kept to a minimum to reduce potential leakage.
- ☐ Use short and straight sections of hose only. Use formed tubes when bends are required. Otherwise the use of formed tubes is not recommended.

- ☐ Bends should be smooth and have a generous radius. Avoid mitered bends and crush-bend tubing.
- ☐ Beaded pipe ends *must* be used to prevent the hose from separating from the pipe.
- ☐ Fittings on the lines (especially fill line) *must not* reduce effective size.
- ☐ Quality constant tension hose clamps *must* be used to maintain tension and prevent leakage during both cold and hot operation. Use the correct style of clamp when silicone hoses are used.
- ☐ Connections *must* be flexible enough to accommodate relative motion between connecting components.
- ☐ Quality hoses that can withstand the expected temperatures, pressures, coolants, and inhibitors *must* be used.
- ☐ Corrugated hoses are not recommended.
- ☐ Hoses must be fuel and oil resistant.
- ☐ Hoses should not span more than a .6 m (2 ft) unsupported section. Use reinforced hose for longer spans.
- ☐ Care should be taken to keep hose connections on the same plane. Use short straight sections of hose.
- ☐ All connecting hoses and pipes *must* provide adequate support to prevent collapse and rupture. Loose internal springs are not recommended.
- ☐ All lines *must* have a continuous downward slope without droops to ensure good cooling system draining and refilling capabilities. Additional drains and vents may be required if this is not possible.
- ☐ All vent to fill lines must have a continuous upward slope to the radiator top tank.
- ☐ Locate a drain plug/cock on the lowest portion of the cooling system to ensure complete draining and removal of any sediment (remember that the bottom tank may not be the lowest point).

Auxiliary Coolant Flow Path Circuitry

Consider the following when using add on components such as cab heater systems, air compressors, auxiliary oil coolers, retarders, exhaust gas cooler, etc.:

- ☐ Location of coolant supply and return connection points.
- ☐ Restriction to coolant flow. Select engine connection points that will give adequate flow under all operating conditions, but do not adversely affect main engine/radiator flow.
- ☐ Location of auxiliary components. Components should be mounted below the top tank or surge tank coolant level whenever possible. This will allow removal of trapped air and to help complete filling of the cooling system.

- ☐ Special vents which may be required to ensure excessive air can be purged during system fill, if components are mounted above the coolant level. The engine *must*be run after the system has been filled to purge any remaining trapped air. Add makeup coolant as required.

Specific considerations are as follows:

- ☐ Connect auxiliary oil coolers and retarder heat exchangers in series with the main coolant flow on the pressure side of the pump. Coolers located on the inlet side of the water pump require modifications to the engine water bypass circuit to provide coolant flow through the cooler during closed thermostat operation. Modifications *must not* hinder air from being purged from the water pump. Engine coolant warm-up problems may occur when coolers are located in the radiator bottom tank. Connect the heater supply at the water pump discharge and the return to the thermostat housing base. See the installation drawings for specific locations.
- ☐ Give special care to excessively cold ambient operating conditions.
- ☐ Enhance driver/passenger comfort through the use of highly efficient, low restriction heater cores. Highly efficient, modern engines reject less heat to the coolant. It may be necessary to increase idle speed to maintain coolant temperatures.

Water Pumps

A water pump is used to circulate the coolant throughout the cooling system, including customer add-on features such as cab heaters, filters, and auxiliary oil coolers. Pumps are sensitive to inlet restrictions, coolant temperature, coolant type and aerated coolant. Discharge flow can be seriously reduced and damaging cavitation can occur if the cooling system is not designed properly.

Water pump inlet restriction *must* be kept to a minimum to prevent cavitation. This means radiators, auxiliary oil coolers located between the radiator and the pump inlet (not preferred location), as well as the associated plumbing *must* introduce minimal restriction. Lines connected to the water pump inlet *must* have at least the same area as the pump inlet. Bends should be kept to a minimum and they should have a generous radius (no mitered bends). The water pump inlet pressure (suction) *must not* exceed allowable limits The actual limits is listed in the “Technical Data” section of this manual (refer to section 14). The lowest pressure in the entire cooling system is found at the water pump inlet. This pressure can be below atmospheric; thus cavitation (boiling) will occur below 100°C (212°F) at sea level. Altitude causes higher probability of cavitation in cooling systems.

The pump can easily become air bound if a large volume of air is trapped in the pump during coolant filling, or if air is fed to the pump when the pump is running. Vehicle heater systems can be a major source of air. Air can also be introduced into the cooling system from a severely agitated or improperly designed top tank.

7.11 CHARGE AIR COOLING DESIGN GUIDELINES

The air to air CAC system should be designed for the highest horsepower engine offered in the application. The same system can be used for derated versions of the engine, which offers the following advantages:

- ☐ Reduces the number of components in the manufacturing and part systems
- ☐ Lower power engines may achieve even greater fuel economy from the additional reduction in engine intake air temperature
- ☐ Extends engine life

The following guidelines will assist in the design and selection of the various components that make up the charge air system. It is critical that these components offer maximum air temperature reduction with minimal loss of pressure. The integrity of the components must provide for long life in its operating environment.

Air system operating parameters such as heat rejection, engine air flow, air pressure, maximum pressure drop, and minimum temperature loss are available on the published Engine Performance Curves (sheet #2).

Charge air cooler considerations include size, cooling air flow restriction, material specifications, header tanks, location, and fan systems.

7.11.1 SIZE

The size of the heat exchanger depends on performance requirements, cooling air flow available, and usable frontal area. Using the largest possible frontal area usually results in the most efficient core with the least amount of system pressure drop. Consult your supplier to determine the proper heat exchanger for your application.

7.11.2 COOLING AIR FLOW RESTRICTION

Core selection and location must meet charge air system temperature and pressure drop limits, and must be compatible for good coolant radiator performance. Charge air coolers have a cooling air flow restriction typically between .19 and .37 kPa (0.75 and 1.5 in. H_2O).

7.11.3 MATERIAL

Most charge air coolers are made of aluminum alloys because of their light weight, cost advantages and good heat transfer characteristics. In general, aluminum, aluminized steel, and stainless steel are recommended materials for CAC system design. Other materials may be used with approval from DDC Applications Engineering. The use of untreated steel and other similar material is not approved because of rust formation.

7.11.4 HEADER TANKS

Header tanks should be designed for minimum pressure loss and uniform airflow distribution across the core. Rounded corners and smooth interior surfaces provide a smooth transition of the air flow resulting in minimum pressure loss. The inlet and outlet diameters of the header tanks should be the same as the pipework to and from the engine. A 101.6 mm (4 in.) minimum diameter is required for the MBE 4000 engines. The tube ends require a 2.3 mm (0.09 in.) minimum bead to retain hose and clamp connections.

7.11.5 LOCATION

The cooler is typically mounted directly in front (upstream of air flow) or along side the engine coolant radiator. Other locations are acceptable as long as performance requirements are met. The cooler should be located as close to the engine as practical to minimize pipe length and pressure losses.

Leave access space between the cores when stacked in front of one another so debris may be removed.

7.11.6 PIPEWORK

Give careful attention to the pipework and associated fittings used in the inlet system, in order to minimize restriction and maintain reliable sealing.

Pipework length should be as short as possible in order to minimize the restriction incurred in the system and to keep the number of bends to a minimum. Use smooth bend elbows with an R/D (bend radius to tube diameter) ratio of at least 2.0 and preferably 4.0. The cross-sectional area of all pipework to and from the charge air cooler must not be less than that of the intake manifold inlet.

The recommended tube diameter for the MBE 4000 engines is 101.6 mm (4 in.) for both the turbocharger to CAC heat exchanger, and from the CAC heat exchanger to the engine air intake manifold.

7.12 HEAT EXCHANGER SELECTION

Heat exchanger cores are available in a wide variety of configurations. Heat exchanger materials, construction and design can be any of the materials and designs listed in Table 7-2.

Materials, Construction, and Design	Choices
Heat Exchanger Materials	Copper, Brass, Aluminum, Steel
Heat Exchanger Construction	Lead Soldered, No Lead Soldered, Brazed, Welded, Mechanical Bond
Fin Geometry	Plate, Serpentine, Square, Louvered, Non Louvered
Tube Geometry	Oval, Round, Internally Finned, Turbulated
Coolant Flow	Down Flow, Cross Flow, Multiple Pass Series Flow, Multiple Pass Counter Flow

Table 7-2 Heat Exchanger Materials, Construction, and Design Choices

All of these variations can have an effect on heat exchanger size, performance and resistance to flow on both the fin side and tube side for both radiators and charge air coolers.

Meet the following design criteria to achieve greatest efficiency for fan cooled applications:

- ☐ Utilize the largest practical frontal area in order to minimize restriction to air flow.
- ☐ Use square cores. The square core allows maximum fan sweep area, thus providing most effective fan performance.
- ☐ Keep core thickness and fin density (fins per unit length) to a minimum. This keeps air flow restriction low, helps prevent plugging, and promotes easier core cleaning.
- ☐ Fin density in excess of 10 fins per inch should be reviewed with Detroit Diesel Application Engineering.
- ☐ Use the largest possible fan diameter to permit operating at slower fan speeds, resulting in lower noise and horsepower demand.

Meet the following criteria to achieve greatest efficiency for liquid to liquid cooled applications:

- ☐ Tube velocity
- ☐ Water pump restriction
- ☐ Size and shape determined by installation

7.13 FAN SYSTEM RECOMMENDATIONS AND FAN SELECTION

Proper selection and matching of the fan and radiator as well as careful positioning will maximize system efficiency and will promote adequate cooling at the lowest possible parasitic horsepower and noise level. Obtain radiator and fan performance curves from the manufacturer to estimate air system static pressure drop and determine if a satisfactory match is possible.

Installations using the largest fan diameter possible, turning at the lowest speed to deliver the desired air flow, are the most economical.

NOTE:
Fan blades should not extend beyond the radiator core. Blades that reach beyond the core are of minimal or no benefit.

Other important considerations include:

- ☐ Cooling air flow required by the radiator core
- ☐ Cooling air system total pressure drop
- ☐ Space available
- ☐ Noise level limit
- ☐ Fan drive limits
- ☐ Fan speed limit
- ☐ Fan weight and support capabilities
- ☐ Fan spacers

Fan tip speed in excess of 18,000 fpm should be reviewed with Detroit Diesel Application Engineering.

7.13.1 BLOWER VS SUCTION FANS

The application will generally dictate the type of fan to be used (i.e. mobile applications normally use a suction fan, and stationary units frequently use blower fans). Blower fans are generally more efficient in terms of power expended for a given mass flow, since they will always operate with lower temperature air as compared to a suction fan. Air entering a suction fan is heated as it passes through the radiator where a blower fan, even when engine mounted, can receive air closer to ambient temperatures.

Proper fan spacing from the core and good shroud design are required, so air flow is completely distributed across the core to obtain high efficiency.

A suction fan, when mounted, will generally have the concave side of the blade facing the engine, whereas a blower fan will have the concave side facing the radiator; see Figure 7-9. A suction fan cannot be made into a blower fan by simply mounting the fan backwards. Fan rotation *must* also be correct.

