APPLICATION AND INSTALLATION GUIDE

COOLING SYSTEMS

CAT®

Contents

Foreword

This section of the Application and Installation Guide generally describes Cooling Systems for Cat® engines listed on the cover of this section. Additional engine systems, components and dynamics are addressed in other sections of this Application and Installation Guide.

Engine-specific information and data is available from a variety of sources. Refer to the Introduction section of this guide for additional references.

Systems and components described in this guide may not be available or applicable for every engine.

Cooling Systems

All internal combustion engines produce heat as a byproduct of combustion and friction. This heat can reach temperatures up to 1925°C (3500°F) and can have catastrophic affects on engine components. Pistons, valves and cylinder heads must be cooled to reduce the risk of detonation. Cylinder temperatures need to be controlled so lubricating oil can maintain a protective film on the cylinder surfaces and the lubricating oil should be cooled to ensure its integrity.

In addition to overheating, overcooling can have negative effects on the engine. Overcooling can reduce engine performance and shorten the engine's service life.

Cooling systems are used to manage engine heat. Cooling systems must be properly designed, operated and maintained for proper engine operation and service life. This guide describes and explains methods of managing engine heat for various engine applications.

SECTION CONTENTS

Cooling System Basics

Typical Cooling System

Figure 1 shows the basic components of a common engine cooling system. The basic components are the coolant, water pump, engine oil cooler, coolant temperature regulators, radiator fan and the radiator. In many instances, heat exchangers and other similar devices are used instead of radiators. For this discussion, "radiator" will be used to describe all such devices.

Typical Cooling System

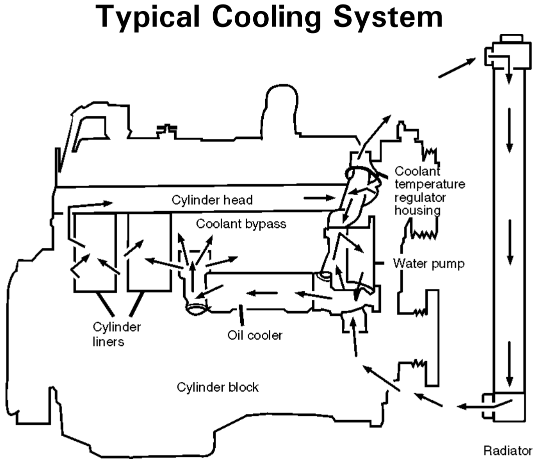


Figure 1

In operation, the water pump pushes coolant through the engine oil cooler and into the cylinder block. The coolant then flows through the cylinder block and into the cylinder head(s) where it flows to the hot areas of the cylinder head(s). Additional components that will transfer heat to the coolant are aftercoolers, water-cooled exhaust manifolds, water-cooled turbochargers, water-cooled shields and oil coolers. After flowing through the cylinder head(s), the coolant goes into the coolant temperature regulator housing.

When the engine is cold, the temperature regulators bypass the radiator and direct the coolant back to the water pump. As the temperature of the bypass coolant flow becomes warmer, the temperature regulators begin to open and permit some of the coolant to flow to the radiator.

The regulator opens to maintain the correct engine temperature. The amount that the regulator opens and the percent of coolant flow to the radiator depends on the load on the engine, and the outside air temperature.

The fan pushes or pulls air through the radiator and around the tubes that extend from the top to the bottom of the radiator. When the hot coolant goes through the tubes in the radiator, the flow of air around the tubes lowers the temperature of the coolant. The coolant then flows back through the water pump.

Coolant expands as it is heated. Expansion tanks are used on some applications to contain the increased volume.

Heat Transfer

There are three common components used to transfer heat from the engine.

- Jacket Water
- Oil Cooler
- Aftercooler

The components are used in various combinations and have specific design criteria that must be met to ensure proper cooling of the engine.

Water Jacket

The water jacket in an internal combustion engine is a series of cavities and passages that carry coolant throughout the engine. Heat is transferred from the engine to the coolant and carried away to a radiator or similar device where the heat can be dissipated.

The jacket water, or coolant, also flows through the cylinder head to remove more heat. In gas engines, the combustion chamber and spark plug bosses are cooled by jacket water flowing through the cylinder head. Carefully sized passages in the cylinder head aid in regulating water flow and help to maintain uniform temperature throughout the block.

Water jacket coolant is often circulated through aftercoolers and oil coolers to collect heat and carry it away from the engine.

Aftercooler

Intake air temperature increases when compressed by the turbocharger. On a diesel engine, an aftercooler is used to reduce the air temperature for better combustion. In a gas engine, the reduced air temperature increases power density and detonation margin.

Coolant is circulated through the aftercooler to absorb the heat from the compressed intake air.

Aftercooler fouling is a threat to optimum aftercooler performance. If dirt or oil accumulates in the aftercooler core, heat transfer to the coolant is reduced and the air temperature will rise. This can raise piston temperature and lower engine horsepower.

Oil Cooler

The lubrication system of a modern engine does more than reduce friction between moving parts; it is also used to cool internal engine parts, which cannot be directly cooled by the water jacket coolant. Heat is transferred to the lubricating oil as it passes around engine components such as bearings and pistons. Oil cooler is used to dissipate heat from the oil to maintain optimum temperatures for proper lubrication.

Coolant is circulated through the oil cooler to absorb the heat from the lubricating oil.

Note: If excessive oil temperatures are permitted during operation, oil life will be shortened and engine damage can occur.

Depending on the basic system configuration, the oil cooler may be part of the jacket water circuit or the aftercooler circuit.

Basic System Configurations

Cat engines offer different cooling system configurations and options to fulfill the specific requirements of any application.

Three basic cooling system configurations are used.

- Separate Circuit
- Combined Circuit (also known as single circuit)
- Air-to-Air Aftercooling

All three of the configurations are designed to supply regulated nominal jacket water temperature to the block and regulated oil to the bearings.

Separate Circuit Configuration

The separate circuit cooling system configuration, also called the standard cooling system for gas engines, cools the engine jacket on one circuit and the aftercooler on another circuit. The oil cooler is part of the aftercooler circuit on 3600/G3600 engines, and part of the jacket water circuit on 3500/G3500 and smaller engines.

The separate circuit system is used on all gas engines and is recommended for high ambient temperature diesel engine installations to reduce the external cooling package size.

Note: All pressure and temperature values in this publication are gauge values unless otherwise specified.

Advantages of the separate circuit include:

- The total radiator surface area may be 20% less at 45°C (110°F) ambient and up to 30% less at higher ambient temperatures, when compared to a combined circuit.
- Nominal water temperature to the aftercooler is maintained while rejecting heat from the cylinder block and heads at higher temperatures.
- The total external flow is approximately twice the external flow of the single circuit system. Half of the flow, the high temperature circuit, must be cooled to nominal jacket water temperature and the other half, the low temperature circuit, must be cooled to nominal aftercooler water temperature.

The jacket water circuit and the aftercooler circuit both require a minimum expansion volume to contain the increased volume. This is typically provided by separate expansion tanks; however, some applications may allow the use of a single expansion tank for the jacket water circuit that is connected via shunt and vent lines to the aftercooler circuit. Refer to the section on Expansion Tanks for different types of expansion tanks, sizing guidelines and information about factory provided expansion tanks. Vent lines are required on both circuits to return to the expansion tank and eliminate air traps in the circuit. Refer to the section on Venting and Filling for recommended vent line sizes and venting locations. Refer to **Figure 2** and **Figure 3** for typical separate circuit schematics.

Separate Circuit Cooling System - Inlet Controlled (with full flow expansion tanks)

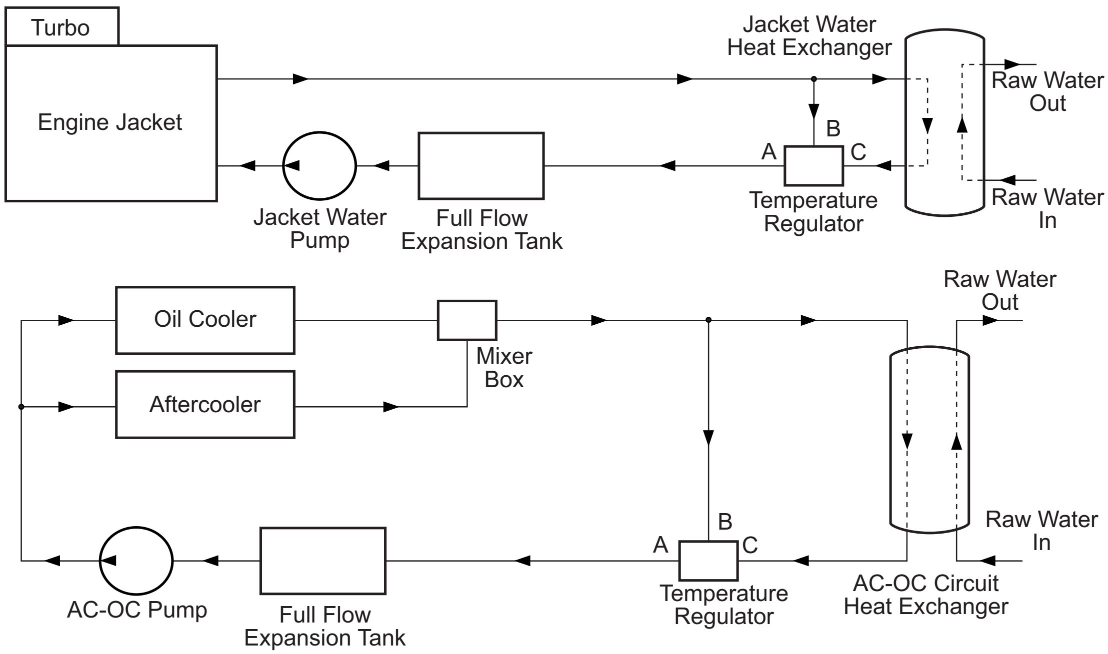


Figure 2

Separate Circuit Cooling System - Outlet Controlled (with full flow expansion tanks)

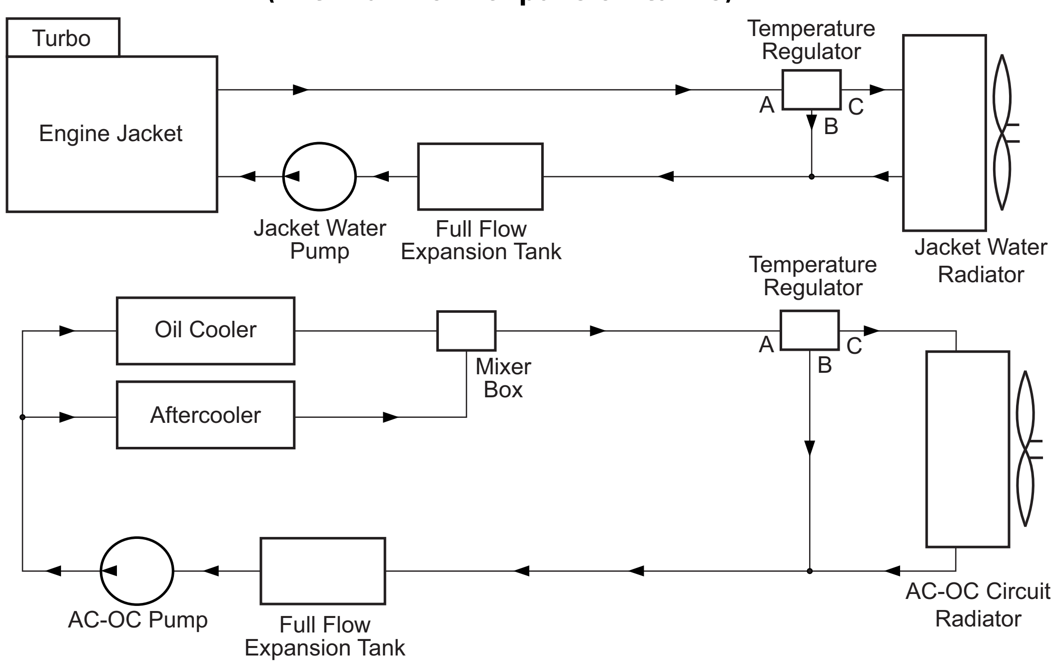


Figure 3

Combined Circuit Configuration

The combined circuit configuration is often referred to as the single circuit — two pump system. It is typically used for diesel engine applications where a single radiator or heat exchanger is applied.

The aftercooler circuit is externally regulated to nominal temperature (fluid inlet temperature control). The system uses the aftercooler outlet water to cool a portion of the high temperature outlet water to maintain nominal jacket water temperature to the cylinder block. The block is a closed circuit contained on the engine; therefore, only the water returning to the aftercooler pump requires a cooling source. This results in a relatively simple coolant piping installation. Refer to **Figure 4** and **Figure 5** for typical combined circuit schematics.

Combined Circuit Cooling System - Inlet Controlled (with full flow expansion tanks)

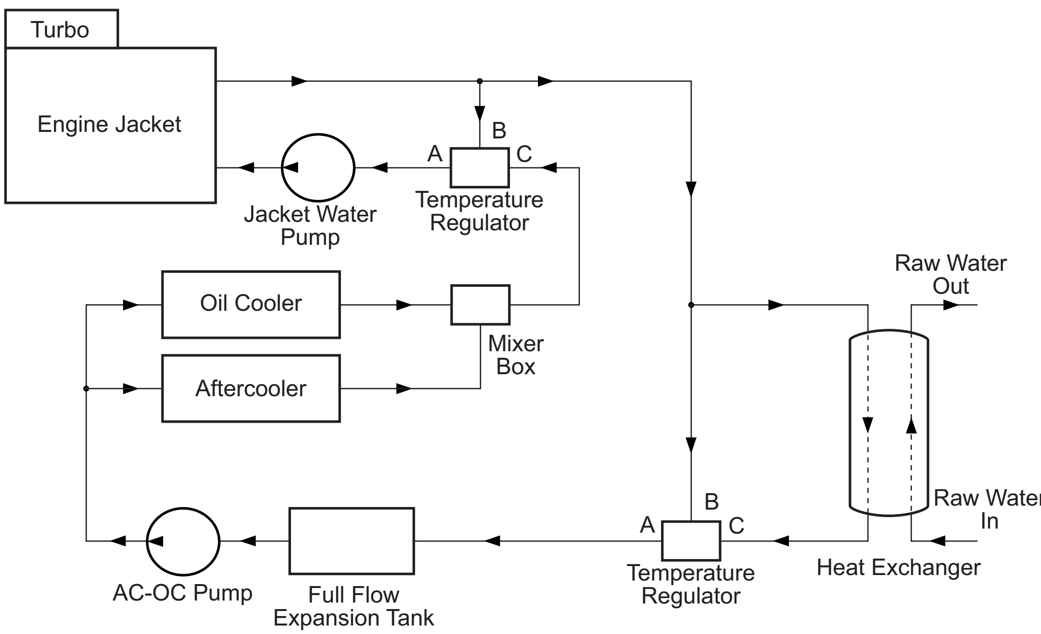


Figure 4

Combined Circuit Cooling System - Outlet Controlled (with full flow expansion tanks)

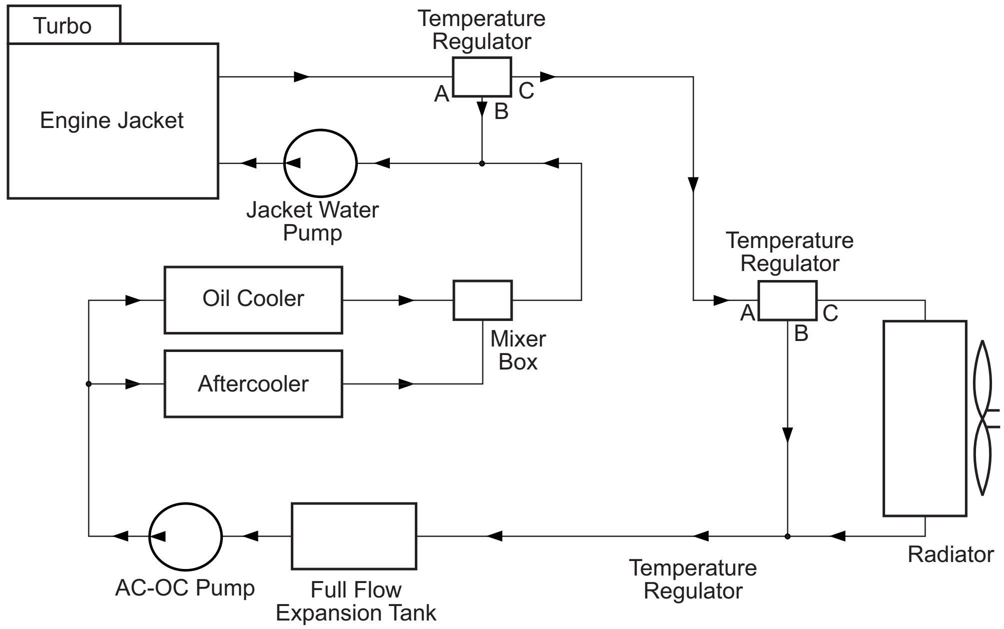


Figure 5

Air-to-Air Aftercooling

Air-to-Air Aftercooled (ATAAC) systems can be applied to some turbocharged and aftercooled engines in order to improve fuel consumption, reduce emissions to meet government regulations and in some cases permit increased horsepower. The success of this cooling system configuration is dependent on the reduction of engine intake air manifold temperature. The intake manifold temperature (IMT) affects the pressure and temperature in the cylinder and hence the combustion efficiency. For this effect, the IMT is monitored by the ECM and makes adjustments to injection to maximize performance and meet emission requirements.

This configuration uses a dual-core radiator and fan. One section of this radiator is an air-to-air heat exchanger, known as a charge air cooler (CAC). The CAC is used for the aftercooler circuit. The heated charge air from the turbocharger is ducted to the CAC, which is positioned in series or in parallel with the conventional engine radiator. The engine fan moves cooling air through the CAC and reduces the charge air temperature. The air is then ducted to the engine intake manifold. Air ducting or piping must be fabricated to direct air from the turbocharger to the CAC and return it to the engine.

The ATAAC design must be able to meet the IMT requirements of the engine. In some cases, depending on customer selectable parameters and engine model, electronic engines may derate at elevated inlet manifold temperatures. Refer to product specific documentation for further information. IMT's that are excessively cold also affects the combustion of the engine. It may be required in arctic type conditions to minimize fan speed by utilizing a variable speed fan or to allow bypass of the charged air cooler to prevent overcooling of the charged air. A thermostat control should be used when the flow is diverted so that the flow can be diverted back to the cooler when the charge air needs cooling. Normally the thermostat setting is around 30°C (90°F). As is the case with the SCAC systems, the ATAAC system may require the combustion air to be heated in extreme artic conditions. Most diesel engines need to have IMT of +10°C (50°F) before they will start easily. This varies greatly depending on engine compression ratio and design. Low load operation in cold ambient temperatures will cause engine slobbering on diesel engines and incomplete combustion if the IMT is less than +10°C (50°F). For additional information, see Form SEBU5338-01 Cold Weather Operation and Extreme Cold Weather Considerations section in this guide.

Another parameter that needs to be considered to properly apply an ATAAC is the pressure drop between the turbo and the manifold. This maximum drop includes not only the ATAAC core, but also the piping associated with it. The maximum pressure drop for a given engine is available in TMI.

For ATAAC engines with air shutoffs and large charge air coolers, it is possible that if the air shutoffs are active while running near full load (emergency shutdown) that the charged air in the system can cause the turbochargers to turn in reverse while the engine is not running and could harm the turbo bearings. In these types of applications it is recommended to have oil accumulators on the turbochargers to provide oil to the bearings in these conditions.

Design of the aftercooler core and related piping are critical to prevent corrosion of the core, water entry into the engine and excessive pressure drop of the intake air across the aftercooler circuit. A schematic for a typical ATAAC system is shown in **Figure 6**.

For engine only sales in which the customer will design/build his own ATAAC system for use with the Cat engine:

The customer designed ATAAC system should be designed to (1) accept the particular engines boost level and (2) the resulting forces acting on the customer designed piping system due to included bends or pipe size decreases. The forces acting on the ATAAC system due to the engines rated boost levels can be extreme. If the customer designed piping is not properly restrained and supported, movement relative to the engine could occur causing a displacement of the hose connecting the engine to the customer ATAAC piping. No customer designed piping or portion of the customer designed ATAAC system can be supported by the engine, engine piping, or engine brackets. (Refer to LEXH6521)

On G3400 low emission engines, a temperature control valve is required to maintain a constant air temperature of 43°C (110°F) to the engine. The control valve modulates to bypass air around the aftercooler core. Some of the air flows directly from the turbocharger into the carburetor.

On engines without a postlube system, both diesel and gas, a gas (CO_2)-over-oil accumulator is available and recommended to provide oil pressure to the turbocharger bearings after engine shutdown. This is required because the pressurized air trapped in the aftercooler after shutdown will flow out through the turbocharger and cause it to spin. Since the engine is shutdown, there is no engine supplied oil pressure to the turbocharger bearings. The accumulator provides a reserve of pressurized oil directed to the turbocharger for lubrication.

ATAAC Critical Design Criteria

The piping and heat exchanger core must be sized so the total pressure drop from the compressor outlet to the inlet manifold meets TMI specs. (For Petroleum products refer to TMI systems data. (Refer to LEXH6521)

Install 1/4 in pipe-threaded test fittings in the piping at the compressor outlets and carburetor inlet, so both the pressure and temperature at these points can be monitored. Measurements at these points are required to determine if the installation meets the design requirements.

Typical Air-to-Air Aftercooling System for Gas Engine

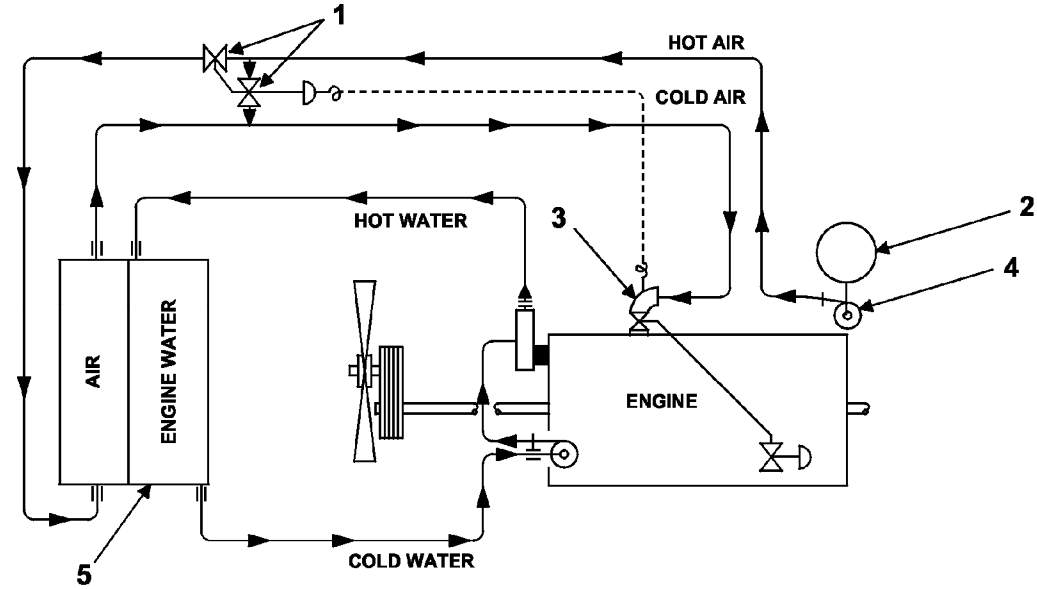


Figure 6

1. Actuator with Valve Positioner
2. Air Cleaner
3. Carburetor
4. Turbocharger
5. Cooling Unit

Because large amounts of water can be condensed from the air, the aftercooler core must be made from a corrosion resistant material such as brass (not to be used with gas containing H_2S), aluminum, or stainless steel. The piping to and from the aftercooler core must also be a corrosion resistant material, possibly aluminized steel or aluminum.

Provisions to remove the condensed water from the aftercooler core and piping must be included in the design. With humid air and ambient temperatures above freezing, a significant amount of water will be condensed in the aftercooler core. This water can be easily drained if the intake air enters the bottom of the core on one side and exits high on the opposite side. A valve to automatically drain the condensed water should be plumbed into the bottom side of the core, opposite the entrance of the intake air. The drain valve should not be allowed to freeze in cold temperatures.

Install a condensate trap in the intake piping close to the engine intake manifold. Condensate traps are designed to quickly change airflow direction, usually by a minimum of 180°, and throw the heavier water droplets onto a wall of the trap. The collected water then drains through a float valve. The condensate trap must be sized and designed so that its pressure drop is not excessive; the total system resistance from the turbocharger outlet to the inlet manifold cannot be more than 38 mm Hg (1.5 in Hg).

Caution: After fabrication, the piping and cooler core must be cleaned thoroughly of weld slag, debris or anything left in the piping that could break loose, pass into the engine and cause serious engine damage.

Caution: The ATAAC engine configuration cannot be used with low gas pressure arrangements. This combination creates a rather large volume of combustible air and gas mixture that flows through the aftercooler core. If this mixture is ignited, damage may result to the aftercooler core.

Temperature Control

The function of the temperature regulator is to control minimum operating temperatures of the engine cooling system. All cooling systems must have a method of maintaining minimum operating temperature. If minimum-operating temperature is not maintained, severe maintenance problems may result.

Factory supplied temperature regulators are provided with most applications for Cat engines. The regulators may be assembled with the factory packaged cooling system or shipped loose to be connected with the customer's cooling system.

The factory supplied temperature regulator is only capable of controlling the minimum temperature of the cooling circuit. It cannot control the maximum temperature of the cooling circuit. Maximum temperature must be controlled by the correct sizing of the radiator, heat exchanger or similar device.

There are two basic methods of thermostatic control of minimum operating temperature in cooling systems; inlet controlled and outlet controlled.

Inlet Controlled Cooling Systems

Inlet controlled cooling systems provide a constant temperature to the inlet of the jacket water circuit, aftercooler, and/or oil cooler. An example is shown in **Figure 2**. This design is used to minimize overcooling when very cold or thermally large cooling sources are involved. The sensing bulb of the thermostat is placed in the inlet flow to the expansion tank. The thermostat then balances the hot water directly from the engine with cool water from a heat exchanging device such as a radiator or heat exchanger.

Outlet Controlled Cooling System

Outlet controlled cooling systems provide a constant outlet temperature from the engine by regulating the flow between the bypass and cooling circuits. This is illustrated in **Figure 3**. Usually applied with radiator-cooled systems, the sensing bulb of the thermostat is placed in the outlet flow from the engine. If the outlet temperature becomes too high, more water is allowed to flow to the cooling system. If the water is too cool, the water is directed through the bypass and is recirculated to the engine without being cooled. Unless specified otherwise, all Cat radiator cooled systems use an outlet regulated cooling system.

Selection of Inlet or Outlet Controlled Systems

There are certain applications that are better suited for either inlet controlled or outlet controlled systems. In general, inlet controlled systems work well with heat exchangers and outlet controlled systems work best with radiators. However, Combined Heat and Power (CHP) systems will be inlet controlled for both heat exchanger and radiator applications.

To understand which control method is the better choice for the system under consideration, the following items should be considered.

- A shunt line is required on inlet controlled systems that do not use a full flow expansion tank. This is to prevent the possibility of pump cavitation by providing a positive head on the suction side of the pump. Outlet controlled systems generally do not have this requirement as full head pressure is not restricted by the temperature regulator and a shunt line is not required.
- Full engine outlet pressure is present at all times on the heat exchanging device for the inlet controlled system. This can be a concern with a radiator, since the outlet pressures are in the same range as the structural capability of some solder tube radiators. Outlet controlled systems tend to isolate the cooler from the pressure during bypass operation.
- Nuisance high temperature shutdowns can be experienced with an inlet controlled system if the system flow is inadequate. This is true even if there is adequate cooling capacity in the system. The inlet controlled system provides a fixed temperature coolant to the engine independent of the amount of flow. If the flow is low, the temperature rise across the engine will be high. If the temperature rise

is higher than the maximum allowable outlet temperature, the engine monitoring system will shut the engine down. An outlet-controlled system would not have this problem since it will reduce the bypass flow and increase cooler flow. The temperature rise across the engine may be higher than desired for a short period until the system stabilizes but the engine will continue to operate.

- Thermal shock is caused when the temperature regulator tries to open and close to maintain temperature on an outlet control system. Thermal shock of the engine is a potential problem with an outlet controlled system because the coolant must pass through the engine before the temperature regulator detects the coolant temperature. If cool return temperature of coolant is possible, the inlet controlled system will prevent the thermal shock to the engine components. An outlet controlled system with a full flow expansion tank will also prevent this problem.

The deficiencies of both inlet and outlet controlled systems can be overcome with proper system design; specifically, a full flow expansion tank. Engine side system pressures are usually the highest at full bypass. System pressures are lowest when nearly equal flow is in bypass and the cooler flow. System pressures at full open flow are near maximum and should match external resistance targets. The external pressure drops of both systems are identical at full open flow condition.

"Full open flow" is the term used when the coolant has reached the full open temperature of the regulator and coolant flow is directed to the radiator or heat exchanger instead of bypassing to the engine. The engine monitoring system provides warnings and shutdown for high water temperature on cooling systems.

The selection of expansion tanks for inlet and outlet controlled systems is discussed and illustrated in the section on Expansion Tanks.

Pressure Control

System Pressure Control

The cooling system and its components must meet both maximum and minimum pressure design limits. The minimum pressure at any location in the cooling system shall not fall below the vapor pressure of the coolant to prevent boiling. However, Pressure in the system shall not fall below the pressure that would cause a non-rigid component to collapse. A minimum pressure/head is also required at the pump inlet to avoid cavitation, minimizing metal erosion and noise. Similarly, the pressure at any point in the cooling system shall not exceed the maximum pressure for the local components, I.e. a radiator.

The purpose of an engine cooling system is to maintain an appropriate coolant operating temperature for the engine over a wide range of operating and ambient conditions without failure in its lifespan. Overheating of the engine occurs when coolant boils and increases the risk of permanent engine damage. While the engine is running, heat is transferred from the engine to the coolant by means of forced convection and occasionally by means of nucleate boiling at very high heat fluxes where discrete vapor bubbles form on the wall and detach. When the local heat flux is above the critical heat flux, nucleate boiling becomes film boiling, in which a blanket of vapor over the metal surface interferes with heat transfer and causes damage on interior surfaces.

After Boil

After boil can occur after an engine hot shut-down, when coolant flow ceases, local hot spots begin boiling, and without adequate pressure control steam is created. Use of a pressure cap with an integral relief or a separate relief valve is necessary to increase the boiling point. For a standard system with jacket water outlet temperature up to 99C the relief pressure is set above atmospheric (typically 4 to 7 psi gauge), allowing the cooling system to pressurize thus raising the boiling point. This also helps mitigate pump cavitation problems which can lead to reduced flow in the cooling system. The relief valve protects components from a catastrophic failure by releasing pressure. The typical 4 to 7 psi gauge pressure cap rating is recommended for engines with maximum jacket water outlet temperature of 99°C.

For Low Energy Fuel Engine Cooling System engines operating with **landfill** gas and **High Temperature Cooling System / Solid Water System**, in which elevated jacket water outlet temperatures 110-127°C (230-260°F) are used, typically 15-21 psi gauge pressure is needed. **For Example: Low Energy Fuel Engine Cooling System engines with max operating water temperature of 110°C. From the Steam Tables: 110°C steam forms at 20.47 PSIA. 20.47 + 7 = 27.47 - 14.7 = 12.77 PSIG. Therefore, a 15 PSI cap is used. By using a 15 PSI cap: 15 PSI + 14.7 PSI = 29.7 PSI - 20.47 PSI = 9.33 PSI boiling safety margin.**

Glycol based coolant with a boiling point higher than water can also mitigate some after boil.

The selection of a pressure cap rating should not only take into account the expected max temperature of the cooling system, but also recognize the affect of altitude on boiling point. Increased pressure is needed to maintain boiling point safety margin at higher altitudes. **(See Figure 51)** Therefore, extra cap rating margin should be added to compensate for the engine installation altitude.

Cooling system component pressures such as the radiator must be limited to the maximum pressure specified by the radiator manufacturer. If internal pressures exceed the specified limit, the oval tubes can balloon causing distortion of the fins, and reduced heat transfer performance. Pressures inside a component can be decreased by increasing hydraulic resistance upstream of the component, or by decreasing hydraulic resistance downstream of the component, or by decreasing pump output pressure. Therefore mounting the thermostat upstream of the radiator (outlet controlled) can reduce pressures inside the radiator, because the thermostat is often the most significant single source of resistance in the system.

Expansion

As mentioned in the **Temperature Control** section, the expansion tank can be utilized to mitigate various impacts from different cooling system selection, such as outlet vs. inlet temperature control, pump cavitation avoidance, and coolant pressurization, aeration, filling and after boil relief. External mechanical only vent valves that must be manually opened are not acceptable for the continuous venting requirement. Extra expansion volume may be required for cooling systems with higher than 99 degree C operating temperatures to provide larger after-boil relief margin. See the sections on **Expansion Tanks and Venting** for details.

Gas Engine Cooling System Configurations

Standard Cooling System

G3600

The standard G3600 cooling system utilizes the separate circuit cooling system configuration, cooling the engine jacket on one circuit and aftercooler and oil cooler on the other. The aftercooler and oil cooler are connected in parallel. This system is available with the option of an inlet controlled system or outlet controlled system.

G3500

All Cat G3500 Engines come standard with the oil cooler and jacket water combined. If the engine is turbocharged, it utilizes a separate circuit aftercooler (SCAC) pump and thermostat to maintain the incoming water at the required minimum temperature.

G3500B, G3500C, and G3500E series engines utilize a two-stage aftercooler in order to improve engine performance and reduce emissions.

Inlet controlled systems must be maintained within ±4°C (±9°F) of rated SCAC temperature within any given 5 minute time span. It is important that temperature changes do not occur more quickly than approximately 1°C per second. Fluctuations in the SCAC inlet water temperature will adversely affect engine performance and emissions.

G3300 & G3400

All Cat G3300 & G3400 engines are equipped with the oil cooler and jacket water connected in series. If the engine is aftercooled, it is equipped with a SCAC and pump; however, the thermostat must be supplied by the customer.

Combined Heat and Power Cooling System (CHP)

G3600

In applications where the heat energy from various engine components is used to provide hot water for domestic and industrial end users, the aftercooler, oil cooler and engine jacket are all cooled with the same water source. Typically, the water in these applications is from the local utility. This water is known as district water and is untreated. The engine block should be cooled by treated water only, so for these CHP applications, the jacket water circuit is designed as a closed circuit to control the quality of the coolant used in the engine jacket.

The jacket water circuit is inlet controlled with factory mounted temperature regulators, an engine mounted pump, expansion tank and heat exchanger. The district water recovers the jacket water heat load from the heat exchanger. The external system relies on district water pressure to flow water through the circuit.

The aftercooler and oil cooler can tolerate higher amounts of contaminants than the jacket water circuit, permitting district water to be used to cool them directly.

The aftercooler/oil cooler circuit requires a customer provided booster pump and does not require a temperature regulator. The automatic derating system on the engine starts to derate the engine when the aftercooler water inlet temperature exceeds the maximum temperature limit.

This type of open system requires that permanent strainers must be installed to prevent debris from clogging water passages in the aftercooler an oil cooler circuits.

For additional design guidelines to be followed for the CHP cooling system, refer to the section on Design Criteria for Standard Temperature Systems in the section on Heat Recovery.

G3500

The ability to produce steam or high temperature water is a necessity for some co-generation installations. See the Heat Recovery Section for more discussion. Attachment groups allow the G3500 engines to perform either task. With these attachments, the engines have a higher maximum outlet temperature for the jacket water. A customer supplied water pump maintains the appropriate water flow. The water leaving the engine can be flashed to steam in an external boiler or used in the liquid phase. Heat recovery from the exhaust can be combined with jacket water for greater heat recovery.

With high temperature cooling, the oil cooler is separate from the jacket water circuit. The aftercooler circuit and the oil cooler circuit can be ordered either combined or separate. In the combined system (2-circuit), the auxiliary pump circulates water in series through the aftercooler and the oil cooler. This system is most often used when the oil cooler heat cannot be effectively recovered. If the oil cooler heat is recoverable, separate aftercooler and oil cooler circuits (3-circuit) are available.

With a 3-circuit system, an auxiliary pump supplies the aftercooler circuit while a new pump supplies the oil cooler. This new pump is mounted in the location normally used by the jacket water pump. In both cases, the minimum oil temperature is controlled by a thermostat in contact with the oil.

There are no engine mounted jacket water thermostats. They are to be supplied by the customer. In sizing the thermostats, jacket water pump, and heat recovery/rejection equipment for cogeneration systems, there are several considerations to keep in mind.

- The jacket water outlet temperature must be maintained within preset limits.
- When sizing the pump, the jacket water flow should be kept between the maximum and minimum as indicated on the block resistance curves found in the technical information and performance books.

- If the system results in a combined static and dynamic head above the engine's capabilities, then a heat exchanger must be used to isolate the engine from the systems high static and dynamic heads.

Low Energy Fuel Engine Cooling System

Engines operating with **landfill** gas, digester gas or any other low energy fuel or corrosive gas need to maintain higher cooling circuit operating temperatures for long engine and oil life. This helps to prevent condensation of acids formed during combustion in the oil. On the Low Energy Fuel Engine cooling system, the jacket water circuit and the aftercooler-oil cooler circuit are both outlet controlled with factory supplied temperature regulators. Engine mounted pumps supply water for both the jacket water circuit and the aftercooler-oil cooler circuit.

The expansion volume for both jacket water and the aftercooler-oil cooler circuit should be provided and is typically provided in the radiator tanks. This cooling system must be pressurized to prevent steam formation at this high operating temperatures and appropriate expansion tank cap or radiator cap should be used to maintain system pressure. (See **Pressure Control**)

Note: The low energy fuel engine arrangements can be ordered with high temperature cooling for heat recovery by way of a Design-to Order (DTO) process.

Note: The preceding text has described standard product. If an application requires special features or a unique cooling system configuration, order through the factory by way of a Design-to Order (DTO) process.

High Temperature Cooling System

The ability to produce low pressure steam or high temperature water is a necessity for some cogeneration applications. The High Temperature Cooling System is designed to provide a higher outlet temperature on the jacket water circuit. The aftercooler/oil cooler system is similar to that of the Standard Cooling System can be inlet controlled or outlet controlled.

A customer-supplied pump and temperature regulating system is required to maintain flow through the jacket water circuit and the water leaving the engine can be flashed to steam in an external boiler or used in the liquid phase. Steam formation inside the engine jacket is not allowed at any time and the control system will shut the engine down if there is any drop in coolant pressure which leads to steam formation. The operating pressure in the system should be maintained above the minimum specification to prevent water from vaporizing to steam inside the engine which causes serious damage to engine components. (See **Pressure Control**) If the system results in a combined static and dynamic head above the engine's capabilities, then a heat exchanger must be used to isolate the engine from the system's high static and dynamic heads. In sizing the jacket water pump, heat exchangers and other cogeneration equipment, adhere to limits specified in the Technical Information Appendix. The design guidelines for the high temperature cooling system are given in the Heat Recovery section. This section also discusses several other recommended configurations for heat recovery circuits.

