CATERPILLAR®

Electric Power Application and Installation Guide

Cooling System

LEBX0028-01

WHERE THE WORLD TURNS FOR POWER

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Cooling Systems

All internal combustion engines produce heat as a by-product of combustion and friction which can create temperatures of up to 1925°C (3500°F).

The cooling system has a direct effect on the operation and service life of the engine. If the cooling system is not correctly sized, does not have good maintenance, or is not operated correctly, the engine can overheat or overcool. This can shorten the engine service life and/or result in poor engine performance.

There are many areas in an engine where it is critical that heat be removed. Cylinder walls must be cooled to maintain a film of lubrication for the piston to slide upon. Cylinder components (pistons, valves, heads) must be properly cooled to reduce the risk of detonation. The engine oil must be cooled to ensure its integrity. As a general rule, 20-40% of the energy input into an engine must be removed by the cooling system.

Cooling System Functions

Most diesel and gas engines are liquid-cooled, although a few of the small and high-speed engines are air-cooled.

Figure 1 shows the basic components of common liquid cooled engine cooling systems. These basic components are: coolant, the water pump, the engine oil cooler, coolant temperature regulators, the fan and the radiator. 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 turbocharger shields and housing and oil coolers. After flowing through the cylinder head(s), the coolant goes into the coolant temperature regulator housing.

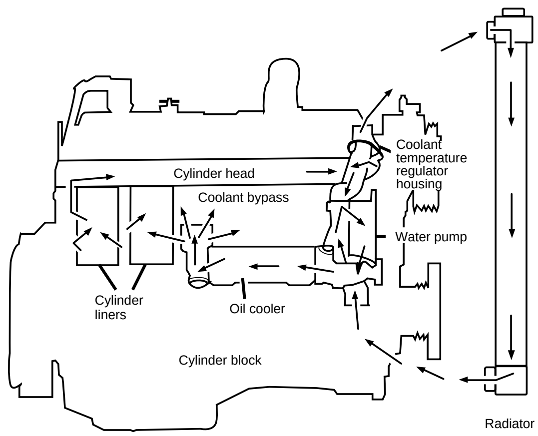


Figure 1. Cooling systems basic functions.

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

Each system has specific design criteria that must be met to ensure proper cooling of the engine.

All the pressure and temperature values in this publication are gauge values unless otherwise specified. All units are shown in the Metric convention with English units in parentheses, [e.g. meter (feet)].

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 the Performance and Technical Information books 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.

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

Where:

Total Heat Input (Q_{Total})

The Total Heat Input is calculated by multiplying the Brake Specific Fuel Consumption (BSFC) and the Power Output bkW(bhp).

$$Q_{Total}\ (\text{MJ/hr}) = \text{BSFC (MJ/bkW–hr)} \times \text{Power Output (bkW)}$$

$$Q_{Total}\ (\text{Btu/hr}) = \text{BSFC (Btu/bhp–hr)} \times \text{Power Output (bhp)}$$

Work Output (W)

The work output is the total power created from the energy contained in the fuel. It is expressed in kW (bhp) where one brake horsepower = 0.7457 kW.

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 low heat value and do not include the heat of vaporization. The exact exhaust temperature varies from engine to engine depending on rating and respiration. The value can be found in TMI.

Heat Loss to the Surroundings (Q_{Sur})

There is a certain amount of heat that is rejected from the engines surface to the surrounding ambient conditions. This is due to convective and radiation effects.

Jacket Water Heat (Q_{JW})

Jacket Water Heat is the total amount of heat dissipated to the engine cooling system. Caterpillar engines are designed to operate with a jacket water temperature (coolant) differential of less than 11.1°C (20°F) measured across the engine under full load.

Oil Cooler Heat (Q_{OC})

The Oil Cooler Heat rejection (Q_{OC}) is included in the jacket water heat (Q_{JW}) when not listed separately. Most of the heat in the oil comes from oil that is sprayed on the bottom side of the pistons.