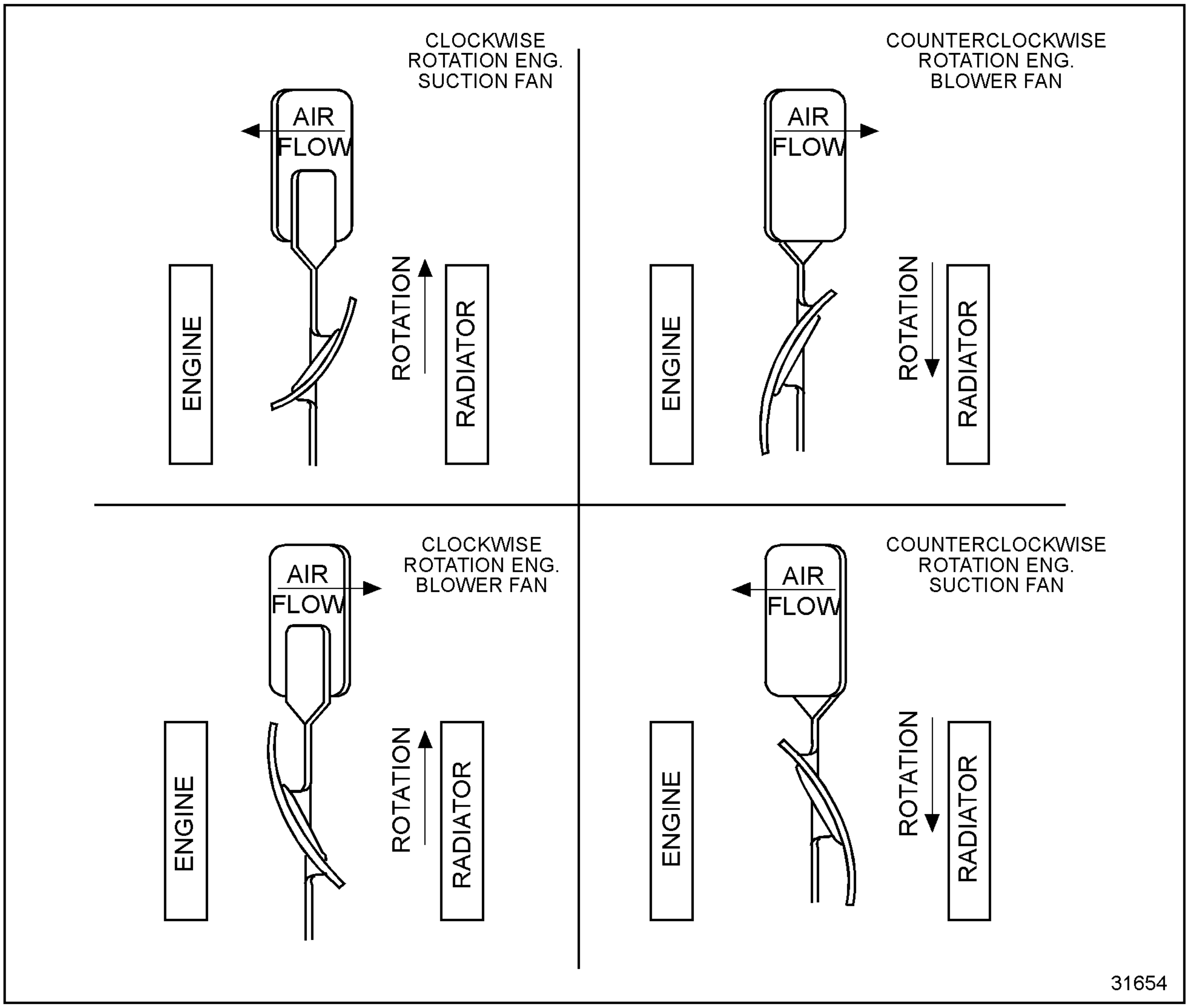


Figure 7-9 Blower vs. Suction Fans

Fan Performance

Fan curve air flow (m^3/min [ft^3/min]) is a theoretical output value which is seldom achieved. This value can be approached with a well formed, tight fitting shroud and proper fan positioning (fan tip clearances of 1.59 mm [1/16 in.] or less). Consult the fan supplier on how to determine what the realistic fan air flow delivery will be on the installation.

Select a fan/core match with sufficient reserve cooling capacity to allow for some degradation. This degradation occurs as the unit gets older and there is fouling from airborne debris. These conditions cause higher air restriction and/or lower heat transfer capability. This is especially true for applications such as agriculture, earth moving, or mining. Fin density should be as low as practical to keep air flow high, minimize plugging, and permit easier cleaning. Typical fin spacing for construction and industrial applications is eight to ten fins per inch.

NOTE:
Fin density in excess of 10 fins per inch should be reviewed with Detroit Diesel Application Engineering.

Increasing core thickness increases the restriction to air flow. This condition causes fouling to occur faster.

Consider the following when analyzing fan performance:

- ☐ Speed
- ☐ Static Pressure
- ☐ Horsepower

The following fan law relationships are useful when interpreting basic fan curves:

- ☐ Air flow varies directly with fan speed
  $ft^3/min_2 = (ft^3/min_1) \times (r/min_2) / (r/min_1)$
- ☐ Static head varies with the square of fan speed
  $P_{S2} = (P_{S1}) \times [(r/min_2) / (r/min_1)]^2$
- ☐ Horsepower varies with the cube of fan speed
  $hp_2 = (hp_1) \times [(r/min_2) / (r/min_1)]^3$

Additional factors that affect the installed performance of a fan are listed in Table 7-3.

Installed Fan	Factors Affecting Performance
Fan Position	Fan to Core Distance, Fan to Engine Distance
Air Flow Restriction	Radiator Core, Engine and Engine Compartment Configuration, Grills and Bumpers, Air Conditioning Condenser, Air-to-Oil Cooler, Air-to-Air Cores
Shroud	Shroud-to-Fan Tip Clearance, Shroud-to-Fan Position, Shroud Type (i.e. Ring, Box, Venturi), Shroud-to-Core Seal, Shutters, Bug Screens, and Winterfronts

Table 7-3 Installed Fan Performance Factors

Typical fan performance graphs have total pressure curves and power absorption curves for a given speed of rotation. The pressure, measured in water gage, represents the resistance to flow. The higher the resistance, the lower the flow. The fan horsepower absorption follows a similar, but not exactly the same, characteristic to the pressure curve. Depending on the installed system characteristics, the fan operates only at one point of water gage and power.

Most fans have some region in which the flow separates from the blade and the flow becomes unstable. This is called a stall region. Operation in the stall region is not recommended because results are not consistent and the fan is inefficient and noisy.

There are maximum tip speeds in the range of 18,000 to 23,000 feet per minute that the fan manufacturer based on his design. Check with the fan manufacturer.

The system characteristics are defined by the air flow restrictions that are a result of:

- Engine enclosure louvers
- Engine and accessories
- Fan guard
- Radiator core
- Charge air cooler if in tandem with radiator
- Oil cooler if in tandem with radiator
- Bug screen
- any other internal or external obstructions

NOTICE:
The fan should never operate in the stall area, where a small change in static pressure results in no change in airflow.

NOTICE:
The air side of the cooling system is critical and a change in the air flow will generally have a greater impact on cooling than a similar percentage change in coolant flow.

Consider these additional factors to determine actual fan performance at worst case operating conditions.

- ☐ Air temperature
- ☐ Atmospheric pressure

Fan curves are generated at standard conditions (77°F, 25°C, 0 elevation). If the fan is operating in different temperature or pressure (altitude) than standard the performance must be adjusted.

Fan Position

Fan position relative to the radiator depends on the fan diameter and the radiator frontal area. Position the fan further away from the core as the fan swept area becomes less than the radiator frontal area. This allows the air to spread over the full core area. The fan will not spread air over the entire core area if it is mounted too close to the radiator.

The optimum position of the fan blade on a blower or suction fan with respect to the shroud opening is dependent on the fan design as well as the many variables associated with an installation. Different system performance may occur for the same fan positions in different applications due to air flow restriction and flow obstructions. Consult the fan manufacturer for assistance in optimizing the fan positioning.

Keep fan tip-to-shroud clearance to a minimum because it influences air flow and noise level significantly. Minimum clearance is achieved by using a shroud with a round opening. An adjustable fan shroud is recommended if the fan pulley is adjustable for belt tightening. Consider allowances for engine/radiator movement when determining tip clearance.

Consider components located behind the fan so air flow is not adversely affected or vibration introduced to the fan. These conditions will cause premature failures, or increased noise, or both. Fan height is also important.

Fan Shrouds

The use of a fan shroud is required for achieving good cooling system performance. A properly designed shroud will distribute the air across the core more uniformly, increase core air flow, and prevent air recirculation around the fan. Seal holes and seams in the shroud. An air tight seal between the shroud and the radiator core will maximize air flow through the core.

There are three basic types of shrouds: the well rounded entrance venturi shroud, the ring shroud, and the box shroud; see Figure 7-10. The ring and box type shrouds are most common because they are easier to fabricate.

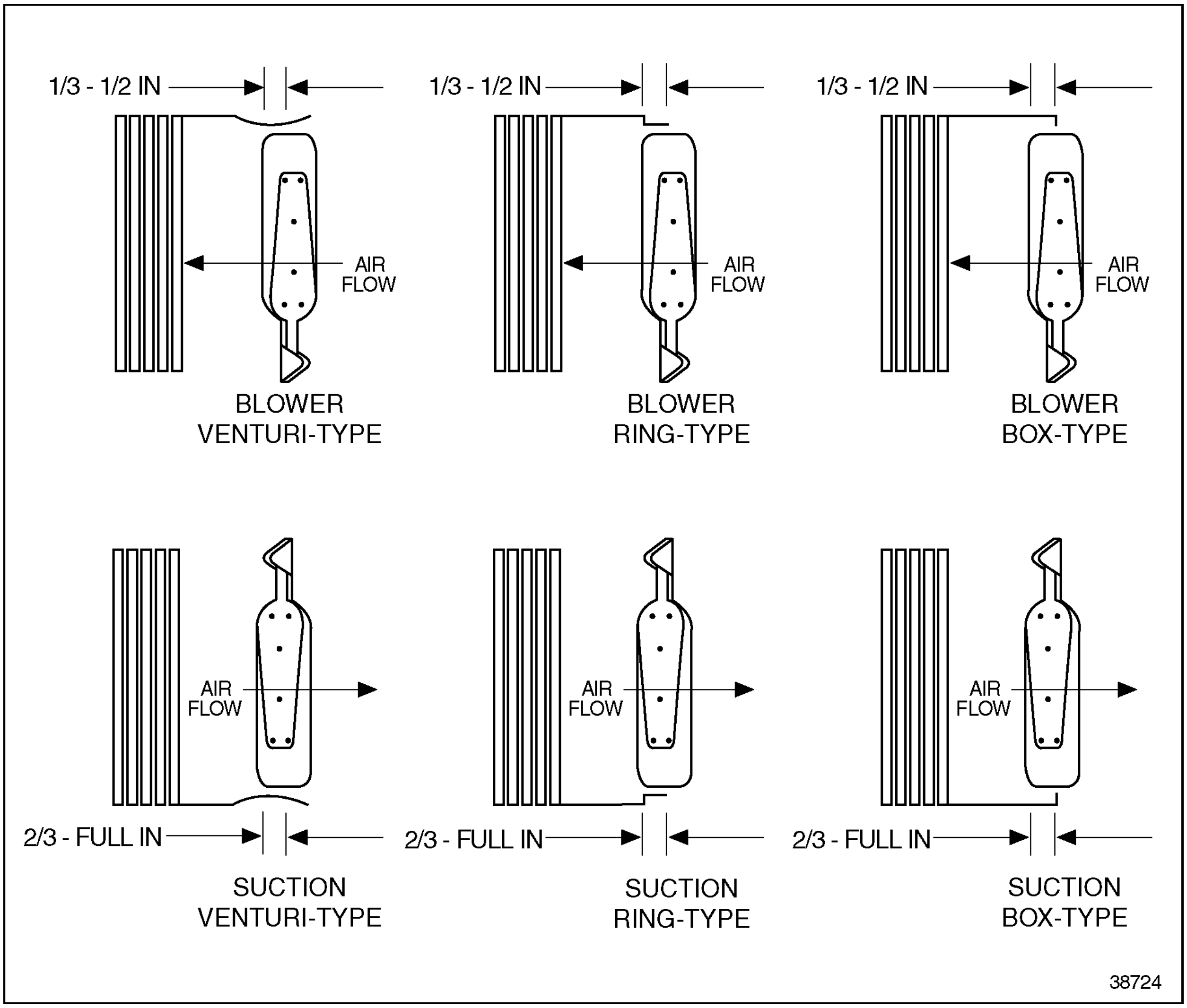


Figure 7-10 Fan Shroud Types

Fan System Assemblies

Do not exceed the design limits of any component when OEM components such as fans, fan drives, spacers, etc. are attached to Detroit Diesel supplied components (fan hub and pulley assemblies). Vibration tests must be performed when the customer wants to use a fan system not previously approved by DDC.