Two-Stage Aftercooler Cooling Systems

The two-stage aftercooler, currently offered for some gas engines, is intended to provide high temperature heat recovery for Electric Power Generation (EPG) applications and reduce overall radiator sizing for Gas Compression applications. There are two coolant stages on the two-stage aftercooler; the first stage uses high temperature coolant to cool the charge air to an intermediate temperature and the second stage cools the air down to engine rating requirements. The two-stage aftercooler can allow much higher coolant inlet pressure to both stages than the single stage aftercooler.

There are various cooling systems available for use with the two-stage aftercooler. These are offered in the Gas Engine Price List. Contact Caterpillar for more details on these cooling systems.

Compressor Oil Coolers

A compressor oil cooler (or other external heat load) should be connected into the aftercooler circuit after the water has left the aftercooler. The return line back into the circuit should be placed before the thermostat. If full flow is not needed to the compressor oil cooler, a bypass line along with any necessary valves can be installed in parallel with the compressor oil cooler. The additional heat load into to the aftercooler circuit needs to be included when sizing the radiator. The additional restriction of the compressor oil cooler and bypass must be included in the circuit's external restriction calculations. The total circuit restriction must not exceed the maximum allowable external restriction. The flow to the aftercooler is critical in gas engines. If the inlet manifold air is not properly cooled by the aftercooler, there is a higher risk of detonation. See **Figure 7** for a typical G3600 system configureation and **Figure 8** for a typical G3500 or smaller system configuration.

Special Cooling Systems

The systems discussed so far are the various production configurations offered. If an application requires special features or a unique cooling system configuration, order through Caterpillar using the Design-to-Order (DTO) process.

G3600 Separate Circuit Cooling System with External Heat Load

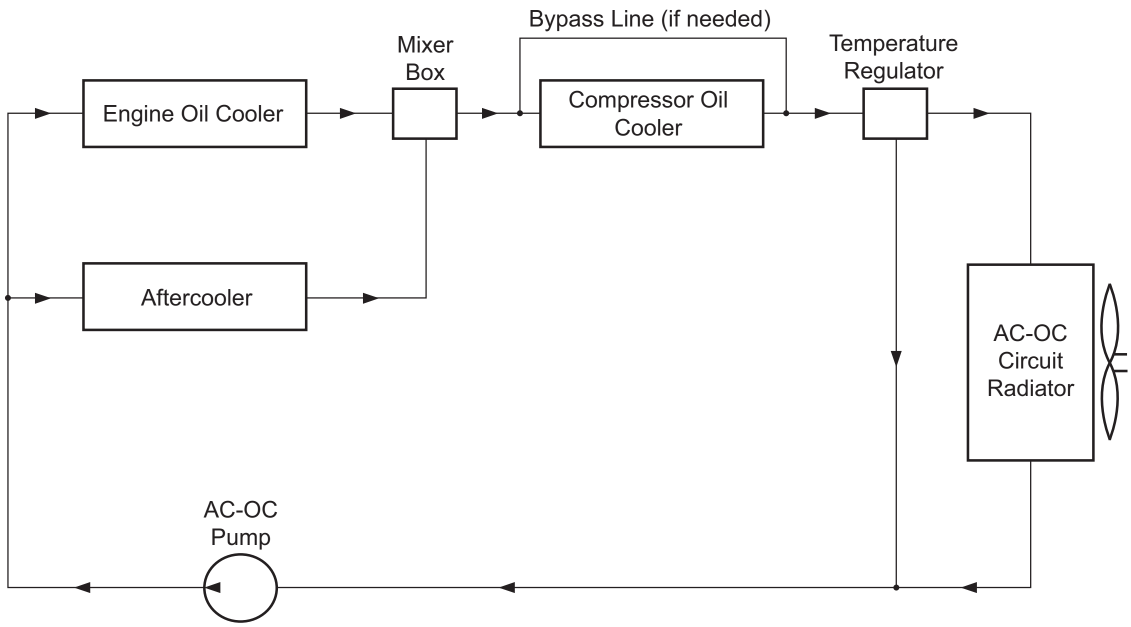


Figure 7

G3500 and Smaller Separate Circuit Cooling System with External Heat Load

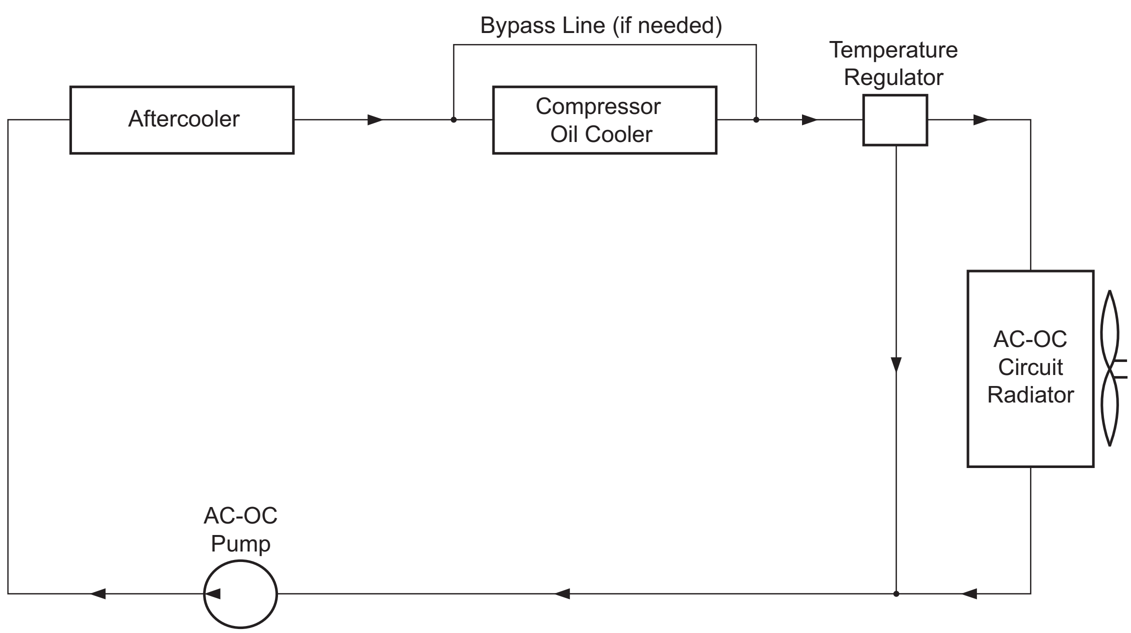


Figure 8

Cooling System Sizing

Cooling System Design Requirements

The primary purpose of the engine cooling system is to reject heat from the jacket water coolant and auxiliary circuit if equipped, at greatest engine load, highest ambient temperature, and altitude. This section will outline the proper methods to be used for cooling system sizing.

Heat Rejection

Before a cooling system can be designed, the designer must understand how much heat is being rejected through each of the cooling circuits. This information is available in the Technical Marketing Information (TMI), and on the Engine technical data sheets available for each engine model. The following guide will help the designer in interpreting and applying the heat rejection data.

The heat balance: The heat input into the engine equals the sum of the heat and work outputs. This equation is typically applied with all factors either in kW or Btu/min units.

$$Q_{Total} = W + Q_{Exh} + Q_{Sur} + Q_{JW} + Q_{OC} + Q_{AC}$$

Where:

Total Heat Input (Q_{Total})

The Total Heat Input, or total fuel consumed by the engine, is calculated by multiplying the Brake Specific Fuel Consumption (BSFC) and the Power Output bkW (bhp). The resulting formula reads as follows:

$$QTotal\ (kW) =$$

$$BSFC\ (MJ/bkW\text{–}hr) \times Power\ Output\ (bkW) \div 3.6\ (MJ/kWh)$$

$$QTotal\ (Btu/min) =$$

$$BSFC\ (BTU/(BHP - hr)) \times Power\ Output\ (bhp) \times 0.01666\ (hr/min)$$

Some technical data sheets list the Heat Input with the Heat Balance Data under the name "Fuel Input" or "LHV Input".

Work Output (W)

The work output is the shaft power created from the engine. It is the power that the engine generates from the fuel and is the total of the flywheel power and any driven equipment. Driven equipment includes alternators, equipment driven off the accessory drives and equipment on the front stub shaft such as a radiator fan. The power used internal to the engine is included in the heat load values. These include the jacket water pump, aftercooler pump, friction and gear train loads.

Work Output is expressed in bkW or bhp. To convert between units of horsepower and kW, use the factor: 1hp = 0.7457 kW. To convert bhp to Btu/min, use the factor: 1hp = 42.42 Btu/min.

Total Exhaust Heat (Q_{Exh})

The total exhaust heat is the total heat available in the exhaust when it is cooled from the stack temperature down to standard conditions of 25°C (77°F). Values shown are lower heating values and do not include the heat of vaporization. The exact exhaust temperature varies from engine to engine depending on rating and respiration.

Heat Loss to the Surroundings (Q_{Sur})

Some of the heat that is rejected from the engine's surface is lost to the surrounding environment. This is due to convective and radiation effects. Heat loss to the surroundings is commonly listed on the tech data sheet as “Heat Rejection to Atmosphere”.

Jacket Water Heat (Q_{JW})

Jacket Water Heat is the total amount of heat dissipated from the engine jacket water cooling system. Cat engines are designed to operate with a jacket water temperature (coolant) differential typically less than 11°C (20°F), measured across the engine under full load. However, this differential will vary according to engine model and type.

Oil Cooler Heat (Q_{OC})

The amount of heat transferred from the lubricating oil to the cooling system. Most of the heat in the oil comes from oil that is sprayed on the bottom side of the pistons.

The oil cooler is often cooled with the engine jacket water; therefore, the oil cooler heat rejection may not be stated separately in the engine technical data. However, for the sake of completeness, the oil cooler heat rejection may be stated separately as well as being included with the jacket water total. The heat balance equation is a quick and reliable way to verify whether or not the oil cooler heat rejection is included in the jacket water heat rejection figure.

Aftercooler Heat Rejection (Q_{AC})

The aftercooler heat rejection is the amount of heat imparted by the turbocharger on the boost air that must be rejected via the engine aftercooler. Aftercooler heat rejection is given for standard conditions of 25°C (77°F) and150 m (500 ft) altitude.

The aftercooler temperature listed on the engine technical data sheet is the water supply temperature to the aftercooler.

The air fuel ratio and inlet manifold temperature are key parameters for gas engine combustion performance. For equivalent performance, a gas engine must deliver the same amount of air at altitude as is provided at rated conditions. Therefore, at altitude, the turbocharger of a given engine configuration works harder and delivers higher temperature boost air than at standard conditions, and to cool the boost air to the same inlet manifold temperature, the aftercooler at altitude must reject more heat than at standard conditions.

An aftercooler heat rejection factor is used to quantify the additional aftercooler heat rejection at altitude. A table of factors for various combinations of altitude and ambient temperature is typically provided with a gas engine technical data sheet.

Failure to consider these factors for gas engines will result in an undersized cooling system and excessive inlet manifold temperatures which will likely cause the engine to detonate and result in engine shutdown or failure.

Diesel engines operate at high levels of excess air, so the turbocharger can provide roughly the same amount of work at altitude, deliver a lower mass airflow, and still have sufficient excess air to provide equivalent engine performance. Therefore, aftercooler heat rejection factors are not applicable to diesel engines (they are assumed to be 1.0).

More important to diesel engine ratings is the aftercooler supply temperature. Diesel emission levels are impacted by inlet manifold temperature and an emission certified rating carries with it a separate circuit aftercooler inlet temperature requirement.

Recoverable Heat

Recoverable heat in the exhaust is not a separate component of the heat balance equation, but is the customary number used in heat recovery calculations. It represents the heat available when cooling the exhaust from the stack temperature to a given reference temperature. The recoverable heat figures included in the Engine technical data sheets are based on 177°C (350°F) for English units and 120°C (250°F) for metric units. The different reference temperatures are based on the differing standards in North America and Europe.

If exhaust temperature other than 177°C (350°F) is desired, the recoverable heat can be approximated by the following formula.

$$Q = C_p \times M \times (T_1 - T_2)$$

Note: The actual formula used to calculate TMI data is more complex and requires data not available in published sources.

Where:

Q = Heat rejection in kW (Btu/min) where one kW = 56.86 btu/min.

Cp = Specific heat of exhaust gas: [kJ/kg/°C (Btu/lb/°F)]

1.163 (0.277) – TA standard gas engines

1.121 (0.267) – TA low gas emission engines

1.186 (0.280) – NA gas engines

See TMI – diesel engines

M = Exhaust mass flow, kg/min (lb/min)

T_1 = Exhaust from engine, °C (°F)

T_2 = Exhaust out of heat recovery silencer, °C (°F)

Note: Exhaust gas flow is the flow at standard pressure and exhaust stack temperature.

Heat Rejection Tolerances

In every calculation using engine data, there is a tolerance band or a deviation from the norm. Heat balance tolerances must be applied when sizing cooling system components. The tolerances recommended by Caterpillar may vary depending on the engine model and are noted on the engine technical data sheets.

Basic Operating Parameters

All engine cooling circuits are designated by the maximum permissible inlet or outlet temperature to that circuit. In addition, each engine cooling system component has static and dynamic pressure limitations that must be observed in order to preserve the integrity of the cooling system. These temperature and pressure limits can be found in TMI.

Cooling System Sizing Procedure

The following is a step-by-step procedure for design and sizing of cooling systems for Cat engines.

- Obtain heat rejection data for specific engine model and rating. This information is available from the engine technical data sheet. For cooling system design, use the maximum heat rejection (nominal + tolerance) values.
- Find the appropriate density and specific heat values for the specific coolant formulation. **Table 1** provides these values for standard atmospheric conditions. These values can be used for cooling system calculations even at higher temperatures.
- Select a coolant flow rate for the circuit based on the allowable temperature rise and the minimum and maximum flow rates for the circuit. For some models, these limits are stated explicitly and the flow rate is calculated. For others, these limits are essentially built into the external restriction vs. coolant flow curve. When a temperature rise is not provided for an engine, simply select a coolant flow rate near the middle of the external restriction vs. flow curve.
- Once the design coolant flow is obtained, determine the allowable resistance for the circuit using the external restriction vs. coolant flow curve provided for the engine configuration. In cases where the pump is not supplied with the engine, an internal system restriction vs. flow curve is provided so the external pump can be sized properly. If a module mounted expansion tank or temperature regulator is used, correct for its internal restriction.
- Add an additional external circuit system tolerance to the heat rejection to account for system fouling or degradation. Depending on the type cooling system and operating conditions, this tolerance should be on the order of 1% to 10%.
- With the heat rejection, flow rate, and a temperature (either the water supply temperature or exit temperature) and a maximum restriction, a cooling system can be designed.
- Once the system is designed, recheck the external system restriction against the restriction vs. flow curve for the engine. Do not extrapolate. The operating point needs to be on the restriction vs. flow curve for the system to be acceptable. Excessively high restriction will result in inadequate coolant flow. Cooling system design changes will be needed to correct the problem. Low restriction will result in too much flow, which can cause internal wearing. Low restriction can be addressed by inserting an orifice in the cooling system.

The worksheets provided on **Page 125** and **Page 122** provide step by step instructions for calculating the heat rejection, flow rate, and maximum restriction that an external heat sink (radiator, heat exchanger, or other cooling device) must operate to for a successful installation.

Coolant Calculation Constants

Table 1 shows the density and specific heat capacities needed in the coolant flow calculation for commonly used coolants. The values in the last column show the density multiplied by the specific heat capacity; this is a good indicator of the heat absorption capacity of the coolant. Since heat absorption capacity of coolant vary, it is important to use the correct coolant properties in cooling system calculations.

Coolant Density & Specific Heat Values			
Coolant	**Density kg/L (lb/gal)**	**Specific Heat kW min/kg °C (Btu/lb °F)**	**Specific Heat x Density kW min/L °C (Btu/gal °F)**
Pure Water	0.98 (8.1)	0.071 (1.00)	0.0696 (8.1)
50% Ethylene-Glycol / 50% Water	1.03 (8.6)	0.060 (0.85)	0.0618 (7.31)
50% Propylene-Glycol / 50% Water	1.01 (8.4)	0.065 (0.92)	0.0657 (7.728)

Table 1

Coolant Flow Calculation

The coolant flow required for each circuit to transfer the heat load from the engine components to the heat exchangers or radiators can be calculated using the following equation:

$$\text{Flow (L/min)} = \frac{\text{Heat Rejection (kW)}}{\Delta T(^\circ C) \times \text{Density (kg/L)} \times \text{Spec. Heat (kW-min/kg}^\circ\text{C)}}$$

$$\text{Flow (gpm)} = \frac{\text{Heat Rejection (Btu/min)}}{\Delta T(^\circ F) \times \text{Density (lb/gal)} \times \text{Spec. Heat (Btu/lb}^\circ\text{F)}}$$

Where ΔT is the temperature rise of the circuit:

ΔT = Outlet Temperature – Inlet Temperature (for the particular circuit).

Depending on the engine model, the temperature rise, ΔT, may be given in the form of maximum top tank and bottom tank temperatures or directly as a temperature rise limit.

Example:

A diesel 3412C TA with engine speed @ 1800 rpm has:

- Maximum top tank temperature of 99°C (210°F)
- Maximum bottom tank temperature of 88°C (190°F)
- Engine coolant heat rejection of 508 kW (28,890 Btu/min)

$$\text{Flow (L/min)} = \frac{508}{(99\text{-}88) \times 1.03 \times 0.06} = 747 \text{ L/min}$$

$$\text{Flow (gpm)} = \frac{28{,}890}{(210\text{-}190) \times 8.6 \times 0.85} = 198 \text{ gpm}$$

External Restriction and Pump Flows

After determining the required coolant flow rate, pump performance establishes maximum allowable external resistance. Piping and heat transfer equipment resist water flow, causing an external pressure head which opposes the engine-driven pump. The water flow is reduced as the external resistance increases. The total system resistance must be minimized in order to ensure adequate flow. A cooling system with excessive external heads will require pumps with additional pressure capacity.

The following items will affect the flow resistance:

- Size and length of pipe
- Quantity, size and type of fittings and valves used
- Coolant flow rate
- Heat transfer devices

When designing an engine cooling system, the pressure drop (resistance) in the external cooling system can be calculated by totaling the pressure drop in each of the system's components.

The Piping System Basic Information Application and Installation Guide can be used to determine pressure drop through pipe fittings and valves. The guide can also be used to determine flow velocities in tubes and pipes for a given volume of flow. It is important to observe the water velocity guidelines to help insure proper operation of the cooling system and to extend its life. Excessive velocities lead to erosive tube wear.

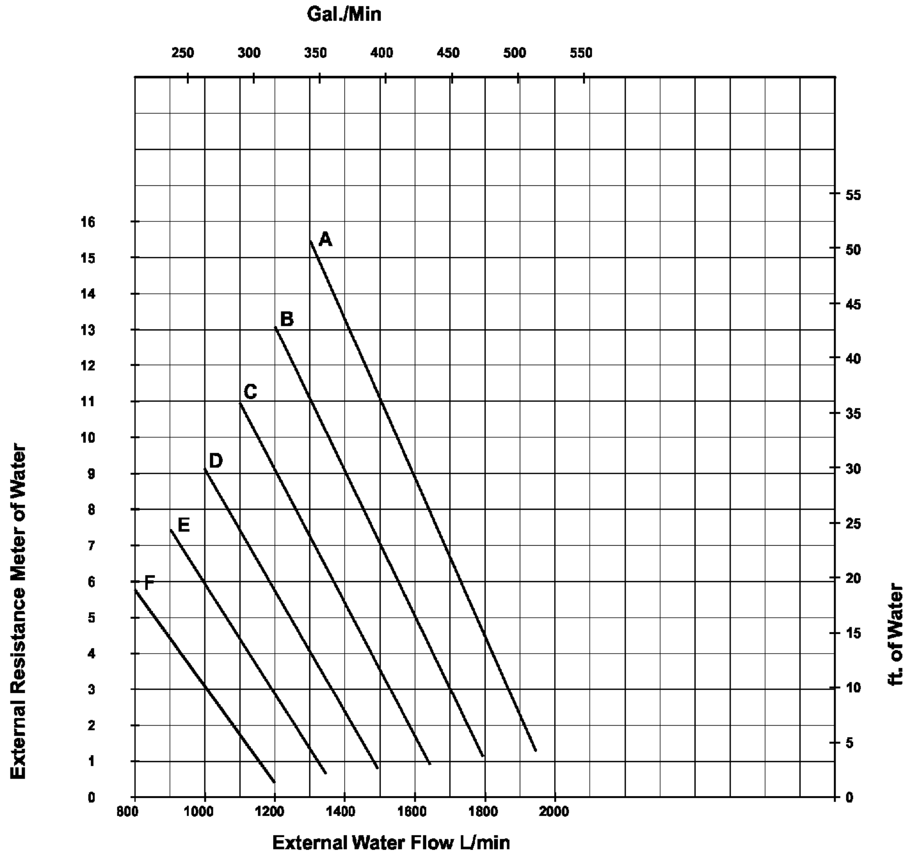
Suppliers of other components such as strainers and heat transfer equipment can provide the required data on their components.

It is always necessary to evaluate the design and installation of cooling circuits. An installation audit tests the operation and effectiveness of the completed system to ensure proper performance and life.

Both TMI and the Engine technical data sheets contain pump curves that show coolant flow versus external system head for the various engine-mounted pumps in metric and English units. An example of a pump curve is shown in **Figure 9**. The data is shown in both tabular and graphical form.

Figure 9 illustrates a maximum external head allowable equal to 10.7 meters (35 ft) of water. Maximum external resistance must not be exceeded in the cooling circuit added by the customer, in order to maintain the minimum water flow for proper cooling.

Example of Jacket Water System Performance



Curve Data

Curve Label	A	B	C	D	E	F
Engine Speed rpm	1300	1200	1100	1000	900	800
Pump Speed rpm	2600	2400	2200	2000	1800	1600
External Flow L/min	**External Resistance Meter of Water**					
800						5.8
900					7.4	4.4
1000				9.1	5.8	3.1
1100			11.0	7.3	4.4	1.8
1200		13.1	9.2	5.7	2.8	0.4
1400	13.2	9.0	5.4	2.4		
1600	8.8	5.0	1.7			
1800	4.4	1.0				
1900	2.3					

Curve Data

Curve Label	A	B	C	D	E	F
Engine Speed rpm	1300	1200	1100	1000	900	800
Pump Speed rpm	2600	2400	2200	2000	1800	1600
External Flow gal/min	**External Resistance feet of Water**					
211.4						19.0
237.8					24.3	14.6
269.2				29.9	19.1	10.2
290.6			36.1	24.1	14.3	5.7
317.0		43.0	30.0	18.8	9.2	1.3
364.9	43.2	29.5	17.8	7.8		
422.7	28.7	16.4	5.6			
475.6	14.5	3.3				
502.0	7.4					

Effective Serial No. 3RC00001

Engine equipped with water cooled exhaust manifolds or dry exhaust manifolds JW Aftercooler.

Drive ratio 2.0 tp 1

For low speed (1300 rpm and below) ratings

Curves indicate maximum allowable external resistance.

Do not project curves.

2W9729 JW Pump

Figure 9

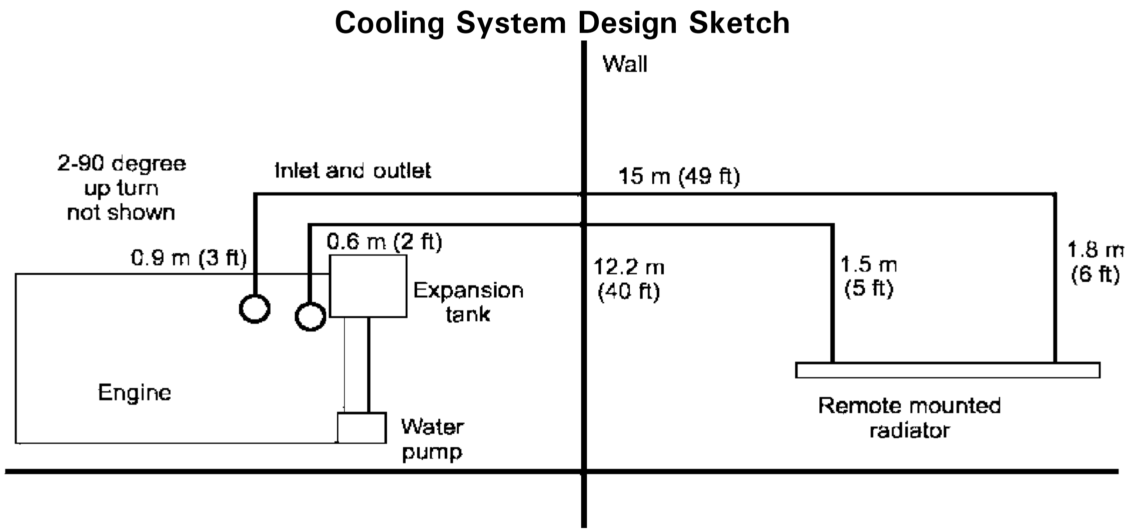


Figure 10

Pipe Size (Inch)	Straight Length m (ft)	Restriction per Elbow (Equivalent Length) m (ft)	Restriction per Valve (Equivalent Length) m (ft)	Total System (Effective Straight) m (ft)
4	32 (105)	3.35 (11)	0.76 (2.5)	53.6 (176)
5	32 (105)	4.27 (14)	0.90 (3.0)	59.4 (195)
6	32 (105)	4.88 (16)	1.07 (3.5)	65.0 (214)
8	32 (105)	6.40 (21)	1.37 (4.5)	73.1 (240)

Table 2a

Pipe Size (Inch)	Equivalent Length m (ft)	Restriction/100 ft @ 1325 L/min (350 gpm)	Total Restriction m H_2O (ft H_2O)
4	53.6 (176)	12.40	6.64 (21.8)
5	59.4 (195)	4.19	2.49 (8.17)
6	65.0 (214)	1.70	1.10 (3.60)
8	73.1 (240)	0.43	0.31 (1.03)

Table 2b

Example Restriction Calculation:
A G3516 Gas engine running at 1200 rpm requires a 1325 L/min (350 gpm) flow to provide cooling. **Figure 10** shows a cooling system designed for this application.

This example is comprised of two gate valves, six 90° elbows and 32 m (105 ft) of pipe connected between the engine and a remote-mounted radiator.

To calculate the restriction, the effective straight length of the system components shown in **Figure 10** must be determined. To aid calculation, non-straight components such as elbows and valves should be converted to effective straight length values. **Table 2a** shows example effective straight length values for components in this system.

Effective straight length =

Straight Length + 6 x Effective Elbow + 2 x Effective Valve

Effective straight length using 6 inch pipe =

32m + 29.28m + 2.14m = 63.42m

(105 ft + 96 ft + 7 ft = 208 ft)

Using the information in the Piping System Basic Information Application and Installation Guide, with the previously found equivalent length, the total restriction can be calculated as:

(Restriction/100 ft) x Equivalent Length

Table 2b shows the restriction for various pipe diameters.

Types of Cooling Systems

There is a myriad of different types of cooling systems. No one system is correct for every location, size and application of Cat engine. It is important to work with our experienced engineers and/or the local dealer when designing the best cooling system for each application. This section discusses some of the more common types of cooling systems.

There are two basic types of cooling systems, open and closed.

Open System

Open systems include cooling towers (without heat exchanger), spray ponds and bodies of water. Open systems are not recommended.

In the open system, the cooling water is exposed directly to the air and is cooled by evaporation and water-to-air heat transfer. About 75% of the total heat is removed by evaporation, and 25% by convective heat transfer. The continued process of evaporation means that any scale-forming salts present in the water will gradually be concentrated, and the water may pick up further contaminants from the air. These impurities can result in the buildup of scale on the walls of the cooling water passages in the engine, decreasing the cooling system efficiency, and increasing the possibility of overheating. Open cooling systems are not recommended. The exceptions are when specific precautions have been taken to accommodate an open system. For example, some engines can be equipped with a cleanable aftercooler core and corrosion resistant piping. These aftercoolers are of a round tube/plate fin design and can be disassembled and cleaned, allowing them to be used in an open system.

Closed System

Closed systems include cooling towers (with heat exchanger), radiators, heat exchangers and evaporative coolers.

In the closed system, proper coolant treatment can virtually eliminate scale formation and corrosion. The coolant does not come into direct contact with the air but is cooled by a process of heat transfer to a cooler medium, usually air or water. The amount of coolant in the engine closed system is relatively small and confined, and can be economically treated.

Closed systems are normally designed to operate under pressure. Slight system pressure minimizes pump cavitation (voids in water) even at high altitude, and increases pump efficiency.

Radiators

Radiator cooling is the most common type of closed cooling system, providing a self-contained system that is both simple and practical for most installations. **Figure 10** shows a schematic of a typical radiator design.

Cooling of the engine parts is accomplished by keeping the coolant circulating and in contact with the metal surfaces to be cooled. The pump draws the coolant from the bottom of the radiator, forces it through the jackets and passages, and ejects it into a tank on top of the radiator. The coolant passes through a set of tubes in the radiator core to the bottom of the radiator and again is circulated through the engine by the water pump, or system cooling pump. A fan draws air over the outside of the tubes in the radiator and cools the coolant as it flows downward. It should be noted that the coolant is pumped through the radiator from the top down. The reason for this is that when the coolant is heated in the jackets of the engine, it expands slightly and as a result becomes lighter and flows upward to the top of the radiator. As cooling then takes place in the radiator tubes, the coolant contracts, becomes heavier and sinks to the bottom. This desirable action, however, cannot take place if the coolant level is allowed to become too low.

The top tank is used for filling, expansion, and deaeration of engine coolant. For cooling systems with additional volume due to plumbing or additional components, the expansion tank may need to be enlarged to allow for the expansion of the additional volume of the system. The top tank is fitted with a pressure cap. This cap allows coolant level to be checked and replenished as necessary. The cap also seals the cooling system and limits its pressure with a spring-loaded disc valve.

Typical Radiator Design with Sample Coolant Flow

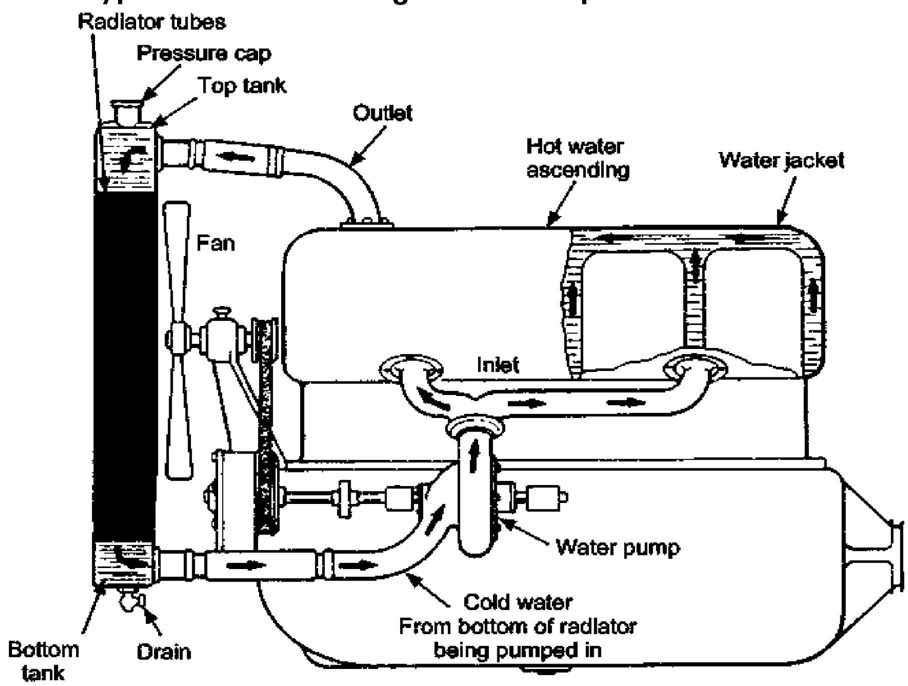


Figure 11

As previously mentioned, the cooling system is designed to operate under a slight pressure of 27.6 to 48.3 kPa (4 to 7 psi) which keeps the coolant from boiling or evaporating as the coolant temperature approaches the boiling point. This limit prevents steam formation in the engine water jacket. (See **Pressure Control**)

Radiator Performance Criteria

Since many of the radiators used by equipment manufacturers will not be designed by Caterpillar, a complete evaluation is required to prove the capability of the system.

Caterpillar Application Engineering or EDS 50.5 – Cooling System Field Test can provide specific information on methods and criteria used to evaluate radiator performance criteria.

A cooling system test needs to be performed in accordance with this document when a Cat radiator or expansion tank are not used.

Radiator Design Criteria and Considerations

The following factors must be considered when designing and installing a radiator cooling system.

- Size the radiator to accommodate a heat rejection rate approximately 10% greater than the engine's heat rejection at rated power. The additional 10% will compensate for possible variations from published or calculated heat rejection rates, overload and system deterioration.
- Radiator sizing should be corrected to account for operating site altitude. Altitude above sea level reduces the density of the air and its ability to cool the radiator. The radiator must be oversized to adjust for the maximum altitude at which the engine is to be operated. These factors are provided for all gas engines and some diesel engines on the Engine technical data sheets.
- Ambient air temperature may not be the same as the air temperature flowing across the radiator core. An engine equipped with an engine mounted radiator and blower fan will increase the air temperature as it flows across the engine to the radiator. Typical ambient temperature rise for different radiator locations is found in **Table 3**.

	Blower Fan	Suction Fan
Engine only, outside or in a large engine room	3°C (5.4°F)	None
Engine & generator outside or in a large engine room	4°C (7.2°F)	Not Recommended with generator
Engine & generator in enclosure with external muffler	7°C (12.6°F)	Not Recommended with generator
Engine & generator in enclosure with internal insulated muffler	9°C (16.2°F)	Not Recommended with generator

Table 3

- Additional air temperature rise will come from components or equipment located in the air intake flow that to the heat load. This additional heat load must be calculated in order to increase the estimated air to core rise shown in **Table 3**. This additional heat load could be due to lights, electrical equipment, hot surfaces, heaters, etc. that are located in the engine room.
- The effects of antifreeze must be considered when sizing a radiator. The ability to transfer heat diminishes when water is mixed with ethylene glycol. The loss in ambient capability due to antifreeze is about 1°C (1.8°F) for each 10% glycol, up to 50%.
- Fan noise should be considered when selecting radiator location. Fan noise transmits through the air inlet as well as the outlet. Soft

flexible joints between the radiator and the ducting will reduce vibration and noise transmission.

- Position the radiator so prevailing winds do not act against the fan, which can reduce the cooling air flow volume and cause over-heating. One form of wind protection is to shelter the radiator from the wind with a baffle or wall located several feet from the radiator exhaust. Another method is to duct the radiator discharge outside the wall and if needed, mount the air inlet vertically. Large radius bends and turning vanes help to reduce excessive air flow restriction.
- It is important to make sure that the hot radiator air discharge is not recirculated to the engine, generator or radiator air inlet. Item **A** and item **B** in **Figure 12** demonstrates this problem for a radiator. Radiators must be arranged so that engine exhaust gases and/or crankcase ventilation gases are not drawn into the air inlet of the radiator as shown in item **C** of **Figure 12.**
- Backpressure or air flow restriction reduces radiator performance. If radiator air flow is to be ducted, consult TMI or your radiator manufacturer regarding the allowable backpressure. An engine installation in an enclosed space requires that the inlet air flow rate to the enclosed space include the combustion air requirements of the engine, unless the air for the engine is ducted directly to the engine from the outside.
- Aluminum radiators will require a Coolant Conditioner to be added when newly installed to prevent nitrite depletion and color fading when used with Cat ELC (Extended Life Coolant) or ELI (Extended Life Inhibitor for treated water applications). Nitrites are included in Cat coolants to provide cylinder liner pitting protection. Refer to special instruction REHS7296-00 for more information. Do not use this Coolant Conditioner in conventional coolants that contain SCA additives, for example, Cat DEAC.

Radiator Recirculation

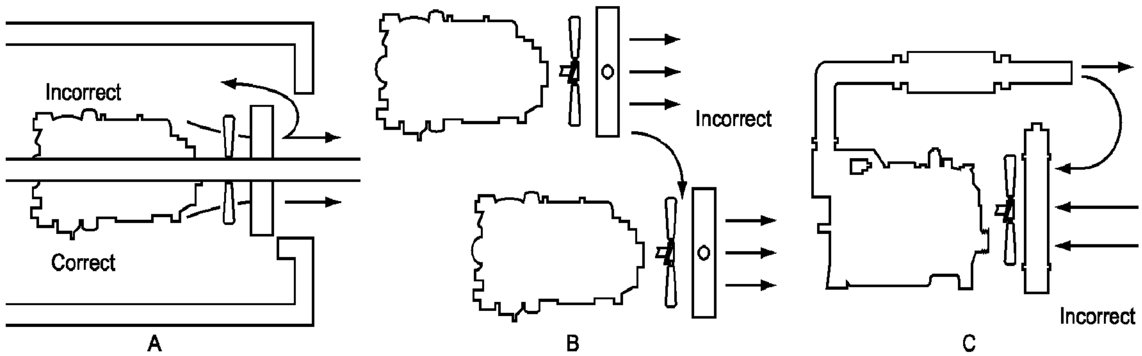


Figure 12

Radiator/Fan Performance

Air density, flow restrictions, and speed affect fan performance, which can possibly limit radiator ambient temperature capabilities. Performance changes are estimated by the following relationships.

Air Density

Revised Static Pressure =

$$\text{Original Static Pressure X } \frac{\text{Revised Air Density}}{\text{Original Air Density}}$$

Revised Fan Horsepower =

$$\text{Original Fan Horsepower X } \frac{\text{Revised Air Density}}{\text{Original Air Density}}$$

Speed

Revised Air Flow =

$$\text{Original Air Flow X } \left(\frac{\text{Revised Fan Speed}}{\text{Original Fan Speed}}\right)$$

Revised Static Pressure =

$$\text{Original Static Pressure X } \left(\frac{\text{Revised Fan Speed}}{\text{Original Fan Speed}}\right)^2$$

Revised Fan Horsepower =

$$\text{Original Fan Horsepower X } \left(\frac{\text{Revised Fan Speed}}{\text{Original Fan Speed}}\right)^3$$

Temperature

Revised Coolant Temperature =

$$\text{Original Coolant Temp X } \left(\frac{\text{Original Air Flow}}{\text{Revised Air Flow}}\right)^{0.7}$$

Revised Coolant Temperature =

$$\text{Original Coolant Temp. X } \left(\frac{\text{Original Fan Speed}}{\text{Revised Fan Speed}}\right)^{0.7}$$

$$\text{Radiator Ambient Temp. Capability} = \frac{99°\text{C – Revised Coolant Temp.}}{\text{Coolant Temperature}}$$

$$\text{Radiator Ambient Temp. Capability} = \frac{210°\text{F – Revised Coolant Temp.}}{\text{Coolant Temperature}}$$

Where:

Coolant Temperature Differential = Coolant top tank temperature minus air temperature to radiator.

Air Density = gm/cu•cm (lb/cu•cm)

Air Flow = cu•m/min (cfm)

Coolant Temperature =

$$99°\text{C } (210°\text{F}) - \left(\frac{5.5}{2}\right) - \text{Original Radiator Temperature}$$

Original Radiator Temperature = Ambient Air Temperature to the Radiator

Assumptions:

Coolant Top Tank Temperature = 99°F (210°F)

Inlet to Outlet Radiator Temperature Change = 11.1°C (20°F)

Fan Horsepower = kW (hp)

Fan Speed = rpm

Static Pressure = mm H_2O (in H_2O)

Ambient Capability

Ambient capability is a value expressing how well the cooling system cools. The value, therefore, depends on the specific cooling configuration and the operating conditions and can be found in the price list.