Aftercooler Heat Rejection (Q_{AC})

Aftercooler heat rejection is given for standard conditions of 25°C (77°F) and 150 m (500 ft) altitude. Aftercooler heat rejection is increased for higher ambients and higher altitudes. A constant aftercooler outlet temperature is required. As the air temperature to the aftercooler goes up, so does the heat that must be removed. As the air pressure decreases, the turbocharger imparts more energy to the incoming air to increase it to the required boost pressure. The aftercooler heat rejection factor is used to adjust for ambient and altitude conditions. Failure to properly account for these factors could cause the engine to detonate and result in engine shutdown or failure.

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 177°C (350°F).

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 the 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.

C_p = 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 Caterpillar recommended tolerances vary depending on the engine model and are published in TMI.

Design Requirements

Engine Cooling Systems must:

- Reject heat from the jacket water coolant and auxiliary circuit if equipped, at greatest engine load, highest ambient temperature, and altitude.
- Allow filling without air entrapment (false fill).
- Provide sufficient suction head to prevent pump cavitation.
- Vent air introduced into the system by filling, leaks, and engine combustion.
- Maintain a required minimum operating temperature.

Coolant

Coolant must be able to transfer heat from hot engine components to a radiator or heat exchanger where the heat is dissipated.

Coolant generally consists of water combined with corrosion inhibitors or with antifreeze and corrosion inhibitors. The correct selection of coolant has a direct affect on the efficiency and/or service life of both the cooling system and the engine.

Basic Operating Parameters

All engine cooling circuits are designated by the maximum permissible inlet or outlet temperature to that circuit. Table 1 lists the temperature limits for each cooling circuit for gas engines and whether it is specified by an inlet or an outlet temperature for each engine size.

Cooling System	Cooling Circuit	G3300/G3400	G3500
Standard	AC (Inlet) AC (Inlet) JW/OC (Outlet)	32°C (90°F) 54°C (130°F) 99°C (210°F)	32°C (90°F) 54°C (130°F) 99°C (210°F) 92°C (198°F) – G3516B 60 Hz
Low Energy	AC (Inlet) JW/OC (Outlet)	NA NA	54°C (130°F) 110°C (230°F)
High Temperature	AC (Inlet) AC (Inlet) JW/OC (Outlet)	NA NA NA	32°C (90°F) 54°C (130°F) 127°C (260°F)

Table 1. Temperature limits for cooling circuits for gas engines.

Temperature Limits

Diesel

Caterpillar Diesel Engines are designed with coolant outlet temperatures listed in Table 2. An engine is considered overcooled when the coolant is below 70.4°C (160°F).

Engine Family		D3208/D3300	D3400/D3500
Application Prime/Continuous			
	Alarm	102°C (215°F)	102°C (215°F)
	Shutoff	107°C (225°F)	107°C (225°F)
Standby			
	Alarm	107°C (225°F)	102°C (215°F)
	Shutoff	113°C (235°F)	107°C (225°F)

Table 2. Temperature limits for coolant outlet temperature for diesel engines.

Gas

Caterpillar Gas Engines (except the 3600 engine family) are designed to operate with the following maximum temperature differential.

For the three different engine ratings, coolant temperatures should not exceed the following temperature limits shown in Table 3 for a properly sized cooling system.

Aftercooler Rating Inlet Temperature	Maximum Inlet Water Temperature
32°C (90°F)	32°C (90°F)
54°C (130°F)	54°C (130°F)
70°C (158°F)	70°C (158°F)

Table 3. Temperature limits, gas engines.

Note: If 70°C (158°F) aftercooler inlet temperature is used, the Engine Information System, EIS, control module will not be cooled by the aftercooler water. The EIS control module will be air cooled by the surrounding ambient conditions.

Gas

Landfill

- Pressurized 131-152 kPa (19-22 psi) capacity 110°C (230°F) Outlet

Co-gen

- Pressurized 196.5 kPa (28.5 psi) relief valve 127°C (260°F) Outlet

Diesel and Gas

Oil Cooler

- Inlet Temperature of 82°C (180°F)

Jacket Water - standard

- Pressurized 27-48.2 kPa (4-7 psi) capacity 99°C (210°F) Outlet
  [G3516B 60 Hz – 92°C (198°F) Outlet]

Failure to abide by the above limits could result in poor engine performance and/or engine failure.

Pressure Limits

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.

Diesel

The coolant pressure drop through the aftercooler at rated speed and load must not exceed 13.6 kPa (2 psi).