Fan Drives

A typical MBE/OM application will mount 6the fan on the water pump or the crankshaft. Additionally a remote fan bracket is available for on-highway engines for fan heights 20 in. above the crankshaft. Contact DDC Application Engineering for details.

Baffles to Prevent Air Recirculation

Use baffles around the perimeter of the radiator assembly to prevent hot air which has passed through the radiator core from being recirculated back through the core. The cooling capability of the system may be seriously hindered if this baffling is not utilized.

Shutters

Shutters are not required under most operating conditions with a properly designed cooling system. Shutters may improve performance under extreme cold ambient conditions and long term idling or light loading.

NOTICE:
All warning and shutdown monitoring devices must be properly located and always in good operating condition. Improperly installed or maintained devices may lead to reduced engine life, loss of power, and poor fuel economy.

Shutters should open approximately 3°C (5°F) before the thermostat start to open temperature. The shutter control should sense engine water out (before thermostat) temperature and the probe must be fully submerged in coolant flow.

Winterfronts

Winterfronts are not required under most operating conditions with a properly designed cooling system. Some operators reduce the airflow through the radiator during cold weather operation to increase engine operating temperature. Consider on/off fans and shutters if long term idling during severe cold weather is necessary.

Improperly used winterfronts may cause excessive temperatures of coolant, oil, and charge air. This condition can lead to reduced engine life, loss of power, and poor fuel economy. Winterfronts may also put abnormal stress on the fan and fan drive components.

Never totally close or apply the winterfront directly to the radiator core. At least 25% of the area in the center of the grill should remain open at all times. All monitoring, warning, and shutdown devices should be properly located and in good working condition.

7.14 RADIATOR COMPONENT DESIGN

The design of individual radiator components may have an effect on cooling system performance. The following sections describe these considerations.

7.14.1 DOWN FLOW AND CROSS FLOW RADIATORS

Down flow radiators are customarily used and required for heavy duty diesel engine applications. A cross flow radiator, see Figure 7-11, may be used if height limitations exist, but deaeration, thermal stratification, adequate core tube coverage and freeze damage are generally more difficult to control.

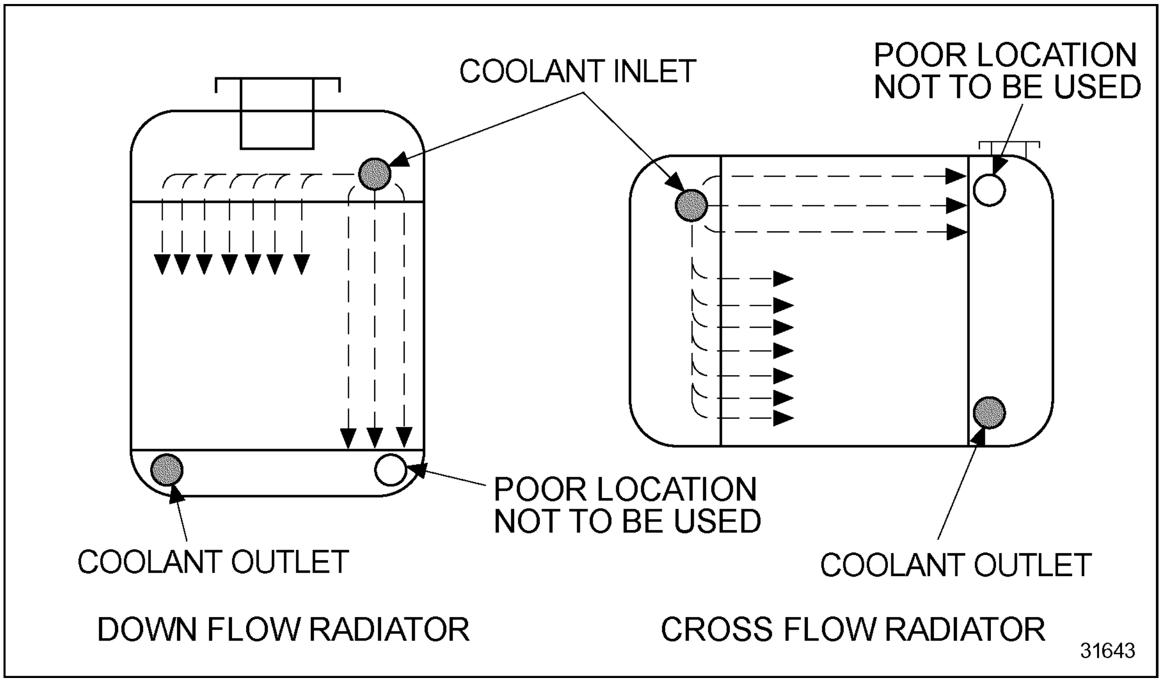


Figure 7-11 Down Flow Radiator and Cross Flow Radiator

Horizontal Radiator

Horizontal radiators may be used in situations where space restrictions preclude the use of other types. It is essential that vent lines go to the fill tank with the cap. Consult DDC Application Engineering for assistance in applying horizontal radiators.

Rapid Warm-up Deaeration Tank - Down Flow Radiator

The rapid warm-up deaeration tank consists of an integral top tank or a remote tank with the same design features. The top tank design should provide the following characteristics:

- ☐ A non turbulent chamber for separating air (gases) from the coolant
- ☐ Ability to fill at a minimum specified rate
- ☐ Adequate expansion and deaeration volume as well as sufficient coolant volume so the system will operate satisfactorily with partial loss of coolant
- ☐ Impose a positive head on the water pump
- ☐ Prevent coolant flow through the radiator core during closed thermostat operation
- ☐ Prevent introduction of air into the cooling system during maximum tilt or angle operation

Remote Mounted Radiators/Heat Exchanger

Consult an authorized distributor, radiator supplier, or DDC Application Engineering when remote (i.e. non engine driven fans) mounted radiators/heat exchangers are being considered as many variables *must* be considered for each application. The requirements that must be met for remote mount are:

- ☐ Standard DDC installation and test requirements including restriction to flow and coolant flow rate
- ☐ Maximum allowable static head pressure is 35 ft of water column
- ☐ Installations where flow rate restrictions cannot be met may require using an inline pump

Integral Top Tank

The following top tank component guidelines are provided to assist in the design of a new tank, to critique existing tanks, and to troubleshoot problem cooling systems. See Figure 7-12.

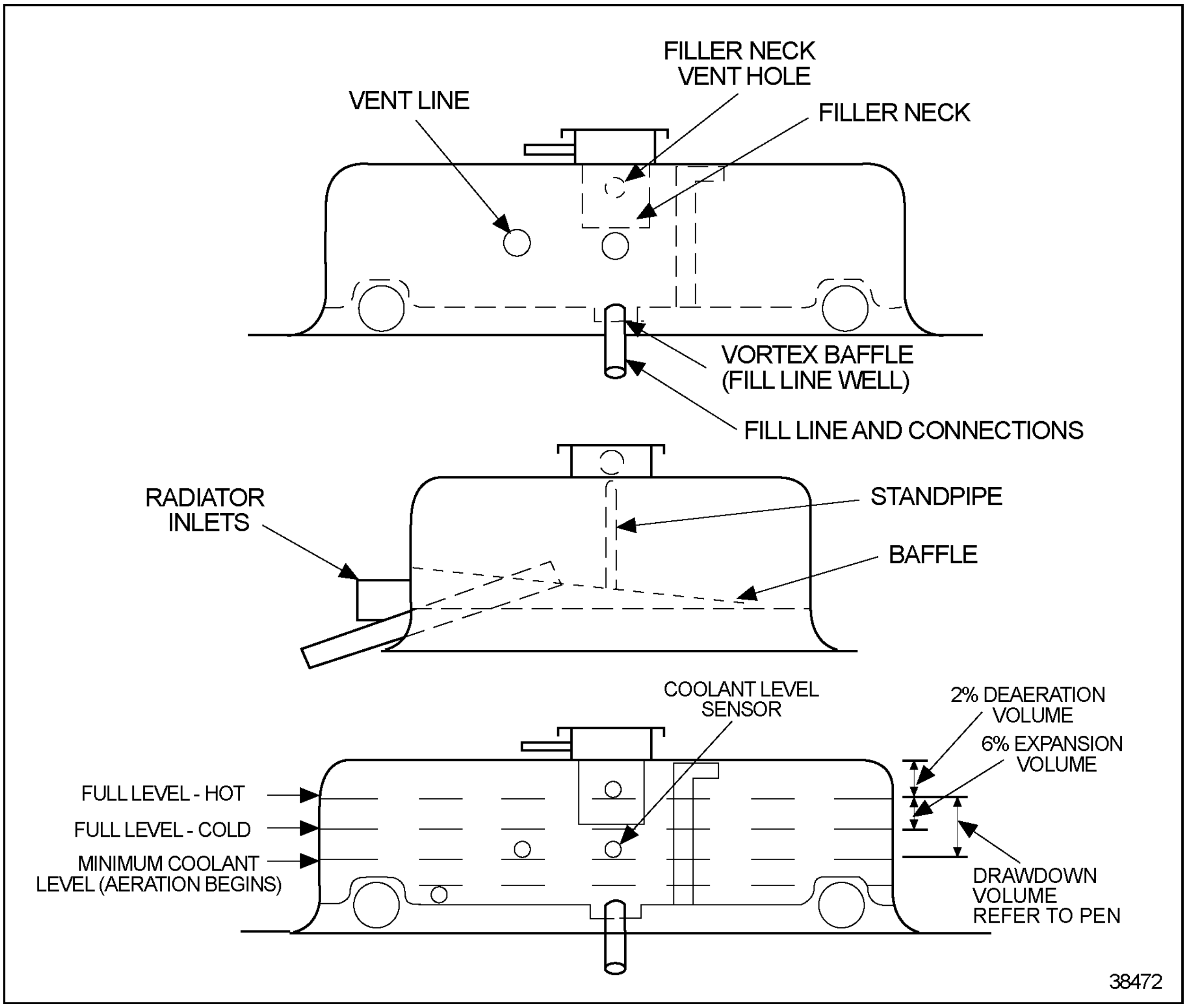


Figure 7-12 Rapid Warm-up Down Flow Radiator Top Tank

The guidelines for the design of an integral top tank are listed in Table 7-4 and Table7-5.