Fan Speed

Fan speed affects the performance of a fan in respect to radiator ambient temperature capabilities. Revised air horsepower can be calculated using revised and original fan speed.

Steel bladed fans should not exceed the tip speed guidelines as the fan will produce excessive noise and could potentially fail. Recommended maximum tip speeds are 3660 m/min (12,000 ft/min) for low noise, and 4575 m/min (15,000 ft/min) for higher but acceptable noise.

The formula for calculating fan blade tip speed is:

Fan diameter meters x π x Fan rpm = Fan blade tip speed meters per minute

(Fan diameter feet x π x Fan rpm = Fan blade tip speed feet per minute)

Ducting

Radiator ducting, when required, should be larger than the radiator core. A standard rule of thumb is to make the inlet air ducts 1.5 times greater than air outlet ducts.

Louvers are often used to protect the engine and engine room from rain, snow, and vandalism. Since louvers restrict air flow, the radiator ducting area must be increased a minimum of 25% when flat louvers are used. Total air flow restriction due to engine room ventilation, duct work, etc. should be limited to 12.7 mm (0.5 in.) of water. Fan performance will suffer if this limit is exceeded.

If movable louvers are used, specify those which use mechanical force. Pneumatic and electric-actuated louvers are satisfactory. Use of louvers which open from the discharge pressure of the radiator fan are discouraged. Rain, ice, and snow can render them inoperative within a short period of time and cause an unwanted engine shutdown due to overheating.

Standby Ducting

Standby or emergency power units will be loaded immediately and will require full air flow upon startup. Therefore, louvers should be activated immediately on engine start-up.

Emergency units are frequently exercised at no load. The full air flow under these conditions may result in maintenance problems from overcooling, and therefore, the air flow across the radiator should be restricted to allow for the proper cooling.

Engine Mounted Radiator

If an engine-mounted radiator is used and the generator set is installed in a room, a blower fan can be used and a radiator duct provided to the outside.

Ducts directing radiator air to the outside will reduce recirculation and high room temperatures; refer to **Figure 13**. Some generator set packages have, as standard, radiator duct flanges available for installation ease.

The duct length is short and direct to minimize backpressure, with total inlet and outlet restriction on the radiator fan less than 12.7 mm (0.5 in) of water.

Ducting to the Outside

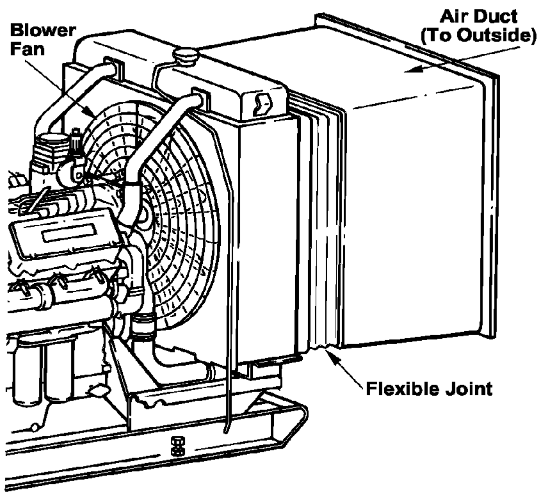


Figure 13

Restrictions

- If common window screening is used, the size of the opening should be increased by 40%.
- Solid walls perpendicular to fan air flow must not be closer than two fan diameters from the radiator.
- Avoid uneven loading of the fan caused by obstructions or auxiliary coolers partially obstructing air flow.
- Fatigue failure of fan blades as well as air turbulence may occur when obstructions are too close to the face of the fan. Maintain a minimum spacing equal to 8% of the fan diameter.

Remote Mounted Radiator

On installations where it is desirable or necessary to locate the radiator at some distance from the engine, a remote radiator can be used.

Remote systems impose added restriction on coolant flow by the use of additional piping and fittings. An auxiliary pump in series with the engine-mounted pump should not be used to overcome this restriction. Consideration should first be given to radiator design and the use of larger piping. If that does not provide an effective solution, then it may be necessary to replace the engine driven pump with an electric motor driven pump that is sized to handle the increased systems restrictions.

If the empty radiator is exposed to extreme cold, initial flow of unprotected coolant can freeze and block the core. Antifreeze must be included in the coolant treatment to assure uninterrupted flow.

The radiator inlet tank loses its air venting capability if it is located below the level of the engine regulator housing. When a radiator must be mounted lower than the engine, a separate expansion tank must be used. In addition, remove the radiator cap and seal the opening. This prevents untrained personnel from causing problems.

If an engine mounted expansion tank is used, it should include a “radiator” fill cap. The radiator must be selected with consideration to the inlet controlled guidelines. The core must also withstand full pump pressure. This will usually require a round tube radiator. If the core is vertical, water flow can be reversed through the radiator. This ensures gas or air is not trapped in the radiator inlet tank.

Preferred location is an elevation lower than the expansion tank, but higher than the engine pump inlet. Radiators connected with straight piping and mounted at engine outlet level minimize air traps, see **Figure 14**. Bleed valves or automatic air release valves may still be required on the radiator unit itself.

Dips in engine outlet piping trap air during the initial fill and during engine operation and should be avoided. Vent lines or automatic air-release valves must be provided at each potential trap, see **Figure 15**.

Radiators are sometimes located above the engine outlet level. This situation is most common in rooftop mounting as shown in **Figure 16**, **Figure 17** and **Figure 18**. Never locate remote mounted radiators more than 17.4 m (57 ft) above the pump. At greater heights, the static resistance developed may cause leakage at the engine water pump seal. Static head is the maximum height the coolant is raised; refer to **Figure 16**. Note the use of an auxiliary expansion tank and appropriate vent lines.

In **Figure 17**, the main (Cat) expansion tank provides the regulator mounting location and deaeration function for the cooling system. The auxiliary expansion tank is the highest point in the system and provides the fill location, coolant level gauge, pressure cap, vent line termination point, and expansion volume required. In some cases, the auxiliary expansion tank may be incorporated in the radiator package itself as shown in **Figure 16**.

Radiator design operating pressure must be increased by 6.9 kPa (1 psi) for every 610 mm (2 ft) the engine is above the radiator. All elevated radiator cooling systems must be evaluated to assure that system pressures are within acceptable limits.

Additional precautions must be taken with shunt type cooling systems. As the flow-through type expansion tank is eliminated, a deaeration chamber must be provided at the engine outlet. Vent lines from the deaeration device and potential traps must be routed to the expansion tank. The tank must be the highest point in the system, and a make-up line routed to the water pump inlet piping. The system, must meet acceptance criteria. The shunt system shown in **Figure 18** uses rooftop mounting, but is applicable for any radiator location.

Vertical Remote

Vertical remote radiators should be positioned so prevailing winds or structures do not impede fan air flow or cause the heated air to recirculate through the radiator core.

Horizontal Remote

Horizontal remote radiators nullify the effects of wind, but may require protection from rain, snow and ice.

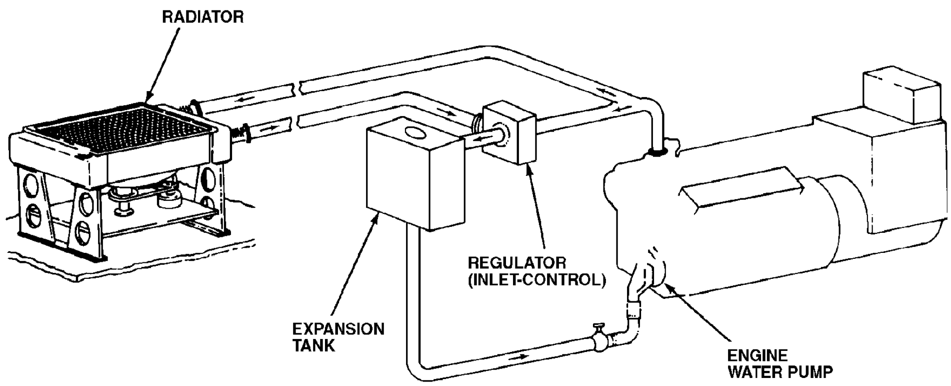


Figure 14

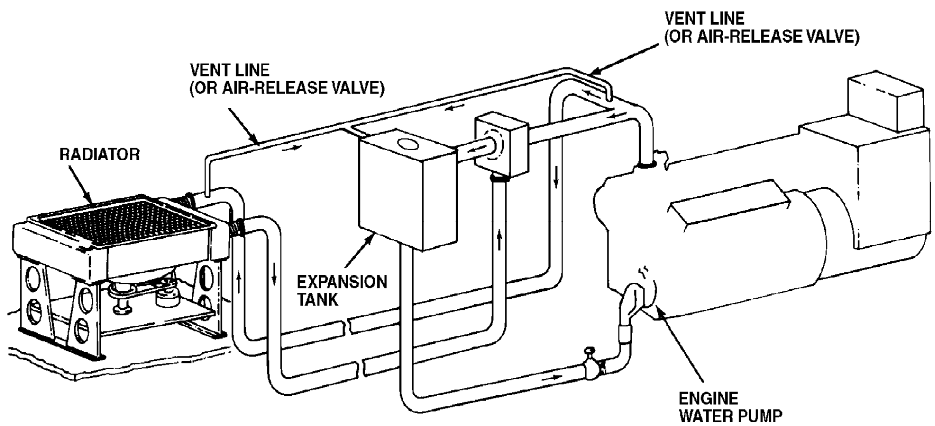


Figure 15

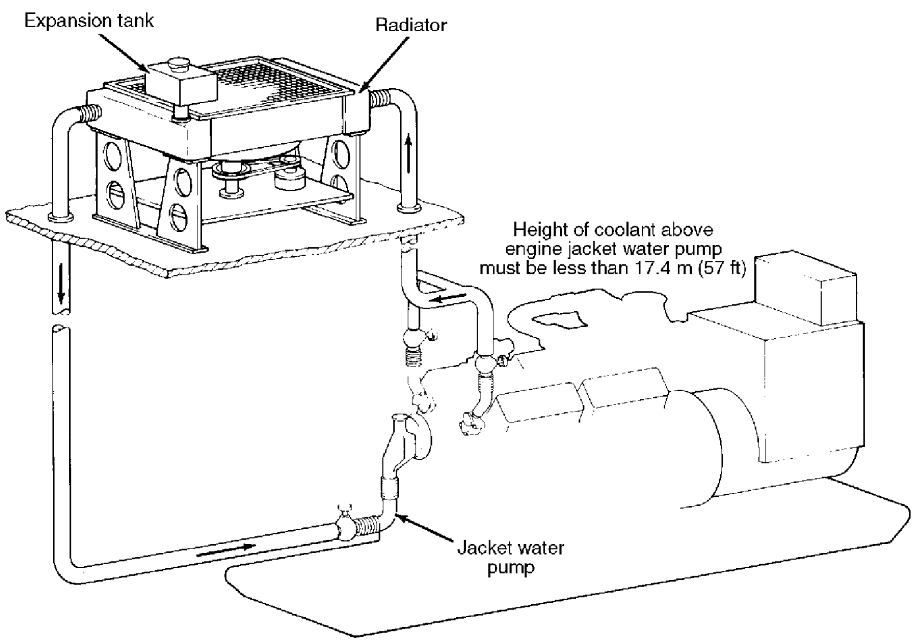


Figure 16

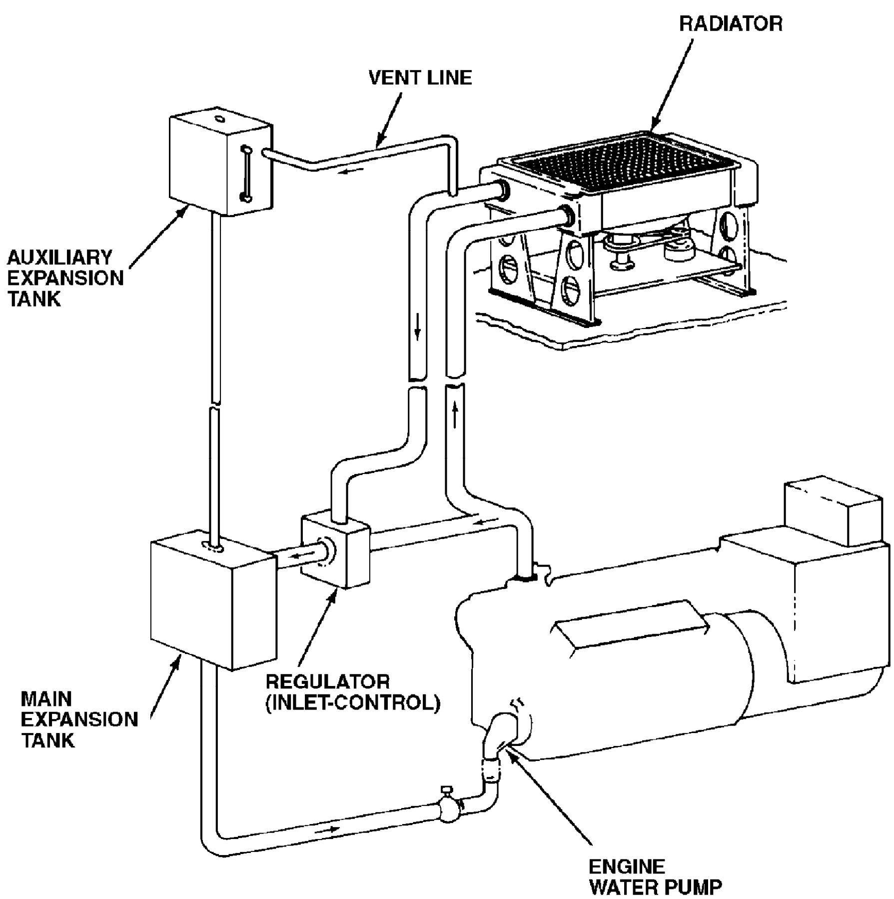


Figure 17

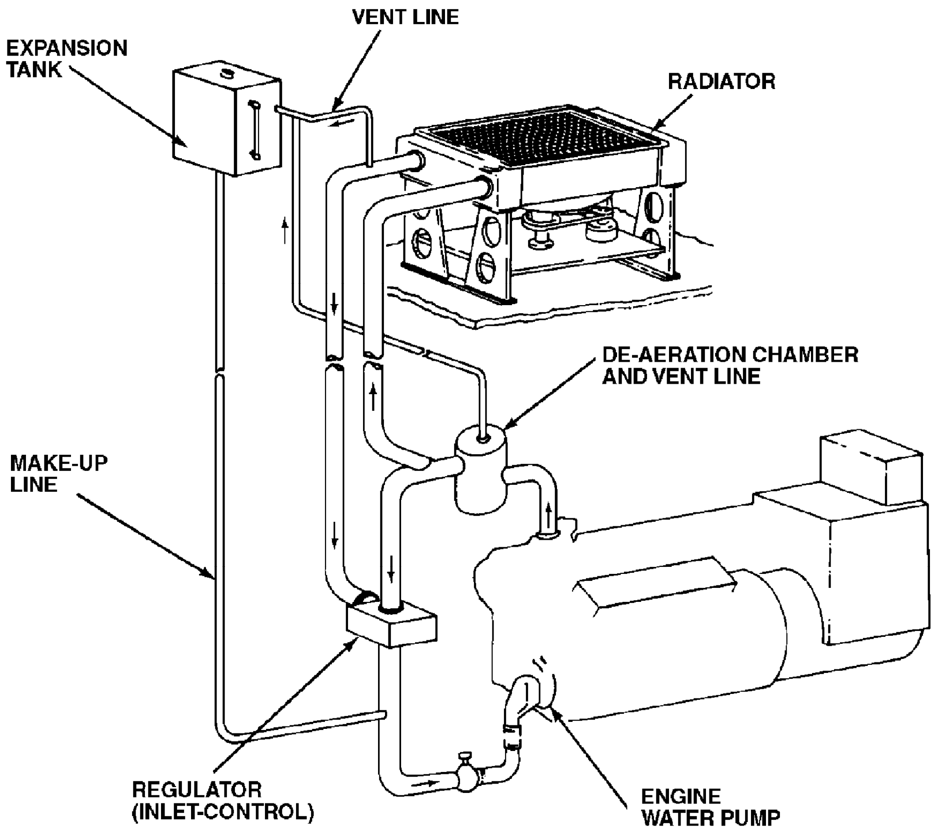

VENT LINE
EXPANSION TANK
RADIATOR
DE-AERATION CHAMBER AND VENT LINE
MAKE-UP LINE
REGULATOR (INLET-CONTROL)
ENGINE WATER PUMP

Figure 18

Heat Exchangers

A heat exchanger can be used to cool the engine when ventilation air is limited, or when excessive static resistance on the engine must be avoided. Heat exchangers are typically classified according to flow arrangement and type of construction.

Advantages to using a heat exchanger are: that there is no fan noise, it reduces the air flow requirements, the parasitic load will be less, and the fuel consumption will be improved. When a source of water is readily available, this is an effective method for cooling the engine.

Some of the disadvantages are that a heat exchanger requires a separate cooling source and a separate expansion tank which means using an extra pump and plumbing. Provisions for room ventilation will also be required.

Shell and Tube Type

The most common type of heat exchanger is the shell and tube type as shown in **Figure 19.** In a shell and tube heat exchanger, the engine coolant is cooled by the transfer of heat to another liquid at a lower temperature. The design parameters available to the shell and tube heat exchanger designer include the diameter, length, number of tubes, the number of raw or treated water passes, the number and cutoff height of shell side baffles. These heat exchangers can have single-pass, or multiple-pass flows. A single pass heat exchanger has the cooling media pass through the heat exchanger only once before exiting. A multiple-pass heat exchanger allows cooling media to pass through the heat exchanger multiple times before exiting. The engine coolant is usually piped to flow through the shell side, so that the raw water flows through the tubes. This permits the raw water side to be readily cleaned by mechanical means.

The direction of flow of the raw water will affect the heat transfer from the engine's coolant. In a single-pass heat exchanger the raw water can flow in the same direction as the coolant (Parallel-flow) or it can flow in the opposite direction as the coolant, (Counter-flow). A given heat exchanger can transfer more heat when connected for counter flow than it can when connected for parallel flow.

Heat Exchanger (shell and tube type)

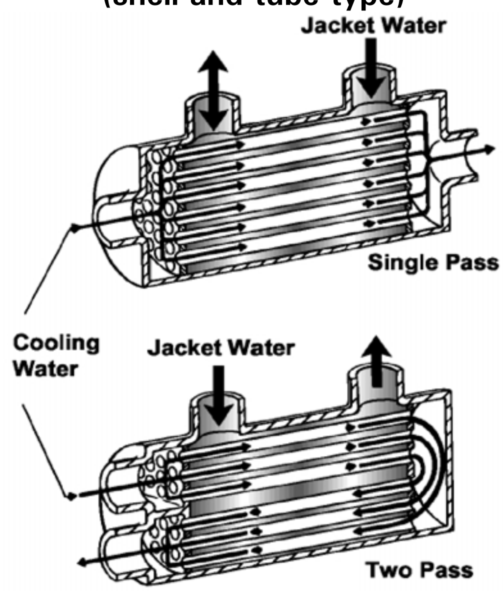


Figure 19

Plate Type

Another common type of heat exchanger is the plate type heat exchanger as shown in **Figure 20**. The design parameters available to the plate type heat exchanger designer include the size and number of plates, the turbulator design and the number of raw or treated water passes. Tight baffling around the heat exchanger is critical to obtaining good heat transfer performance.

Heat Exchanger (plate and frame type)

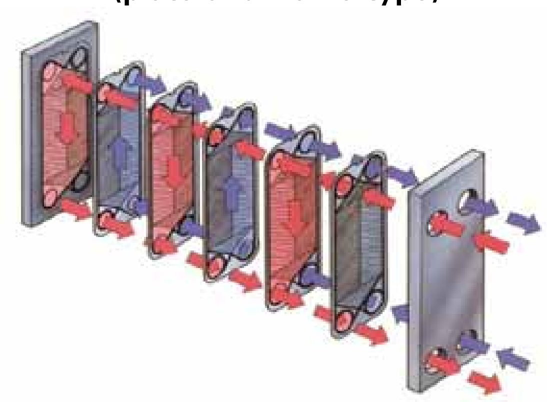


Figure 20

Design Criteria and Considerations
Many engine models have attachment heat exchangers in the price list. Consider the following factors when designing and installing a heat exchanger cooling system.

Size the heat exchanger to accommodate a heat rejection rate approximately 10% greater than the engine's heat rejection. The additional 10% will compensate for possible variations from published or calculated heat rejection rates and engine overload.

The cooling capacities vary for different cooling mediums, and tend to reduce heat transfer. A fouling factor is assumed during equipment sizing, which will affect the heat transfer of a heat exchanger. Factors for common types of water can be found in **Table 4**.

The fouling factor relationship is:

$$FF = [(1/UCoolant) - (1/UClean\ Core)]$$

Where:

FF = Fouling factor, hr-m^2-°C/kJ (hr-ft^2-°F/Btu)

UCoolant = Heat Transfer Coefficient of core with coolant, kJ/hr-m^2-°C (Btu/hr-ft^2 °F)

UClean Core = Heat Transfer Coefficient of clean core kJ/hr-m^2-°C (Btu/hr-ft^2 °F)

Fouling Factor Chart for Water (hr-ft^2-°F/Btu)		
Engine Coolant Temperature < 116°C (240°F) Raw Water Temperature < 52°C (125°F)		
Water Types	Raw Water Velocity	
	≤0.9 m/s (3 ft/sec)	>0.9 m/s (3 ft/sec)
Seawater	0.0005	0.0005
Brackish Water	0.002	0.001
Cooling Tower and Artificial Spray Pond: Treated Makeup Spray Pond: Untreated	0.001 0.003	0.001 0.003
City or Well Water (such as Great Lakes)	0.001	0.001
River Water	0.003	0.003
Hard (over 15 grains/gal)	0.003	0.003
Engine Jacket	0.001	0.001
Treated Boiler Feedwater	0.001	0.0005

Note: *1 hr-ft^2-°F/Btu = 0.0545 hr-m^2-°C/kJ*

Table 4

For the coolants listed in **Table 4**, fouling factors greater than 0.001 will result in significant change in the heat transfer capacity. Use **Table 5** to correct the heat capacity of the heat exchanger given in TMI for fouling factor different from the base of 0.001. For coolants with fouling factors less than 0.001 the values have been left unchanged.

Caterpillar does not recommend designing for a fouling factor less than 0.001.

Since heat exchanger tubes can be cleaned more easily than the surrounding shell (jacket), the raw water should be passed through the tubes and the engine cooling water through the shell or jacket.

Fouling Factor Chart Correction Factors		
Engine Coolant Temperature < 116°C (240°F) Raw Water Temperature < 52°C (125°F)		
Water Types	Raw Water Velocity	
	≤0.9 m/s (3 ft/sec)	>0.9 m/s (3 ft/sec)
Seawater	1.0	1.0
Brackish Water	0.83	1.0
Cooling Tower and Artificial Spray Pond: Treated Makeup Spray Pond: Untreated	1.0 0.71	1.0 0.56
City or Well Water (such as Great Lakes)	1.0	1.0
River Water	0.71	0.71
Hard (over 15 grains/gal)	0.71	0.56
Engine Jacket	1.0	1.0
Treated Boiler Feedwater	1.0	1.0

Table 5

If solenoid valves are used to control cooling water, position them upstream of the heat exchanger. The drain for the heat exchanger is always open and the heat exchanger is relieved of pressure when inoperative. If solenoid valves are installed on both sides, raw water could be trapped in the tubes if the solenoids fail to open. Water trapped during engine operation expands and could rupture the exchanger. All solenoid valves should include a manual bypass.

Do not add temperature regulators in raw water supplies. Engine jacket water is controlled by a temperature regulator; additional controls add expense, restriction and decrease reliability.

Heat Exchanger Sizing

Occasionally, special applications exist which require an inboard heat exchanger size that is not available from Caterpillar. When these conditions exist, it is necessary to obtain a heat exchanger from a supplier other than Caterpillar. In order to expedite the selection of a nonstandard heat exchanger, a Heat Exchanger Selection Worksheet is provided in this guide; refer to **Page 128**. Heat exchanger suppliers will provide information and aid in selecting the proper size and material for the application.

For a given jacket water flow rate, the performance of a heat exchanger depends on both the cold water flow rate and differential temperature. To reduce tube erosion, the flow velocity of the cold water through the tubes should not exceed 183 cm/s (6 fps).

At the same seawater flow rate, the flow resistance and the flow velocity will be greater through a two-pass heat exchanger than through a single-pass heat exchanger. The heat exchanger should be selected to accommodate the cold water temperature and flow rate needed to keep the temperature differential of the jacket water below about 8.3°C (15°F) at maximum engine heat rejection. Thermostats must be retained in the jacket system to assure that the temperature of the jacket water coolant returned to the engine is approximately 79°C (175°F).

Size heat exchangers to accommodate a heat rejection rate approximately 10% greater than the tabulated engine heat rejection. The additional capacity is intended to compensate for possible variations from published or calculated heat rejection rates, overloads or engine malfunctions which might increase the heat rejection rate momentarily. It is not intended to replace all factors which affect heat transfer, such as fouling factor and shell velocity.

Pay particular attention to the shell side pressure drop to ensure that the entire cooling system flow resistance does not exceed the limitations of the engine's freshwater pump.

Submerged Pipe Cooling

Submerged Pipe Cooling is a simple, but yet effective way of rejecting heat from the engine and can be used if the engine is located near a supply of relatively cool water, preferably 29°C (85°F) or less. In this system, the engine coolant water is pumped through coils (or lengths of pipe) that are submerged in the nearby cool water. **Figure 21** shows an example of a typical submerged pipe cooling system.

A concrete catch basin or tank should be placed in the source of the cooling water. This will help ensure a consistent volume of water around the coils and help keep mud and silt from burying the coils. The pipes must be supported up, off the bottom of the tank to ensure maximum cooling efficiency.

Submerged Pipe Cooling System

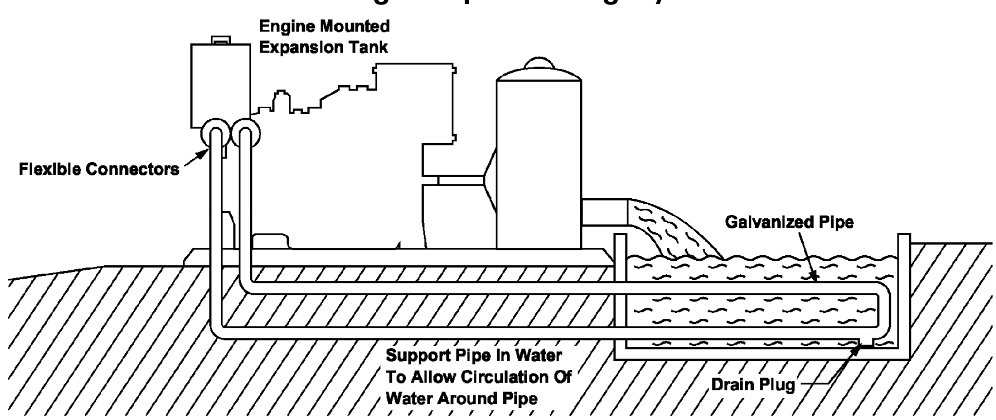


Figure 21

Engine heat rejection and the temperature of the cooling medium must be carefully considered in determining the correct amount of pipe to use. As a rule-of-thumb, 0.003 m^2 (0.0353 ft^2) of submerged pipe surface area is required for every 1.055 kJ/min (1 Btu/min) of jacket water heat rejection that must be removed. This rule-of-thumb is for raw water temperatures up to 29°C (85°F).

A trial and error method can be used if jacket water temperature is too high or too low; by adding or removing pipe as necessary, the engine cooling water temperature can be maximized.

The system should be connected so that jacket water flows from the engine, to the cooling coils, and to the expansion tank, before returning to the water pump inlet.

Cooling Towers

Since radiators are often ineffective for cooling Separate Circuit Aftercooling (SCAC) water below 54°C (130°F), an alternate source of water is needed for low temperature cooling circuits of 32°C (90°F) SCAC. In such cases, cooling towers are used when a large supply of cool water such as a river, lake or cooling pond is not available or not usable for environmental reasons.

Though there are several types of cooling towers, the basic method of heat transfer is the same. Air is brought in direct contact with the cooling water. Cooling by cooling towers is accomplished in two ways. Approximately 75% occurs by water evaporation, and about 25% by direct heat transfer from the water spray to the passing air. Since the primary mechanism for cooling the water is through evaporation, the ability of the air flow to absorb moisture is critical to the effectiveness of a cooling tower. It is for this reason that the performance of a cooling tower depends on the relative humidity of the ambient air.

Relative humidity is a measure of the air's ability to absorb moisture. When the relative humidity is 100%, the wet-bulb and dry-bulb temperatures are equal and the air cannot absorb additional moisture. Therefore, there will be no evaporation and little cooling. However, when the relative humidity is less than 100%, the wet-bulb temperature is less than the dry-bulb temperature and the air can absorb moisture by evaporation.

The prevailing wet-bulb temperature is a key factor in the design of a cooling tower; it is the theoretical limit to which a cooling tower will cool. However, in the practical application of a cooling tower, the coolant temperature can only be maintained down to about 5.6°C (10°F) above the wet-bulb temperature.

There are two types of cooling towers.

- Open-Type
- Closed-loop-Type or Evaporative Cooler

Open Cooling Tower

In open cooling systems using cooling towers, the engine cooling water is sprayed directly into the tower and is subjected to the inherent concentration of water contaminants of this system. Unless special provisions are made, such as a cleanable aftercooler and corrosion resistant plumbing, the use of an open cooling system is not recommended for Cat engines.

Closed Cooling Tower

Figure 22 demonstrates how a heat exchanger can be used to maintain a closed cooling system for the engine while using a cooling tower. In this system, raw water is circulated by an auxiliary water pump driven from the engine, or by an electric motor. The pump flows cool water from a basin at the bottom to the cooling tower, forces it through the heat exchanger, and to the distribution system at the top of the tower. As the heated water passes through the tower, it cools and collects in the basin.

For the closed-loop cooling tower, the engine coolant can be circulated to the cooler eliminating the heat exchanger at the engine; refer to **Figure 23**. The coolant in a closed-loop system can be treated to prevent corrosion, eliminating the need for corrosion resistant piping.

Closed Cooling Tower with Externally Mounted Heat Exchanger

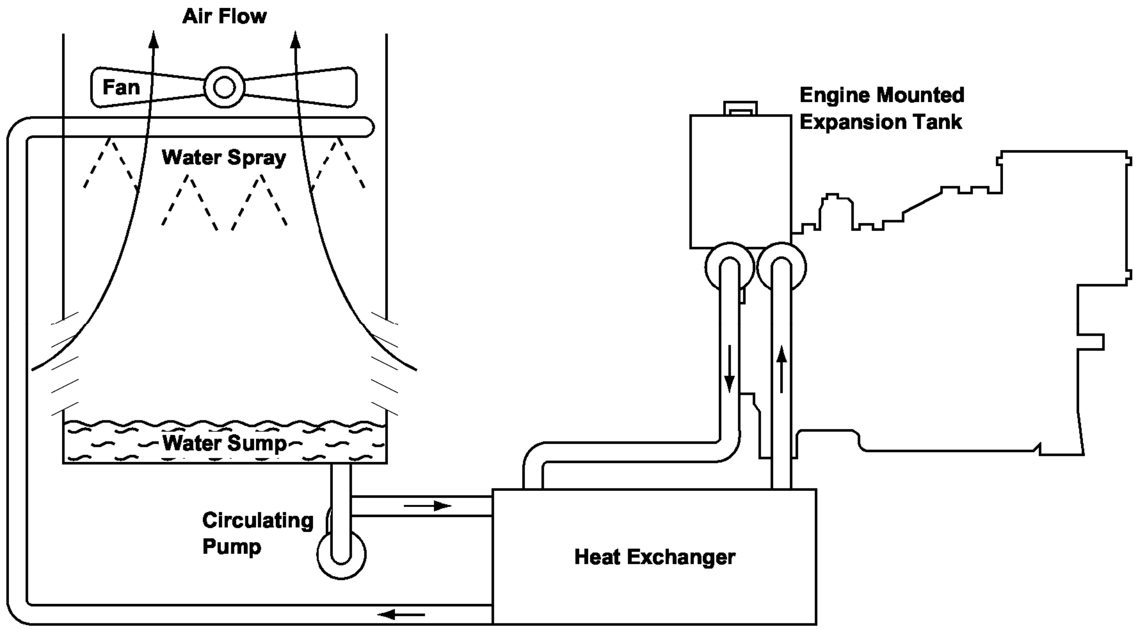


Figure 22

Closed Loop Cooling Tower

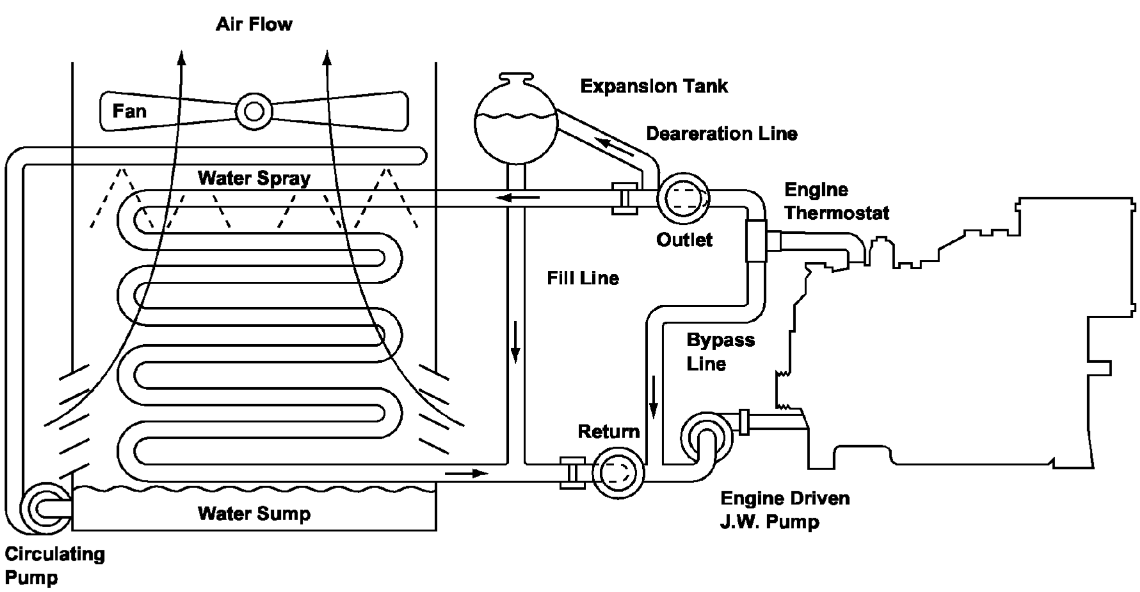


Figure 23

Cooling Tower Design Criteria

As a rule, cooling towers are most effective in areas with an ambient dry-bulb temperature above 37.8°C (100°F), and an average relative humidity below 50%.

Cooling towers are very sensitive to approach temperatures (i.e. the temperature between the wet bulb temperature and the desired coolant temperature). To go from an approach temperature of 8.3°C (15°F) to an approach temperature of 5.6°C (10°F), the cooling tower size would have to be increased by as much as 50%. Any approach temperature below 2.8°C (5°F) becomes unrealistic.

As with radiators, cooling towers are very sensitive to recirculation and the presence of other upwind cooling towers; refer to **Figure 24**. Any recirculation or ingestion of exhaust from another cooling tower effectively reduces the approach and wet-bulb temperature of the incoming air. As was demonstrated earlier, the approach temperature has a significant effect on cooling tower size. Therefore, factors such as location of the towers, direction of the prevailing winds, and height of the towers (a taller tower will reduce recirculation), should be taken into consideration.

The continued process of evaporation means that any scale-forming salts present in the water will gradually be concentrated; the water may pick up further contaminants from the air. These impurities can result in the build-up of scale on the cooling water passages, decreasing the cooling system efficiency. As these salts and minerals build, they must be drained and the tower water diluted with fresh water. Solids such as dust may also accumulate in the tower water. Filters or centrifugal separators can be installed to reduce these contaminants.

If the tower water is used in the engine circuits such as the aftercooler, it should be treated with corrosion inhibitors to be compatible with engine piping and components. Even with treated water, a cleanable aftercooler core is required when used with cooling tower water.

Cooling towers installed in frigid locations require additional design requirements to prevent freezing.

Tower Recirculation Due to Wind

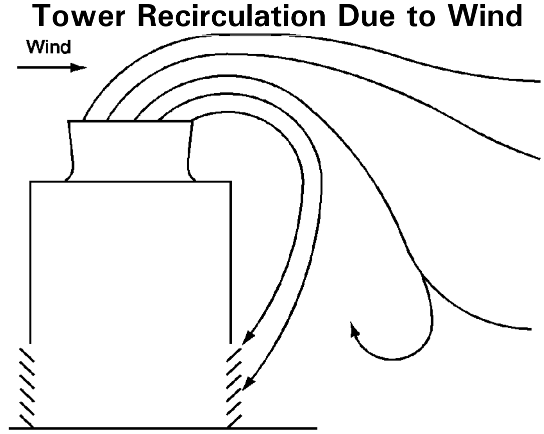


Figure 24

Keel Coolers

A keel cooler is an outboard heat exchanger which is either attached to, or built as part of, the submerged part of a ship's hull. They are typically used in marine applications operating on inland waterways and rivers, where there is potential for encountering muddy or silt-laden cooling water. The heated water from the engine is circulated through the keel cooler by an engine driven water pump.

Figure 25, **Figure 26** and **Figure 27** represent three (3) typical keel cooler system configurations.

- Jacket Water Aftercooled with Keel Cooler
- Separate Circuit Aftercooled with Keel Coolers
- Separate Circuit Aftercooled with Keel Coolers (with Aftercooler Keel Cooler Bypass)

Jacket Water Aftercooled with Keel Cooler

Jacket water aftercooling uses engine jacket water in the tube side of the aftercooler and results in inlet manifold temperatures lower than those obtained in non-aftercooled turbocharged engines. The lower inlet manifold air temperature allows a jacket water aftercooled engine to achieve a rating higher than either a naturally aspirated or a turbocharged-only engine. Jacket water aftercooled circuits are completely installed at the factory.

Jacket water aftercooling, when feasible for a particular application, represents the simplest cooling system possible. When coupled with the use of a keel cooler, it becomes even simpler, with only one cooling circuit required per engine.

Jacket Water Aftercooled – Keel Cooler

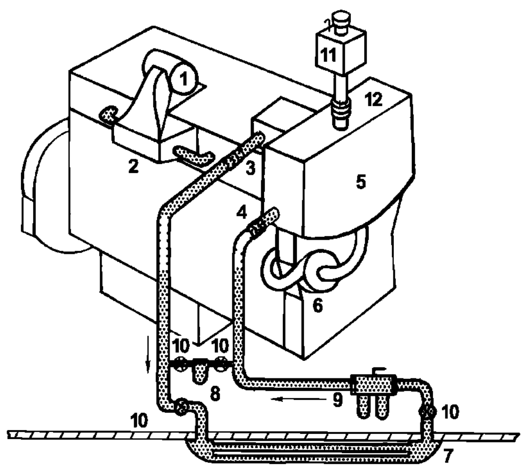


Figure 25

1. Turbocharger
2. Aftercooler, Jacket Water Cooled
3. Jacket Water Outlet Connection
4. Jacket Water Inlet Connection
5. Expansion Tank
6. Jacket Water Pump
7. Keel Cooler
8. Bypass Filter
9. Duplex Full-Flow Strainer
10. Shut-Off Valve
11. Auxiliary Expansion Tank
12. Flexible Connection

Separate Circuit Aftercooled with Keel Coolers

The use of keel coolers in the aftercooler circuit allows a low temperature, fresh water, closed circulating system to be used. All closed fresh water aftercooler circuits require the installation of an expansion tank. Refer to the section of auxiliary expansion tanks. The use of an inlet manifold air temperature gauge, or alarm, can provide guidance for required cleaning of the system in order to maintain the desired engine performance, and is strongly recommended.

Caution must be used when using the aftercooler keel cooler water circuit to cool an auxiliary piece of equipment such as a marine transmission. The auxiliary equipment cooler should be connected to the water circuit after it leaves the engine aftercooler to avoid adding any heat to the water before it enters the aftercooler. The additional resistance of the auxiliary equipment cooling circuit must be held to a minimum to avoid reducing the flow of water to the aftercooler.

Separate Circuit Aftercooled – Keel Coolers

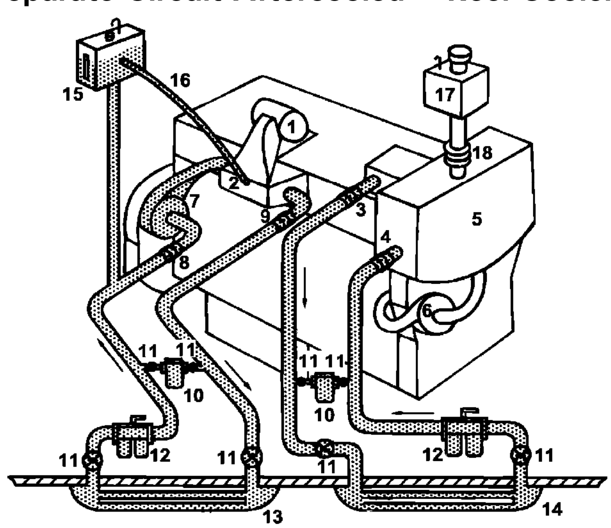


Figure 26

1. Turbocharger
2. Aftercooler, Keel Cooled
3. Jacket Water Outlet Connection
4. Jacket Water Inlet Connection
5. Expansion Tank
6. Jacket Water Pump
7. Auxiliary Fresh Water Pump
8. Auxiliary Fresh Water Inlet Connection
9. Aftercooler Outlet Connection
10. Bypass Filter
11. Shut-Off Valve
12. Duplex Full-Flow Strainer
13. Keel Cooler for Aftercooler
14. Keel Cooler for Jacket Water
15. Expansion Tank for Aftercooler Circuit
16. Vent Line for Aftercooler Circuit
17. Auxiliary Expansion Tank
18. Flexible Connection

Separate Circuit Aftercooled with Keel Coolers and Aftercooler Keel Cooler Bypass

The separate circuit aftercooler cooling system must be designed with sufficient capacity for the hottest water and the higher ambient air conditions for operation in climates where both air and seawater temperatures run to extremes. This results in a cooler with excess capacity in cold seawater and warm air conditions. This can result in condensation in the engine's intake system, especially during prolonged light engine load.

To minimize condensation during light engine load in separate circuit aftercooled systems, it is desirable to maintain the inlet manifold temperature between 38°C and 52°C (100°F and 125°F). This may be achieved by recirculating the aftercooler cooling water back to the auxiliary water pump inlet until the desired temperature is reached. Cool water should then be mixed with the recirculated water to maintain the temperature. The temperature of the water to the aftercooler can be controlled by using a thermostatically controlled three-way valve.

Separate Circuit Aftercooled – Aftercooler Keel Cooler Bypass

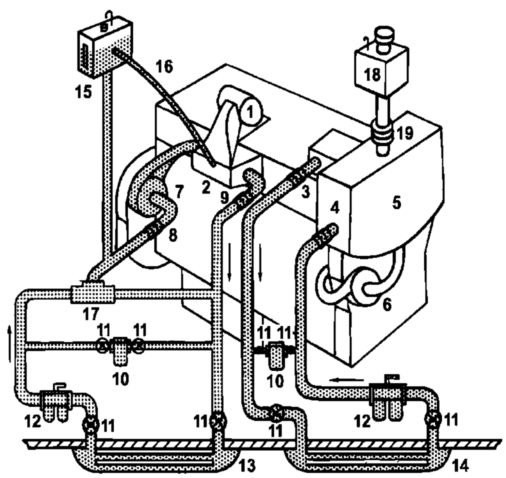


Figure 27

1. Turbocharger
2. Aftercooler, Keel Cooled
3. Jacket Water Outlet Connection
4. Jacket Water Inlet Connection
5. Expansion Tank
6. Jacket Water Pump
7. Auxiliary Fresh Water Pump
8. Auxiliary Fresh Water Inlet Connection
9. Aftercooler Outlet Connection
10. Bypass Filter
11. Shut-Off Valve
12. Duplex Full-Flow Strainer
13. Keel Cooler for Aftercooler
14. Keel Cooler for Jacket Water
15. Expansion Tank for Aftercooler Circuit
16. Vent Line for Aftercooler Circuit
17. Bypass Valve, Thermostatically Controlled
18. Auxiliary Expansion Tank
19. Flexible Connection

Fabricated Keel Coolers
Fabricated keel coolers may be made of pipe, tubing, channel, I-beams, angle or other available shapes. The choice of materials used is dependent on the waters in which the vessel will operate. These materials must be compatible with materials used in the vessel's hull in order to prevent galvanic corrosion.

Sizing of Fabricated Keel Coolers
Engine water temperature maximum limits are controlled by size of the keel cooler. Heat transfer rates through any cooler depend mainly on cooling water temperature, cooling water flow and heat transfer surface area. A cooler may have to operate at its maximum capacity at zero hull speed, as in the case of an auxiliary generating set, operating while the vessel is in port. The minimum area calculated includes a fouling factor. Materials used in cooler construction, condition of waters in which the vessel will operate and service life expectancy will influence the size selection of a new cooler.

The keel cooler sizing worksheet on **Page 129** and the keel cooler area recommendations contained in **Figure 28**, **Figure 29** and **Figure 30** apply only to keel coolers made of structural steel (channel, angle, half pipe, etc.) welded to the ship's shell plating. These recommendations take into account the thermal resistance to heat transfer of the steel plate, the internal and external water films, and the internal and external surface corrosion factors. The coefficient of heat transfer of the fresh water film flowing inside the cooler is based upon a flow velocity of 0.9 m/sec (3 ft/sec). The coefficient of heat transfer for the raw water film varies with the velocity of water flow past the cooler due to vessel speed. Surface corrosion factors are based on treated fresh water and polluted river water. Miscellaneous factors become so predominant in the resultant heat transfer rate that the type of material used and thickness of metal become minor considerations.

Normal deterioration of the cooler's inner and outer surfaces in the form of rust, scale and pitting progressively reduce a keel cooler's effectiveness over a period of years. Protective coatings and marine growths will also reduce the rate of heat transfer. It can take four to five years before deterioration stabilizes in keel coolers. It must be designed considerably oversized when new.

Because of the severe deterioration of heat transfer characteristics associated with structural steel coolers, adequate cooler size sometimes becomes impractical. This is particularly true where seawater temperatures are over 30°C (85°F). In these high seawater temperature regions, the use of "packaged" keel coolers, or box coolers, made of corrosion-resistant materials is suggested. These coolers can provide more heat exchange surface area in a given volume on, or within the hull, than the coolers made of structural steel.

Marine Gear Heat Rejection
Marine gears, or transmissions, whether offered by Caterpillar or provided by a marine gear manufacturer or supplier, will all generate heat. Typical marine gears are 95% to 97% efficient, with the 3% to 5% efficiency loss (or power loss factor) representing the amount of heat being rejected to the marine gear oil.

While the actual marine gear efficiency can be provided by the gear manufacturer based on the specific application, a good rule for cooler sizing is to use 95% efficiency with a 5% power loss factor.

Maximum heat rejection to the marine gear cooling system is equal to the transmitted power from the engine multiplied by the power loss factor.

H marine gear = P engine x F power loss

Where:

H marine gear = Heat rejection of the marine gear oil

P engine = Power generated in the engine and transmitted through the marine gear

F power loss = A factor relating the heat generated in the marine gear oil to the marine gear efficiency

The following conversion factors are tabulated below.

31.63 x kW = Btu/min

42.41 x hp = Btu/min

Aftercooler Water Keel Cooler Area Requirements

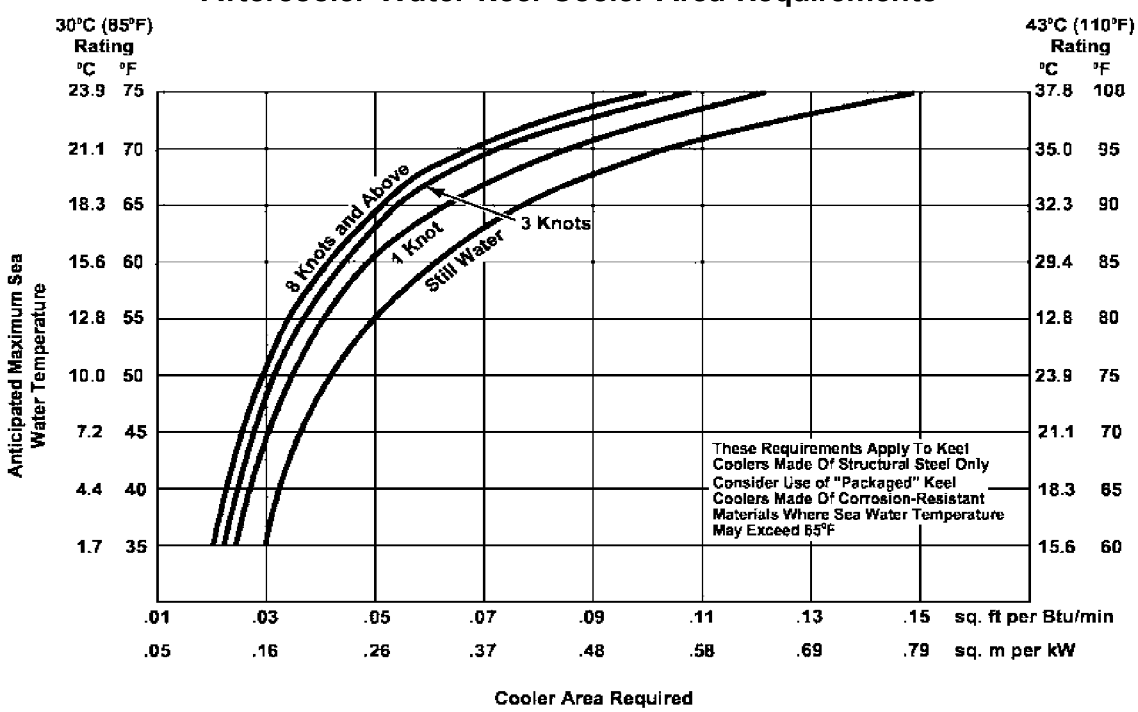


Figure 28

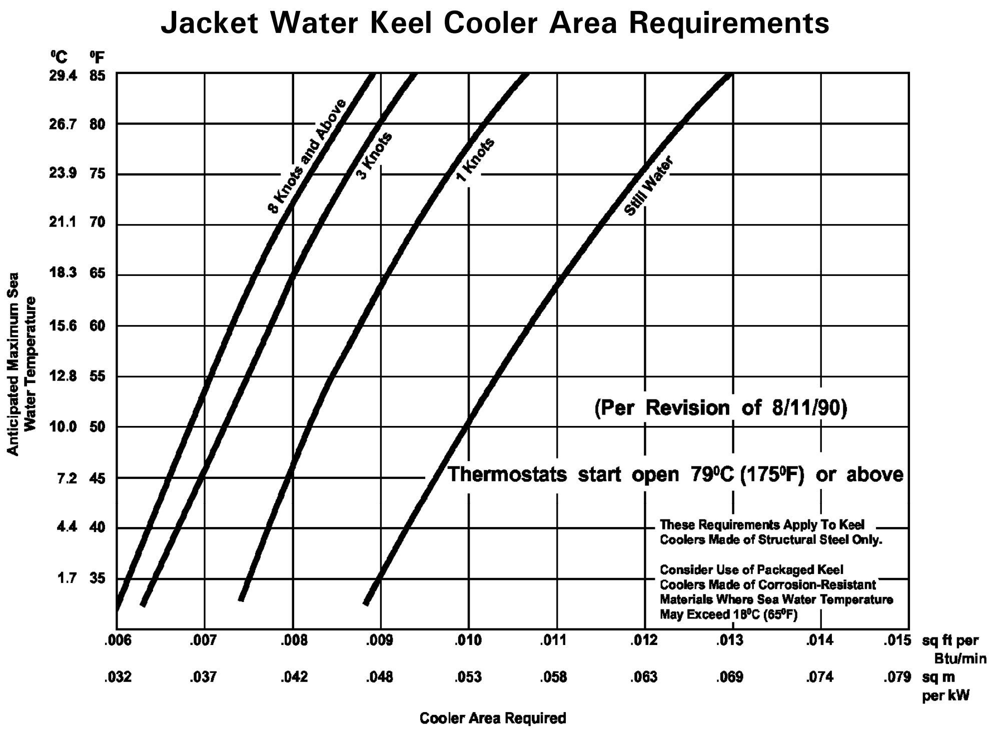


Figure 29

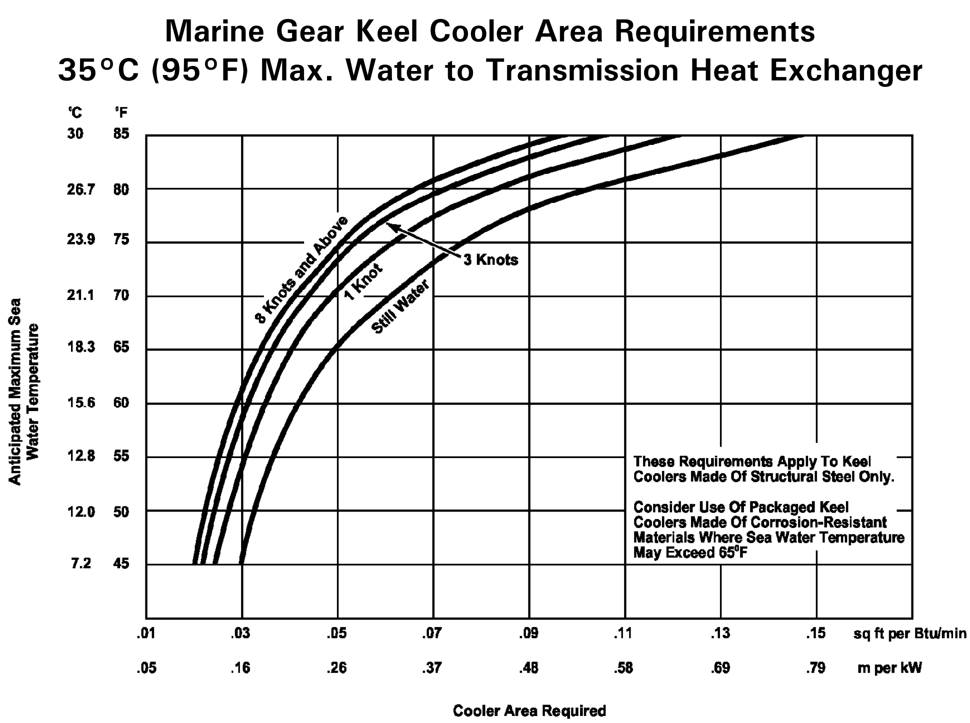


Figure 30

Design/Installation Considerations

Water Velocity Inside the Cooler

If water flow through the keel cooler is too fast, the cooler can be damaged. Water velocity over 2.5 m/sec (8 ft/sec) will erode internal components, particularly near manifold entrances and exits, elbows and other discontinuities in the water flow.

If the water flows through the keel coolers too slowly, cooler efficiency will be reduced. Water velocity less than 0.6 m/sec (2 ft/sec) will allow rust particles, sand and other particulate matter to settle out of the water and into the cooler. This tends to choke off the flow and degrade the transfer of heat.

Use the following procedure to determine the proper flow pattern through the keel cooler.

- Determine the maximum and minimum expected water flow through the keel cooler. This can be determined from the engines water pump performance data.
- Subtract the minimum expected water flow from the maximum expected water flow.
- Multiply the resultant difference (between the min and max flow) by 2/3. Add 2/3 the resultant difference (from the prior step) to the minimum flow*. This is the most likely water flow. Use this figure to determine how to distribute the water flow through the keel cooler passages.

  * For design purposes, this is the most likely water flow through the keel cooler. This is dependent on the use of good practice in sizing the connecting piping.
- Determine the cross-sectional area of one keel cooler passage. This is best done by consulting the manufacturer or an engineering reference on shapes of structural channel, pipes, angles and other flow details.
- Use a good conversion factor table to convert the most likely water flow to units of m^3/min (ft^3/min).
- Use a good conversion factor table to convert cross-sectional area of one keel cooler passage to units of m^2 (ft^2).
- Divide the most likely water flow by the cross-sectional area of one keel cooler passage.
- The result will be the average velocity through the keel cooler flow passages. If the average velocity through the keel cooler flow passages is greater than 2.5 m/sec (8 ft/sec), arrange the water flow in parallel, so it passes through two or more of the keel cooler passages per pass through the keel cooler. If the average velocity through the keel cooler flow passages is less than 0.6 m/sec (2 ft/sec), use a keel cooler passage with a smaller cross section.

Use of Keel Inserts to Improve Local Flow Velocity

It is economically desirable to use steel channels for keel cooler passages which are large in cross-sectional area. Unfortunately, this design produces water flow that is too slow for effective heat transfer. Keel cooler inserts are used in these coolers to cause localized high water velocity or turbulence within the keel cooler passage.

An effective design for keel cooler inserts is a ladder-like device, inserted into the full length of the keel cooler passages. Typical inserts should have the following design features:

- The inserts must be made of the same metal alloy as the hull and keel cooler to protect against galvanic corrosion.
- The "rails" of this ladder shape should be made of 6 mm (1/4 in) diameter rod.
- The "rungs" of this ladder shape should be made from flat bar that has approximately the same shape, but 70% of, the cross sectional area of the keel cooler flow passages
- The flat bar cross pieces must not restrict flow through the keel cooler flow passages, but simply redirect the flow to avoid laminar flow due to too slow an average velocity.

Insert the ladder into the keel cooler flow passages and weld on the end fittings (inlet and outlet manifolds).

Direction of Flow through Keel Coolers

Engine coolant should flow through the keel cooler from the rear of the vessel toward the front of the vessel. This is counter-flow to the seawater and will significantly increase the effectiveness of the heat transfer. This is rarely practical to implement completely since the flow must be divided through the various flow passages in the keel cooler. If the flow is divided through too many passages, the velocity becomes too slow to maintain turbulent flow conditions. This will reduce heat transfer. The best compromise is to manifold the coolant in such a way that the flow, in the largest practical number of flow passages, is from rear to the fore end of the vessel.

Bypass Filters

Welded structural steel keel or skin cooler systems require the installation of strainers between the cooler and the pump inlet. Material, such as weld slag and corrosion products, must be removed from the system to prevent wear and plugging of cooling system components. Use a continuous bypass filter to remove smaller particles and sediment. The element size of the continuous bypass filter should be 20 to 50 microns (0.000787 to 0.000197 inches). Do not exceed 19 L/min (5 gal/min) water flow through the bypass and filter.

Strainers

Full-flow strainers are desirable. The strainer screens should be sized no larger than 1.6 mm (.063 in) mesh for use in closed freshwater circuits. The strainer connections should be no smaller than the recommended line size. The use of a differential pressure gauge across the duplex strainers will indicate the pressure drop, and enables the operator to determine when the strainers need servicing.

The pressure drop across a strainer at the maximum water flow must be considered part of the system's external resistance. Suppliers can help in the proper selection of strainers and furnish the values of pressure drop versus flow rate. The strainer should be selected to impose no more than 3 ft (1 m) water restriction to flow under clean strainer conditions.

Packaged Keel Coolers

Although the channel type keel cooling system discussed so far provides advantages over seawater cooling by eliminating silt/sand build-up and protecting against corrosion, their bulk size and location can reduce a vessel's capacity and increase its drag. They are also prone to seaweed fouling. A more compact and streamlined keel cooler can be provided with a packaged type keel cooler as shown in **Figure 31**.

Typical Packaged Keel Cooler

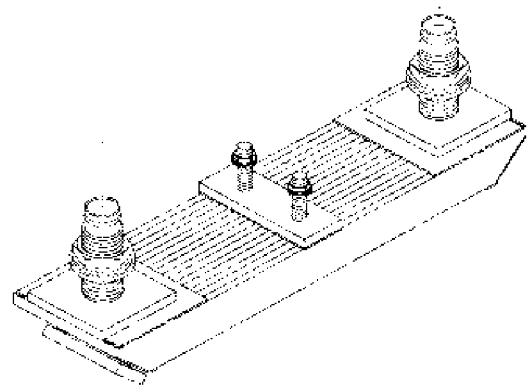


Figure 31

Packaged keel coolers are purchased as prefabricated units and mounted to the outside of a ship's hull. Manufacturers offer keel coolers in many configurations. They are generally made of copper-nickel alloys and are initially toxic to marine growth. This is one of their more important advantages. Another important advantage of packaged keel coolers is their compactness and lightweight when compared to fabricated keel coolers. Some packaged keel coolers are able to cool an engine with less than 20% of the heat transfer surface of an analogous fabricated keel cooler.

Sizing of Packaged Keel Coolers

Manufacturers of packaged keel coolers publish sizing guides which help users determine the proper cooler size for specific conditions. Caterpillar does not offer guidance outside of manufacturers guidelines, other than providing the worksheet on **Page 130** for the collection of appropriate keel cooler sizing data. This data can then be used by the keel cooler manufacturer to determine the proper keel cooler.

Location of Keel Coolers on the Hull
Keel coolers can be mounted almost anywhere on a ship's hull, providing the flexibility to match a cooler's installation to the hull design and operating conditions of most ships. For example; on shallow draft riverboats, the coolers may be mounted on the side of the hull or on the skeg. On towboats, they may be mounted near the propeller, in order to take advantage of the slipstream during heavy towing operations. On fast vessels, they are usually recessed along side the keel.

Mount the keel cooler in a well-protected area on the hull. This is particularly true of packaged keel coolers which are manufactured of lighter gauge material than fabricated keel coolers.

To achieve the greatest possible heat transfer, mount separate keel coolers for the aftercooler low on the hull and forward of other keel coolers. As with jacket water routing, the aftercooler coolant should flow through the keel cooler from the rear of the vessel toward the front of the vessel. This arrangement assures maximum heat transfer with the vessel moving forward or motionless.

Although the area immediately forward of the propeller is a region of high water velocity and high enough on the hull to be protected from grounding damage, one must consider the effects on the keel cooler from the propeller. During backing maneuvers, the propeller will create a sandblasting effect by casting sand and debris toward the cooler.

Additional considerations for keel cooler mounting:

- Seawater must flow over the entire length of the unit.
- Cooler must be parallel to the skeg or keel.
- When mounted on the side of the hull, the cooler must be positioned below the lowest water line to avoid aerated surface water.
- On fast vessels, keel coolers should be located as far aft as possible to avoid aeration.
- Keel coolers should not be located directly above propellers, in any known high vibration area, or near any raw water suction or discharge ports.

Pumps for Keel Cooler Circuits
Ordinarily, the engine water pump will satisfactorily circulate the engine jacket water through the keel cooler, if the water lines to and from the cooler are relatively short, of adequate size, with minimum bends and if the keel cooler restriction is low. If the total external flow resistance cannot be held within the jacket water pump's capacity, then the engine driven pump may need to be replaced with a suitably sized electric motor driven pump.

Venting and Piping of Keel Coolers
Locate the cooler and its through-hull connections so the length of water piping will be kept to a minimum and the cooler will be well vented. Extend water piping downward from the engine to the keel cooler, without high points.

It is very difficult to purge trapped air from the high points of some keel coolers. The air must be bled off during initial fill or when the system is completely drained. Vent plugs must be designed into the keel coolers where they rise toward the bow and stern, and any other high points where air may be trapped.

Corrosion Inhibitors
A suitable corrosion inhibitor, carefully maintained, will minimize internal corrosive effects. See the section on Cooling System Protection.

Box Coolers

Box coolers represent another type of packaged cooler that is sometimes used in marine applications. As seen in **Figure 32**, box coolers are mounted inside a vessel's sea chest. This location provides excellent protection from mechanical damage, but does negate the benefit that vessel speed through the water provides for keel cooler installations. However, box coolers, like keel coolers, eliminate the need for the raw water system associated with the use of inboard heat exchangers.

Typical Box Cooler

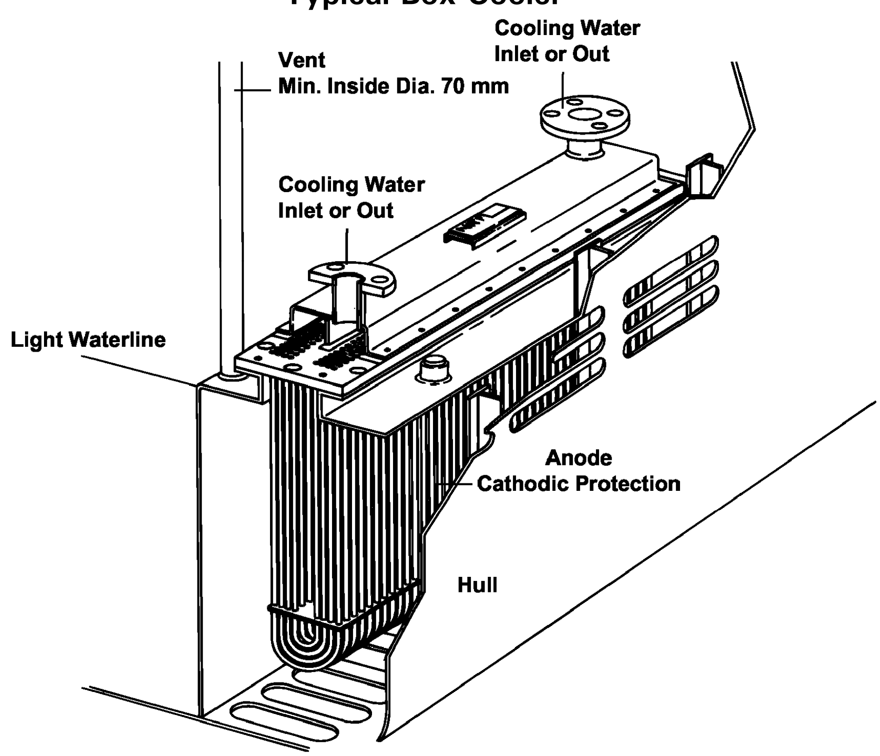


Figure 32

Seawater Systems

Due to its obvious proximity and excellent heat transfer capabilities, seawater is commonly used as a cooling medium in marine and offshore applications.

Seawater cooling systems, similar to other types of cooling systems, have many special design considerations that must be taken into account in order to ensure satisfactory engine operation and service life.

Typical seawater cooling system configurations are represented in **Figure 33**, **Figure 34**, **Figure 35** and **Figure 36**.

- Jacket Water Aftercooled with Heat Exchanger
- Seawater Aftercooled
- Separate Circuit Aftercooled with Heat Exchangers
- Separate Circuit Aftercooled with Heat Exchangers (with Aftercooler Seawater Recirculation)

Jacket Water Aftercooled with Heat Exchanger

Heat exchangers can be mounted on the engine or remote from the engine. Engine-mounted heat exchangers require the least amount of pipe fitting since the jacket water connections to the heat exchanger are provided by the factory.

Remote-mounted heat exchangers require connecting the jacket water inlet and outlet at the engine to the shell side of the exchanger. As shown in **Figure 33**, an engine driven seawater pump is used to circulate the cooling water through the heat exchanger.

Jacket Water Aftercooled with Heat Exchanger

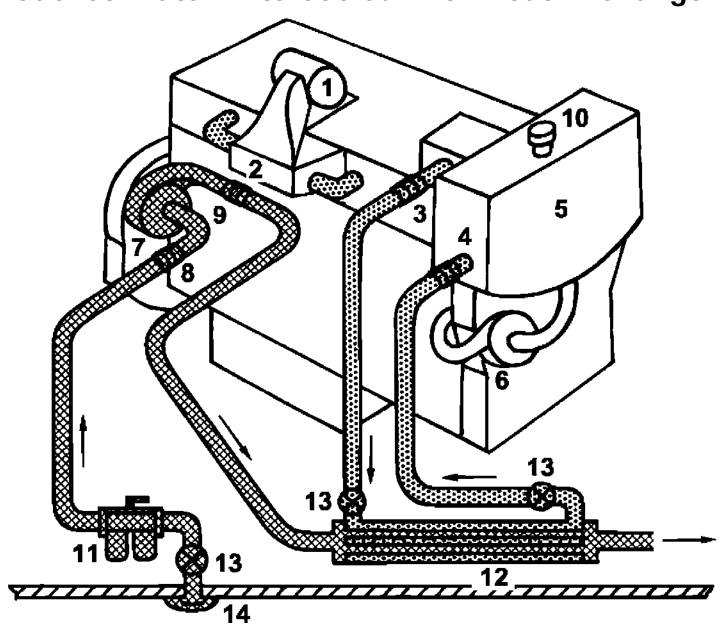


Figure 33

1. Turbocharger
2. Aftercooler, Jacket Water Cooled
3. Jacket Water Outlet Connection
4. Jacket Water Inlet Connection
5. Expansion Tank
6. Jacket Water Pump
7. Auxiliary Seawater Pump
8. Seawater Inlet Connection
9. Seawater Outlet Connection
10. Pressure Cap
11. Duplex Full-Flow Strainer
12. Heat Exchanger
13. Shut-Off Valve
14. Seawater Intake

Seawater Aftercooled

Engines equipped with seawater aftercoolers use untreated water in the tube side of the aftercooler. Seawater refers not only to salt water but also includes river water, lake water or any source of untreated water. Use of seawater for aftercooling achieves inlet manifold air temperatures lower than those resulting from jacket water or separate circuit fresh water aftercooling. This lower inlet manifold air temperature permits ratings of seawater aftercooled engines that exceed those of jacket water aftercooled engines.

Seawater Aftercooled

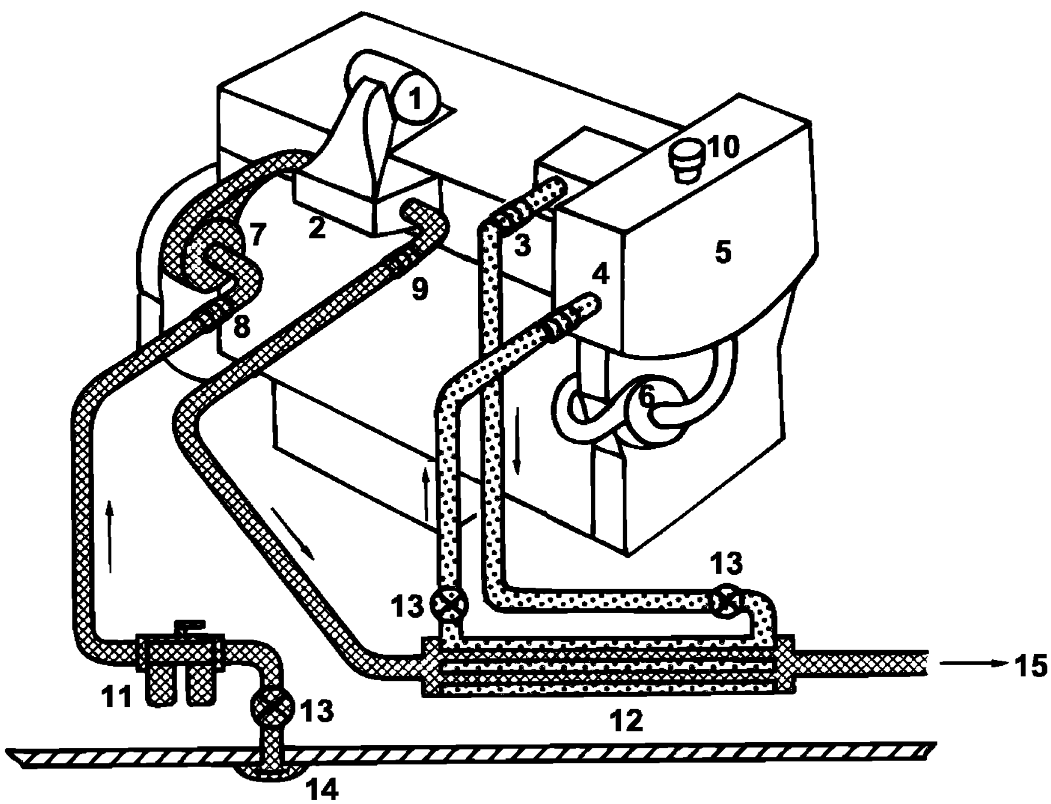


Figure 34

1. Turbocharger
2. Aftercooler, Seawater Cooled
3. Jacket Water Outlet Connection
4. Jacket Water Inlet Connection
5. Expansion Tank
6. Jacket Water Pump
7. Auxiliary Seawater Pump
8. Auxiliary Seawater Inlet Connection
9. Aftercooler Outlet Connection
10. Pressure Cap
11. Duplex Full-Flow Strainer
12. Heat Exchanger
13. Shut-Off Valve
14. Seawater Intake
15. Seawater Discharge

Separate Circuit Aftercooled with Heat Exchangers

A heat exchanger will also provide cooling for fresh aftercooler water if the seawater temperatures are cold enough to provide adequate cooling. The use of an inboard heat exchanger for the aftercooler circuit requires the use of a seawater pump in addition to the freshwater pump used to circulate water through the aftercooler. An expansion tank is also required for the aftercooler circuit.

Separate Circuit Aftercooled with Heat Exchangers

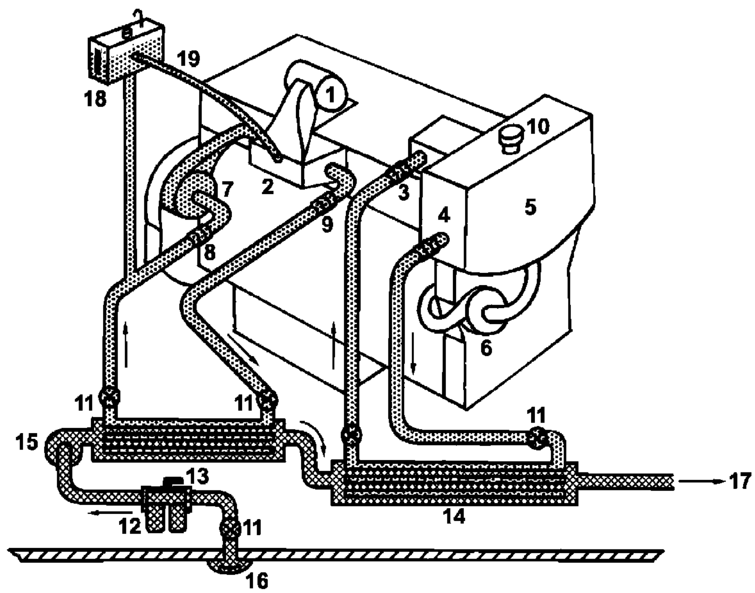


Figure 35

1. Turbocharger
2. Aftercooler, Heat Exchanger Cooler
3. Jacket Water Outlet Connection
4. Jacket Water Inlet Connection
5. Expansion Tank
6. Jacket Water Pump
7. Auxiliary Fresh Water Pump
8. Auxiliary Fresh Water Inlet Connection
9. Aftercooler Outlet Connection
10. Pressure Cap
11. Shut-Off Valve
12. Duplex Full-Flow Strainer
13. Heat Exchanger for Aftercooler
14. Heat Exchanger for Jacket Water
15. Customer–Provided Seawater Pump
16. Seawater Intake
17. Seawater Discharge
18. Expansion Tank for Aftercooler Circuit
19. Vent Line for Aftercooler Circuit

Separate Circuit Aftercooled with Heat Exchangers with Aftercooler Seawater Recirculation

The separate circuit aftercooler cooling system must be designed with sufficient capacity for the hottest water and the higher ambient air conditions for operation in climates where both air and seawater temperatures run to extremes. This results in a cooler with excess capacity in cold seawater and warm air conditions. This can result in condensation in the engine's intake system, especially during prolonged light engine load. Extremely cold seawater in the aftercooler can also cause condensation when engine inlet air temperatures are relatively warm with high moisture content.

The thermostatic valve used should not allow the temperature of the water to the aftercooler to exceed 30°C (85°F). The heat exchanger and marine transmission oil cooler used must be sized for this maximum temperature. A thermostatically controlled 3-way valve that is equipped with a remote sensor to monitor the inlet manifold air temperature can be used. Adjust the remote sensor to insure that the thermostatic valve does not permit recirculation when the inlet manifold temperature reaches 49°C (120°F).

Separate Circuit Aftercooled with Heat Exchangers (with Aftercooler Seawater Recirculation)

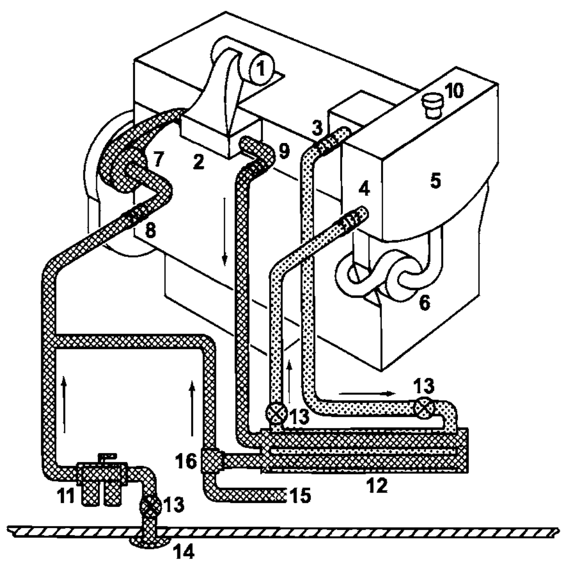


Figure 36

1. Turbocharger
2. Aftercooler, Seawater Cooled
3. Jacket Water Outlet Connection
4. Jacket Water Inlet Connection
5. Expansion Tank
6. Jacket Water Pump
7. Auxiliary Seawater Pump
8. Auxiliary Seawater Inlet Connection
9. Aftercooler Outlet Connection
10. Pressure Cap
11. Duplex Full-Flow Strainer
12. Heat Exchanger
13. Shut-Off Valve
14. Seawater Intake
15. Seawater Discharge
16. Bypass Valve Thermostatically-Controlled

It is important that water be recirculated rather than be throttled to reduce flow. It is essential that unrestricted water flow through the aftercooler be maintained regardless of temperature conditions. Thermostatic valve plumbing must be sized to have internal diameters as large, or larger, than the inlet connection of the auxiliary pump. Use an air intake manifold temperature alarm set for 52 to 57°C (125 to 135°F) maximum to warn of a system malfunction.