Component	Guidelines
Standpipe(s)	Locate the standpipe(s) as far away from radiator inlet(s) as practical and center over core. This is the area of least coolant turbulence, thus best for separating air out of the coolant.
Standpipe(s)	Use 1 or 2 standpipes with 6.35 mm (0.25 in.) inside diameter (general rule).
Standpipe(s)	Bottom of tube *must not*protrude below baffle.
Standpipe(s)	Top of tube *must* extend above hot full coolant level. The flow *must* be directed away from the low coolant level sensor, as well as the filler neck and/or pressure relief valve opening. This minimizes coolant loss.
Baffle	A clearance of 25.4 mm (1 in.) or more should be maintained between the top of the radiator core and the bottom of the top tank baffle. This produces a good transition of the coolant flow and enhances air separation from the coolant.
Baffle	Seal baffle completely so the only flow path between the deaeration tank and the radiator core is through the standpipe(s). This is essential for proper engine warm-up, preventing top tank coolant agitation, and providing a positive head on the water pump.
Vortex Baffle	Use a vortex baffle to prevent formation of a coolant vortex. This also permits maximum usage of top tank coolant volume.
Vortex Baffle	A vertical baffle is preferred. Horizontal vortex baffles at the fill line opening may hinder the venting of trapped air.
Fill Line and Connections	The recommended minimum inside diameter is 25.4 mm (1 in.).
Fill Line and Connections	Fill line connections (fittings) *must not* reduce the minimum inside diameter requirement.
Fill Line and Connections	Locate the fill line as low as possible above the baffle and at the center of the tank. This minimizes uncovering the fill opening and drawing air into the cooling system during vehicle operations.
Fill Line and Connections	Make the engine connection as close to the water pump inlet as practical. This will provide maximum head to the water pump and minimize heat migration to the radiator core, resulting in quicker engine warm-up. Avoid connecting the fill line to the coolant bypass circuit. A continuous downward slope (including fittings) *must* be maintained from the top tank to the water pump inlet to ensure good filling capabilities.
Vent (deaeration) Line -- High Position (above coolant level)	Locate the vent line at the top of the top tank above the coolant level in the deaeration space.
Vent (deaeration) Line -- High Position (above coolant level)	The recommended line size is 4.76 mm (3/16 in.) inside diameter. A 4.5 mm restriction must be included.
Vent (deaeration) Line -- High Position (above coolant level)	Do not direct deaeration line coolant flow toward the fill neck, pressure relief valve openings, or low coolant level sensor
Vent (deaeration) Line -- High Position (above coolant level)	All vent lines must maintain a continuous downward slope
Radiator Inlet	Locate the radiator inlet as low as possible with at least the lower half of the inlet below the baffle level to minimize air trapped during fill.
Radiator Inlet	The inside diameter of the inlet should match the inside diameter of the thermostat housing.
Radiator Inlet	Design the radiator inlet to uniformly spread coolant under the baffle.
Radiator Inlet	Locate the vent line as far as possible from the radiator inlet.
Radiator Inlet	No vent holes. Extend the fill neck into the tank to establish the cold coolant full level, allowing for expansion (6%) and deaeration (2%) volume.

Table 7-4 Top Tank Component Guidelines — Standpipe(s), Baffle, Vortex Baffle, Fill Line and Connections, Vent Line, and Radiator Inlet

Component	Guidelines
Fill Neck	Select the fill neck size capable of accepting highest rated pressure cap required for application
	The fill neck cap *must* provide safe release of system pressure upon removal of the cap when a separate pressure relief valve is used.
	Locate the fill neck at the top center of the top tank. This will ensure a complete fill if unit is in a tilted position.
Fill Neck Vent Hole	A 3.18 mm (1/8 in.) vent hole located at the top of the fill neck extension is required for venting air and preventing coolant loss.
Engine Coolant Level Sensor (optional)	Location *must* be above the satisfactory drawdown coolant level. This is generally a height representing 98% of the drawdown quantity.
	Coolant flow and/or splash from deaeration line and standpipe(s) *must not* contact sensor. A shroud around the sensor may be beneficial.
	Locating the sensor in the middle of the tank will minimize tilt operation sensitivity.

Table 7-5 Top Tank Component Guidelines- Fill Neck, Fill Neck Vent Hole, and Coolant Level Sensor

General guidelines for top tank design, critique, or troubleshooting are:

- ☐ Increasing top tank depth permits maximum usage of coolant volume and reduces tilt operation problems.
- ☐ Consider hose fitting inside diameters when determining vent and fill line inside diameter requirements.
- ☐ Low fill line flow velocity (large inside diameter line) will generally improve drawdown capacity and maintain higher pressure on the water pump.
- ☐ Oversized and/or excessive number of deaeration line(s) and standpipe(s) can result in poor deaeration and drawdown capabilities and increases coolant flow bypassing the radiator core.
- ☐ Undersizing deaeration line(s) and standpipe(s) may not provide adequate deaeration and they can become plugged easier.
- ☐ Make observations of top tank agitation, deaeration and fill line(s), flow direction, and velocity during both open and closed thermostat operations (throughout engine speed range), to determine satisfactory system design. The observations are especially helpful during fill and drawdown evaluation tests.
- ☐ A sight glass in the radiator top tank to determine proper coolant level will eliminate unnecessary removal of the radiator cap.

Remote Tank

The design of the remote tank, see Figure 7-13, *must* provide the same features as the integral top tank design. The guidelines for the radiator inlet tank are listed in Table 7-6.

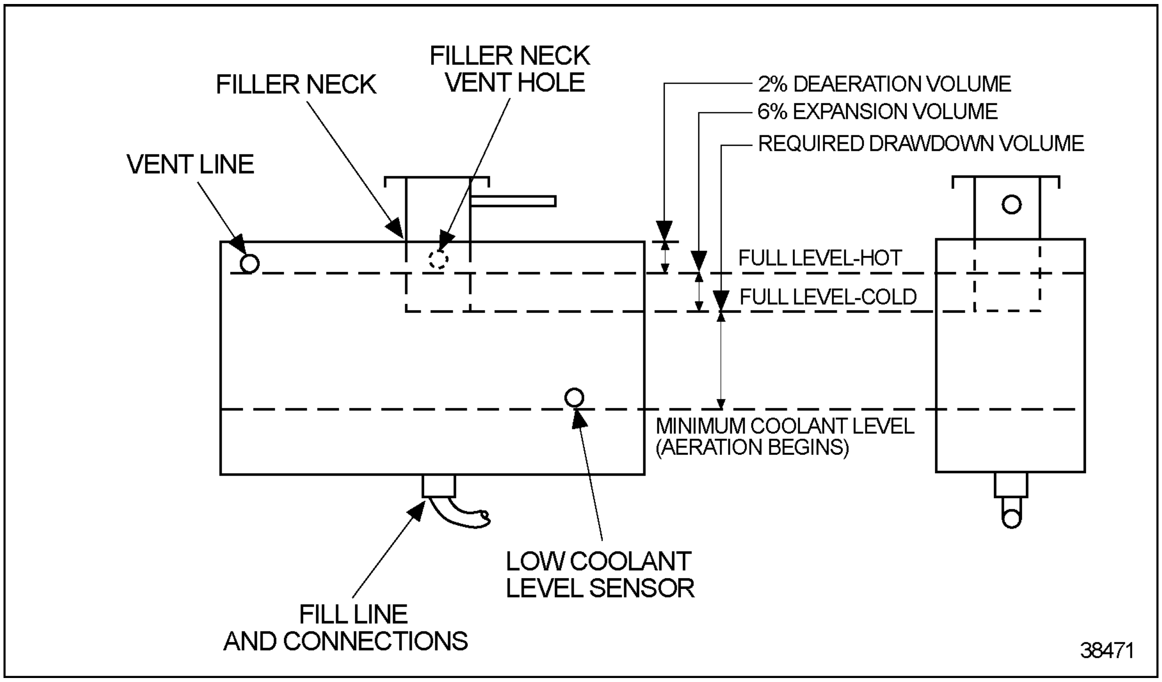


Figure 7-13 Remote Surge Tank Design for Rapid Warm-up Cooling System

Component and Location	Guidelines
Radiator Inlet Tank	*Must* be large enough so air can be separated from the coolant.
	The deaeration line from the radiator inlet tank to the remote/top tank *must* be at the highest point of each and generally as far away from the inlet as practical. See Figure 7-14.
Location	Locate tank as high as practical. The bottom of the tank should be above the rest of the cooling system. This will prevent coolant level equalization problems.
	Generally, low mounted tanks make filling the system more difficult, especially near the end of the fill, because of small head differential. Also, equalization of the coolant level occurs during engine stop or low speed operation.

Table 7-6 Component Design and Location Guidelines for the Remote Top Tank

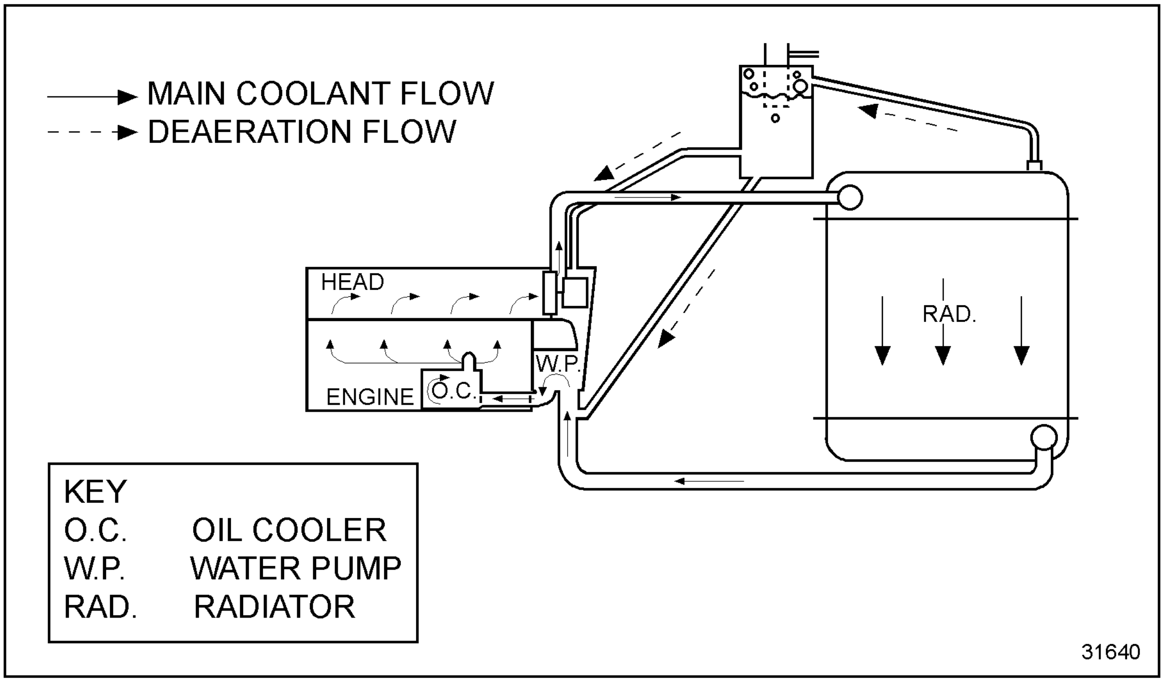


Figure 7-14 Down Flow Radiator Inlet Tank Deaeration Line Boss Position

Radiator Bottom Tank

Consider the following guidelines when designing the radiator bottom tank.

- ☐ Locate the coolant opening diagonally opposite the inlet tank opening or as far away as is practical. This provides uniform distribution of the coolant across the core and prevents short circuiting; see Figure 7-15.

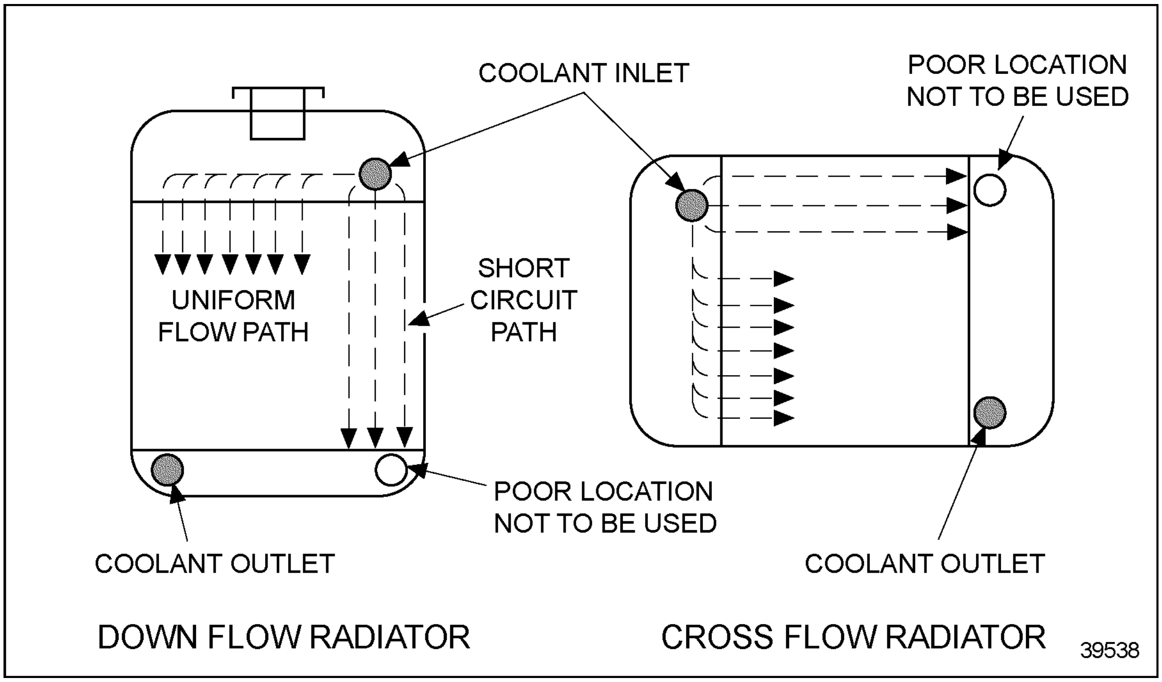


Figure 7-15 Coolant Inlet/Outlet Locations

- ☐ Inside diameter of outlet *must* be greater than, or equal to respective inlet connections.
- ☐ A well rounded coolant outlet exit area is preferred, see Figure 7-16, to minimize restriction and aeration.