In situations where condensation can be a problem, a corrosion-resistant water trap can be attached to the intake manifold(s) of the engine; refer to **Figure 37**.

Condensate Valve Group

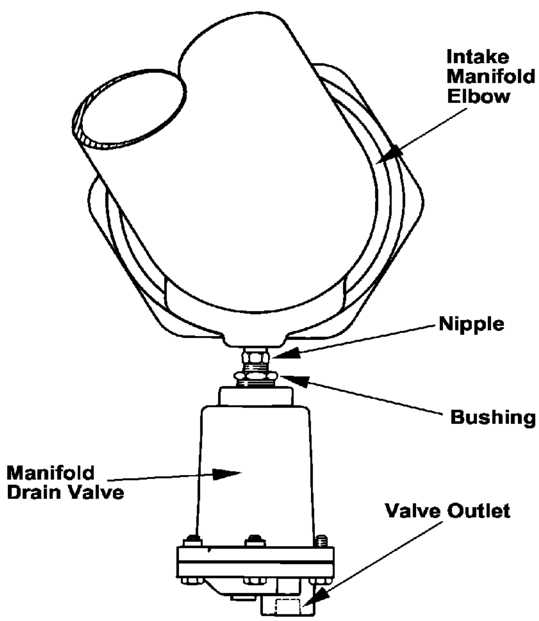


Figure 37

3600 Combined Circuit System

Figure 38 is a typical combined circuit seawater cooling system designed for 3600 marine applications. The fresh water circuit is cooled with seawater having a maximum temperature of 32°C (90°F). Since the lubricating oil and air aftercooler are cooled directly by water from the fresh water cooling circuit, only one fresh water heat exchanger is required. The aftercooler and oil cooler systems are an integral part of the basic engine design; nothing is required from the shipyard to pipe these systems. The arrangement reduces the seawater piping system and lowers the cost of expensive copper-nickel alloy piping, fittings, and valves. The result is less wear, corrosion problems, and maintenance.

Typical Seawater Cooling System

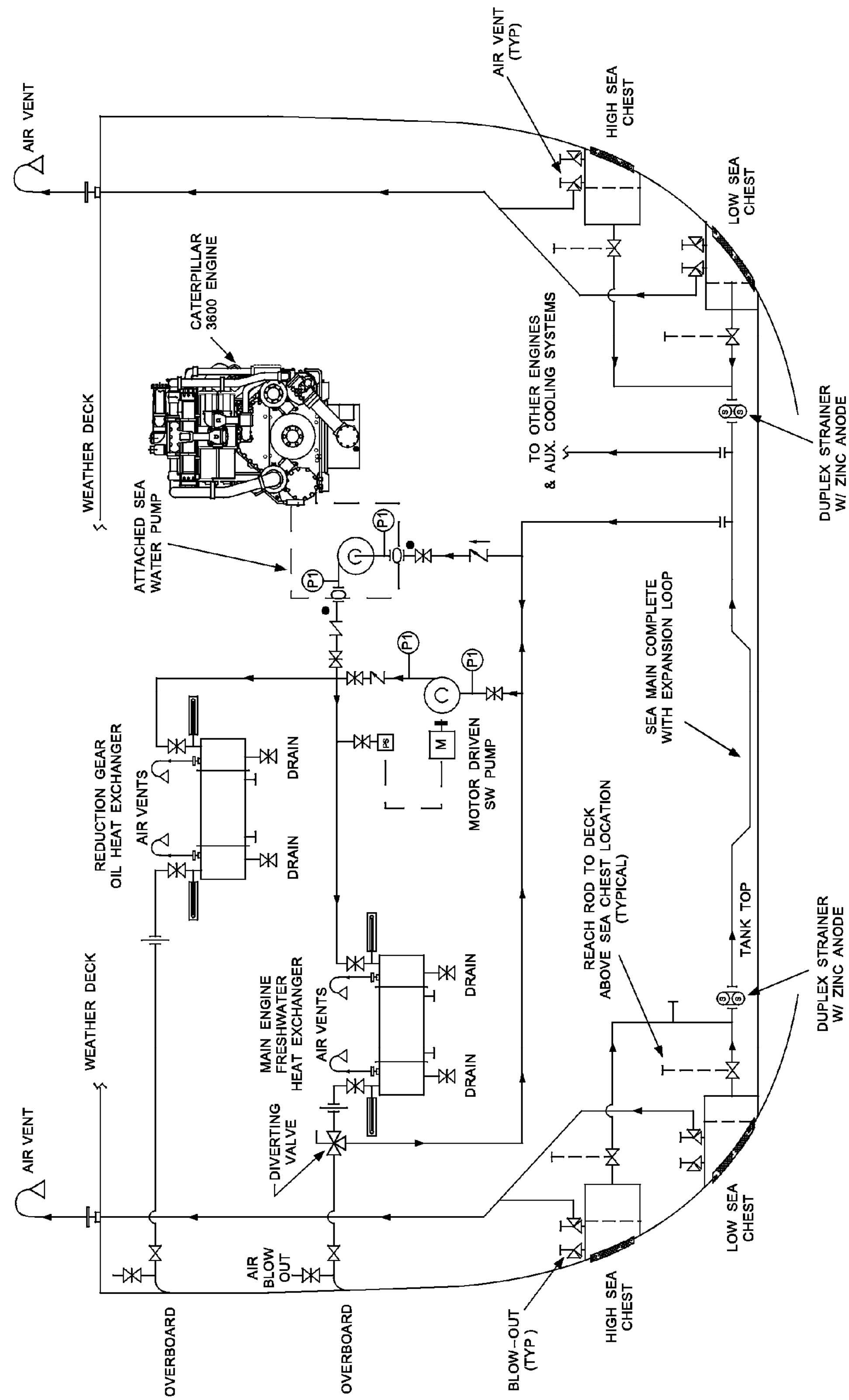


Figure 38

Sea Chest

The sea chest serves the following functions:

- Provides a low restriction connection for the seawater inlet plumbing.
- Provides a connection point for the sea cock. The sea cock is a seawater shutoff valve that is installed between the seawater inlet and the seawater inlet plumbing.
- Provides a way to separate air from the seawater required for cooling. Sea chests must have vent connections to allow air, forced under the hull during maneuvering, to be purged before it is able to reach the centrifugal seawater pump.

Suction Line

The installation, size and material of the seawater suction lines are extremely important.

The seawater suction lines should be below the vessel water line as much as possible and designed without air traps.

Install a water pressure actuated check valve downstream of the strainer and as close to it as possible. The function of the check valve is to prevent water from draining out of the pump inlet while the pump is not operating and during cleaning of the strainer. Install a vent valve between the strainer and the check valve to allow venting of trapped air after cleaning the strainer and opening the sea cock. If the pump is above the vessel water line, install a piping loop above the pump inlet elbow to trap enough water to keep the pump and priming chamber filled.

Sea Valve

Where practical, all sea valves should be flanged gate or globe type. Lug type butterfly valves may also be used. Angle valves can be used where the installation of gate, globe or butterfly valves are impractical.

Sea valves should be controllable from a deck above the sea chest. Fit all valves with open/close indicators.

The recommended materials for sea chest or overboard discharge valves are cast steel, bronze or nodular iron. Cast iron and malleable iron valves are not recommended. The valve seat, disk, and stem must be made from corrosion resistant material such as monel alloys.

Seawater Strainers

Strainers are required in order to protect the seawater pump, aftercooler, heat exchanger and other cooling system components from foreign material in the seawater. The foreign material can plug and/or coat heat transfer surfaces, causing overheating of the engine and shortened life of components. If the foreign material is abrasive, it will erode pump impellers and soft metal parts, reducing their effectiveness.

Seawater strainers should be installed below the water line and as close to the seawater inlet or sea chest as possible. The strainers should also be installed adjacent to the sea cock and before the first component of the cooling system. The strainer must be installed so it can be easily cleaned, even in the worst weather conditions.

Although simplex strainers will adequately protect the engine, they require the seawater flow to be shutoff during servicing. Duplex strainers can be cleaned without interrupting seawater flow or engine power and greater safety will result. It is strongly recommended to use a serviceable strainer in order to allow frequent cleaning.

Appropriately sized strainers will impose no more than 9 kPa (3 ft H_2O) restriction to flow at full seawater flow conditions. Suppliers can help in the proper selection of strainer size by providing the flow restriction of each size of strainer at varying water flow conditions.

Strainer media of 2.0 mm (0.079 in) diameter hole size or less is required. Strainer media of 1.6 mm (0.0625 in) diameter hole size is recommended in applications where sea grass and/or other debris are present, or cases when plugging of engine cooling components persists with the use of 2.0 mm diameter media.

Schools of small fish, ice chips and floating debris such as plastic bags and plant material can plug a clean strainer in a few seconds. When this happens, the differential pressure across the strainer will rise. This is an indication that the strainer should be cleaned. A differential pressure switch will provide early warning of strainer plugging and resultant loss of engine cooling. In time, high engine water temperature alarms will also warn of a loss of seawater flow, but the differential pressure sensor will give early warning and the precise location of the problem. Even with a differential pressure sensor, best practice is to clean the strainer frequently in order to ensure optimum engine performance and reduce stress on the cooling system components.

Priming

All seawater pumps (self priming, centrifugal and water ring pumps) MUST be filled with water prior to initial start up to ensure that the pump primes and also to avoid damaging the mechanical seal and impeller. Once initial priming has taken place, there is no need to re-fill the pump unless the system has been fully drained.

Seawater Pumps

Two centrifugal seawater pumps are typically required for marine propulsion applications; one is engine driven and one electrically driven.

The engine driven seawater pump is not self-priming, so it must be located below the light water line of the ship or a priming arrangement must be provided. The engine power required to drive the Caterpillar supplied pump is shown in TMI.

The electrically driven seawater pump capacity is determined by the type of cooler used, heat to be dissipated, and the seawater inlet temperature. The heat to be dissipated in the main engine fresh water heat exchanger is listed on the engine technical data sheets.

In many seawater systems, the pump supplying cooling water to the main engine heat exchanger also supplies cooling water to auxiliary heat exchangers, such as the reduction gear oil cooler. In these arrangements, the capacity of the seawater pump must be increased to allow for the additional requirements.

Start and stop control of the electric motor driven pump should be with a pressure switch installed in the common discharge line from the pumps. The switch starts the pump at 35 kPa (5 psi) and stops at 245 kPa (35 psi). The pipes connecting to the individual pumps must be at least equal to the pump suction diameter, to minimize the restrictions in the suction piping.

The suggested materials for seawater pumps are shown in **Table 6**.

Suggested Material for Seawater Pumps	
Component	**Material/Type**
Casing	Bronze
Impeller	Bronze
Shaft	Monel
Seal Type	Mechanical

Table 6

Caterpillar offers three types of seawater pumps.

- Rubber Impeller
- Water Ring
- Centrifugal

Rubber Impeller Seawater Pumps

Rubber impeller seawater pumps are characterized by excellent priming characteristics, though they often suffer relatively short life in abrasive waters.

Water Ring Seawater Pumps

Their priming characteristics are less than rubber impellers, but can lift up to 1.5 m (5 ft).

Caution: A goose neck may be necessary with these pumps to keep water in the pump for priming. The goose necks are made entirely of corrosion resistant metals, with no elastometric components.

Centrifugal Seawater Pumps

Centrifugal seawater pumps must be installed with their inlet below the boats light waterline. Air allowed to enter centrifugal seawater pumps will likely result in loss of prime and probable engine damage due to loss of cooling. Do not start an engine equipped with a centrifugal pump unless the pump and priming chamber are full of water.

Seawater Piping

Flow restriction in the seawater suction piping will result in abnormally high engine temperatures which can lead to unscheduled shutdowns and, in severe cases, reduced engine life. To minimize flow restriction, pipes and hoses should be at least as large as the seawater pump suction opening.

If the distance to the through-hull fitting or sea chest is large or if many pipe elbows or bends in the hose are used, the pipe or hose size should be one size larger than the seawater pump opening (suction connection). In no case should the seawater pressure, measured at the seawater pump suction, be less than 24 kPa (3.5 psi) vacuum.

Piping System Materials

An excellent material for piping carrying seawater is of the copper- nickel alloys; CuNi 90/10 UNS C70600 is recommended. The cost of such piping makes its use unusual for all but the most critical systems.

The material of all the seawater piping should be the same, whenever practical. If parts of the seawater piping, made of different metals, make contact with each other, one of the metals will corrode, sometimes very rapidly.

The materials will corrode according to their position in the electromotive series. See electromotive series chart in section of Useful Tables to Designers of Cooling Systems.

Black iron pipe is often used in seawater service (replacement should be planned every two or three years). If it is necessary to use pipe or other cooling system components of more than one material, avoid letting the dissimilar metals touch, even by mutual contact with an electrically conductive third material.

Corrosion will be much more severe if a flow of electrons is able to pass freely from one of the metals to the other.

Fresh Water Heat Exchangers

Caterpillar supplies both shell and tube and plate and frame type coolers for the fresh water heat exchanger.

The suggested materials for the shell and tube type heat exchangers are shown in **Table 7**.

Suggested Material for Shell & Tube Type Heat Exchangers	
Component	**Material/Type**
Shell	Steel
Heads	Iron
Tubes	90/10 CuNi
Tube Sheets	90/10 CuNi
Baffles	Steel

Table 7

A plate and frame type heat exchanger can be substituted for the shell and tube type. If installed, the suggested materials for the plate and frame heat exchanger are shown in **Table 8**.

Suggested Material for Plate & Frame Type Heat Exchangers	
Component	**Material/Type**
Frame	Mild Steel, Painted
Seawater Plates	Titanium or Aluminum Brass
Fresh Water Plates	Stainless Steel
Seawater Nozzles	Steel, Coated
Fresh Water Nozzles	Steel, Coated
Gaskets	Nitrile

Table 8

Classification societies may require a spray shroud around the plates to prevent liquid spray on equipment or personnel if a gasket fails.

The engine technical data sheets include heat rejection to the seawater for the various propulsion engine ratings. Add a safety margin of 10% to the total heat rejection to allow for heat exchanger fouling.

Marine Gear Oil Cooler

Reduction gear lube oil coolers normally use seawater taken directly from the engine seawater circulating system. The water flow required is obtained from the gear manufacturer.

Stern Tube Lubrication & Cooling

It is good practice to divert a small portion of the engine's seawater to lubricate and cool the stern tube and stuffing box (sometimes called the packing gland) before discharging it overboard. Generally, 4-12 L/min (1-3 gal/min) are adequate.

The engine's seawater strainer and the flow of water from the stuffing box end of the stern tube will tend to keep sand and other abrasive material out of the stern tube.

Avoid using excessive quantities of the engine's flow of seawater, as this practice tends to increase the seawater system restriction, making the engine more likely to overheat.

Seawater Temperature

In some instances, the seawater temperature may be too low for the fresh water heat exchanger. It can be raised by installing a locally or remote controlled three-way valve just inboard of the overboard discharge valve. The valve bypass feeds warmed discharge water directly back to the common suction pipe of the seawater circulating pumps.

Note: Pressure drop across the valve would normally be about 35 kPa (5 psi), and must be included in the seawater pump total dynamic head requirements.

Marine Growth

Marine plants and animals will enter seawater systems and take up residence in the piping and passages of the heat exchanger. Many forms of sea life are very comfortable within engine cooling system piping and will grow to a size that will threaten adequate cooling system flow. The lack of predators, darkness and abundance of suspended food particles combine to create prime growth conditions for sponges, barnacles and like creatures. Strainers are no protection against creatures that are microscopic in size during their infant stages of life.

Periodic operation in fresh water will exterminate salt-water life in the cooling system. Likewise, periodic operation in salt-water will exterminate fresh water life. However, the cooling system piping and passages must be cleaned to remove the deceased organisms. Heat exchangers must be periodically disassembled to remove marine growth in the heads and tubes.

Periodic chemical treatment combats marine growth. Chemical type and concentration must be carefully controlled to prevent deterioration of the seawater cooling system components. Contact a knowledgeable chemical supplier. Continuous low-concentration chemical treatment via either bulk chemical or self-generating electrical processes is offered by various manufacturers.

High water temperature alarms, seawater pump pressure switches and other instrumentation can be used and are highly recommended to warn of the gradual loss of seawater flow.

Potential Problems

Non-reinforced Seawater Pump Suction Hose

The vacuum inside the Seawater Pump Suction Hose can become quite high. If the hose is not internally reinforced, atmospheric pressure will collapse it. That will severely impede the flow of seawater with potentially dangerous results. Use a hose which is sufficiently strong to resist collapse due to high suction vacuum.

Internal Hose Deterioration
Some hose will shred internally, releasing bits of rubber which can plug cooling passages. It is good practice to use good quality hoses. If users are unsure of their hoses' quality, it is good practice to examine hoses internally at least once during their life. Replace them with good quality hose every three years.

Achieving and Maintaining Seawater Pump Prime
Pump speeds and suction pressures must fall within certain limits for seawater pumps to achieve prime (start pumping water). The priming characteristics of Cat seawater pumps are available from the factory.

Seawater Discharge through Exhaust System
Wet exhaust systems use seawater, after it has passed through the various heat exchangers and coolers, to cool the hot exhaust gases. After seawater is injected into the hot exhaust gas (generally immediately downstream of the engine's turbocharger), the temperature of the gas is reduced enough to allow use of sections of rubber hose, fiberglass-reinforced plastic pipe or other similar materials to be used as exhaust pipe. It is critical that nothing interfere with the flow of seawater which cools the exhaust gas. Anytime the engine is operating, the flow of seawater must be present.

Corrosion

Galvanic Corrosion in Seawater
When two dissimilar metals are electrically connected and both submerged in saltwater, they form a battery and an electrochemical reaction takes place. In this process, one metal is eaten away. The rate of deterioration is proportional to a number of factors:

- The differential potential between the two metals on the electrochemical series (see Useful Tables to Designers of Cooling Systems).
- The relative areas of the two metals: If there is a small area of the more noble metal relative to the less noble metal, the deterioration will be slow and relatively minor. If there is a large area of the more noble metal such as copper sheathing on a wooden hull, and a much smaller area of the less noble metal, such as iron nails holding the copper sheathing to the wood, the wasting away of the iron nails will be violent and rapid.
- Stray electrical currents will accelerate the electrochemical reaction. Proper grounding and isolation from all electrical sources is required.

Dissimilar Metal Combinations to Avoid

- Bronze Propeller on Steel Shaft
- Mill Scale on Hull Plate (Internal or External)
- Aluminum Fairwaters Fastened to a Steel Hull
- Steel Bolts in Bronze Plates

- Bronze Unions and Elbows Used With Galvanized Pipe
- Bronze Sea Cocks on Iron Drain Pipes
- Brass Bilge Pumps on Boats With Steel Frames
- Brass, Bronze, or Copper Fasteners in Steel Frames
- Stainless Steel Pennants on Steel Mooring Chains
- Bronze or Brass Rudder Posts With Steel Rudders
- Bronze Rudders With Steel Stopper-Chains
- Steel Skegs (Rudder Shoes) Fastened With Bronze or Brass Leg Screws
- Steel and Brass Parts in the Same Pump

Many of the combinations above follow this basic rule:

Do not put iron or steel close to or connected with alloys of copper in salt water.

The Protective Role of Zinc

If alloys of copper (bronze, brass), iron (steel), and zinc are all connected together and submerged in salt water, the zinc will be eaten away, protecting the iron (steel). It is necessary to have a metallic electrical connection to the metals to be protected. This is usually easy to accomplish on a steel hull. It is more difficult on a fiberglass hull, since special electrical connection may be required unless the zincs are connected directly to one of the metals, preferably the copper alloy.

Note: The zinc must never be painted or its protective quality will be lost.

Zincs are not necessary for keel cooled systems and should be removed when converting to fresh water system. For seawater cooled systems, zincs should only be installed on the discharge of the pump. Zincs installed on the inlet side of the pump after the strainer could result in pump damage.

When electrical contact is made through the fastening studs, it is desirable to put galvanized or brass bushings in the holes in the zincs so that contact will be maintained as the zincs corrode.

Zinc anode rods should be initially inspected after the first 50 hours of operation. The condition of the zinc rod will determine how often the zinc rods should be inspected for possible replacement. As zinc rods work, a white, crust-like deposit of zinc oxides and salts form on the surface. This is normal. If it does not form and the zincs remain clean and like new, they are not protecting the structure. This would indicate that the zinc anodes are either not connected electrically to the less noble metal or the anode is not located in the right location to protect the less noble components. This should be corrected immediately as the less noble metal will quickly be eaten away be corrosion.

Zinc anodes are available in two types, threaded and press fit. The press fit type is where the zinc anode is pressed into the threaded plug. The threaded type is where the zinc anode is threaded into the threaded plug that is inserted into the desired plumbing location. Caterpillar recommends using the threaded type. The press fit type can fail prematurely and fall out of the threaded plug. Then the desired protection to the system will not be provided. Zinc anodes are made in two types of material. Type 1 contains zinc and cadmium. This is the most common standard type of anode. Type 2 contains almost pure zinc. This is the standard for under ground mining applications. Caterpillar recommends using only the Type 2 threaded anodes as the anode will last longer, and the cadmium is a hazardous material to the environment. Inspect the zinc plugs within 24 hours of filling the piping with seawater. If no significant corrosion is noted, inspect them again after 50 operating hours. Inspect them again in 7 days of seawater submersion. If no significant deterioration is noted, inspect them again in 60 to 90 days. Thereafter, inspect on a regular basis determined by the life of the zinc anodes and replace them when necessary. Time after submersion is a critical factor since corrosion continues when the engine is not running.

Seawater flow rate is critical to system component life. A protective film is produced on the surface of copper nickel if fresh clean oxygenated seawater continuously flows at a minimum rate of 1 meter/second. Too little or too much flow rate can cause component failure. The system should not be left idle or stagnant (without circulation flow) when ever possible. If the system is to be shut down for more than a few hours then the system should be drained and blown dry with compressed air. Localized pitting of components can occur quickly if salt water is left uncirculated in the plumbing. A minimum flow rate of 1 m/sec should be maintained even if the engine is not running. Flow rates greater than 3.5 meters per second can cause the protective film to be eroded.

Pressure taps should be installed before and after the seawater heat exchanger to allow for flow measurement.

Contaminants

Flow rates should not exceed 2 meters per second if the seawater contains sand or debris to prevent erosion.

Contaminants in the cooling system can cause component failure quickly if the zinc anodes are not properly installed and maintained. Dissimilar metals are common on tubes and piping from the manufacturer due to the machinery forming the material or from fabrication and installation of the plumbing system. This can leave small particles of metal on the formed metal and can cause pitting of the formed piece if not protected. Even with washing and cleaning some of these particles remain on the surfaced of the desired component. This is common for many materials and the effect is accelerated when seawater is present in the system. This is why it is very critical to properly maintain the zinc anodes as they are the protection for the entire seawater cooling system. Without their protection failure can happen in a matter of hours.

Electrochemical Series

The following series of elements is listed in order of highest reactivity or corrosiveness to lowest, as they relate to cooling system components.

Corroded End — Least Noble
Magnesium
Magnesium Alloys
Zinc
Beryllim
Aluminum Alloys
Cadmium
Mild Steel or Iron
Cast Iron
Low Alloy Steel
Austanitic Cast Iron
Aluminum Bronze
Naval Brass
Yellow Brass
Red Brass
18-8 Stainless Steel (Active)
18-8-3 Stainless Steel (Active)
Lead-Tin Solders
Lead
70-30 Copper Nickel
Tin
Brasses
Copper
Bronzes
Copper-Nickel Alloys
Monel
Admiralty Brass, Aluminum Brass
Manganese Bronze
Silicon Bronze
Tin Bronze
Silver Solder
Nickel (Passive)
Chromium-Iron (Passive)
18-8 Stainless Steel (Passive)
18-8-3 Stainless Steel (Passive)
Silver
Ni-Cr-Mo Alloy 8
Titanium
Ni-Cr-Mo Alloy C
Gold
Platinum
Graphite
Protected End – Most Noble

General Corrosion

A protective film is produced on the surface of copper-nickel if fresh clean oxygenated seawater continuously flows at a minimum rate of 1 meter/second. If long stagnant conditions are expected, blow-drying the system is recommended.

Flow rates greater than 3.5 meters per second can cause the protective film to be eroded.

Polluted water containing sulfides is especially corrosive to copper alloys and should be avoided.

Erosion

Flow rates should not exceed 2 meters per second if the seawater contains sand or debris.

Pressure taps should be installed before and after the seawater heat exchanger to allow for flow measurement.

Heat Recovery

Heat recovery refers to the capture and utilization of heat energy which is normally wasted. This process, increasingly common today, improves total system efficiency and return on investment.

Reciprocating engines convert about 30-42% of their input fuel energy into mechanical power. Another 20-40% is rejected to the jacket water, 30-40% to exhaust, and 5-7% is radiated to the environment.

The heat rejected by the jacket water can be totally recovered and 50-70% of the exhaust energy is economically recoverable. Total heat recovery results in approximately 80% efficiency.

Heat recovery design best suited for any installation depends on many considerations, both technical and economic. The chief function of any design is to cool the engine. The engine must be cooled even when heat demand is low, but power is still required.

There are two heat recovery methods: standard temperature and high temperature. Standard temperature heat recovery systems recover heat from coolant at up to 99°C (210°F) outlet temperature. High temperature heat recovery systems recover heat from coolant at up to 127°C (260°F) outlet temperature. High temperature systems are further divided into solid water, water and steam, and ebullient steam systems.

Heat Balance

The typical heat balance for a Cat engine is shown in **Figure 39**. Heat rejection values for the following components are provided for all engines in the Technical Data Manual or Specification Sheets.

- Jacket Water Heat Rejection
- Oil Cooler Heat Rejection
- Aftercooler Heat Rejection
- Exhaust Heat Rejection
- Exhaust Heat Recoverable

Typical Heat Balance for Cat Engines

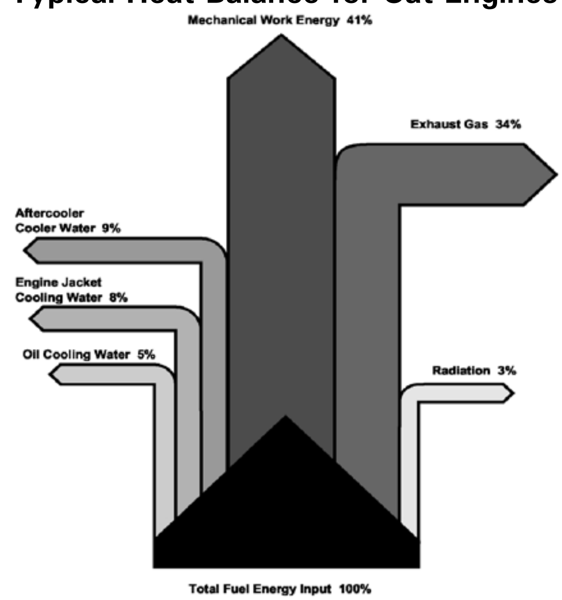


Figure 39

Heat Balance Calculation

Typical heat balance calculations are illustrated in the following example. The values used in the example are for illustration purposes and should not be used for design. Refer to the published heat rejection data for the specific engine for design calculations.

HEAT BALANCE EXAMPLE

Using a G3612 Combined Heat and Power (CHP) Engine with 11:1 compression ratio rated at 2990 bKw Prime Power at 1000 rpm, with the CHP cooling system, as an example:

Engine Output	2990 bkW (4010 bhp)	(At 100% load conditions)
Generator Output	2875 kW	(At 96.2% Generator Efficiency)

Heat Rejection Available (from Specification Sheet):	kW	(Btu/min)
a) Engine Jacket (cylinder block) water at 99°C (210°F)	534	(30,321)
b) Oil Cooler (std. shell & tube, 3 coolers)	365	(20,725)
c) Aftercooler (single stage)	652	(37,021)
Total Heat Rejected to the cooling system	**1551**	**(88,066)**

Fuel input can be taken from the specification sheet or calculated as shown below,

Total Fuel Input $= \dfrac{BSFC \times bkW}{3.6}$ in kW or $= \dfrac{BSFC \times bhp}{60}$ in Btu/min

$= \dfrac{8.66 \times 2990}{3.6} = 7192$ kW (409,009 Btu/min)

Recoverable Heat rejection can be taken from the Specification sheets or calculated.

Total Exhaust flow from Specification Sheet	= 20892 KG/hr	(45.962 lb/hr)
Exhaust Stack Temperature	=359°C	(678°F)

Recoverable Exhaust Heat Rejection at 120°C (248°F)*

	kW	(Btu/min)
= Specific Heat of Exhaust Gas × Total Exhaust Flow × ΔT		
= 1.107 KJ/KG.°C × (20892/3600) KG/sec × (359 − 120)°C	**1554**	**(88,376)**

where Specific Heat of Exhaust Gases, Cp, is given in the *Heat Rejection* section of the *Cooling System* chapter

Total Recoverable Heat Energy = Jacket water heat energy + Oil cooler heat energy
+ Aftercooler heat energy
+ Exhaust heat energy (at 120°C or 248°F)
= 534 + 365 + 652 + 1554 =
= **3105 kW (176,581 Btu/min)**

Recoverable Heat in % = 3105 kW/Fuel input kW = (3105/7192) 100 = **43.2%**

Brake Thermal Efficiency, η =bkW/Fuel input kW = (2990/7192) 100 = **41.6%**

Total Thermal Efficiency = Brake thermal efficiency + Recoverable Heat energy
= 41.6 + 43.2

Total Thermal Efficiency **= 84.8%**

* The values of Recoverable Exhaust Heat Rejection calculated with this formula will vary by ±3% from the specification sheet values due to changes in Cp value with temperature and other conditions.

Standard Temperature Heat Recovery

Heat recovery of a standard engine may amount to nothing more than utilizing heat transferred from the engine radiator. This air is usually 38-65°C (100-150°F). The recovered heat is quite suitable for preheating boiler combustion air, space heating or drying grain and lumber. The system cost is minimal and overall efficiency will increase to approximately 60%.

A more versatile method of recovering heat from a standard temperature system uses a heat exchanger to transfer rejected engine heat to a secondary circuit, usually process water. An example system is illustrated in **Figure 40**. There are many advantages inherent with this design. The standard engine jacket water pump, thermostatic configuration, and water bypass line are retained. The engine system is independent from the load process loop, which allows operation with antifreeze and coolant conditioner. This relieves concern for problems associated with using process water to cool the engine.

When normal process load is insufficient to absorb enough heat, load balancing thermostatic valves limit jacket water inlet temperature by directing coolant through a secondary cooling source (load balancing heat exchanger).

Note: The load balancing heat exchanger must be incorporated in the engine loop, not the load loop. The load balancing condenser may be either a heat exchanger or radiator. Heat transfer through the load balancer is usually cyclical. If a radiator is used, it must be designed to withstand thermal shocks developed from cyclic loading.

Standard Temperature Water System

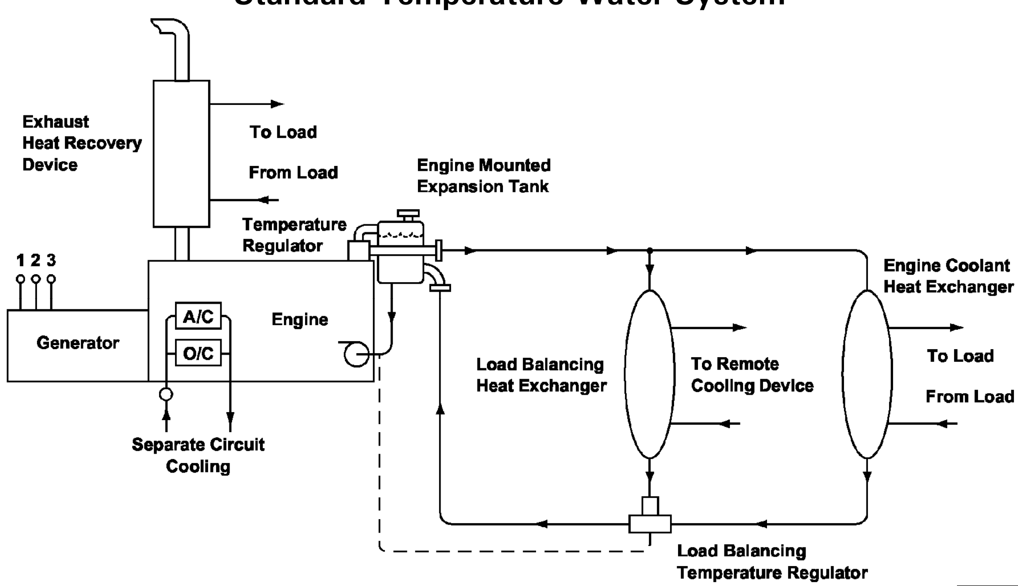


Figure 40

A second variation on the standard temperature system includes an exhaust heat recovery device in the system in series, parallel, or as a separate water or steam circuit. Consult the manufacturer for design details for the unit in question. **Figure 41** shows a muffler included in series with the engine system. Note the engine loop is still separate from the load loop. The engine expansion tank may be utilized. Generally, boiler water is used as a medium in the load loop. Boiler water is pumped through the jacket water heat exchanger and exhaust heat recovery device in series where it is heated to the desired temperature. As shown, water flow through the expansion tank provides deaeration.

Standard Temperature Water System with Muffler In Series

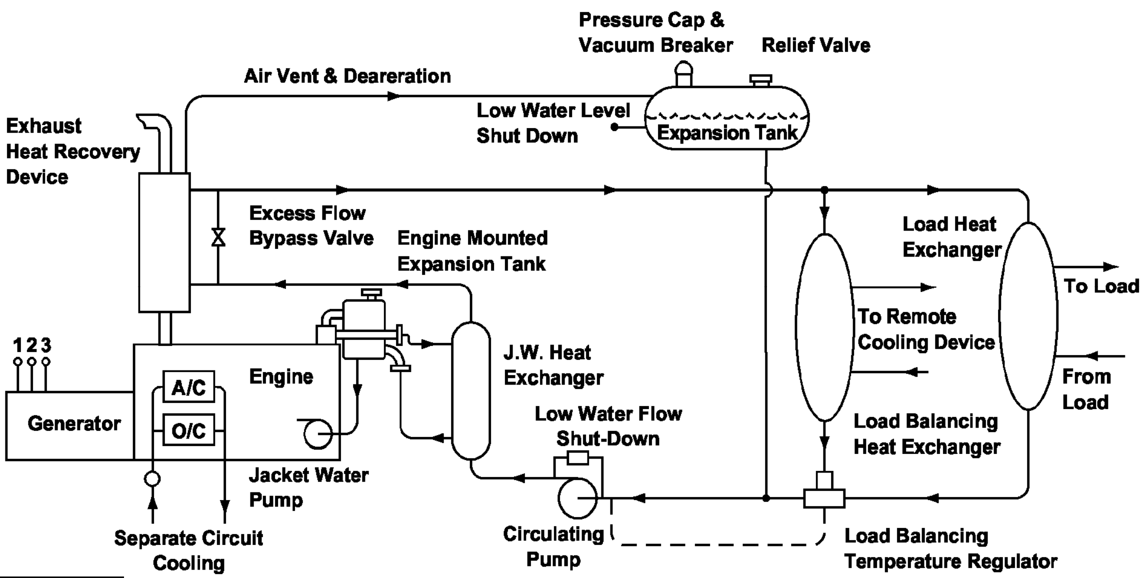


Figure 41

A third variation on the standard temperature system is to incorporate the exhaust heat recovery device into the engine cooling loop, **Figure 42**. To ensure coolant flow through the muffler, the engine thermostats and the bypass line must be removed and an external warm-up thermostat is added. (The added external resistance of the heat recovery device may exceed the allowable resistance available from the engine mounted pump.) An auxiliary circulation pump may be required. The advantages of this system are that the obtainable process water temperature is usually higher and there are fewer components. The disadvantages to this system are the engine cooling system is modified, and the design of the system becomes more critical to successful engine operation.

Caution: Any heat recovery system where the process water circulates in the engine is not recommended. Experience has shown that, in most cases, the user cannot economically treat the quantity of process water to the level required to avoid maintenance problems with the engine.

Standard Temperature Water System with Exhaust Heat Recovery Device Incorporated

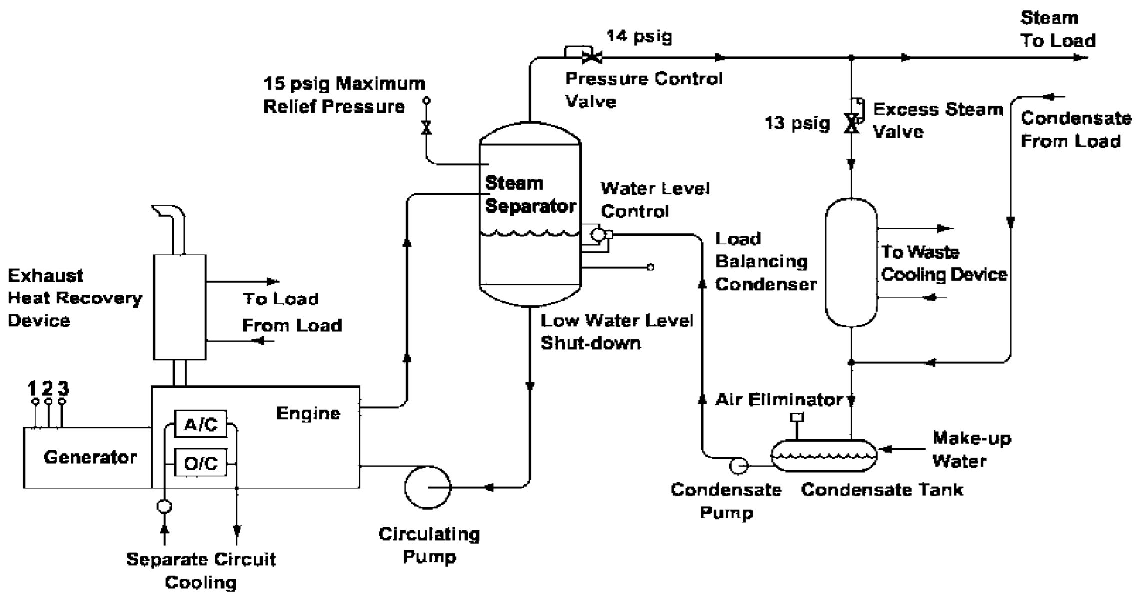


Figure 42

Critical Design Criteria for Standard Temperature Heat Recovery

The purpose of the following discussion is to call attention to certain basic criteria necessary for proper operation of a heat recovery system. In no way should this be considered an all-inclusive list. Contact a consulting engineer for specific requirements.

- The system must provide adequate coolant flow through the engine so the engine coolant temperature differential (outlet minus inlet) does not exceed 11.1°C (20°F).
- The expansion tank must be the highest point in both the engine and load loop cooling systems. The pressure cap on the expansion tank should be rated for a pressure higher than the inlet pressure requirements of the jacket water pump.
- Use only coolant or treated water in the engine cooling circuit.
- Incorporate deaeration circuit and air vents to eliminate air traps and locks.
- A load balancing thermostatic valve must be used to direct coolant through a secondary cooling source to limit jacket water inlet temperature.
- Coolant must continually flow through the exhaust heat recovery device when the engine is operating to avoid thermal shock on hot muffler surfaces. This may be accomplished using a low water flow shutdown device.
- After engine shutdown, the coolant must continue to flow through the engine until the coolant temperature falls below 94°C (194°F) to avoid steam pockets forming inside the engine.
- If the engine thermostats are removed, an external warm-up thermostat is required.
- To keep external head within allowable limits for the engine-mounted pump, locate heat recovery mufflers and heat exchangers as near the engine as possible. While static head on the jacket water pump is limited to 172 kPa (25 psi) static head greater than 35 kPa (5 psi) requires the expansion tank to be vented to air, i.e., no pressure cap.

High Temperature Heat Recovery Circuits

To ensure proper cooling in all types of high temperature systems, the engine oil cooler and aftercooler require a cooling water circuit separate from the engine jacket water. A thermostat in the oil system bypasses the oil cooler to control lubricating oil minimum temperatures and prevent overcooling. If the coolant in the oil cooler circuit can be below 10°C (50°F), an external control valve is recommended to allow the oil to reach operating temperature, prevent oil gelling, and ensure oil flow through the oil cooler.

High Temperature Solid Water System

This system functions similar to a standard temperature water system except elevated jacket water temperatures 99-127°C (210-260°F) are used. The standard thermostat and bypass are removed and replaced by an external control. A pressure cap or static head must be provided in the engine coolant circuit to assure a pressure of 27.6-48.3 kPa (4-7 psig) above the pressure at which steam forms. (See **Pressure Control**)

The source of this pressure may be a static head imposed by an elevated expansion tank or controlled air pressure in the expansion tank. For 127°C (260°F) water, the pressure at the engine should be approximately 172 kPa (25 psig). Maximum system pressure allowed on the engine water jacket is 276 kPa (40 psig). This is measured by taking the total of circulating differential pressure, system pressure, and static resistance on the system. The standard jacket water pump is removed and must be replaced by one with high temperature and pressure capabilities.

Critical Design Criteria for High Temperature Solid Water

High temperature solid water systems include the same basic requirements as a standard temperature system, but the following points must also be considered.

- A high temperature system requires a pressure control valve for the engine coolant circuit.
- Water pumps must be suitable for use with elevated temperatures and pressures.
- The engine oil cooler requires a cooling circuit separate from the engine jacket water.
- The load balancing heat exchanger must be incorporated in the engine loop, not the load loop. The load balancing condenser may be either a heat exchanger or radiator. Heat transfer through the load balancer is usually cyclical. Thus, if a radiator is used, it must be designed to withstand thermal shocks developed from cyclic loading.
- For multiple units that share a single steam separator, all circulating pumps must run when any one engine operates. This practice prevents a severe thermal shock if a unit is started later.
- High jacket water temperatures will result in after-boil if there is a hot shutdown. Add an additional 10% of system volume to the normal expansion tank sizing guidelines to provide expansion volume (25% total for high temperature solid water systems).

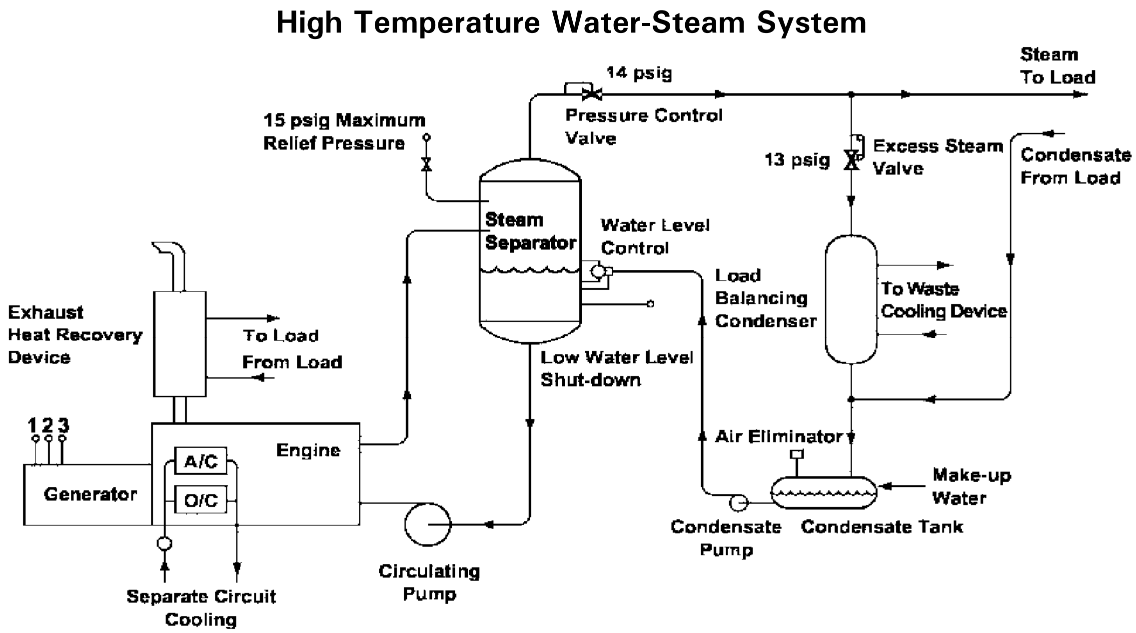


Figure 43

High Temperature Water-Steam System

The high temperature water-steam system provides solid water to cool the engine, but then flashes it to steam to be used for loads requiring low-pressure steam, 96 kPa (14 psig). A circulation pump forces water through the cylinder block to the steam separator. In the steam separator, some of the water flashes to steam and the water returns to the engine.

The pressures shown in **Figure 43** are representative values. The relief valve pressure 103 kPa (15 psig) is set by boiler codes qualifying low-pressure steam. Pressure in the separator is controlled by the pressure control valve. When the pressure builds to 96 kPa (14 psig), the control valve will allow steam to flow. The actual steam pressure in the load line is a function of load requirements. If the load is not consuming steam, the pressure in the steam line will increase. Once pressure reaches 90 kPa (13 psig), the excess steam valve will open to transfer engine heat to the waste cooling device (load balancing condenser). The excess steam valve must be located downstream from the pressure control valve to function properly.

Critical Design Criteria for High Temperature Water-Steam

High temperature water-steam systems include the same basic requirements as a standard temperature system and a high temperature solid water system, but there are also the following additional points which are important to consider:

- There are no elevation or static resistance requirements for the steam separator other than what suction head is required for the circulation pump. Thus, this system may be used in locations with limited overhead clearance.

- The maximum temperature at the engine outlet must not exceed 130°C (266°F). Inlet pressure to the pump must be maintained within limits to prevent cavitation at the high temperatures.
- A pressure switch is required at the jacket water inlet to the engine in order to monitor absolute pressure.
- A low water flow shutdown device is required on high temperature cooling engines. This is accomplished by using a differential pressure gauge across the engine water jacket. When the water flow rate slows or stops the lack of a pressure drop across the engine block will shutdown the engine. Since an electric motor driven pump is used, it is important to insure the pump is operating while the engine is running. The pump should continue running approximately five minutes after the engine is stopped to cool the engine.
- Use only treated water in the cooling circuit. Continuous water chemistry monitoring with automatic boiler blow-down devices are recommended.
- A low water level shutdown on the steam separator device is required. A low water level pre-alarm is also recommended. Low water level could cause engine overheating and serious damage.
- The excess steam valve cannot be in the steam separator and must be downstream of the pressure control valve.
- A warm-up thermostat is not required since the pressure control valve does not allow any heat (steam) to exit the system until the engine has warmed up and the separator has reached system pressure.

Water Quality and Treatment for Heat Recovery Cooling Systems

Standard Cooling Systems
The coolant recommendations outlined previously for typical diesel and gas engine applications apply here.

High Temperature Cooling Systems
The engine cooling water in a low-pressure steam or high temperature water system can be circulated within the engine water jacket at temperatures above 100°C (212°F). As a result, there is a potential for steam to form in both of these applications. Since several localized areas of the engine jacket water system can have very high heat flux rates and narrow water flow passages, the engine water chemistry will have the same requirements as a close tolerance steam boiler.

Note: The coolant specifications in this guide and in the Cat operator's manual have been written for ethylene glycol systems with temperatures less than 100°C (210°F). This is not applicable for low-pressure steam and high temperature heat recovery systems.

Minerals in the water can precipitate during the heating process and form deposits within the cooling system of the engine. These deposits can restrict the heat transfer and water circulation, resulting in engine failure. To prevent these deposits from forming in the cooling system, the following engine jacket water (boiler water) quality guidelines are recommended.

Make-up Water

Make up water is added to a low-pressure steam system to replace steam and blowdown losses. It should not exceed the following maximum concentrations:

Iron: 0.1 ppm

Copper: 0.05 ppm

Total Hardness: 0.3 ppm as $CaCO_3$

The make-up water can be treated to reduce, or remove, the impurities from the water. In general, the water is treated when one or more of the feed water impurities are too high to be tolerated by the system. There are many types of water treatment. Softening, evaporation, deaeration and ion exchange are typical methods used to treat makeup water for a particular system.

Feed Water

Feed water is a mixture of returning condensate and make-up water that enters the engine jacket water loop to replace steam that has left the loop. Water treatment chemicals that are added to the system are usually mixed with the feed water as it enters the engine jacket water system.

Engine Jacket Water

Engine jacket water (boiler water) is a mixture of feed water and resident water. It is the water circulated within the water jacket of the engine to cool the engine and recover heat. Engine jacket water should not exceed the following maximum concentrations:

Silica concentration:

150 ppm as SiO_2

Total alkalinity:

700 ppm as calcium $CaCO_3$

Specific conductance:

3500 micro mho per cm

Total suspended solids:

10 ppm

These stringent guidelines are based on established limits of the American Boiler Manufacturer's Association (ABMA) and recommendations of the ASME Research Committee on Water in Thermal Power Systems.

In addition to the above chemistry, Caterpillar recommends the engine jacket water (boiler water) be treated with chemicals:

- An oxygen scavenger to remove oxygen from the feed water with sufficient reserve in the engine jacket water (boiler water) to remove all oxygen from the water.
- Maintain 200 to 400 ppm as CaCO3 equivalent of hydroxide alkalinity in the engine jacket water (boiler water). The reserve alkalinity prevents corrosion and causes precipitation of iron and silica in a form that can be removed by blow-down.
- A blend of dispersants to adequately condition and suspend the precipitated solids in the water. The dispersants keep the solids suspended until they are removed during blow-down.
- Appropriate treatment of the steam to provide condensate

returning to the engine that meets the engine jacket water (boiler water) specifications.

Total Dissolved and Suspended Solids

Depending on the make-up water source and quality of treatment, the feed water will contain some dissolved and suspended solids. On a low-pressure steam system, the steam will leave the engine; however, the minerals and chemicals will remain. This results in a concentrating of the Total Dissolved Solids (TDS).

Engine water jacket scale forms when the concentration of solids reaches a critical point. This depends on the type of contaminants in the feed water, engine operating temperature, and other factors.

Measurement of TDS and Control

TDS can be measured by parts per million, ppm (grains/gal), or by conductivity (micro mhos/cm). The Cat level for TDS is given in micro mhos/cm because conductivity is easier to measure with commercial continuous monitoring equipment or hand-held equipment. There is a direct relationship between ppm and conductance, 2680 ppm = 3500 micro mhos/cm.

To avoid exceeding the maximum allowable conductivity, it is necessary to drain off some of the engine jacket water (boiler water) periodically. This is referred to as boiler blow-down. As this occurs, new feed water is added to dilute the water in the engine water jacket, thereby reducing its conductivity.

Historically, operators have performed blow-down manually by periodically opening a valve to drain the steam separator. This may be done once per hour, once per shift, or some other interval, depending on the circumstances.

Because blow-down is only performed periodically, significant dilution is needed to ensure that the engine jacket water (boiler water) conductivity does not exceed the maximum before the operator returns to blow-down the engine again. Note that the conductivity can exceed targeted maximum or even absolute maximum if the operator does not blow-down the boiler at the appointed time, or if the engine steaming rate increases between blow-down operations. If the absolute maximum is exceeded, scaling will occur. Because small amounts of scale wastes energy and can lead to engine damage, it is very important to stay below the absolute maximum.

Conversely, the steam production rate may decrease, and as a result, the operator would blow-down the engine sooner than necessary. Therefore, Caterpillar recommends continuous monitoring of TDS and automatic blow-down controls.

Conductivity runs high for ELC — carboxylated type coolants (as compared to traditional coolant inhibitors), usually 4000 micro mhos/cm despite low dissolved solids.

A less common method of monitoring TDS is to measure chlorides in both the engine jacket water and the make-up water by a titration process. Since chlorides are not reduced by chemical treatment, the operator can determine the number of concentrations that have occurred in the engine jacket water by comparing the ratio of the two values. Based on known values of the make-up water, the operator can calculate the acceptable number of concentrations that can occur before blow-down is required.

Alkalinity

Alkalinity is required in high temperature water and a low pressure steam system to prevent corrosion. Alkalinity holds silica in solution and causes iron to precipitate in a form removable by blow-down. Too much alkalinity can result in a high pH and cause caustic cracking and caustic attack to external engine compartments.

Total Alkalinity

Total alkalinity is usually measured on site by a titration with methyl orange and is frequently referred to as "M" alkalinity. Many coolant analysis companies refer to the pH of coolant water as its alkalinity. Because of the wide variation in local make-up water and commercial treatments, there is no direct correlation between total alkalinity and pH. Generally, in high temperature water and low pressure steam systems, the pH will be in a range of 10.0 to 11.5 pH.

Reserve of Hydroxide Alkalinity

To prevent corrosion and scale deposits, a reserve of hydroxide (OH) alkalinity is required. The OH alkalinity is not easily measured in the field, but can be calculated. A "P" alkalinity is measured with phenolphthalein indicator in a sulfuric acid titration. Once "P" value is determined, the following formula is used to calculate "OH" alkalinity.

"OH" Alkalinity =

2 x "P" Alkalinity - "M" Alkalinity

Low-pressure steam engines will have special requirements if the unit does not run continuously. Any low-pressure steam engine that is shut down frequently can be prone to deposits even with a good water treatment program. Once the engine is shut down, the dispersants in the feed water can no longer keep the solids in suspension. They will settle to the low parts of the system, which is usually the engine. These solids will collect and harden to form scales and can result in engine failure. For turbocharged and aftercooled (TA) ebullient and all ebullient engines that do not run continuously, a circulating pump of 100 kg water/kg of steam (100 lb water/lb of steam) capacity is recommended. The circulating pump should be operated even while the engine is shutdown to keep the solids in suspension. High output TA engines can benefit from the addition of a circulating pump to prevent hot spots and reduce deposits.

The above water chemistry limits are stringent, but not excessive when considering that deposits formed within the engine are cumulative. Co-generation and heat recovery equipment is intended to last 20 years or longer.

To maintain the performance and value of equipment, it is important to eliminate scale deposits within the engine. Once a deposit is formed, it is very difficult and may be economically impractical to remove.

Note: Scale formation is cumulative. The most successful method of preventing scale problems is to avoid the conditions that allow scale to form.

These guidelines are based on established limits of the American Boiler Manufacturer's Association (ABMA) and suggested guidelines by the ASME Research Committee on Water in Thermal Power Systems.

Operators who adhere to these guidelines are likely to have years of deposit-free and scale-free performance from their Cat engines.

Since water chemistry and water treatment are very regional items and vary considerably around the world, the engine owner has the ultimate responsibility for the engine cooling water treatment.

Cooling System Design Considerations

Expansion Tanks

An expansion tank is an integral part of an engine's cooling system. The primary function of an expansion tank is to allow for the thermal expansion of the coolant. However, the expansion tank of a well-designed cooling system will perform all of the following functions.

- Provide expansion volume to prevent coolant loss when the coolant expands due to temperature change.
- Vent gases in the coolant and prevent hot spots due to trapped gas in the coolant system reducing the ability of the coolant to cool the hot surfaces in the engine, to reduce corrosion and to prevent loss of coolant due to displacement by gases.
- Provide a positive head on the system pump to prevent cavitation.
- Provide a place to fill the system and maintain its corrosion inhibiting chemical additives.
- Provide a place to monitor the system coolant level; an alarm switch located in the expansion tank will give early warning of coolant loss, or a sight glass can be used for visual inspection.

In order to perform these functions, the expansion tank must meet the following guidelines.

- The expansion tank must be the highest point in the system. If the engine-mounted expansion tank is not the highest point of the system, an auxiliary expansion tank will be required. The additional added static pressure provided by the auxiliary expansion tank may make the system pressure exceed the allowable limits for the engine or design operating point for the engine-mounted expansion tank. The auxiliary expansion tank adds more cost and may make the engine mounted expansion tank redundant. Those installations may be more successfully designed with a remote expansion tank instead of the engine mounted expansion tank.
- Engine-mounted expansion tanks are normally rated for a maximum pressure of 96 kPa (14 psi); this pressure limit will prohibit using the engine mounted expansion tank for many high temperature system designs.
- The size of the expansion tank should be at least 15% of the total system coolant volume. This provides for expansion plus reserve.
- Depending on location, the tank must be vented to the atmosphere or incorporate a pressure cap to assure system ressure and prevent boiling of the coolant.
- The tank must provide deaeration and can be the means of filling a system.
- Factory supplied engine mounted radiators and most aftermarket-supplied engine mounted radiators have the expansion tank functions listed above as an integral part of the top tank design. Therefore, the

user has no control over the function of the expansion tank. However, many engines can have custom cooling systems and/or remote radiators that have a separate customer specified expansion tank.

Full Flow and Partial (Remote) Flow Expansion Tanks

There are two types of expansion tanks, full flow and partial flow. Partial flow tanks are also called remote flow tanks or shunt tanks.

Full Flow

Since all flow circulated by the cooling system passes through it, a full flow expansion tank performs several functions; refer to **Figure 14**, **Figure 15**, **Figure 17** and **Figure 46**. It provides a large area for the flow to settle and de-aerate the circulated coolant. It also provides a positive suction head pressure at the pump inlet without requiring a shunt line. Since full flow expansion tanks perform the deaeration function, they require greater volume. This type of a tank must be well designed and constructed to withstand the full system pressure which is exerted on the tank.

A full flow expansion tank requires careful attention to design to prevent the tank from causing coolant aeration at high flow. A full flow expansion tank might require a volume several times that of a remote tank to prevent aeration. Generally, a full flow tank should be sized to limit the fluid change rate to an absolute maximum of 50 times per minute at the low-level mark. Fluid change rates of 30 times per minute or less and proper baffling will help insure that the expansion tank will not cause coolant aeration at the low coolant mark.

Partial (Remote) Flow

A partial or remote flow expansion tank is simply a tank mounted preferably at the highest point of the cooling system; refer to **Figure 16**, **Figure 18** and **Figure 44**. Its function is to contain the expansion volume of the coolant as it heats up, provide a positive head to the inlet of the pump and provide a filling and venting location from the system. In this type of an expansion tank, very little flow takes place through the tank itself. The shunt line provides the make-up for the system and any flow leaving the system through the vent lines.

Maintaining Pump Suction Head with the Expansion Tank

An important function of the expansion tank is to maintain positive pressure on the suction side of the circulating pump to prevent cavitation. This function can be difficult to understand since the method depends on whether the system is inlet controlled or outlet controlled.

Inlet Controlled Systems

Inlet controlled systems have the thermostat positioned between the cooling device and the suction side of the circulating pump. The thermostat provides a restriction on the pump suction which can result in pump cavitation. To prevent the negative pressure and pump cavitation a shunt line is connected between the bottom of the expansion tank and the pump suction side as shown in **Figure 44.** The height elevation of the expansion tank provides static resistance on the pump to raise the suction pressure and prevent cavitation. The shunt line should be a minimum of 25.4 mm

(1 in.) diameter. The diameter of the shunt line is important. The area of the shunt line must be at least four times the combined area of the total vent lines connected to the tank. This will minimize any reduction of the static pressure because of vent and deaeration flow. For a full flow or engine mounted expansion tank, the tank is located in the suction line to the pump and no shunt line is needed. Refer to **Figure 45**.

Inlet Controlled System with Partial Flow Expansion Tank and Deaeration Circuit

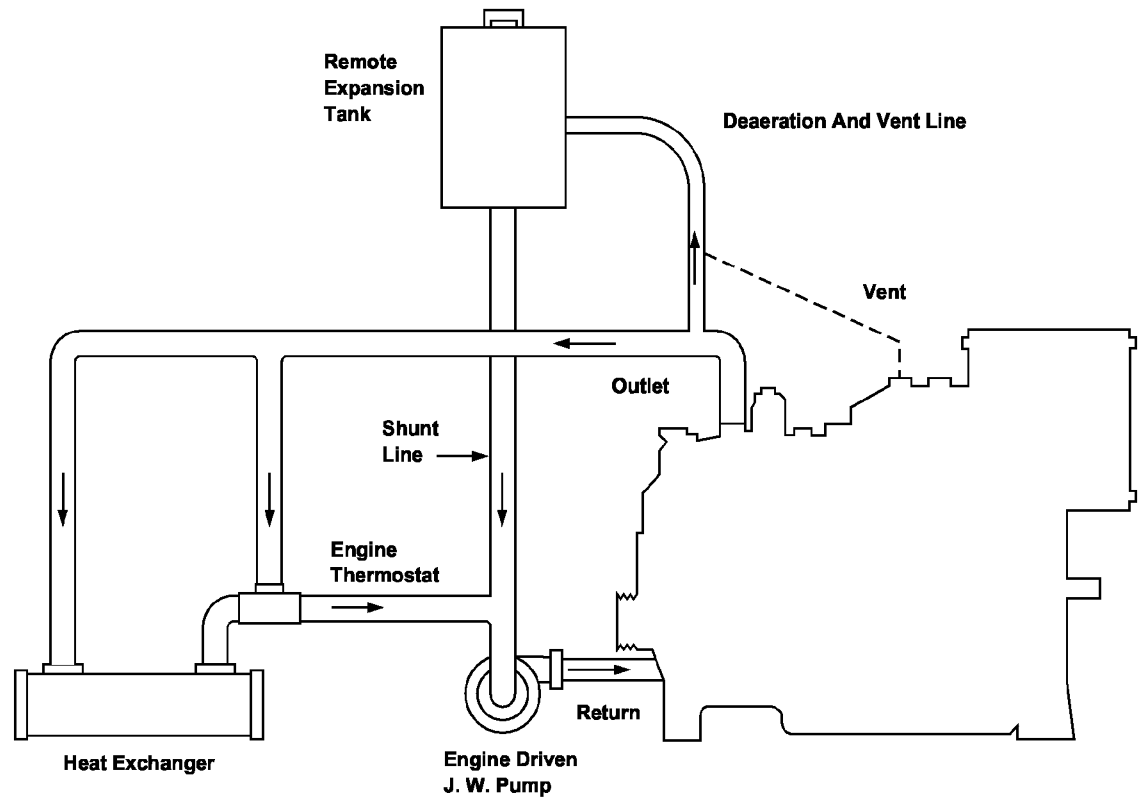


Figure 44

Example of an Inlet Controlled System with Full-Flow Expansion Tank

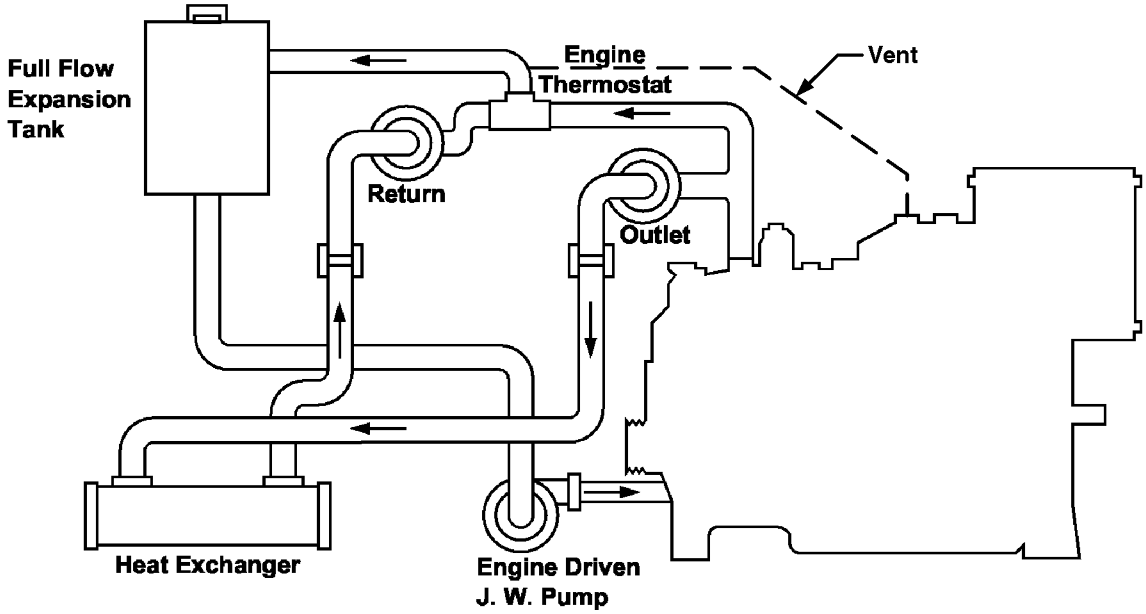


Figure 45

Outlet Controlled Systems

Outlet controlled systems differ from inlet controlled systems in the routing of the expansion tank connection.

On an outlet controlled system, the expansion tank connection is called the fill line. Since there is no thermostat located between the radiator outlet tank and the suction of the pump, the fill line does not need to be plumbed back to the inlet of the pump. The relative size of the return line of the radiator provides minimum pressure loss. This means the expansion tank may be connected to the outlet tank or anywhere in the return line to the pump. Refer to **Figure 46**, **Figure 47** and **Figure 48**. Do not connect the fill line to the inlet tank. There will not be sufficient resistance for the deaeration circuit to function properly. Also, there will not be sufficient resistance on the pump suction which may force coolant to overflow the pressure cap.

Outlet Controlled with Vertical Radiator Core

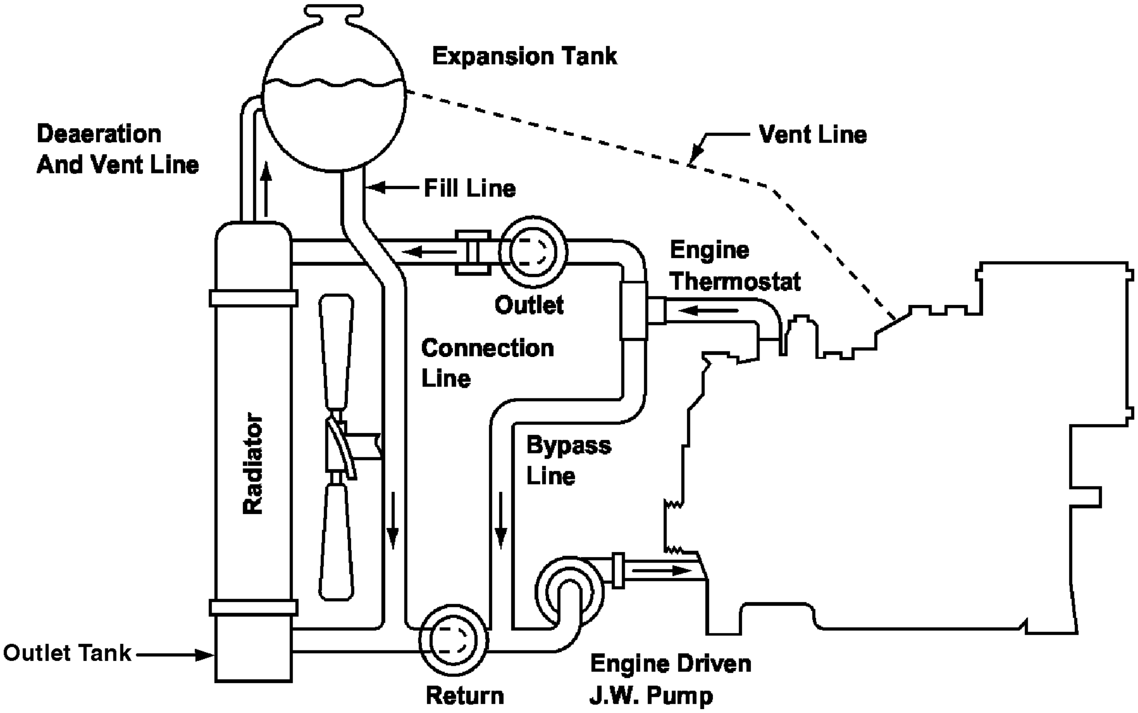


Figure 46

Outlet Controlled with Vertical Cross-Flow Radiator

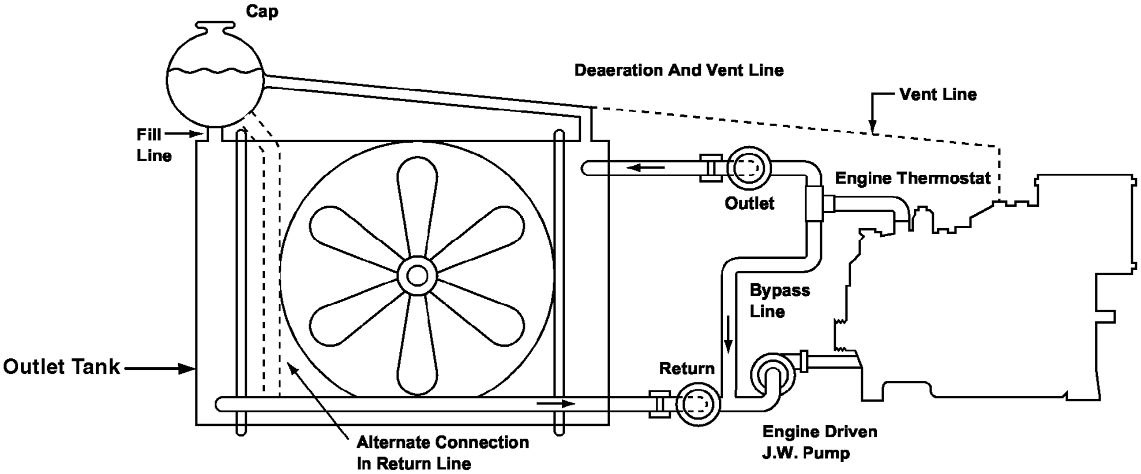


Figure 47

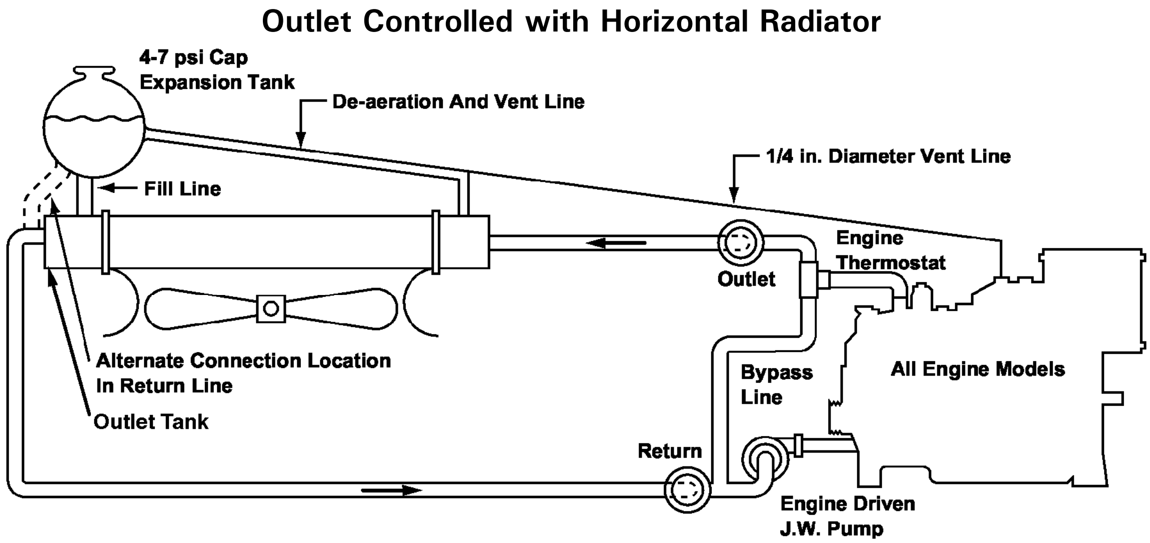


Figure 48

Expansion Rate of Coolant

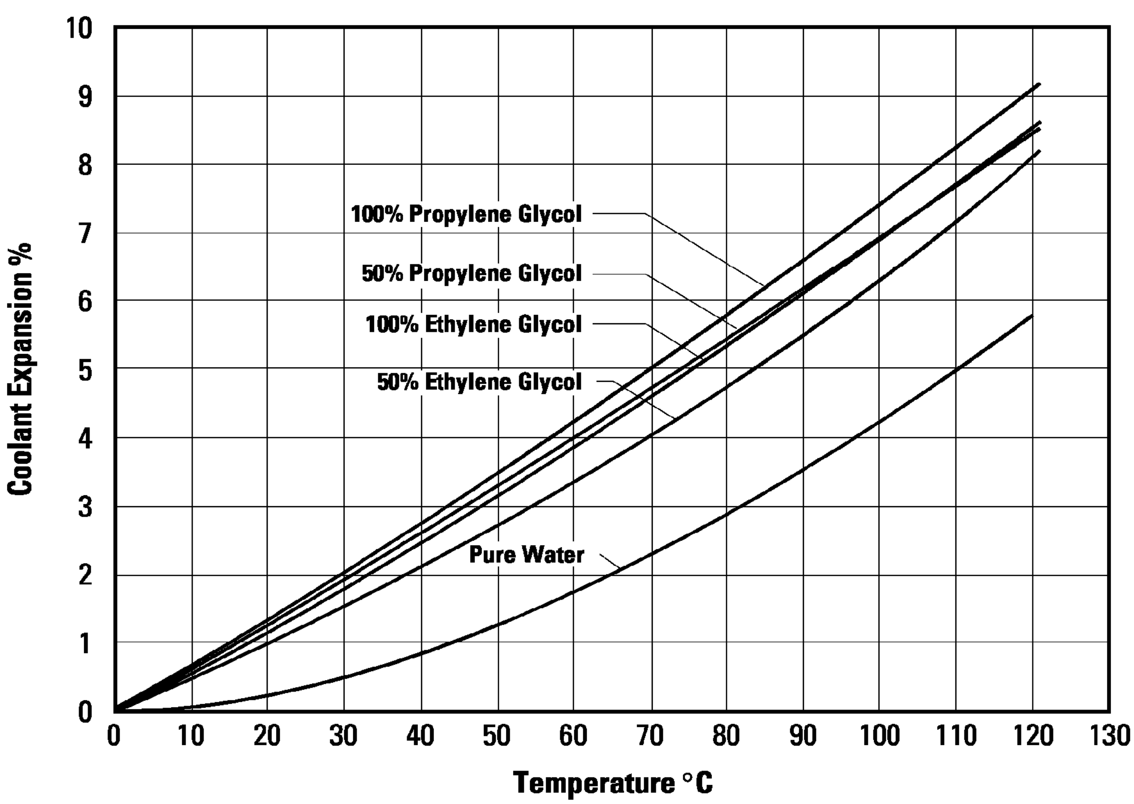


Figure 49

Sizing Expansion Tanks

As discussed earlier, the primary function of an expansion tank is to allow for thermal expansion of the coolant. Coolant expansion is a function of the coolant temperature from coldest ambient temperature to warmest operating temperature. In addition to the thermal expansion, there should also be volume for after-boil and sufficient reserve to allow operation with small leaks until they can be repaired.

The required expansion volume for the jacket water circuit can be calculated based on the coolant temperature change and type of coolant. The expansion rate for the different type of recommended coolants is shown in **Figure 49**. The minimum tank expansion volume for the jacket water on standard cooling systems is 15%. Higher temperature systems (higher than 100°C or 212°F) will need a larger volume to adsorb after-boil that may occur on hot shutdown, see section on High Temperature Solid Water Systems in the Heat Recovery section for more information. Closed accumulator-type tanks are not recommended since they cannot be designed to actively deaerate the coolant.

A separate expansion tank is typically required for the aftercooler-oil cooler cooling circuit of a separate circuit cooling system to eliminate the possibility of coolant exchange between the high temperature jacket water system and this circuit. The maximum expansion required for this circuit is 8%. This is due to the lower coolant temperatures and system volume of the aftercooler-oil cooler circuit.

The system volume for jacket water and standard aftercooler-oil cooler systems is given in the section System Volume. The minimum reserve capacity is determined from **Table 9**.

Total External Circuit Vol. (% of Engine Coolant Vol.)	*Min. Reserve Capacity (% of Total System Vol.)*
≤ 50	10
60	9
70	8
80	7
90	6
≥ 100	5

Table 9

Therefore the minimum acceptable expansion tank volume is:

Minimum Tank Volume =
(Expansion Rate x System Volume) + Minimum Reserve Capacity =
Expansion Volume + Minimum Reserve Capacity

Venting and Filling

The filler cap is usually located on the expansion tank. To accept the maximum fill rate of the system, the line connecting the expansion tank with the pump suction must be sized correctly. The minimum guidelines for filling rate are 19.0 L/min (5 gal/min). Air trapped in high points of the cooling system during the initial fill is difficult to purge and requires venting. For best system operation, vent lines must be connected from the highest points of the system to the expansion tank. Vent lines must enter the expansion tank below normal water level, have a continuous upward slope, and contain no air traps. A minimum vent line size should be

6.3 mm (0.25 in.) inside diameter tubing. Use of a smaller size will clog and may not provide adequate venting ability. Too large a vent tube may introduce a circuit that could contribute either to subcooling or overheating, and can cause the system thermostats to loose their ability to control the system to the desired temperature. Vent line sizing depends on the volume of the system to vented and the length of the vent line. For engine size of 3400 or C32 size or below, the 6.3 mm (0.25 in) diameter is sufficient unless the vent line is long or system volume, due to remote mounted components, is much larger than normal. For 3500 series engines or systems with volumes above 75 gallons, the vent size should be increased to 9 mm (3/8 in) as a minimum. For C175/3600 series engines or system volumes above 150 gallons, a 13 mm (1/2 in) diameter vent line minimum size should be used. These are rule of thumb values; the total system design should be engineered based on the system pressure, pressure drops due to length of vent lines, system volume and expected vent flow rates. For large system designs, it is best to design the vent line oversized. This allows the use of an orifice in the vent line that can be reduced in size if the vent line provides excessive flow and loss of temperature control.

Caution: To allow for expansion, **the full level in the expansion tank must not exceed half the volume of the tank**. Failure to provide adequate expansion volume may result in a boil over. The constant full level in the expansion tank must be above all piping. The full level in the expansion tank must not exceed half the volume of the tank. Vent high points of the engine to the expansion tank to allow a proper fill.

Air can be trapped in the cooling system at initial fill, and after filling, it is possible for gases to be formed by evaporation of coolant at hot surface locations or combustion gases to leak into the cooling circuit. This air and gas must be vented from the system, or system deterioration and water pump cavitation will result. Refer to the 'Coolant (DEAC) – Change' section of the C175 Operation and Maintenance Manual (SEBU8100) for additional details on the venting procedure during coolant drain and fill.