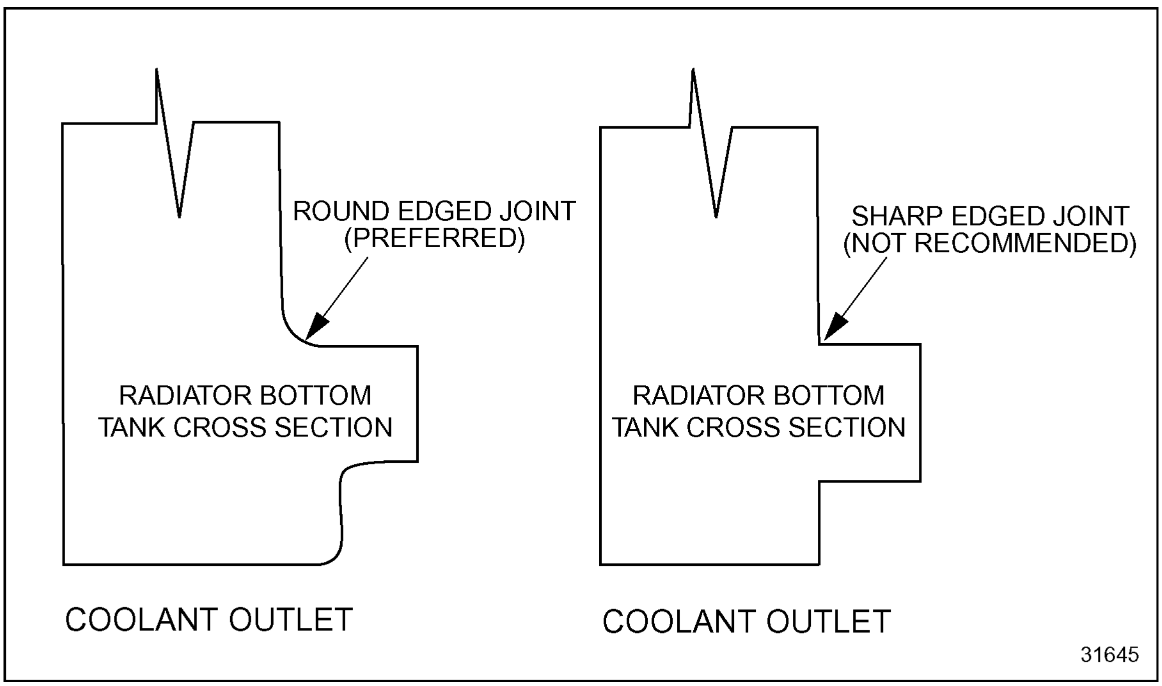


Figure 7-16 Radiator Outlet Contour

- ☐ Depth of the tank should be no less than the diameter of the outlet pipe to minimize restriction.

- ☐ Locate a drain plug/cock on the lowest portion of the cooling system to ensure complete draining and removal of any sediment (remember that the bottom tank may not be the lowest point).

Coolant Pressure Control Caps and Relief Valves

Pressurizing the cooling system:

- ☐ Reduces boiling
- ☐ Prevents coolant loss due to evaporation
- ☐ Maintains water pump performance

Pressurization is obtained by the expansion of the coolant as it is heated and controlled through the use of an integral pressure/fill cap or a separate relief valve.

NOTICE:
System pressurization will not occur if pressure/fill cap is installed when coolant is hot.

Locate the pressure control device high in the deaeration tank above the hot coolant level to minimize coolant loss and dirt contamination of the relief valve seat.

WARNING: **HOT COOLANT**
To avoid scalding from the expulsion of hot coolant, never remove the cooling system pressure cap while the engine is at operating temperature. Wear adequate protective clothing (face shield, rubber gloves, apron, and boots). Remove the cap slowly to relieve pressure.

The pressure valve (in the normally closed position) should maintain top tank pressure to within +/- 6.9 kPa (+/- 1 lb/in.^{2}) of the rating stamped on top of the cap/valve. The valve will lift off the seat, see Figure 7-17, as pressure exceeds the specified rating.

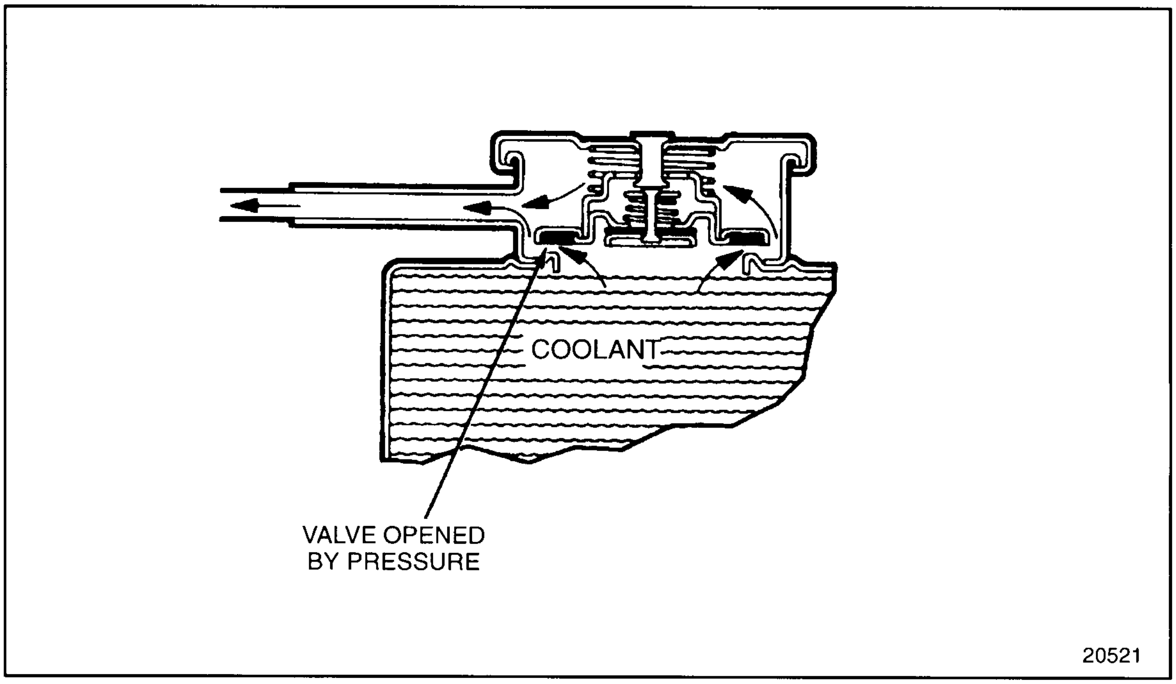


Figure 7-17 Pressure Control Cap — Pressure Valve Open

A vacuum actuated valve is incorporated in the assembly to prevent collapse of hoses and other parts as the coolant cools. See Figure 7-18.

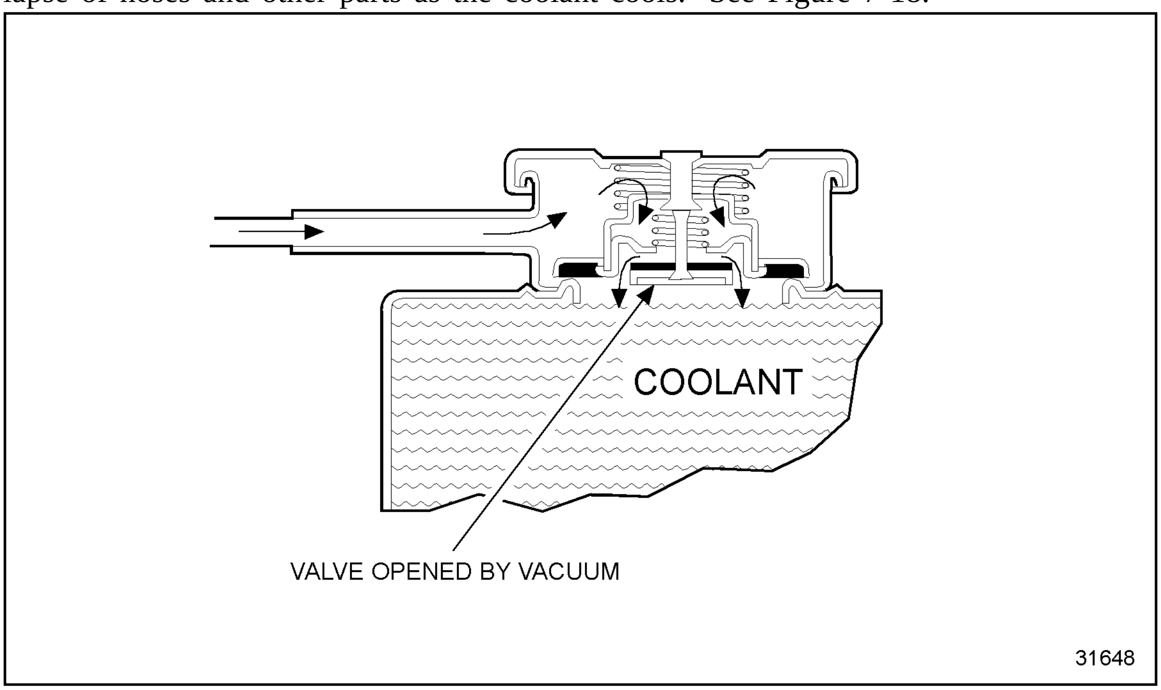


Figure 7-18 Pressure Control Cap — Vacuum Valve Open

The filler neck cap *must*provide for a safe release of the pressure upon cap removal if a separate pressure relief valve is used.

Inspect the valve/cap, periodically, to ensure components are clean, not damaged, and in good operating order.

A 15psi pressure cap is required for most systems and applications. Verify required minimum pressure cap rating by checking the “Technical Data” section of this manual (refer to section 14). Consider higher pressure rated caps for operation at increased altitudes.

Thermostat

A full blocking thermostat is used to automatically regulate coolant temperature by controlling the coolant flow to the radiator and engine bypass circuit. A full blocking thermostat design in the full open position (8° to 9°C [15° to 17°F] above the start to open temperature) controls the engine bypass circuit, and provides maximum coolant flow to the radiator.

The start-to-open thermostat temperature is 83°C (181°F). The full-open thermostat temperature is 95°C (203°F). The engine coolant temperature will be controlled at the thermostat start to open value, under normal operating conditions.

NOTICE:
Never operate the engine without thermostats.

Coolant Sensor Devices

Engine coolant temperature monitors (gauges, alarms, shutdowns, fan and shutter control switches, etc.) *must* be durable, reliable and accurate. Submerge the probe completely in a high flow stream to sense uniform coolant temperature. Locate the probe in an area without air pockets, or mount it in a place where it will not be affected by coolant being returned from parallel circuits such as heater, air compressor, and aftercooler return lines.

The coolant temperature monitor may not respond fast enough to prevent engine damage if a large quantity of coolant is suddenly lost, or if the water pump becomes air bound. Engine Coolant Level Sensors are required with MBE 4000 engines.

Temperature Gauges: Every temperature gauge should have sufficient markings to allow an operator to determine actual operating temperature. The temperature range should go beyond 99°C (210°F) so the operator will know if the maximum coolant temperature is being exceeded. Maintain accuracy of 3°C (+/- 5°F) to prevent inaccurate indication of either hot or cold running engine conditions.

Temperature Alarms: An auxiliary warning device (audible or visible) should be included if a digital gauge is used. Set temperature alarm units at coolant temperature level that is 3°C (5°F) above the maximum allowable coolant temperature. Accuracy should be 3°C (+/- 5°F). Locate each alarm sensor before the thermostat. Special considerations, including testing *must* be done when a coolant recovery system is used.

Temperature Shutdowns: Set temperature shutdown devices for a coolant temperature level of 105°C (223°F). Accuracy should be 1°C (+/- 2°F).

Low Coolant Level Sensor: Locate the sensor for low engine coolant level in the top tank. See tank design section for additional recommendations.

Shutter Control Switches: Mount shutter switches before the engine thermostat so they can sense engine coolant temperature. The various temperature control devices (shutters, fan drives and thermostats) *must* operate in proper sequence to prevent coolant temperature instability or overheat conditions.

The recommended temperature settings of the various coolant sensor devices can be seen in the following illustration (see Figure 7-19).

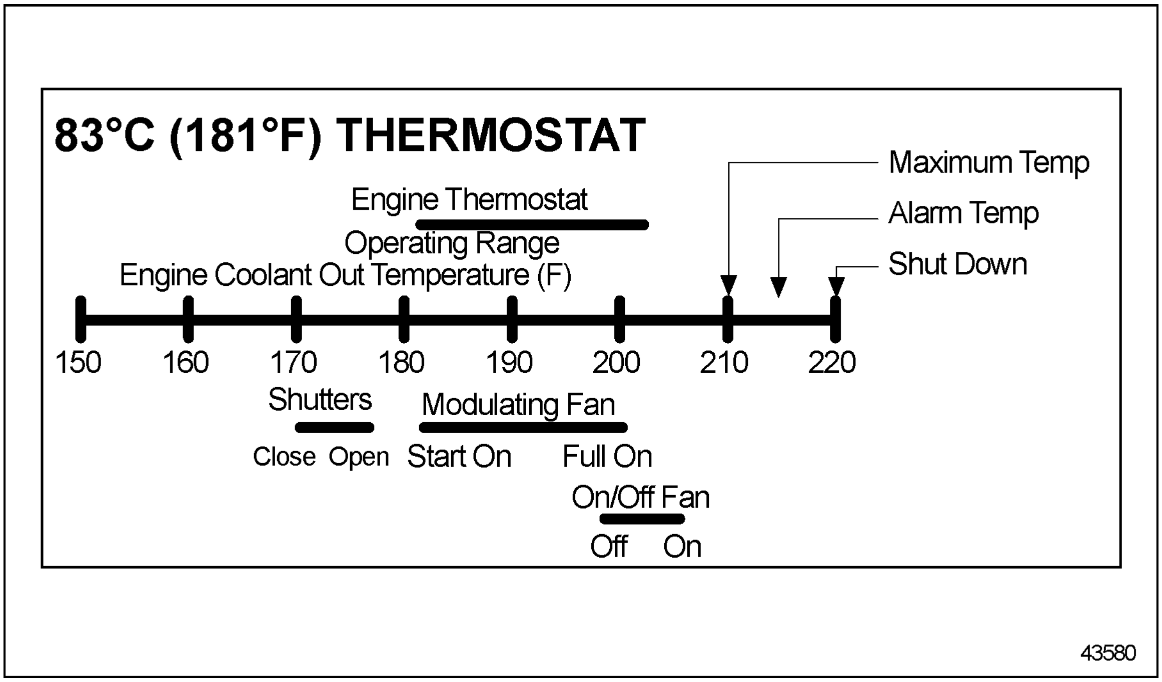


Figure 7-19 Nominal Settings For Coolant Temperature Control Devices — 190°

Coolant Recovery System

Use the coolant recovery tank system (see Figure 7-20, and Figure 7-21) only when adequate expansion, drawdown, and deaeration volume cannot be designed into the radiator or remote top tanks.

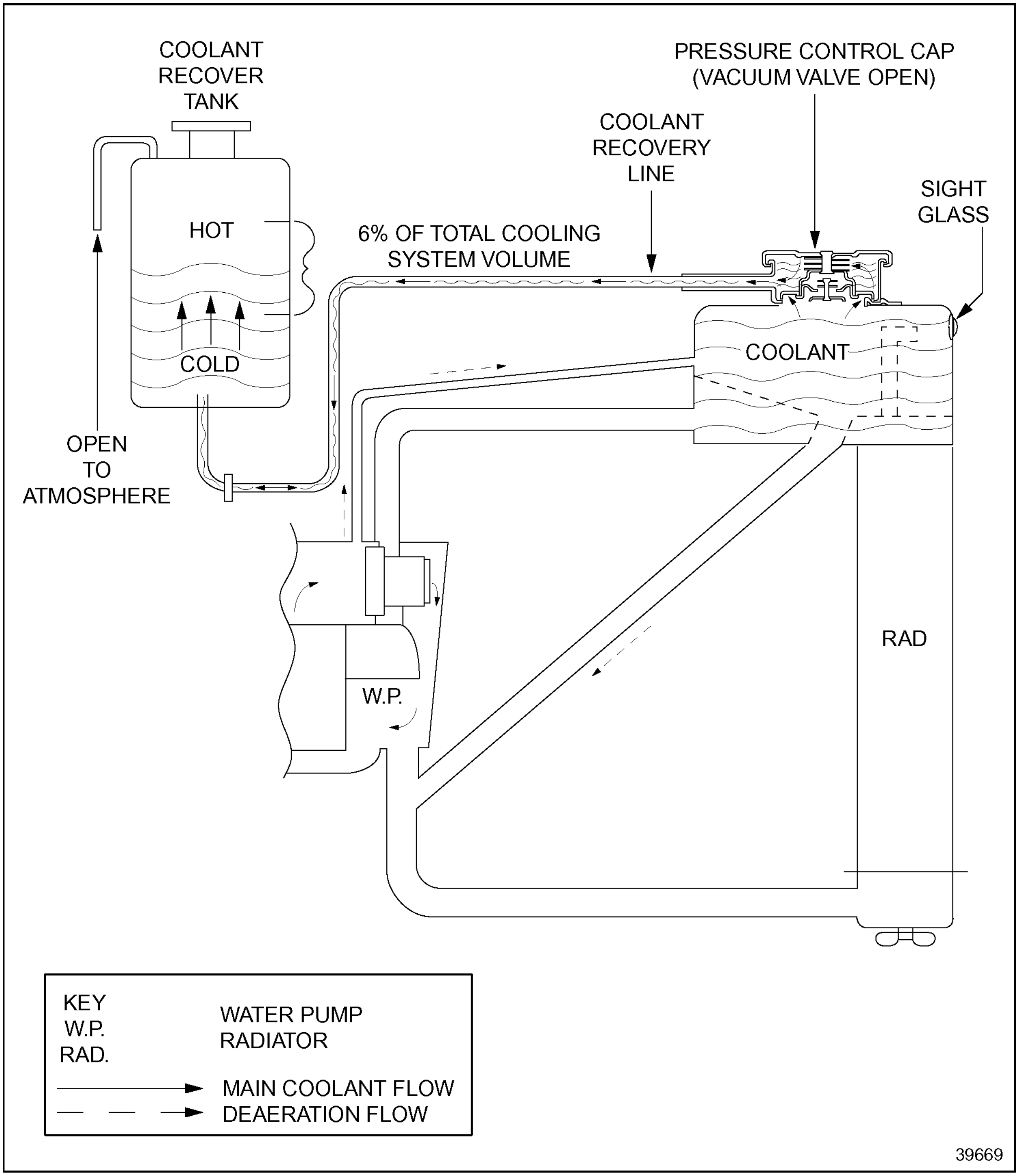


Figure 7-20 Cooling System Design (Warm-up -- Closed Thermostat)

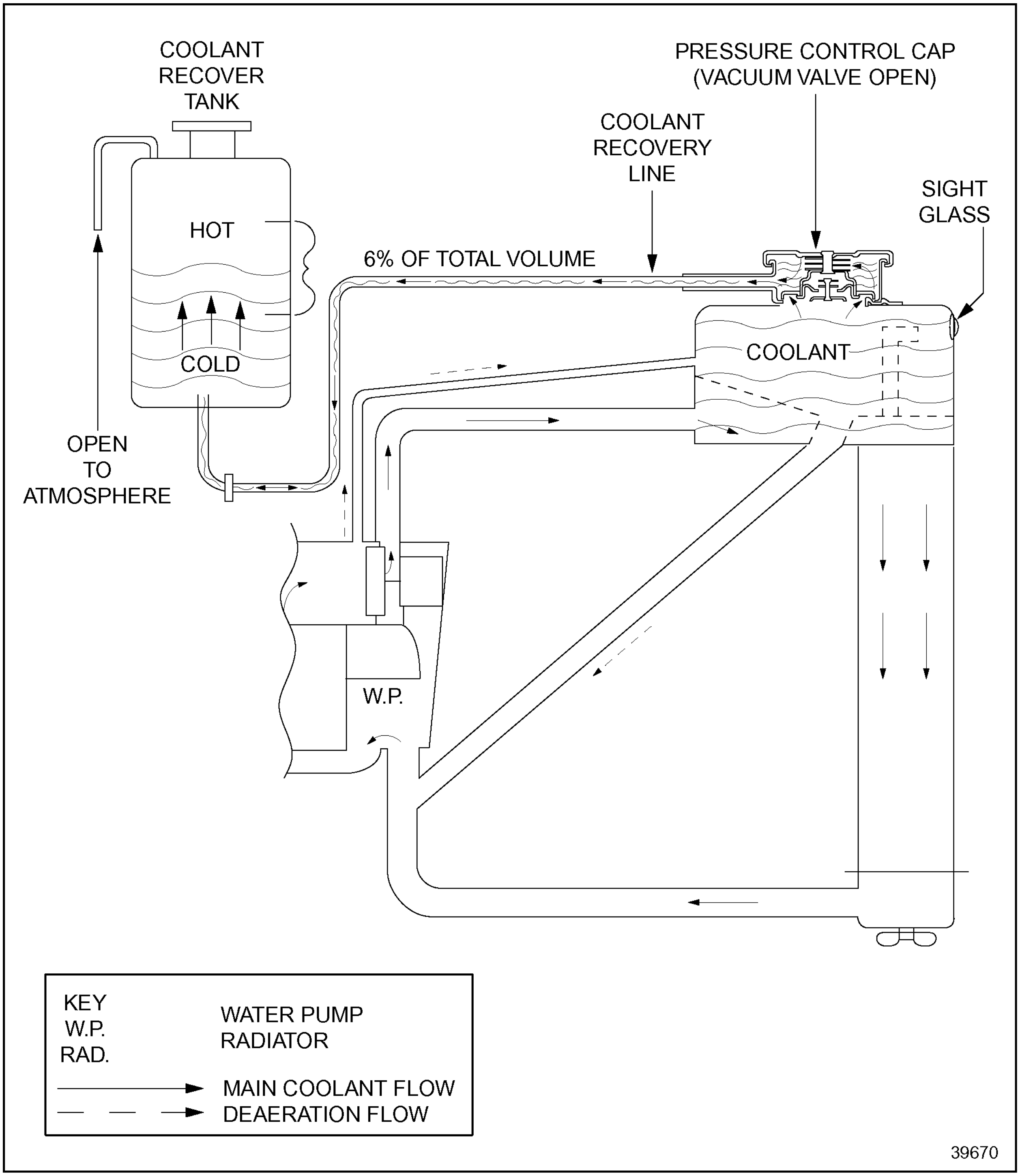


Figure 7-21 Cooling System Design (Stabilized Temperature -- Open Thermostat)

The total coolant volume increases as the engine coolant temperature rises. The pressure valve in the pressure control cap will open due to this pressure causing coolant to flow into the coolant recovery tank. See Figure 7-20 and Figure 7-21.