Entrained gases require deaeration capabilities to be built into the system. Deaeration may be accomplished with a centrifugal deaeration gas separator by venting the gases back to the expansion tank as shown in **Figure 18**. If a centrifugal deaeration gas separator is not used, separation of gas from a liquid medium requires a low coolant velocity of 61 cm/sec (2 ft/sec) with a diverted flow to the expansion tank, where the relatively static velocity in the tank allows the gases to be separated. When using low coolant velocity de-aeration, the tank or low coolant velocity area should be built with an area for the water and gases to separate and collect with a vent to return the gases to the system expansion tank. Therefore, in the areas where deaeration must take place, the water velocity should be held below this limit by increasing the diameter of the water pipe. Refer to **Figure 50**.

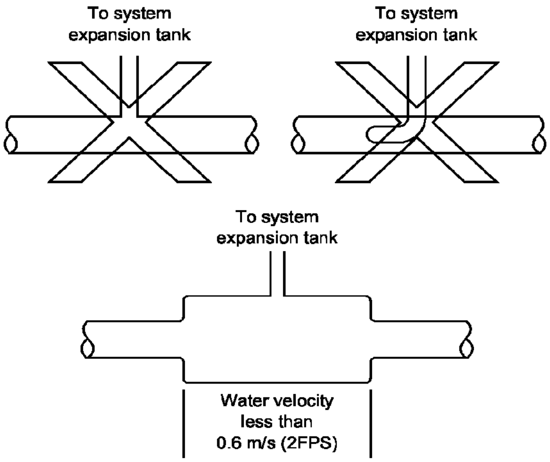


Figure 50

The deaeration line is usually connected to the radiator inlet tank. Most radiator inlet tanks have sufficient cross-sectional area to meet this velocity requirement. Full-flow expansion tanks must be designed with sufficient cross-sectional area to slow the velocity of the water. They must have internal baffles designed to separate the gases from the coolant.

System Pressures

Depending on the altitude of engine site and system operating temperatures, pressurizing the system will help to prevent the coolant from boiling under adverse conditions. Slight system pressures also minimize pump cavitation, even at high altitudes, and increase pump efficiencies.

For each 7 kPa (1 psi) of increase in system pressure, the boiling point of pure water is raised about 2°C (3.5°F). Elevations above 3048 m (10,000 ft) require higher rated pressure caps to avoid boiling.

Ethylene and propylene glycol solutions raise the boiling point. However, alcohol or other volatile antifreezes lower the boiling point. **Figure 51** and **Figure 52** show the effects of system pressure on the boiling point of water and 50% ethylene glycol mixture at various altitudes.

Water Boiling Point Change with Change in Cooling System Pressure

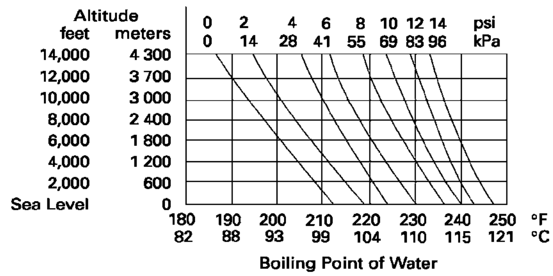


Figure 51

Glycol Mixture Boiling Point Change with Change in Cooling System Pressure

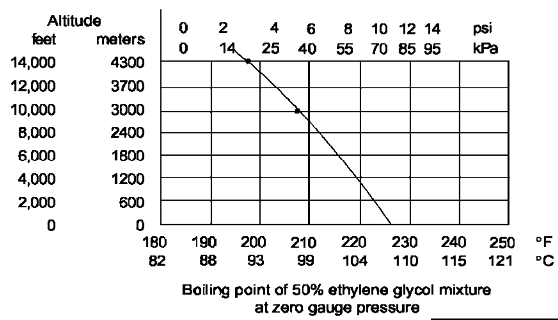


Figure 52

Expansion tanks supplied by Caterpillar have a suitable pressure cap to maintain correct system pressures for normal applications as discussed in the section Attachment Expansion Tank. When a factory expansion tank is not used, the following three methods can be used to ensure the right system pressure.

- Use a pressure cap on the auxiliary expansion tank.
- Providing the pressure with a water column by locating the auxiliary expansion tank at an

elevation above the pump. A pressure cap may be required if the system temperature in the auxiliary expansion tank is near the boiling point.

- A combination of an elevated auxiliary expansion tank with a pressure cap 1 m of water = 9.8 kPa (1 ft = 0.43 psi)

Static head is the maximum height the coolant is raised. Large static heads are encountered when radiators are located one or more floors above the engine. Excessive static head can cause engine mounted pump seal leakage. Refer to **Figure 16** for maximum height.

Dynamic head is the sum of the static pressure head plus the pump rise at operating condition. Excessive dynamic head can cause leakage at gasket joints downstream of the coolant pumps. The combination of static and dynamic head must meet the pressure criteria specified in TMI. Components in the external cooling system, particularly radiators, must meet operating pressure levels. When static and dynamic pressure exceed acceptable limits, isolate the engine side by providing a heat exchanger or hot well; refer to **Figure 53** and **Figure 54**.

Auxiliary Expansion Tank

The function of the engine mounted expansion tank was covered earlier and is applicable for the engine's jacket water circuit. Caterpillar does not provide expansion tanks for the engines auxiliary water circuit (the aftercooler circuit). It can provide adequate expansion volume for only a modest amount of jacket water.

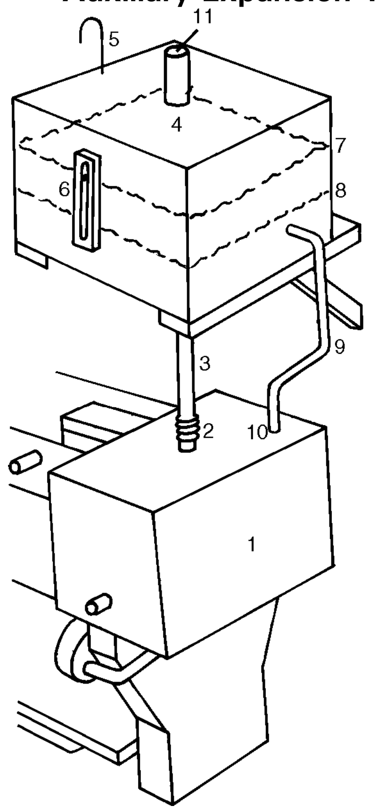
Jacket Water Circuit Auxiliary Expansion Tank

An auxiliary expansion tank is needed when additional expansion volume is required in the cooling system. This generally occurs when remote mounted heat exchangers are used.

The auxiliary tank can consist of a simple tank as shown in **Figure 53**. These tanks are typically fabricated by the engine installer and internal baffles are not required.

The engine-mounted components of the cooling system will adequately separate gases from the coolant. However, the gases, once separated, must be allowed to rise by a continuous upward sloped standpipe or vent to the auxiliary expansion tank. Additional air vent piping may be required if the auxiliary expansion tank is not located directly above the engine mounted expansion tank.

Auxiliary Expansion Tank for Engine Jacket Water

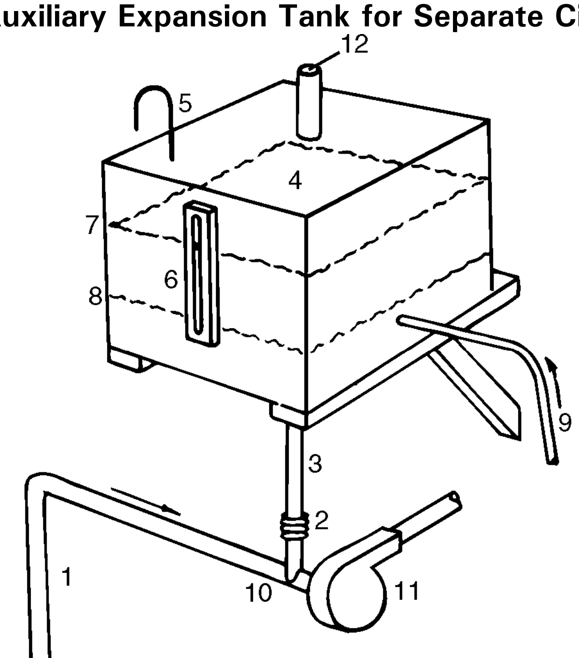


1. Engine mounted expansion tank
2. Flexible connection
3. Connecting pipe
4. Auxiliary expansion tank
5. Tank vent
6. Level gauge
7. Operating level
8. Cold fill level
9. Connecting pipe
10. Connect lower end of fill vent to vent piping entering rear side of engine mounted expansion tank
11. Tank fill

Note: Do not drill engine mounted expansion tank

Figure 53

Auxiliary Expansion Tank for Separate Circuit Aftercooler – Fresh Water



1. Return line from cooler
2. Flexible connection
3. Connecting pipe
4. Auxiliary expansion tank
5. Tank vent
6. Level gauge
7. Operating level
8. Cold fill level
9. Vent line from aftercooler
10. Connecting line to auxiliary pump inlet
11. Auxiliary fresh water pump
12. Tank fill

Figure 54

Aftercooler Circuit Auxiliary Expansion Tank

All closed, fresh water aftercooler circuits require an expansion tank. The tank provides coolant expansion volume, allows system venting and provides a positive pressure on the inlet side of the circulating pump. The expansion tank should be the highest point in the aftercooler water circuit as shown in **Figure 54**. Also, refer to the Mechanical Vent Valves section.

This tank is a simple reservoir with the connecting pipe placed as close to the pump inlet as possible. The tank is usually fabricated by the engine installer.

Sizing the Volume of Auxiliary Expansion Tanks

The minimum volume of the auxiliary tank should include the total jacket water system expansion volume required, plus the volume for the water to the low water level in the tank. The worksheet on **Page 131**, Auxiliary Expansion Tank Sizing, can be used to determine the minimum volume required.

Note: Auxiliary jacket water expansion tanks are not always required.

Installation of Auxiliary Expansion Tank

Use flexible mountings and connections when installing an auxiliary expansion tank. Separately support and isolate the auxiliary tank to protect it from engine-mounted tank vibration.

All closed separate circuit aftercooler circuits require installation of a vent line. A tapped hole is provided at the high point in the engine mounted aftercooler circuit for this purpose.

Install a vent line from the tapped hole in the aftercooler to the aftercooler circuit expansion tank. A 6 mm (0.25 in.) vent line is adequate. The vent line should enter the tank below the low water level and be sloped upwards from the engine to the tank. If possible, water lines connecting to the aftercooler circuit should be level with or below the connecting points on the engine. If the water lines must run above the connection points on the engine, it will be necessary to vent the high points in the external system. Air traps in the external system piping should be avoided.

Pressurization of Systems Containing Auxiliary Expansion Tanks - Afterboil

Generally, pressure caps are not required or desirable on auxiliary expansion tanks. This is to allow free venting and refilling, when required.

An exception exists in the situation of high performance engines, which are prone to be stopped immediately after periods of extended use. In this circumstance, a phenomenon known as afterboil can occur.

Afterboil is the boiling (change of liquid to vapor) of the coolant, caused by hot engine components which have lost coolant flow and pressure when the engine is hastily shut off. This can result in sudden loss of coolant out the vents and fill openings of the expansion tank. This can be dangerous to personnel in the area.

Bladder Type Expansion Tanks

Bladder type expansion tanks are commonly used in high temperature cooling applications when space restrictions and height limitations are involved. These expansion tanks eliminate the need to have the expansion tank at the highest point in the cooling circuit.

Deaeration

Air or gas trapped in the cooling system often results in coolant foaming. Foaming promotes pitting, particularly around water pump impellers, which will affect its performance. Pitting and corrosion increase significantly when exhaust gases introduce bubbles and foam into the cooling system.

Low Velocity

To assure venting of gas entrained in the jacket water system, it is necessary to reduce the water flow to 0.3-0.6 m/sec (1-2 ft/sec) in the top tank of the radiator. This can be accomplished with baffles or a "dog house" built into the tank. A dog house is a fabricated chamber within the radiator top tank water inlet.

Hotwell

Hotwell systems are used when static or dynamic head exceeds acceptable limits or when a boost pump imposes excessive dynamic head. Refer to **Figure 55**.

A hotwell tank accommodates total drain back of the remote cooling device and connecting piping. A baffle divides the tank into a hot and a cold side, but is open sufficiently to assure full engine flow. Baffles are also used where water enters the tank to minimize aeration as shown in **Figure 56**. The baffle shall have sufficient openings to allow the flow of water between the hot and cold sides of the tank. The flow will be the difference in flow rates between the engine-driven and remote pumps.

If the hotwell does not have sufficient volume, the pumps will draw in air during operation. The hotwell tank must be large enough to accept the full volume of the remote radiator and the interconnecting piping, plus some reasonable amount to prevent air ingestion by the pumps. Generally, 110% of the radiator and piping volume is adequate.

The tank bottom must be above the engine coolant outlet level. The recommended minimum is 0.6 m (2 ft).

The auxiliary pump flow must exceed the engine water pump demand. The recommended minimum is 120% of the nominal engine demand at rated speed. Acceptable venting and deaeration of the engine and external circuit must also be provided.

Hotwell System

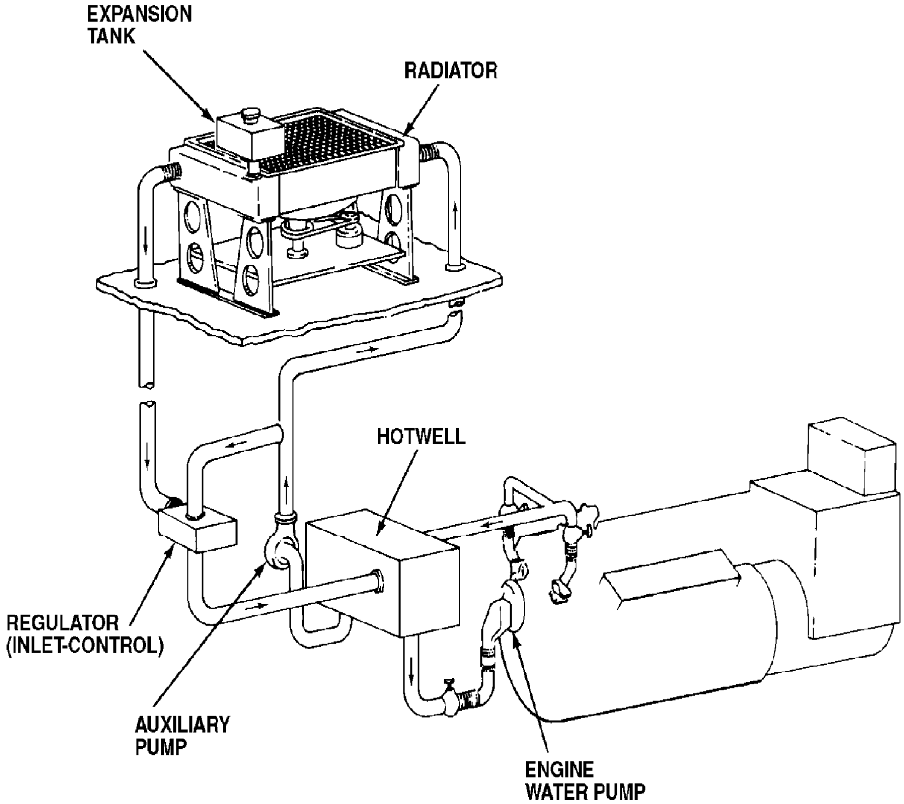


Figure 55

Hotwell Tank

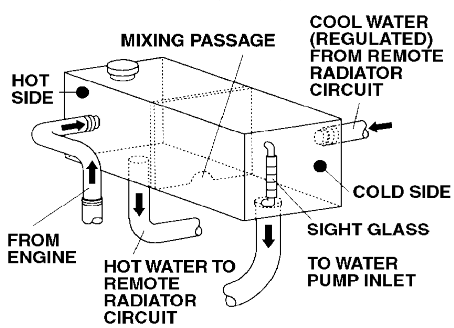


Figure 56

The hotwell must be vented by some means to atmosphere to reduce the overall system pressure and allow the remote system to drain properly back to the hotwell.

Hotwells must be engineered to have proper venting and system pressures evaluated to provide correct system operation. In some cases, it may be necessary to have multiple hotwells to control the system pressures when large elevation differences are present.

Interconnection of Engines

Central cooling systems utilize a single external circuit supplying coolant to several engines. Although separate cooling systems for each engine is preferable, use of a single radiator or heat exchanger system is possible. Practical experience has shown that only identical engines at the same loads and speeds can be successfully combined in a joint cooling system. A failure on one engine can adversely affect all engines. For this reason, interconnected engines should have isolating valves. Check valves are required on the output line of each engine to prevent recirculation through an engine that is shutdown with the thermostats opened.

The cooling system for mixed engines with mixed speeds and loads are very difficult to design and are rarely successful. They must meet required criteria, such as water flow, temperatures and pressures, for each engine while operating in all possible combinations with other units.

Flexible Connections

Use flexible connections for all connections to the engine (rubber hoses are not recommended). The positions of flexible connections are important. Shut off valves should be located to allow replacement of flexible connections without draining the entire cooling system. Orient the flexible connection to take the maximum advantage of the flexibility. When selecting connections, normal thermal expansion and maximum expected movement must be considered. Flexible connections should be rated for conditions well above the anticipated maximum operating temperature and pressure of the cooling system. Clamp-type flexible connections are not recommended for the high temperature circuits on G3600 Engines. Bolted flange-type connections should be used for all jacket water circuits and any other circuit running more than 65°C (150°F). Material compatibility must also be evaluated. The internal surface must be compatible with the coolant used and the liner material must be compatible with potential coolant contaminants, such as lube oil and system cleaning solutions. The outer cover must be compatible with environmental conditions such as temperature extremes, ozone, grease, oil and paint. Factory-provided flexible connections are available for most pipe sizes; refer to the Price List for available options.

Piping Supports

All piping to and from the engine must be suitably supported by means of brackets and clamps.

Piping must not overhang excessively from the pump inlet, mixer box outlet, temperature regulators and expansion tanks.

The weight of the piping combined with the water in the pipes can place a considerable load on engine components; especially when the engine is vibrating during operation.

Piping should be supported adequately on installations where the radiators or heat exchangers are roof-mounted or the piping is routed through the roof.

Jacket Water Heaters

Jacket water heaters are recommended for faster and easier starting in ambient air temperatures below 21°C (70°F).

All automatic starting installations should include jacket water heaters. The heaters should maintain engine jacket water at approximately 32°C (90°F) at minimum ambient room temperature. Jacket water heater sizing information for each engine is available in the TIA. Model-specific heater availability is included in the Price List.

Heater sizing is based on wind velocity of 0 km/h (0 mph) around the engine. When a 24 km/h (15 mph) wind is present, the heater requirement doubles. Factory provided jacket water heaters are available for these specifications.

The normal time required for temperature to stabilize is 10 hours for large engines. Wattage requirements for shorter periods are inversely proportional to the 10-hour requirement.

Physical location and exposure to the elements can affect sizing. Contact Caterpillar for special voltages, three phase current and special heaters for ambient temperatures lower than listed.

For customer-installed systems, the following guidelines should be considered.

- Mount the heater as low as possible; refer to **Figure 57**.
- The cold water inlet to the heater should be from the lowest possible point in the engine cooling system.
- Avoid cold water loops; this is any situation where cold water must rise to enter the heater. Refer to **Figure 57**, location **A**.
- Join the hot water side of the heater near the top of the engine cooling system, but below the temperature regulators.
- Use the same pipe size (or larger) as the heater connections.

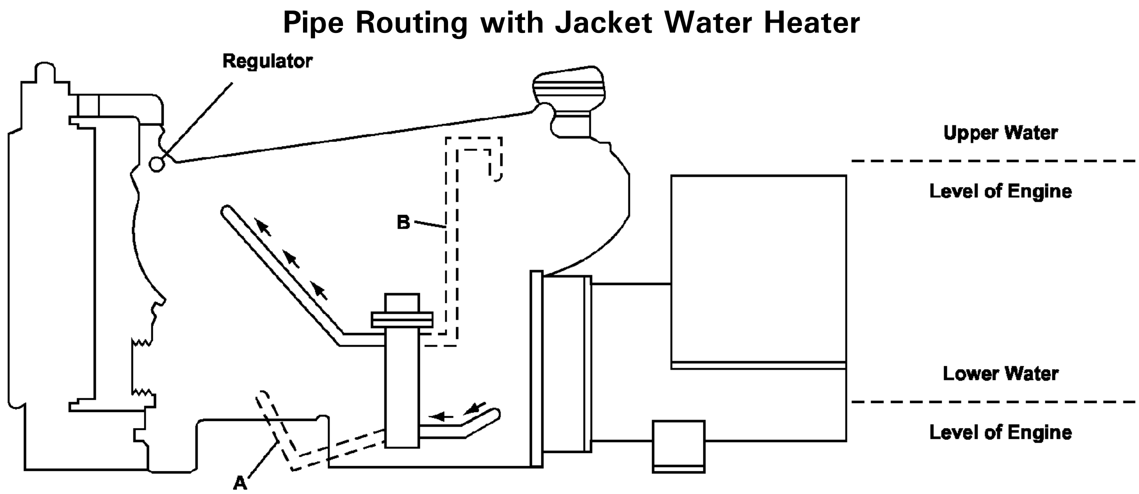


Figure 57

Caution: Do not create hot water loops. Hot water line should enter the engine in either a horizontal or slightly inclined plane, eliminating the possibility of forming a steam pocket; refer to **Figure 57**.

Preparations for Initial Startup

Before the initial start up of any engine installation, all pipe, water passages and radiators, heat exchangers or other equipment external to the engine must be cleaned, the cooling system should be filled with rust inhibitors, and coolant flow should be verified. These precautions apply to an initial start up as well as the first start up after significant modifications are made to the external cooling circuit.

Temporary strainers should be installed in all pipes between the engine and external equipment prior to start up and removed after commissioning to catch contamination that may remain after cleaning. Strainers are available from Caterpillar for 100 mm, 127 mm and 152 mm (4 in, 5 in, and 6 in) pipe sizes and all have 1.6 mm (1/16 in) mesh size.

Caution: Temporary strainers are intended to be temporary. If left in the system indefinitely, they can collapse, causing a great deal of damage to the engine.

Rust inhibitors can be in the form of ethylene or propylene glycol if operating temperatures are expected to go below freezing, or in the form of coolant conditioner. The coolant conditioners or rust inhibitors should be compatible with the antifreeze used in the engine, refer to the documents listed under Reference Material at the end of this section for more information.

If an engine is expected to be stored for long periods without operating or before commissioning, special treatment in the form of Vapor Corrosion Inhibitor (VCI) is required for the cooling system to prevent rust formation. Long-term preservation treatments for cooling systems can be provided by the factory, refer to the Price List for more information.

Serviceability and Isolation Valves

Access to the heat exchangers is required for cleaning or removal of the tube-bundle assemblies or plates. Engine water pumps must be easy to remove. Remote water temperature regulators should be accessible and have appropriate isolation valves to allow servicing of engine and temperature regulators without draining the entire system. Apply similar guidelines to radiators, heat recovery units, deaeration units, jacket water heaters and other components requiring service or replacement.

System Monitoring

Provide locations to measure pressure and temperature differentials across major system components. This allows accurate set-up and performance documentation of the cooling system during the commissioning procedure. Future system problems or component deterioration (such as fouling) are easier to identify if basic data is available. It also provides information for relating field conditions to original factory tests.

Temperature and pressure measurement locations should give accurate reading of fluid stream conditions. Preferred locations are in straight lengths of piping reasonably close to each system component. Avoid pressure measurements in bends, piping transition pieces or turbulent regions. Plan to install monitoring ports during the design and construction of the cooling system. If the ports are installed later, ensure the pipes are cleaned of drill chips and weld slag after the pressure ports are installed. Install sample ports and fittings before the cooling system is filled. The preferred sizes for the ports on the customer side are 1/8 in or 1/4 in NPT and 9/16 in O-ring ports. These port adapters are available as standard Cat parts; refer to the G3600 Price List for part numbers. The recommended locations for measurements and available measurement ports are shown in **Figure 58**.

Self-sealing probe adapters are available in several sizes of male pipe threads and straight threads for g-ring ports. The adapters use a rubber seal allowing temperature and pressure to be measured without leakage. Probe diameters up to 3.2 mm (0.125 in) may be used. The straight threaded adapters are used on the engines with available ports. Pipe threaded adapters are more easily incorporated in the customer supplied system. The adapters are an excellent alternative to permanently installed thermometers, thermocouples or pressure gauges. They are not subject to breakage, fatigue failures and gauge-to-gauge reading variations.

Customer Connections

The customer connection points for all configurations explained in the Basic System Configurations Section are shown in the Engine Installation Drawings.

Mechanical Vent Valves

The ideal system is to have all high points vented to the expansion tank. However, when modifying existing installations, venting all of the high points may not be possible. Mechanical vent valves can be added to these high points to vent air and gases that accumulate. The disadvantages of mechanical vent valves are the fact that they are usually manually operated and can leak coolant or allow air to enter the system during shutdown. There are also automatic vent valves, but they can be troublesome. In some areas, coolant may be considered a hazardous liquid and the use of mechanical vent valves should be minimized.

For G3500 turbocharged engines, a vent line is connected to the turbo charger to ensure that there are no air pockets in the turbocharger's cooling passages; refer to **Figure 58**. This vent line must be connected to the expansion tank used for the jacket water cooling circuit. If an aftermarket expansion tank is used, the customer will be responsible for connecting the vent line to the expansion tank. (See **Pressure Control**)

Watercooled Turbocharger Venting

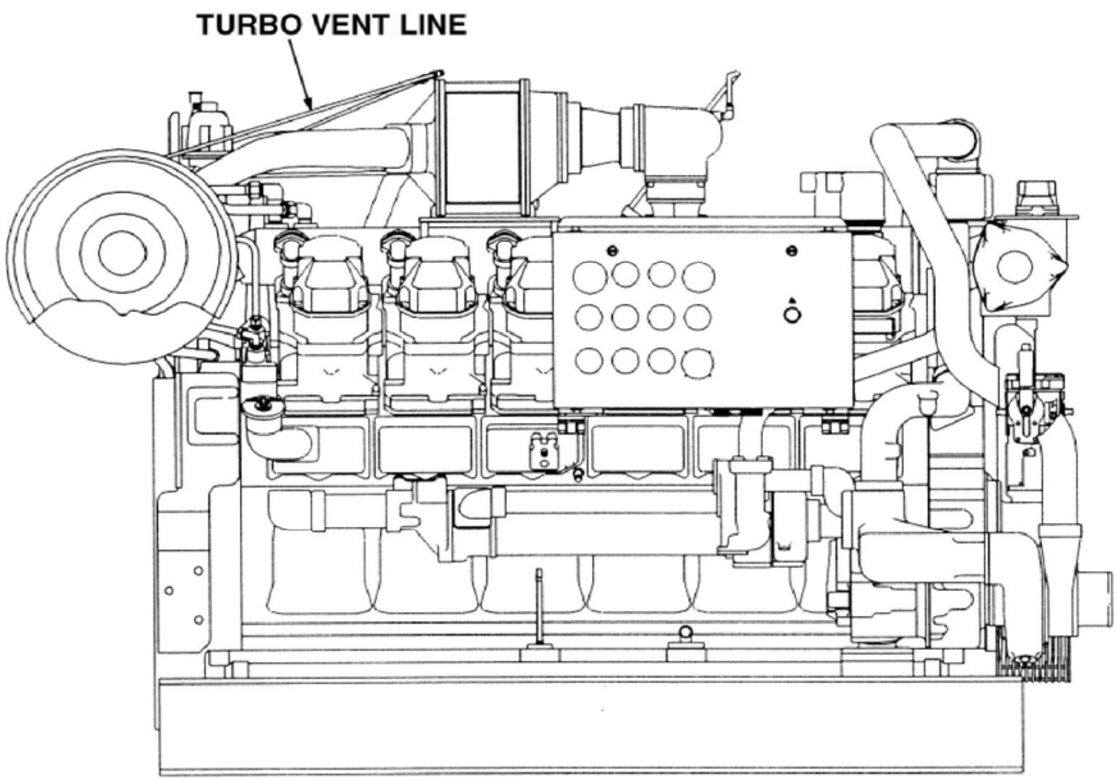


Figure 58

Watermakers, Domestic Water Heaters, Cabin Heaters

Watermakers, domestic water heaters and cabin heaters can put normally-wasted jacket water heat to work. This has the potential for recovery of approximately 15% of the fuel input energy.

Certain aspects of the engine cooling system must be thoroughly understood to avoid misapplication. For example, an engine will only produce significant amounts of waste heat if there is a significant load on the engine. Many engines in marine service are lightly loaded for large parts of their life and are poor choices for installation of watermakers, domestic water heaters, and cabin heaters. When an engine is lightly loaded, almost all of the engine's jacket water flow goes through a bypass line, from the thermostat housing to the jacket water pump inlet, to maintain a constant high flow through the engine's cooling passages.

Watermakers, domestic water heaters and cabin heaters can overcool an engine. If the watermaker, domestic water heater, or cabin heater extracts too much heat from the flow of jacket water, the engine's water temperature sensors/thermostats will sense the engine cooling jacket is operating at a dangerously low temperature. It will attempt to correct the condition by reducing the external flow of cooling water. If there are automatic controls on the watermaker, domestic water heater, or cabin heater, it may shut off having sensed insufficient flow for continued operation. This leads to a troublesome condition of repetitive starting and stopping of the watermaker, domestic water heater, or cabin heater. Automatic control of these devices has proven troublesome and is not recommended. Consider the use of auxiliary water heaters so during periods of light engine load, adequate amounts of heat can be sent to the watermaker, domestic water heater, or cabin heater.

Cooling water piping to and from the watermakers, domestic water heaters, and cabin heaters must not allow entrained air/gases to collect. Trapped air/gases will displace the water required to carry engine heat to the watermakers, domestic water heaters, and cabin heaters and interfere with proper operation. Trapped air/gases can be vented by installing small, approximately 3 mm (0.125 in.), inside diameter-vent lines. The vent lines should carry air/gases from the high points in the domestic water heater and its associated piping to a higher point in the engine jacket water cooling circuit; this is normally an installer-supplied auxiliary expansion tank.

See the engine general dimension drawing for the connection locations of points on the engine where water for this purpose should be extracted and returned. However, please note that not all engine cooling system designs have connections for watermakers.

Watermaker Controls

The watermaker controls may be manually operated valves or thermostatically controlled valves.

Any failure of the watermaker control system, such as electrical or air, must shut off jacket water flow to the watermaker and return the flow to the engine heat exchanger.

The thermostat valve, shown in **Figure 60**, would have a temperature setting that will not interfere with the engine thermostats. This valve should begin to divert water flow to the engine heat exchanger at no more than 88°C (190°F) and be fully diverting at 96°C (205°F). For safety, the bypass valve(s) in the engine heat exchanger circuit should contain 6.35 mm (0.25 in.) orifices so there will be a slight water flow in case all valves are inadvertently left closed. This orifice is then required to assure water flow to actuate an alarm system. The slight water flow from the orifice will also reduce the possibility of thermal shock on the engine cooler. If the watermaker cannot handle the full heat rejection of the engine and/or cannot handle the full water flow of the engine, the automatic system must be used.

Manual Control Watermaker Circuit

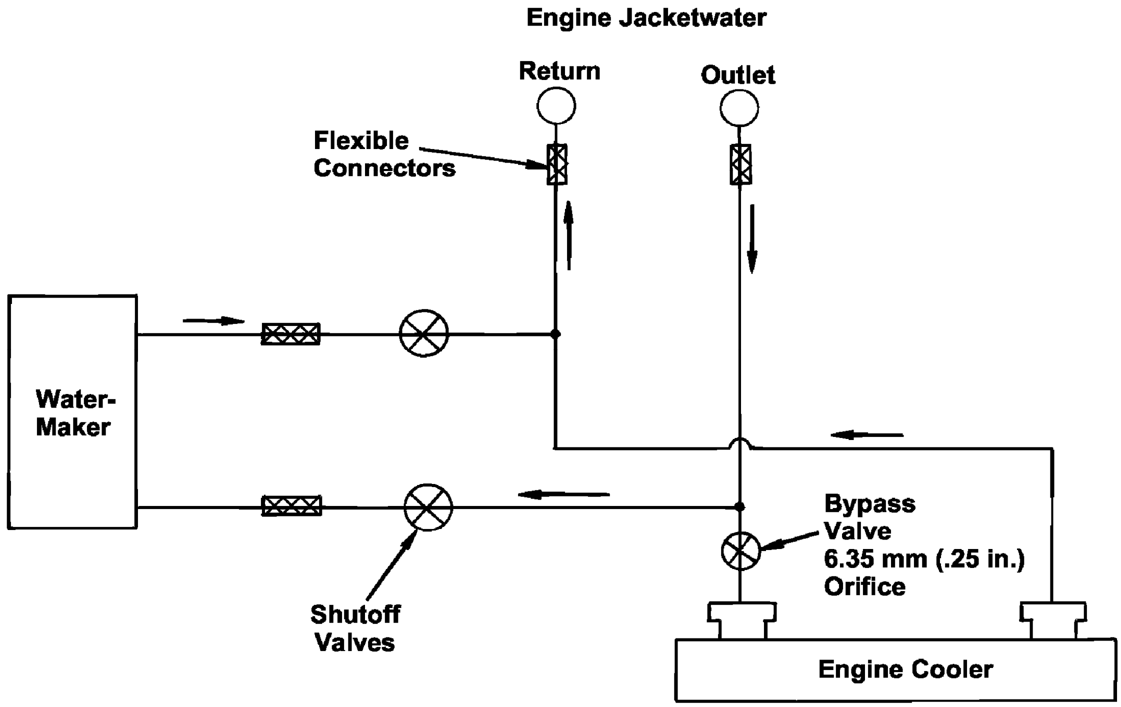


Figure 59

Automatic Control Watermaker Circuit

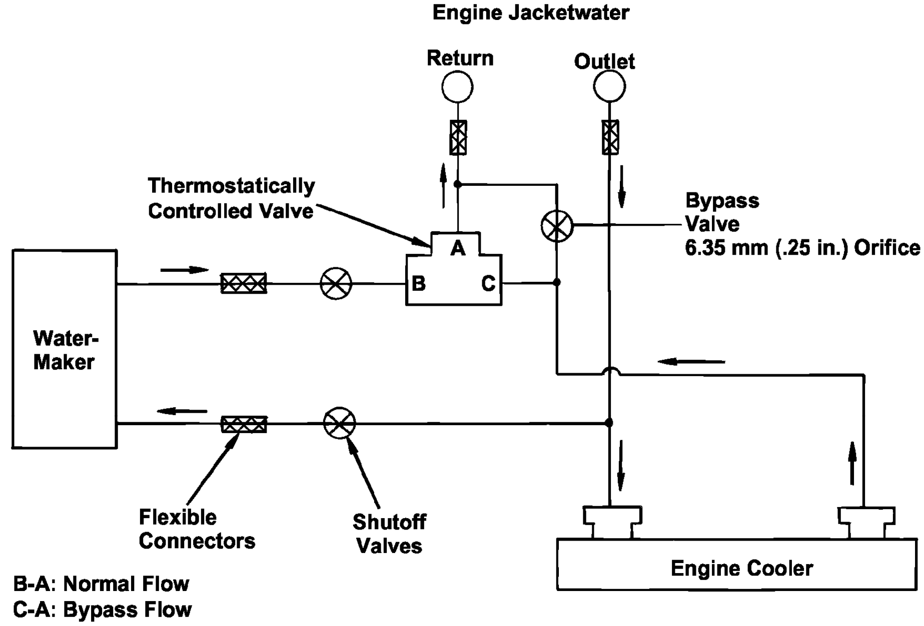


Figure 60

Typical Mixing Tank

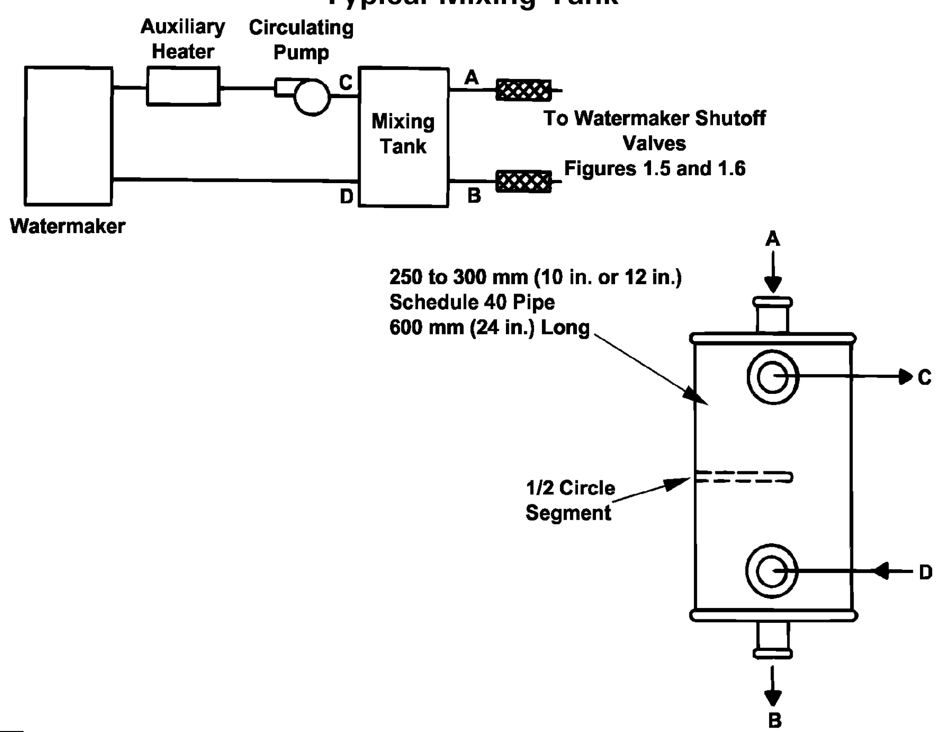


Figure 61

Interconnecting Engines
Several problems arise from interconnection of several engines: unequal water flow, one failure shuts down all engines and excessive external head pressures are just a few. For these reasons, separate connection of one engine per watermaker is recommended. It is the customer's responsibility to provide a system that is compatible with the engine cooling system in all modes of operation.

When the Watermaker is Far from the Engine
When the watermaker is a long distance from the engine or where the watermaker requires a constant water flow, a mixing tank and circulating pump is required. Do not use a circulating pump by itself, because the circulating pump head pressure will damage the engine thermostats in the event they are closed. Although the mixing tank is not supplied by Caterpillar, it can be used with either of the suggested circuits. An auxiliary electrical heater may be installed as shown in **Figure 61**.

Cooling System Protective Devices
A common problem associated with properly installed cooling systems is loss of coolant, generally due to breaking a water hose or overheating, which can have many causes. As with many engine safety devices, the decision to automatically shut down the engine, or to continue operation risking total engine destruction, is for the careful consideration of the owner. In conditions where an entire boat and the lives of those on board are at stake, it may be appropriate to use a safety system which does not have automatic shutdown capability. The boat's pilot has the option to continue operation of a distressed engine to provide a short duration of engine power to escape a more present danger.

Coolant Level Switches
Coolant level switches are devices which can give early warning of coolant loss. They generally consist of a sealed single pole-double throw switch, actuated by a float which rides on the surface of the coolant in the expansion tank. It is good design practice to locate the coolant level switch in the highest part of the cooling system; this will provide the earliest warning of a drop in coolant level. High water temperature switches will not give warning of coolant loss; their temperature sensing portion works best when surrounded by liquid water rather than steam.