When the tank is open to the atmosphere, the coolant will be drawn back into the top tank through the vacuum valve in the pressure control cap when the coolant temperature decreases. The total coolant volume decreases as the engine coolant temperature falls. See Figure 7-22.

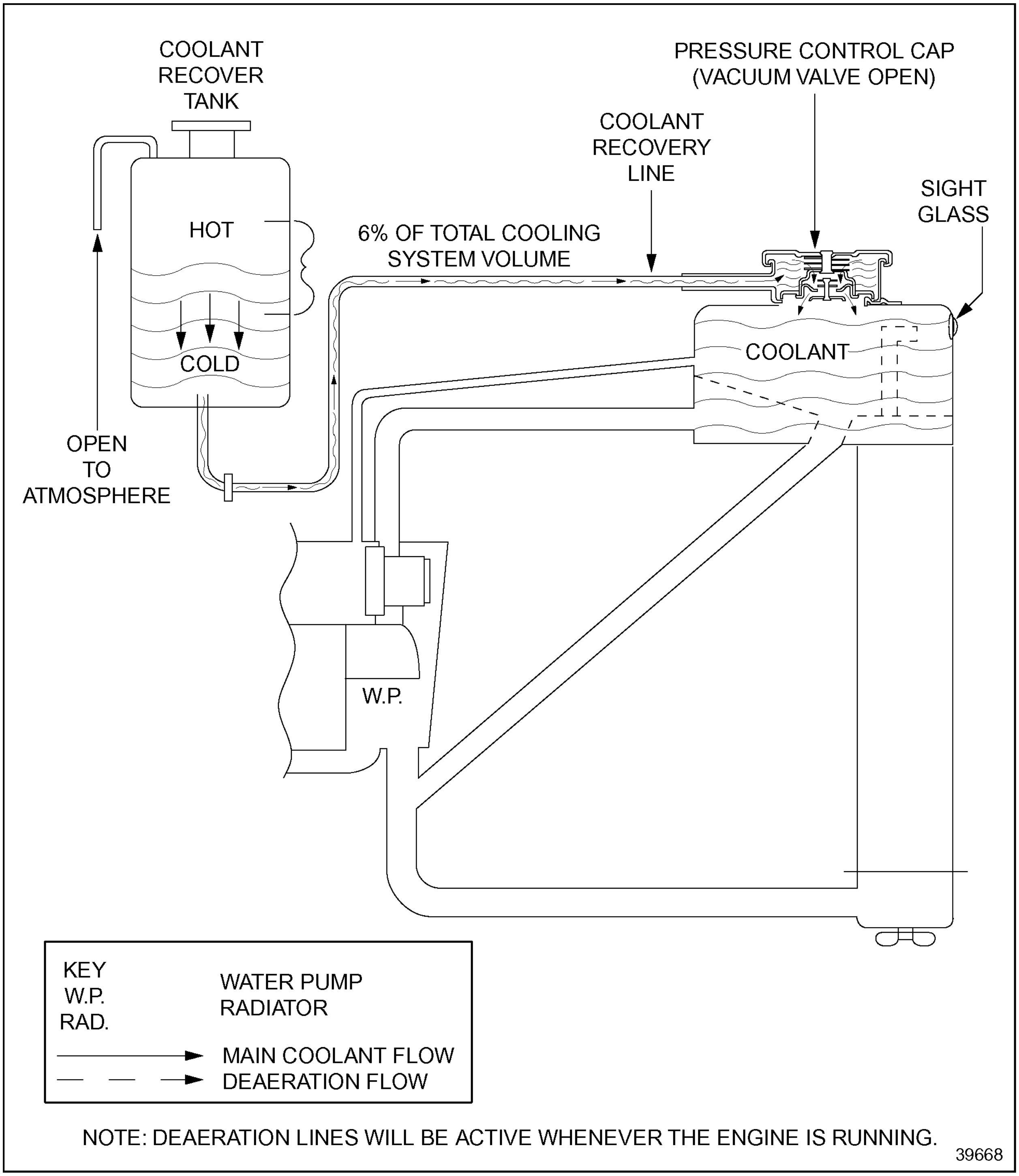


Figure 7-22 Cooling System Design (Cool-down -- Closed Thermostat)

The coolant recovery tank *must* have sufficient volume to meet the coolant expansion requirements of the entire cooling system. A minimum of 6% capacity of the total cooling system volume should exist between the hot and cold levels in the recovery tank.

Mount the coolant recovery tank as close as possible to the pressure control cap.

Locating the tank as high as possible with respect to the control cap may make leaks easier to find and may prevent air from being drawn into the system.

The air-tight line connections become more crucial when the tank is mounted low. Should a leak occur under these conditions air could be drawn into the system.

The coolant recovery line between the tank and radiator is typically 6.35 mm (.25 in.) I.D. Connect this line as close to the bottom of the tank as possible. A standpipe may be used in the tank to prevent sediment from being drawn into the cooling system.

Meet the following design criteria to achieve a properly functioning coolant recovery system:

- ☐ Use an air tight pressure cap
- ☐ Install and maintain air tight seals on either ends of the line
- ☐ Ensure that the coolant level in the tank does not go below the level where the coolant recovery line connects to the recovery tank

Do not visually check the recovery tank because it may give a false indication of the coolant level in the entire cooling system. Use a sight glass in the top tank if a visual check is necessary.

Use a pressure control cap which has a design similar to the cap in Figure 7-21 and Figure 7-22. A minimum of 15 psi (103 kPa) pressure cap is required.

Do not use a cap design in which the vacuum valve opens directly to the atmosphere.

WARNING:

HOT COOLANT

To avoid scalding from the expulsion of hot coolant, never remove the cooling system pressure cap while the engine is at operating temperature. Wear adequate protective clothing (face shield, rubber gloves, apron, and boots). Remove the cap slowly to relieve pressure.

Locate the pressurized control cap at the highest point of the top tank. See Figure 7-23. Do not design a filler neck onto the cap to ensure that air is not trapped at the top of the top tank. See Figure 7-24.

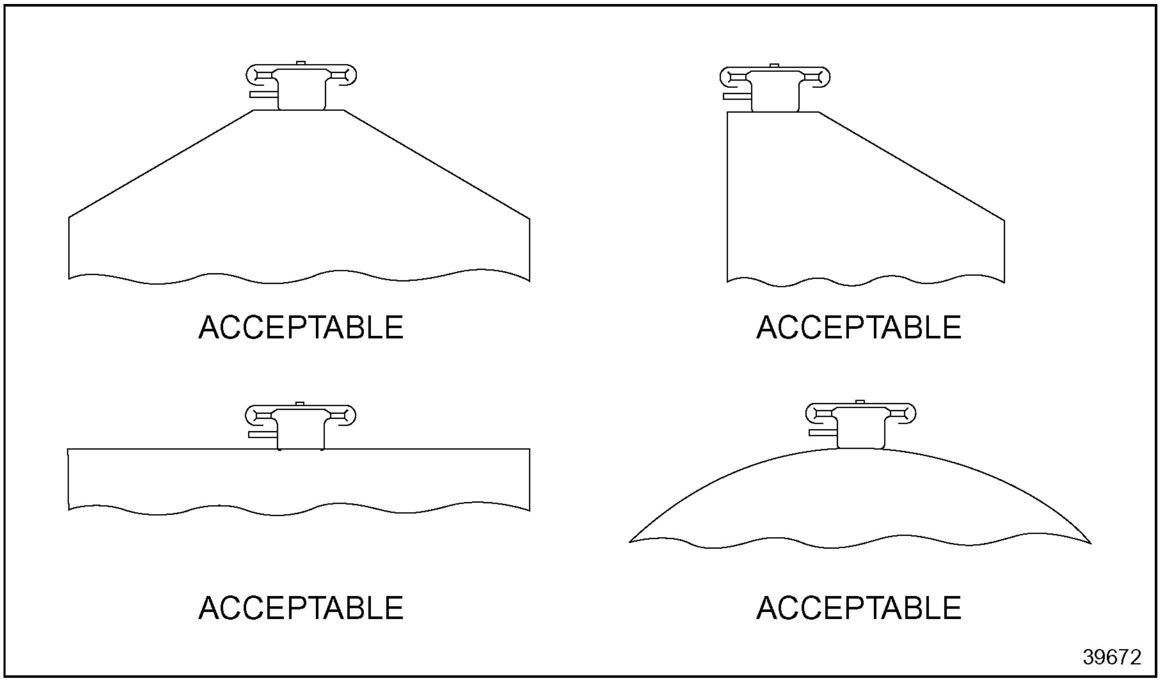


Figure 7-23 Acceptable Top Tank Design

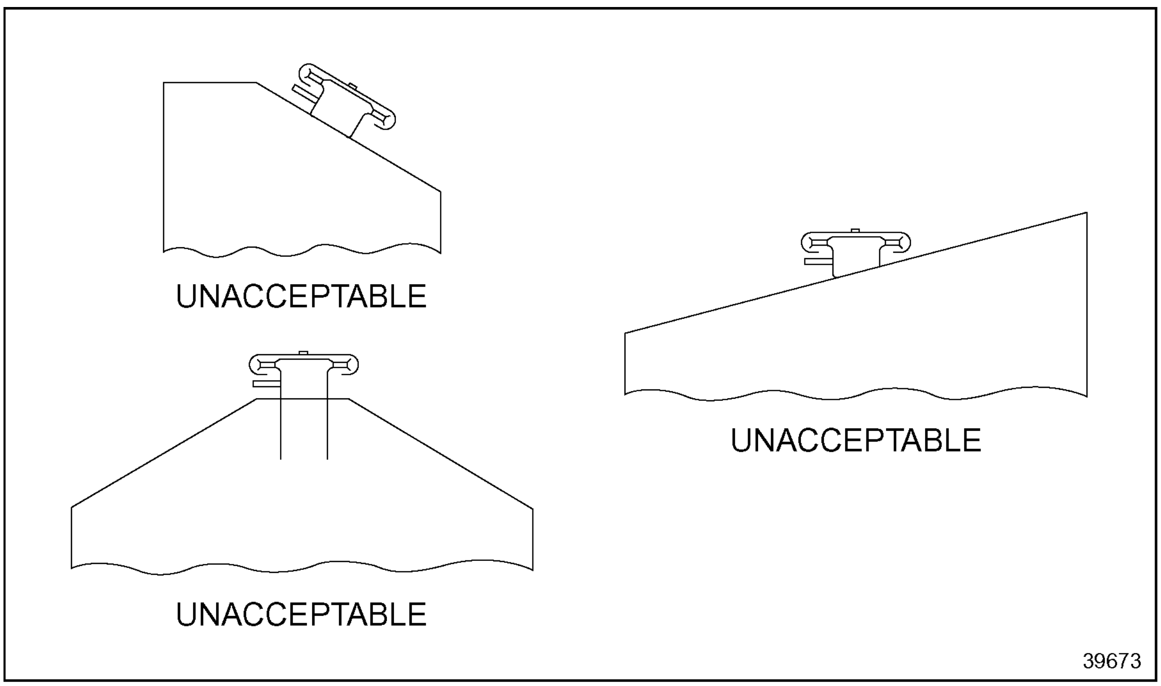


Figure 7-24 Unacceptable Top Tank Design

Connect the deaeration line as high as possible to the top tank when using a coolant recovery system.