High Water Temperature Switches
High water temperature switches are devices which continuously monitor the temperature of some fluid, generally coolant, and actuate switch contacts when the fluid temperature goes above some preset limit. In the case of jacket water coolant, the set point is usually between 96° and 102°C (205° and 215°F), depending on the engine, cooling system type, and whether alarm of impending problems or actuation of engine shutdown systems is desired. Switches can be set for either condition.

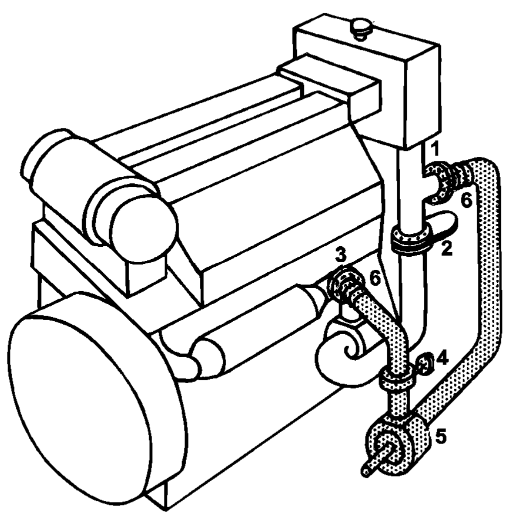
Emergency Systems
Many marine applications require the capability to connect emergency cooling water pumps into the engine's cooling system. Cat engines can be provided with these optional connections when necessary. This is a specific requirement of marine

classification societies for seagoing single propulsion engine applications.

The requirement applies to both the engine jacket water and auxiliary (sea or fresh) water systems. The purpose of the emergency systems is to ensure cooling if either the jacket water or auxiliary (sea or fresh) water pump should fail. The customer-supplied emergency pumps should provide flow equal to the failed pump to permit operation at full, continuous power with the emergency systems. For pump flow requirements of engine-mounted pumps, refer to TMI or consult a Cat dealer. If reduced power operation is acceptable, reduced flows can be utilized. Use flexible connectors at the engine to protect the piping and engine.

Jacket Water Pump Connections
The optional Cat emergency jacket water connections, available for the large vee engines, meet the requirements of the engine and the marine classification societies. Use of these connections permits the emergency system to utilize the normal jacket water as the coolant and to bypass the engine-mounted jacket water pump. The system includes a blanking plate or valve to direct jacket water to the emergency system and flanged connection points on the engine for the emergency system piping. **Figure 62** is a schematic diagram of the system properly connected. The customer-supplied emergency water pump should provide flow equal to the failed pump.

Emergency Jacket Water Pump Connections (Location of Jacket Water Pump May Vary)



1. **Flanged Tee Connection - to Emergency Pump**
2. **Blanking Plate - Closed for Emergency Pump Operation**
3. **Flanged Tee Connection - from Emergency Pump**
4. **Valve - Customer Supplied, Open for Emergency Pump Operation**
5. **Emergency Pump - Customer Supplied**
6. **Flexible Connector - Customer Supplied**

Figure 62

The use of seawater in the engine jacket water system is not recommended. If seawater must be used in the jacket water system to ensure the safety of the ship in an emergency situation, use the lowest engine power level commensurate with the sea state. On reaching port, the jacket water system must be thoroughly flushed and cleaned.

Auxiliary Seawater Pump

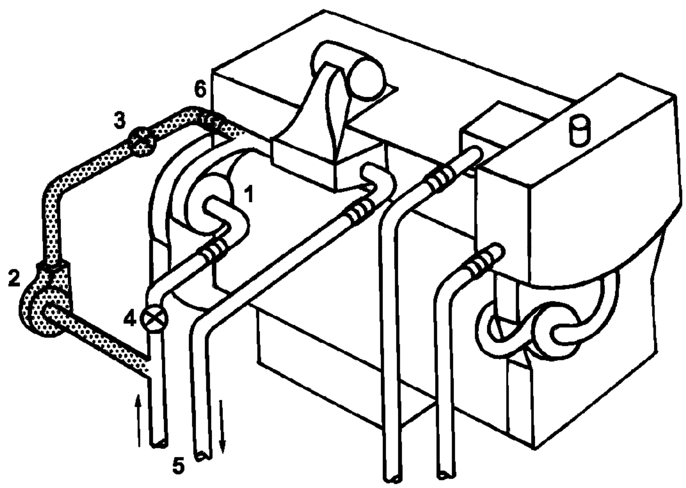
Connections

All emergency seawater cooling connections are to be provided by the installer and connected as indicated in **Figure 63**, illustrating emergency auxiliary pump connections. The emergency seawater pump should provide flow equal to the failed pump.

Auxiliary Freshwater Pump Connections

All emergency connections for separate keel cooled aftercooler circuits are to be provided by the installer, and connected as indicated in the **Figure 63**. The flow required for the emergency separate keel cooled aftercooler pump should equal the failed pump. The use of seawater in the separate keel cooled aftercooler circuit is not recommended. The engine- mounted pump and lines are of ferrous material and have low corrosion resistance in seawater. If seawater must be used in an emergency to ensure the safety of the ship, thoroughly flush the system as mentioned in the jacket water section, and inspect the parts for corrosion damage and deposits.

Emergency Auxiliary Pump Connections



1. **Engine Mounted Auxiliary Pump**
2. **Customer Provided Emergency Auxiliary Pump**
3. **Customer Provided Valve - Normally Closed**
4. **Customer Provided Valve - Normally Open**
5. **Auxiliary Cooling Circuit**
6. **Flexible Connection**

Figure 63

Central Cooling Systems

A central cooling system is defined as one which cools multiple engines and which combines many individual cooling system components (heat exchangers and pumps) into a large central one. However, there are both advantages and disadvantages to a central cooling system that must be considered when making that determination.

A typical marine central cooling system diagram is shown in **Figure 64**.

Advantages of a Central Cooling System

- A central cooling system will reduce the extent of the seawater piping system and thereby reduce wear, corrosion, and maintenance.
- The reduced extent of the seawater system will also significantly reduce the amount of shipyard labor required to install such a system.
- The smaller number of components will reduce the cost of cost procurement, inventory, and support with repair units.
- Larger components are generally more robust and can be expected to last longer.

Disadvantages of a Central Cooling System

- A disadvantage of a central cooling system involves the additional electrical loads required for the additional circulating pumps, and the somewhat higher capital and installation cost associated with them.
- Another disadvantage is the difficulty in diagnosing problems in such a system due to the number of potential modes of operation.
- For example: with a system containing three engines, one heat exchanger, and two pumps, there will be 162 possible combinations or modes of operation.

Suggestions for Design of a Successful Central Cooling System

- Flow Control: There are upper and lower limits to the allowable flow through an engine. The system must be able to throttle the flow through each engine independently.
- Temperature Control: The heat exchanger must be capable of delivering the proper amount of cooling, proportional to engine load.
- Load Control: The amount of external water flow through a Cat Engine is directly proportional to the engine's load. The greater the load, the greater the amount of cooling required and the more water the engine's internal cooling circuitry will discharge for cooling. At light loads, the engine's temperature controls will bypass the external portion of the engine cooling system, recirculating virtually all of the coolant. If the water pressure presented to an engine by a central cooling system is too high, the proper operation of the engine's temperature controls may be overridden, and the engine will suffer over or under cooling problems. It is very difficult to adequately balance and control the flow through several engines,

all of which might be operating at widely varying loads.Keep each engine's jacket water system independent of all others, using a separate jacket water heat exchanger at each engine. The load control problems are not economically solvable. The water pressure on an engine jacket water inlet cannot be allowed to exceed an engine's published pressure limits. Economic factors may encourage many designers to use higher pressures, but this must be discouraged, as higher pressures will significantly reduce water pump seal life.

- Ring Main: Provide a ring main of freshwater, circulated by at least two, parallel water pumps. A third water pump should be kept in reserve to maintain operation when either of the other pumps requires maintenance. Each pump should be identical for ease of parts inventory and maintenance. The ring main is the water source for each engine's independent cooling system. The temperature and pressure of the water in the ring main do not need precise control. Each engine should have an engine-driven, auxiliary (not jacket water) water pump. This pump will draw water from the ring main and return it back to the ring main, downstream.
- Pressure Control Valve: A valve must be installed to balance the system if one or more of the heat exchangers are shut off. In response to pressure differences across the exchangers, the valve will open or close and try to maintain the pressure at its original setting. As a result, the water flowing through the remaining heat exchangers will remain unchanged, and the temperature relationships will remain constant.

Typical Marine Central Cooling System

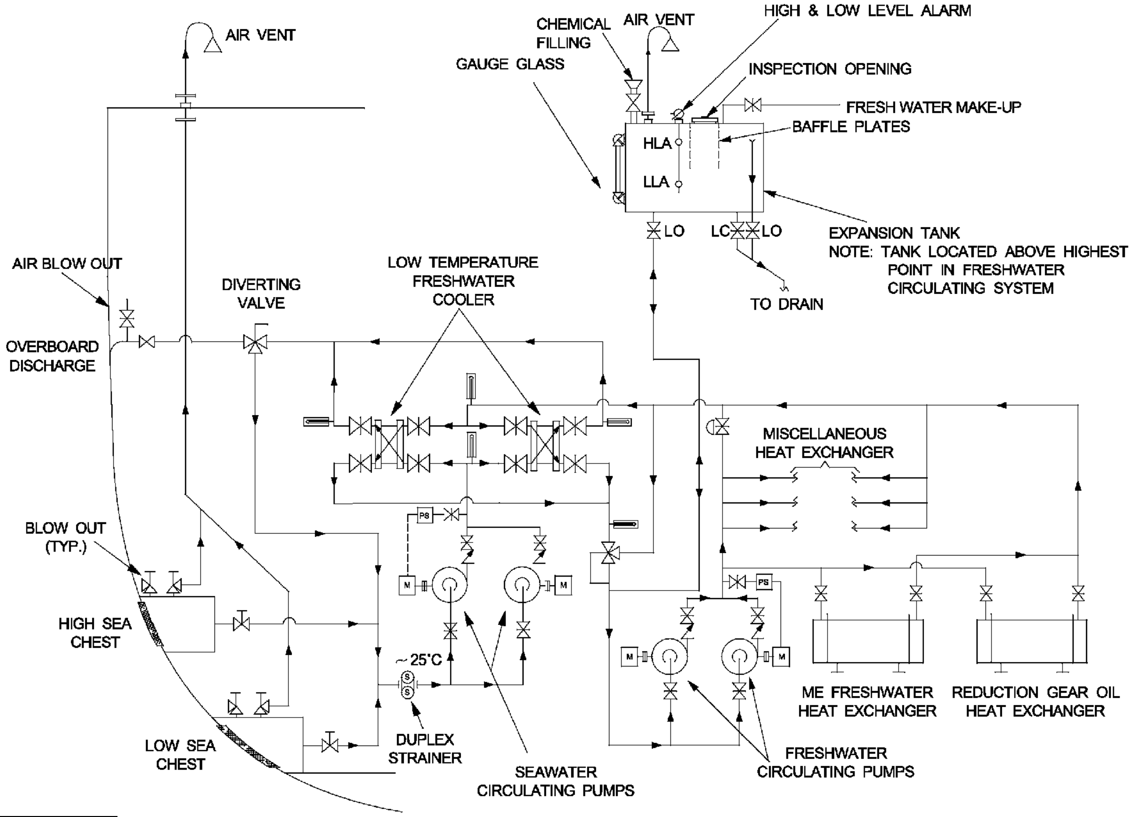


Figure 64

Cold Weather Considerations

Form SEBU5338-01 Cold Weather Operation, contains information on operation, lubrication, and maintenance in cold weather conditions.

Methods of retaining engine heat are discussed below.

Commercially available radiator shutters should be considered. Fan air flow across the engine increases heat lost to radiation. Particularly at light load, shutters minimize this heat loss and raise the engine temperature.

Commercially available diesel fuel fired jacket water heaters should be considered on engines that must start when no AC power is available.

Engine enclosures or engine room enclosures are recommended to retain engine heat.

Extreme Cold Weather Considerations

Extreme conditions require additional protection as shown in **Figure 65**. This protection is commercially available.

The radiator should be in a separate room from the engine. Absence of the radiator air flow will ensure the engine environment is kept at a warmer temperature in cold weather.

Extreme Cold Weather Protection

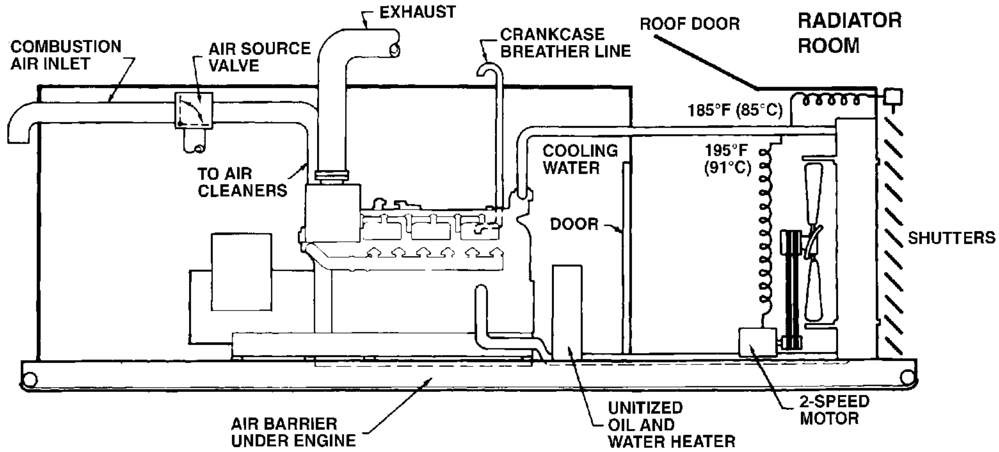


Figure 65

In warm temperatures, the weather enclosure is either removed or opened. Radiator cooling air is drawn in through a roof door in the radiator room during winter operation. Normally, radiator discharge air is utilized for rig heating.

If emissions regulations allow them, two-speed radiator fans are recommended because they offer several advantages for utilization of engine heat. First, lower fan speed reduces air flow and consequently increases air temperature rise of the radiator air flow utilized for rig heating. Second, radiator fan horsepower is considerably reduced.

Sensors for the two-speed motor and shutters have to be protected from being affected by the cold air coming through the roof door. The roof door area is sized to accommodate only the low fan speed air requirements. The opening is adjustable. The enclosure door will have to be opened by hand for summertime operation.

The house should be as airtight as possible. This includes an air barrier under the engine oil pan, as illustrated.

To minimize air changes in the engine room, combustion air can be ducted to the air cleaner from outside, as shown. An air source valve is included so the engine can be started and idled on the warmer air in the engine room. The engine should be operated on outside air. Otherwise, a vacuum may be caused in the engine room, depending upon how airtight the engine room is. Air cleaner adapters are available to connect ducting.

Heavy duty air cleaners can be utilized for protecting the engine from air cleaner plugging due to "ice fogs," if they occur.

Crankcase breather fumes should be piped out of the engine room to minimize oily deposits. In extremely cold weather, the fumes may have to be discharged into the engine room due to breather outlet freezing. Fumes should be discharged as remotely as possible from engine air cleaner inlets.

An alternative sometimes used is to discharge the fumes under the power module base where it is generally warmer.

Lube oil and jacket water heaters should be provided. They are required for cold startup after a rig move. (Power is supplied by a small cold start generator set.) They also can be used to maintain the temperature of an engine that is not running. On many rigs all engines are generally run at all times, as there is no reliable way to keep the engine ready for service at a moment's notice, with a resultant increase in fuel usage. Jacket water heaters are readily available, but oil heaters are not. Oil is difficult to heat without circulation. Thus, immersion-type oil heaters are generally not recommended as they lead to coking of the oil. Unitized oil and water heaters are commercially available which overcome the problem. They employ oil and water circulating pumps for proper system operation.

Exhaust piping should be so arranged that exhaust will NOT be drawn into the radiator or combustion air inlet.

Coolant Considerations

While the quality of fuels and lubricating oils is of primary concern to engine operators, the quality of the engine coolant is just as important. With over 50% of all engine failures related to poor cooling system maintenance, proper coolant selection and maintenance are vital to successful engine service life.

Coolant Function

The engine's cooling system, as we have discussed throughout this section, is designed to meet specific guidelines, driven by the specific project application requirements. The proper coolant/antifreeze will provide the following functions:

- Adequate heat transfer
- Compatibility with the cooling system's components such as hoses, seals, and piping
- Protection from water pump cavitation
- Protection from other cavitation erosion
- Protection from freezing and from boiling
- Protection from the build-up of corrosion, sludge, and scale

Coolant Properties

Coolant/antifreeze is normally composed of three elements: water, glycol, and additives.

Note: Each of these elements must meet specific guidelines.

Additional information on coolant properties and their effect on engines is available in the following Caterpillar service publications.

- Cat Commercial Diesel Engine Fluids Recommendations
- Cat Gas Engine Lubricant, Fuel, and Coolant Recommendations
- 3600 Diesel Engine Fluids Recommendations for Lubricants, Fuels, and Coolants
- Coolant and Your Engine

Media numbers for these publications are available at the end of this guide.

Water

Water is used in the coolant mixture because it is the most efficient, best-known and universally available heat transfer agent. However, each water source contains contaminant levels to various degrees. At operating temperatures of diesel and natural gas engines, these contaminants form acids or scale deposits that can reduce cooling system service life.

Prime consideration in closed cooling systems is to ensure no corrosion or scale forms at any point. Therefore, Caterpillar recommends using distilled or deionized water. If distilled or deionized water is not available, use water that meets Caterpillar's published "minimum acceptable water requirements".

Note: Do not use the following types of water:

- Salt water/seawater
- Hard water
- Softened water that has been conditioned with salt.

Note: Never use water alone as a coolant. Supplemental Coolant Additives (SCA) are required because water is corrosive at engine operating temperatures. When additional protection against boiling or freezing is required, both glycol and SCA are required.

Supplemental Coolant Additives

SCAs help to protect the metal surfaces of the cooling system and help prevent:

- Corrosion
- Formation of mineral deposits
- Rust
- Scale
- Pitting and erosion from cavitation of the cylinder liner
- Foaming of the coolant

Note: Over-treatment should be avoided because this can cause cooling system problems. Do not add SCA or Extender (for Cat ELC & ELI) unless testing shows additive depletion.

Glycol

Glycol in the coolant provides protection against the following conditions:

- Boiling
- Freezing
- Water pump cavitation (ATAAC equipped engines)

For optimum performance in most applications, Caterpillar recommends a 1:1 mixture of an approved water/glycol solution.

Note: Refer to the engine specific Operation and Maintenance Manuals for exceptions.

Note: Aluminum radiators will require a Coolant Conditioner to be added when newly installed to prevent nitrite depletion and color fading when used with Cat ELC (Extended Life Coolant) or ELI (Extended Life Inhibitor for treated water applications). Nitrites are included in Cat coolants to provide cylinder liner pitting protection. Refer to special instruction REHS7296-00 for more information. Do not use this Coolant Conditioner in conventional coolants that contain SCA additives, for example, Cat DEAC.

Coolant Recommendations

The Caterpillar line of coolants includes Cat DEAC (Diesel Engine Antifreeze/Coolant), Cat ELC (Extended Life Coolant), and Cat NGEC (Natural Gas Engine Coolant).

While both Cat DEAC and Cat ELC are acceptable for use in Cat diesel engines, Caterpillar recommends the Cat ELC, as it provides extended coolant service life, corrosion protection, extended water pump seal service life, and extended radiator service life. In addition, Cat ELC requires less ongoing coolant maintenance than conventional coolants such as Cat DEAC.

The Cat ELC anticorrosion package is totally different from conventional coolants. Cat ELC is an ethylene glycol based coolant that contains organic acid corrosion inhibitors, and antifoaming agents.

Note: Cat NGEC is recommended for all Cat natural gas engines. Caterpillar does not recommend Cat ELC for use in natural gas engines.

Coolant Testing

The coolant should be maintained throughout the life of the application. Testing the engine coolant is important to ensure that the engine is protected from internal cavitation, corrosion, boiling and freezing.

S•O•S^SM Coolant Analysis

Coolant analysis can be performed at your Cat dealership. Caterpillar S•O•S^SM coolant analysis is an excellent way to monitor the condition of your coolant and your cooling system.

The S•O•S[SM] coolant analysis is a two level program. The Level 1 analysis tests the properties of the coolant including glycol concentration, additive level, pH, conductivity, hardness, visual appearance and odor. The Level 2 analysis is a comprehensive chemical evaluation of the coolant that includes a full Level 1 analysis, and also checks the overall condition of the inside of the cooling system by identifying the source of metal corrosion, scaling, and contaminants. Contact your Cat dealer for complete information and assistance on the S•O•S[SM] coolant analysis program.

Boiler Type Coolants

If boiler type coolants are used, certain additives known to the system operator must be kept at corrosion arresting levels. These all should be checked at dealer recommended intervals, such as every 250 hours or six months (depending on application), otherwise problems may occur.

Overtreatment should also be avoided since this can cause problems as well; do not add treatment unless testing shows additive depletion. Caterpillar also has specifications covering contaminants such as chlorides, sulfates, hard water minerals, as well as dissolved gases. These must be checked by analytical methods since they can destroy a system even if corrosion inhibitor additives are in correct proportions.

Reference Material

Media List

The following information is provided as an additional reference to subjects discussed in this manual.

The following publications are available for order through your Cat dealer.

Note: The information that is contained in the listed publications is subject to change without notice.

Note: Refer to this publication, the respective product data sheet, and to the appropriate Operation and Maintenance Manual for product application recommendations.

AECQ1042
Caterpillar Product Line Brochure

GECJ0001
Cat Shop Supplies and Tools (catalog)

PECP9067
One Safe Source (catalog)

PEDP7036
S•O•S^{SM} Fluid Analysis

PEDP9131
Fluid Contamination – The Silent Thief

PEEP5027
Label – ELC Radiator Label

PEHJ008
Data Sheet, "Cat Arctic DEO (SAE 0W-30)" (Canada and United States)

PEHJ0021
Data Sheet, "Cat DEO (SAE 10W-30 and SAE 15W-40)" (Worldwide – Except North America, Egypt, Saudi Arabia, and Brazil)

PEHJ0059
Data Sheet, "Cat DEO (SAE 10W-30 and SAE 15W-40)" (North America - Canada, Mexico, and United States)

PEHJ0067
Data Sheet, "Cat ELC (Extended Life Coolant)" (Worldwide)

PEHJ0068
Data Sheet, "Cat Advanced Efficiency Engine Oil Filter"

PEHJ0072
Data Sheet, "Cat DEO (SAE 10W-30 and SAE 15W-40)" (Brazil)

PEHJ0082
Data Sheet, "Cat Fuel/Water Separators and Prime Time Priming Pumps"

PEHJ0091
Data Sheet, "Cat DEO (SAE 10W-30 and SAE 15W-40)" (Egypt and Saudi Arabia)

PEHJ0093
Data Sheet, "Cat DEO (SAE 30 and SAE 40)" (For use in 3600 Series diesel engines and for use in older precombustion chamber diesel engines. Do NOT use in direct injected 3500 Series and smaller diesel engines.)

PEHP6028
Data Sheet, "Cat Ultra High Efficiency Air Filters"

PEHP7032
Data Sheet, "Radial Seal Air Filters"

PEHP7045
Data Sheet, "Fuel Contamination Control for 3500 Series Cat Engines"

PEHP7046
Data Sheet, "Fuel Contamination Control"

PEHP7052
Making the Most of S•O•S^{SM} Services

PEHP7057
S•O•S^{SM} Coolant Analysis

PEHP7062
Data Sheet, "Cat DEO SYN (SAE 5W-40)"

PEHP7076
Understanding S•O•S[SM] Services Tests

PEHP7077
Data Sheet, "Cat Turbine Pre-Cleaners'

PEHP9013
Data Sheet, "Air Filter Service Indicator"

PEHP9554
Data Sheet, "Cat DEAC (Diesel Engine Antifreeze/Coolant) (Concentrate)"

PEPP5027
Label – ELC Radiator Label

PELJ0176
Cat ELC (Extended Life Coolant) 223-9116 Dilution Test Kit

PELJ0179
Cat Engine Crankcase Fluid-1 Specifications (CAT ECF-1) (All International Markets)

PEWJ0074
Cat Filter and Fluid Application Guide

LEKQ7235
Engine Data Sheet 50.5 – Cooling System Field Test

REHS1063
Special Instruction – Know Your Track-Type Tractor Cooling System

SEBD0970
Coolant and Your Engine

SEBU6250
Cat Machine Fluids Recommendations

SEBU6251
Cat Commercial Diesel Engine Fluids Recommendations

SEBU6400
Cat Gas Engine Lubricant, Fuel, and Coolant Recommendations

SEBU7003
3600 Diesel Engine Fluids Recommendations for Lubricants, Fuels, and Coolants

SENR9620
Improving Fuel System Durability

WECAP
Web Engineering Cataloging and Procuring website

LEXH6521
Air to Air Aftercooling system Guide.

REHS7296-00
Instructions for Use of Cat Coolant Conditioner for Aluminum Components

Jacket Water Cooling Circuit Worksheet

Sheet 1 of 3

Engine Model: ________________________ Compression Ratio: ___________

Engine rpm: ________ Water Temperature to Aftercooler: ______ °C or °F

Feature Code: _______________ Rating: _______________

Site Conditions: ____

____

1. Heat Rejection

Determine the cooling system configuration, obtain the heat rejection data for the specific engine model and rating and add the appropriate tolerance.

* Possible configurations: JW only, Combined JW + OC, Combined JW + AC, Combined JW + OC + AC.

Jacket Water Heat Rejection: __________ kW or Btu/min

Jacket Water Heat Rejection x 1.10 tolerance = Heat Rejection with Tolerance

____________x 1.10 tolerance = __________ kW or Btu/min

Oil Cooler Heat Rejection: ____________ kW or Btu/min (if applicable)

Oil Cooler Heat Rejection x 1.20 tolerance = Heat Rejection with Tolerance

_________________ x 1.20 tolerance = __________ kW or Btu/min

Aftercooler Heat Rejection: ___________ kW or Btu/min (if applicable)

Aftercooler Heat Rejection x (ACHRF) x 1.05 tolerance = Heat Rejection with Tolerance

__________________ x ______ x 1.05 tolerance = __________ kW or Btu/min

Add the kW or Btu/min values of the jacket water, oil cooler and aftercooler circuits:

Total Heat Rejection with Tolerance = __________ kW or Btu/min

***Note:** The system configuration is defined on the performance data sheets. For diesel engines, the oil cooler heat rejection is typically included with the jacket water heat load. To check if a circuit load is included, use the following equation to calculate the energy balance. For example, if the JW heat rejection contains the oil cooler heat, the oil heat rejection must be zero for the equation to balance.

Energy Balance Equation:

$$Q_{Total} = W + Q_{Exh} + Q_{Sur} + Q_{JW} + Q_{OC} + Q_{AC}$$

Jacket Water Cooling Circuit Worksheet
Sheet 2 of 3

2. Coolant Flow Rate

Calculate the coolant flow rate using the temperature rise, heat rejection and coolant properties. Density and Specific Heat can be found in **Table 1** on **Page 24** of the Cooling Systems Application & Installation Guide.
Note: If a temperature rise value is not provided for the engine, the coolant flow must be selected from the external restriction vs. coolant flow curve for the engine rather than calculated. Select a flow rate near the midpoint of the curve.

Recommended Temperature Rise (ΔT): ___________ °C or °F

Density of Coolant: ___________ kg/L or lbm/gal

Specific Heat of Coolant: ___________ kW-min/kg °C or Btu/lbm °F

$$\frac{\text{Heat Rejection}}{\Delta T \times \text{Density} \times \text{Specific Heat}} = \text{Cooling Circuit Flow Rate}$$

$$\frac{\qquad\qquad}{\quad \times \quad \times \quad} = \_\_\_\_\_\_\_\_\_\_\_\_ \text{ (Lpm or gpm)}$$

Cooling Circuit Flow Rate = __________ Lpm or gpm

Jacket Water Cooling Circuit Worksheet

Sheet 3 of 3

3. Allowable External Restriction

From the graph of External Restriction vs. Coolant Flow for the Jacket Water Circuit, find the maximum allowable restriction for the flow calculated in step 2.

Maximum Allowable External Restriction for Jacket Water Cooling Circuit: ____________________ **m H_2O or ft H_2O**

4. Jacket Water Circuit Sizing (Radiator, Heat Exchanger or other cooling device)

Add an additional external circuit system tolerance to the Total Heat Rejection with Tolerance value calculated in step 1 to account for system fouling or degradation. This additional tolerance should be 1% to 10%, depending on the cooling system used and operating conditions.

Total Heat Rejection with Tolerance x (1.01 to 1.10) = Jacket Water Circuit Heat Rejection

__________________________ x 1.______ = ________________ kW or Btu/min

Jacket Water Circuit Heat Rejection: ____________________ **kW or Btu/min**

5. Recheck Cooling System Pressure Drop

After selecting a cooling system, calculate the pressure drop of the system and compare it to the external restriction vs. flow curve to determine if the flow rate changed from the assumed value. If the value changed, recheck the cooling system at the new value to assure the system is sized correctly. As long as the operating point is on the given pump curve for the engine and rating, it is an acceptable operating point for the engine. Do not extrapolate the curve as this operating point will not be acceptable for the engine.

Auxiliary Cooling Circuit Design Worksheet

Sheet 1 of 3

Engine Model: ________________________ Compression Ratio: ___________

Engine rpm: _________ Water Temperature to Aftercooler: ______ °C or °F

Feature Code: _______________ Rating: _______________

Site Conditions: ____

____

1. Aftercooler Heat Rejection Factor

Published aftercooler heat rejection data is for the standard conditions of 25°C (77°F) and 500 ft (152.4 m). Use the aftercooler heat rejection factor table provided with the engine technical performance data sheet to determine the aftercooler heat rejection factor for the site conditions. (For diesel engines, the aftercooler heat rejection factor is 1.0.)

Aftercooler Heat Rejection Factor (ACHRF): _________

2. Heat Rejection of Cooling Circuit

Determine the cooling system configuration, obtain the heat rejection data for the specific engine model and rating and add the appropriate tolerance. Possible configurations: SCAC only, Combined SCAC + OC*.

Aftercooler Heat Rejection: __________ Btu/min or kW

Aftercooler Heat Rejection x (ACHRF) x 1.05 tolerance = Heat Reduction with Tolerance

___________________ x ______ x 1.05 tolerance = ___________ kW or Btu/min

Oil Cooler Heat Rejection: ___________ kW or Btu/min

Oil Cooler Heat Rejection x 1.20 tolerance = Heat Reduction with Tolerance

_____________________ x 1.20 tolerance = __________ kW or Btu/min

Add the kW or Btu/min values of the aftercooler and oil cooler circuits:

Total Heat Rejection with Tolerance = __________ kW or Btu/min

***Note:** Most engines have the oil cooler on the jacket water circuit and the heat load is included in the jacket water value. For gas engines and 3600 engines, check the performance data sheet to determine which circuit contains the oil cooler.

Auxiliary Cooling Circuit Design Worksheet

Sheet 2 of 3

3. Coolant Flow Rate

Calculate the coolant flow rate using the temperature rise, heat rejection and coolant properties. Density and Specific Heat can be found in **Table 1** on **Page 24** of the Cooling Systems Application & Installation Guide.

Note: If a temperature rise value is not provided for the engine, the coolant flow must be selected from the external restriction vs. coolant flow curve for the engine rather than calculated. Select a flow rate near the midpoint of the curve.

Recommended Temperature Rise (ΔT): ___________ °C or °F

Density of Coolant: ___________ lbm/gal or kg/L

Specific Heat of Coolant: ___________ kW-min/kg °C or Btu/lbm °F

$$\frac{\text{Heat Rejection}}{\Delta T \times \text{Density} \times \text{Specific Heat}} = \text{Cooling Circuit Flow Rate}$$

$$\frac{\qquad\qquad}{\quad \times \quad \times \quad} = \underline{\qquad\qquad} \text{ (Lpm or gpm)}$$

Cooling Circuit Flow Rate: ____________________ **Lpm or gpm**

4. Allowable External Restriction

From the graph of External Restriction vs. Coolant Flow for the Auxiliary Circuit, find the maximum allowable restriction for the flow calculated in step 3.

Maximum Allowable External Restriction for Auxiliary Cooling Circuit: ____________________ **m H_2O or ft H_2O**

Auxiliary Cooling Circuit Design Worksheet

Sheet 3 of 3

5. Auxiliary Cooling System Sizing (Radiator, Heat Exchanger or other cooling device)

Add an additional external circuit system tolerance to the Total Heat Rejection with Tolerance value calculated in step 2 to account for system fouling or degradation. This additional tolerance should be 1% to 10%, depending on the cooling system used and operating conditions.

Total Heat Rejection with Tolerance x (1.01 to 1.10) = Auxiliary Circuit Heat Rejection

__________________________ x 1.______ = ______________ kW or Btu/min

Auxiliary Circuit Heat Rejection: ____________________ kW or Btu/min

6. Recheck Cooling System Pressure Drop

After selecting a cooling system, calculate the pressure drop of the system and compare it to the external restriction vs. flow curve to determine if the flow rate changed from the assumed value. If the value changed, recheck the cooling system at the new value to assure the system is sized correctly. As long as the operating point is on the given pump curve for the engine, it is an acceptable operating point for the engine. Do not extrapolate the curve, as this operating point will not be acceptable for the engine.

Heat Exchanger Sizing Worksheet

Sheet 1 of 1

Heat Exchanger Sizing Data

Required by Heat Exchanger Supplier

Engine Jacket Water Circuit:

1. Jacket water heat rejection*	________	kW (Btu/min)
2. Jacket water flow*	________	L/sec (Gpm)
3. Anticipated seawater maximum temperature	________	C° (F°)
4. Seawater flow	________	L/sec (Gpm)
5. Allowable jacket water pressure drop	________	m (ft) water
6. Allowable seawater pressure drop	________	m (ft) water

Drop

7. Auxiliary water source (sea water or fresh water)	☐ ☐	seawater fresh water
8. Heat exchanger material (admiralty or copper-nickel)	☐ ☐	adm. metal cu-ni
9. Shell connection size**	________	
10. Tube side fouling factor***	________	

Aftercooler Water Circuit:

1. Aftercooler circuit water heat rejection*	________	kW (Btu/min)
2. Aftercooler circuit water flow*	________	L/s (Gpm)
3. Anticipated seawater maximum temperature	________	C° (F°)
4. Seawater flow*	________	L/s (Gpm)
5. Allowable Aftercooler Circuit Water Pressure Drop*	________	m (ft) water
6. Allowable seawater pressure drop*	________	m (ft) water
7. Auxiliary water source (sea water or fresh water)*	☐ ☐	seawater fresh water
8. Heat exchanger material (admiralty or copper-nickel)	☐ ☐	adm. metal cu- ni
9. Shell connection size**	________	
10. Tube side fouling factor***	________	

* Refer to TMI (Technical Marketing Information)
** Refer to engine general dimension drawing
*** Fouling Factor, a descriptive quantity often found on heat exchanger specifications, refers to the heat exchangers ability to resist fouling. As defined in Caterpillar literature, fouling factor is the percentage of the heat transfer surface which can be fouled without losing the heat exchanger's ability to dissipate the engine's full heat load.

Keel Cooler Sizing Worksheet

Sheet 1 of 1

Engine Jacket Water Circuit:		
1. Jacket water heat rejection*	____________	kW (Btu/min)
2. Jacket water flow*	____________	L/sec (Gpm)
3. Vessel speed classification	☐	8 knots & above
	☐	3 knots
	☐	1 knot
	☐	still water
4. Anticipated seawater maximum temperature	____________	C° (F°)
5. Minimum cooler area required (per unit)	____________	m^2/kW
	____________	(ft^2/Btu/min)
6. Minimum area required (Line 1 times Line 5)	____________	m^2 (ft^2)
Aftercooler Water Circuit:		
1. Aftercooler circuit heat rejection*	____________	kW (Btu/min)
2. Aftercooler circuit water flow*	____________	L/sec (Gpm)
3. Vessel speed classification	☐	8 knots & above
	☐	3 knots
	☐	1 knot
	☐	still water
4. Anticipated seawater maximum temperature	____________	C° (F°)
5. Minimum cooler area required (per unit)	____________	m^2/kW
	____________	(ft^2/Btu/min)
6. Minimum area required (Line 1 times Line 5)	____________	m^2 (ft^2)
Marine Gear Oil Cooling Circuit:		
1. Marine gear heat rejection**	____________	kW (Btu/min)
2. Vessel speed classification	☐	8 knots & above
	☐	3 knots
	☐	1 knot
	☐	still water
3. Anticipated seawater maximum temperature	____________	C° (F°)
4. Minimum cooler area required (per unit)	____________	m^2/kW
	____________	(ft^2/Btu/min
5. Minimum Area Required (Line 1 times Line 5)	____________	m^2 (ft^2)

* Refer to TMI (Technical Marketing Information)

** See section on Marine Gear Heat Rejection

Packaged Keel Cooler Sizing Worksheet

Sheet 1 of 1

Engine Jacket Water Circuit:

1. Jacket water heat rejection*	______________	kW (Btu/min)
2. Jacket water flow*	______________	L/s (Gpm)
3. Vessel speed classification	☐	8 knots & above
	☐	3 knots
	☐	1 knot
	☐	still water
4. Anticipated seawater maximum temperature	______________	°C (°F)

Aftercooler Water Circuit:

1. Aftercooler circuit heat rejection*	______________	kW (Btu/min)
2. Aftercooler circuit water flow*	______________	L/s (Gpm)
3. Vessel speed classification	☐	8 knots & above
	☐	3 knots
	☐	1 knot
	☐	still water
4. Anticipated seawater maximum temperature	______________	°C (°F)

*Refer to TMI (Technical Marketing Information)

Auxiliary Expansion Tank Sizing

Sheet 1 of 1

Engine Model ______________________ Rating ________ hp at ____________ rpm

For Engine Jacket Water, Figure 1.25:

Auxiliary jacket water expansion tanks are not always required.

1. Allowable external volume ________ L/gal, with engine mounted tank. (This value shown in Table 1.1, Column A, on page 37.)
2. Total volume of jacket water contained in external cooling circuit (not furnished as part of engine) ________ L/gal. See Table 1.2, page 47, for volume per length of standard iron pipe.
3. Line 2 minus Line 1 ________ L/gal.
   If this value is zero or less, additional tank is not required.
   If this value is greater than zero, an auxiliary tank is required.
4. If required, the ***minimum*** volume of the auxiliary expansion tank can be determined by:

   a. Engine volume, Table 1.1, Column B ________________________________
   b. External volume Line 2 ________________________________
   c. Total volume—
      sum of line a and line b ________________________________
   d. Multiply line a by 0.06 ________________________________
   e. Multiply line b by 0.04 ________________________________
   f. Multiply line c by 0.01 ________________________________
   g. Total of lines d, e and f ________________________________

   (This is the minimum volume of the jacket water auxiliary expansion tank.)

For Separate Circuit Aftercooler, Figure 1.26:

1. Total volume of aftercooler external water ________ L/gal.
2. Multiply Line 1 by 0.02 ________ L/gal.
3. Add the cold fill volume desired in auxiliary expansion tank to Line 2.
   Total of Line 2 and cold fill volume ________ L/gal.
   (This is the minimum volume of the aftercooler circuit auxiliary expansion tank.)

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