Air handling may be poorer and the coolant in the top tank may be more agitated when a coolant recovery system is used.

Perform the necessary tests to determine whether the cooling system design provides adequate expansion, drawdown, and deaeration volume in the radiator or remote top tanks.

7.14.2 COLD WEATHER OPERATING OPTIMIZATION

Newer fuel efficient engines transfer less heat to the coolant; thus, it is important to maintain proper coolant temperatures for optimum engine and heater performance, especially during severe cold ambient operation. The following guidelines are given to maximize the available heat energy.

Engine

To maximize the available heat energy of the engine:

- ☐ Increase idle speed
- ☐ Avoid long term idle and/or light load operation (maintain minimum exhaust temperature)
- ☐ Use under hood air intake for engine (cold weather only)

Vehicle

To maximize the available heat energy of the vehicle:

- ☐ Use auxiliary heater
- ☐ On/Off fan clutch
- ☐ Auxiliary oil coolers *must not* be located in radiator outlet tank
- ☐ Seal operator's compartment interior to eliminate any direct cold outside air source
- ☐ Consider full winterizing package for maximum comfort level
  - ☐ Thermal windows
  - ☐ Insulate walls, roofs, floors, doors, etc.
  - ☐ Reduce exposed interior metal surfaces
  - ☐ Auxiliary fuel fired coolant heater
- ☐ Install shutters only as a last effort

Cooling System

To maximize the available heat energy of the cooling system:

- ☐ Use optimized Rapid Warm-up System
- ☐ Set coolant antifreeze concentration correctly

Heater Circuit

To maximize the available heat energy of the heater circuit:

- ☐ Use low restriction, high efficiency cores
- ☐ Optimize plumbing to give minimum restriction to coolant flow
- ☐ Do not hinder air side restriction air flow for good distribution of heat
- ☐ Use inside recirculated air (if window fogging is not a problem)
- ☐ Use booster water pump if required
- ☐ Do not place fuel heaters in the cab/sleeper heater circuits
- ☐ Core and air ducts should favor defrost operation and driver/passenger comfort

The recommended heater connect points are listed in the “Technical Data” section of this manual (refer to section 14).

7.14.3 COOLANT HEATERS

Information on coolant heaters can be obtained from the Detroit Diesel Application Engineering.

7.14.4 MULTI-DUTY CYCLE

Cooling systems *must* perform satisfactorily under all operating modes. Consideration *must* be given when an engine is used for prime power under several duty cycles such as cranes, drill/pumping rigs, etc. Cooling system must be sized for the maximum rated load.

7.14.5 OTHER CONSIDERATIONS

Cooling system performance *must* be reevaluated any time engine, cooling system, vehicle components, timing, etc., are changed due to potential increased heat load or reduced cooling system capacity. Conduct a reevaluation of the cooling system if load, duty cycle, or environmental operating conditions are different than originally approved.

7.15 COOLING SYSTEM DIAGNOSTICS AND TROUBLESHOOTING GUIDE

System diagnostics and troubleshooting covers:

- □ Engine overheat
- □ Cold running engine
- □ Poor cab heater performance

7.15.1 ENGINE OVERHEAT

Coolant temperatures should not exceed maximum limit of 105°C (221°F) so metal and oil temperatures can be controlled for optimum engine performance, fuel economy, and life.

Obvious overheat conditions are determined from the coolant temperature gauge, warning, or shutdown devices. Steam vapor or coolant being expelled through the pressure relief overflow tube is another indication of overheat. Reduced engine performance or engine oil having a burnt odor are other indicators.

Troubleshooting for Engine Overheat

Troubleshoot for engine overheat as follows:

1. Check for inaccurate gauge, warning, or shutdown device, insufficient coolant flow, and inadequate heat transfer capabilities during coolant side investigation.

> **WARNING:**
>
> **HOT COOLANT**
>
> **To avoid scalding from the expulsion of hot coolant, never remove the cooling system pressure cap while the engine is at operating temperature. Wear adequate protective clothing (face shield, rubber gloves, apron, and boots). Remove the cap slowly to relieve pressure.**

2. Check that the various temperature monitoring devices are calibrated.
   - [a] Sensor probes *must* be located (before thermostat) in a high temperature, well mixed coolant flow path.
   - [b] The sensor *must* be free of scale and other contamination.
3. Check for insufficient coolant flow. The following may be causes of insufficient coolant flow:
   - □ Thermostat -- Stuck, sluggish, worn, broken

- ☐ Thermostat seal -- Worn, missing, improper installation
- ☐ Water pump -- Impeller loose or damaged, drive belt loose or missing, worn pulley
- ☐ Aerated coolant -- Low coolant level, excessive agitation of deaeration tank coolant, water pump seal failure, exhaust gas leakage (cracked cylinder head or block, damaged seals or gaskets, etc.), incorrect bleed line installation
- ☐ Pressurization loss -- Defective pressure cap/relief valve or seat, debris trapped between seats, internal or external leaks anywhere in the system
- ☐ High restriction -- Radiator plugging (solder bloom), silicate dropout, dirt, debris, etc. collapsed hose(s), foreign objects in the system (shop towels, plugs, etc.)
- ☐ Core Coolant Flow Capacity - Core coolant flow capacity is often described as ‘‘free flow." This term is used to indicate gravity flow rate through the core and should equal or exceed the coolant flow rate given on the performance curve. The design of the radiator inlet and outlet tanks *must* also offer low restriction to coolant flow.
- ☐ Coolant loss -- Internal and external

4. Check for inadequate heat transfer capabilities. The following are possible causes of inadequate heat transfer capabilities:
   - ☐ Radiator selection -- Core selection inadequate for application
   - ☐ Incorrect coolant mixture -- Over/under concentration of antifreeze or inhibitors, corrosive water, incorrect antifreeze or inhibitors
   - ☐ Contamination -- Oil or other material depositing on heat transfer surfaces
5. Check for insufficient air flow. The following are possible causes of insufficient air flow:
   - ☐ High restriction -- Plugged core, damaged or bent fins, shutters not opening correctly, addition of bug screens, winterfronts, noise panels, small air in or air out openings, etc.
   - ☐ Fan/Drives -- Lose or worn belts and pulleys, improper drive engagement, fan installed backwards or damaged, insufficient fan speed (drive ratio), etc.
   - ☐ Shroud -- Damaged or missing, not completely sealed
   - ☐ Fan positioning - Excessive fan tip to shroud clearance, incorrect fan placement in shroud, insufficient fan to core distance, insufficient fan to engine distance
6. Check for inadequate heat transfer capabilities. The following are possible causes of inadequate heat transfer capabilities:
   - ☐ Incorrect fan/radiator match -- Severest operating conditions not correctly identified.
   - ☐ Core degradation -- Tube/fin separation, oil film, debris, contamination, etc.
   - ☐ Air recirculation -- Radiator baffles damaged or missing, fan shroud and seal damaged or missing, wind conditions, etc.
7. Also check the following:
   - ☐ Increased heat rejection or engine horsepower upgrade
   - ☐ Engine, installation, or cooling system modified

- □ Increased engine loading, change in duty cycle
- □ Running at more adverse conditions than original system design permits, higher altitude or temperature

7.15.2 COLD RUNNING ENGINE (OVERCOOLING)

Extended low coolant temperature operation can adversely affect engine performance, fuel economy, and engine life. Overcooling most frequently occurs at extreme low ambient temperatures during long idling or low speed and light load operation.

Consider the following for cold running engines:

- □ Inaccurate gauge, out of calibration, lack of markings to determine actual temperature, sensor probe in poor location or not fully submerged in a high coolant flow area.
- □ Closed thermostat core coolant flow -- Top tank baffle not completely sealed, standpipe too short or missing, improper sizing of dearation line or standpipe(s) so flow to the top tank exceeds fill line capacity, overfilled cooling system, reverse core flow, thermostat coolant leakage. See test procedures for determining these deficiencies.
- □ Defective thermostat -- Stuck open, worn, misaligned, excessive leakage, improper calibration, incorrect start to open setting.
- □ Insufficient engine heat rejection -- Excessive low speed and load or idle operation, idle setting too low, over concentration of antifreeze and/or inhibitors, cab and fuel heaters, charge air fan removing heat faster than engine can supply.
- □ Fixed fans -- Moves air through core when not required.
- □ Shutters/Controls -- Not fully closed, opening temperature too low.

7.15.3 POOR CAB HEATER PERFORMANCE

Poor cab heater performance results from cold running engines.

Inadequate heat in the operator's environment is symptomatic of poor cab heater performance.

Consider the following to solve poor cab heater performance:

- □ Engine coolant temperature below normal.
- □ Coolant-side causes
- □ Air-side causes
- □ Thermostat leakage test
- □ Radiator top tank baffle leakage test
- □ Top tank imbalance test

1. Check coolant-side cause, low flow, by investigating the following:
    - □ Supply and return lines not connected to proper locations on the engine

- ☐ Heater system too restrictive - core, plumbing size, bends, shutoff valves, length of circuitry, etc.
- ☐ Parallel circuitry with multiple cores
- ☐ Boost pump required, defective, not turned on
- ☐ Air in heater circuit and coolant
- ☐ Solder bloom, silicate dropout, dirt, debris, etc.
- ☐ Shutoff valves not fully opened
- ☐ Fuel heater in circuit

2. Check coolant-side cause, reduced heat transfer capabilities, by investigating the following:

- ☐ Improper concentration or grade of antifreeze and inhibitors
- ☐ Undersized heater core(s)
- ☐ Heater plumbing not insulated
- ☐ Low efficiency cores
- ☐ Contamination of core tube surfaces, deposits, etc.
- ☐ Fuel heaters plumbed in cab heater circuit

3. Check the following air-side causes:

- ☐ Low efficiency cores
- ☐ Improper air flow
- ☐ Excess outside air through core
- ☐ Core fins separated from tubes
- ☐ Core surface contamination, dirt, debris, oil film, etc.
- ☐ Leaking air ducts
- ☐ Malfunctioning air flow control valves
- ☐ Undersized heater cores
- ☐ Poor distribution system

Cab interior should be completely sealed to eliminate direct cold air source, in order to conserve available heat energy. Heat loss to outside can be minimized by using thermo windows, reducing exposed metal surfaces, increasing insulation usage, etc.

7.16 MAINTENANCE

The design of the installation must take into account the engine's need for periodic maintenance and allow access to these service points.

A schedule of periodic maintenance will provide for long term efficiency of the cooling system and extended engine life. Daily visual inspections should be made of the coolant level and the overall condition of the system components. This should include looking for obvious leaks and abnormal distress of the following components:

- ☐ Radiator Core and CAC - Contaminated with oil, dirt and debris; fins/tubes damaged
- ☐ Fill Cap/Neck - Dirty or damaged seats; gasket/seal deteriorated
- ☐ Fan - Blades bent, damaged or missing
- ☐ Belts/Pulleys - Loose belts; frayed; worn; missing
- ☐ Fan Shroud - Loose; broken; missing
- ☐ Hoses/Plumbing - Frayed; damaged; ballooning; collapsing; leaking
- ☐ Coolant - Contaminated, concentration
- ☐ Recirculation Baffles - Missing; not sealing

If any of the above conditions are observed, corrective action should be taken immediately. Any time a coolant gauge, warning, shutdown, or low level device is malfunctioning, it should be fixed immediately.

A proper glycol (ethylene, propylene, or extended life organic acid), water, Supplemental Coolant Additive (SCA) mixture meeting DDC requirements is required for year-round usage.

the coolant provides freeze and boil protection and reduces corrosion, sludge formation, and cavitation erosion. antifreeze concentration should not exceed 67% for ethylene glycol (50% for propylene glycol). Detroit Diesel requires SCAs be added to all cooling systems at initial fill and be maintained at the proper concentration. Follow SCA manufacturers' recommendations.

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