Depending on the height of the expansion tank above the jacket water pump inlet and the engine configuration, the system pressure should be between 48-96 kPa (7-14 psi). Refer to the engine data sheet for exact information.

A standard engine block should operate with pressure of 248-276 kPa (36-40 psi) but not exceed 379 kPa (55 psi).

Gas

Tables 4 and 5 contain the suggested operating and maximum pressure for Caterpillar Gas Engine cooling systems.

Component	Operating Pressure kPa (psi)	Maximum Pressure kPa (psi)
Engine Block	248-276 (36-40)	276 (40)
Aftercooler Core	248-276 (36-40)	276 (40)
Pump Inlets		196 (24.7) max. static head
Engine Outlets		196 (24.7) max. static head

Table 4. Operating pressure for the 3300 and 3400 gas engine.

Component	Operating Pressure kPa (psi)	Maximum Pressure kPa (psi)
Engine Block		
Standard	248-276 (36-40)	379 (55)*
Low Energy Fuels	248-276 (36-40)	379 (55)*
High Temp. System	310-345 (45-50	379 (55)*
Aftercooler Core	248-276 (36-40)	276 (40)
Pump Inlet		196 (24.7) max. static head

* If an operating pressure greater than 276 kPa (40 psi) is needed the customer must supply their own jacket water (coolant) pump.

Table 5. Operating pressure for the 3500 gas engine.

Coolant Flow

Calculating Required Coolant Flow

The first step in the design of a cooling system is to calculate the flow required for each circuit to transfer the heat load from the engine components to the Heat Exchangers or Radiators.

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

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

ΔT = Outlet Temperature - Inlet Temperature (for the particular circuit)

It is important to use the correct coolant properties while figuring flow calculations.

Table 6 lists the density and specific heat capacities for pure water and water mixed with Ethylene Glycol.

	Pure Water	50/50 Water-Glycol
Density (kg/L)	0.98	1.03
Density (lb/gal)	8.1	8.6
Specific Heat (kcal/kg-°C)	1.0	0.85
Specific Heat (Btu/lb-°F)	1.0	0.85

Table 6. Density and specific heat @ 82°C (180°F).
Note (kW-sec=kJ=4.19 kcal)

Example: Coolant Flow Rate Calculation

Diesel 3412C TA with engine speed @ 1800 rpm has:
Maximum top tank temperature 99°C (210°F)
Maximum bottom tank temperature 88°C (190°F)
Engine coolant heat rejection 508 kW (28,890 Btu/min)

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

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

Heat Transfer

Heat transfer describes the tendency of thermal energy to move from a higher temperature area to a lower temperature area. The rate of heat transfer is determined partly by the specific heat properties of a given liquid. (Specific heat is the amount of heat energy required to change the temperature of 1 g of a substance by 1°C.) The rate of heat transfer also depends on the temperature difference between the outside air and the coolant itself, plus the conductive properties of the material that surrounds the coolant.

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:

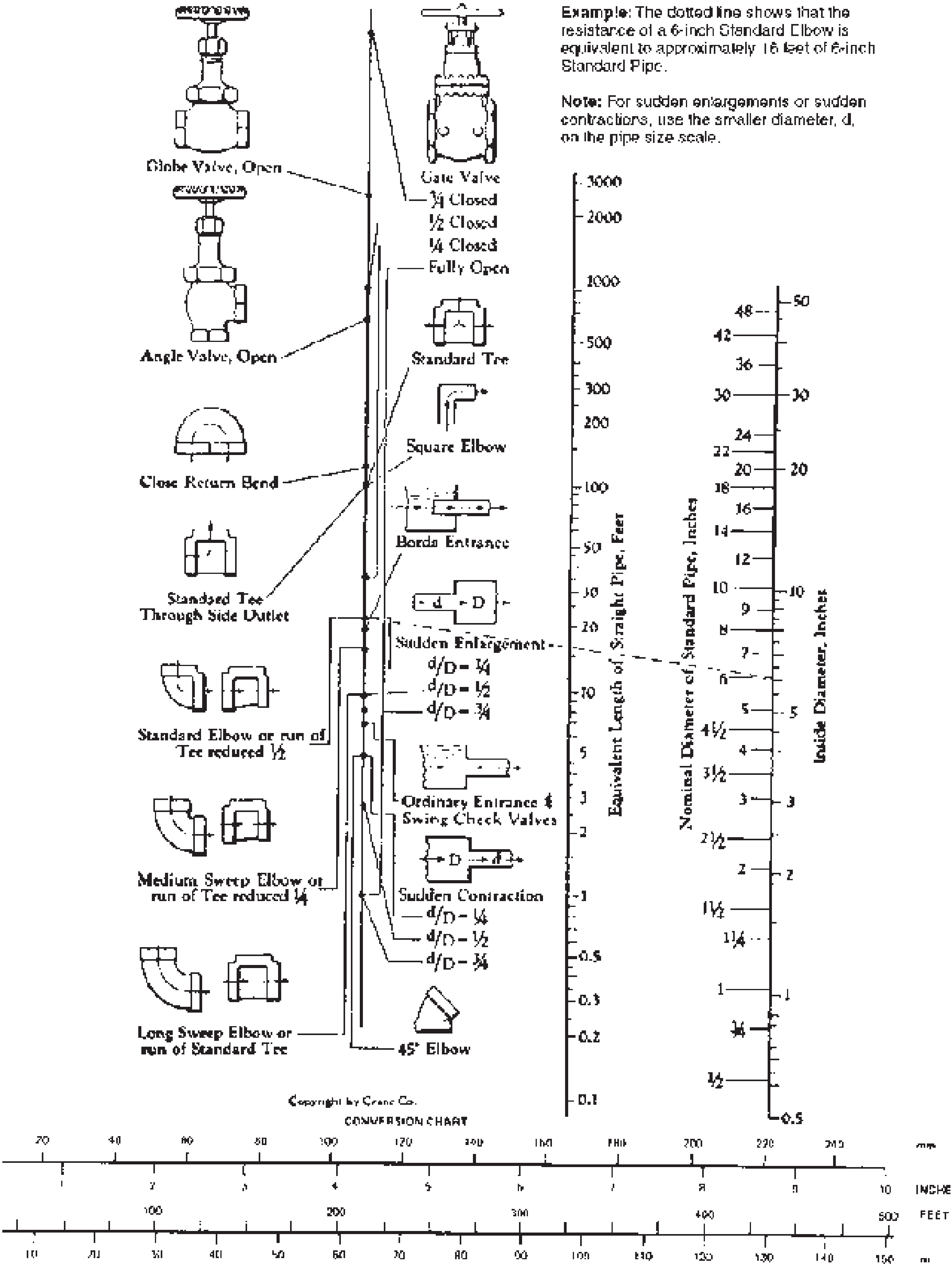
- Size and length of pipe
- Quantity, size and type of fittings and valves used
- Coolant flow rate
- Heat transfer devices

Table 7 lists the typical friction losses of water flowing in a pipe. Figure 2 lists the resistance of valves and fittings to flow of coolant which can be used to determine pressure drop through pipes, fittings and valves. The pressure drop (resistance) in the external cooling system can be calculated by totaling the pressure drop in each of the system's components.

Both the TMI and the Engine Performance and Technical Information books 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 3. The data is shown in both tabular and graphical form.

gpm	**L/s**	**Head Loss in ft/ 100 ft (m per 100 m)**							**gpm**	**L/s**
gpm	L/s	3/4 in. (19.05 mm)	1 in. (25.4 mm)	1 1/4 in. (31.75 mm)	1 1/2 in. (38.1 mm)	2 in. (50.8 mm)	2 1/2 in. (63.5 mm)	3 in. (76.2 mm)	gpm	L/s
5	.34	10.5	3.25	0.84	0.40	0.16	0.05		5	.34
10	.63	38.0	11.7	3.05	1.43	0.50	0.17	0.07	10	.63
15	.95	80.0	25.0	6.50	3.05	1.07	0.37	0.15	15	.95
20	1.26	136.0	42.0	11.1	5.20	1.82	0.61	0.25	20	1.26
25	1.58	4 in. (101.6 mm)	64.0	16.6	7.85	2.73	0.92	0.38	25	1.58
30	1.9	0.13	89.0	23.0	11.0	3.84	1.29	0.54	30	1.9
35	2.21	0.17	119.0	31.2	14.7	5.10	1.72	0.71	35	2.21
40	2.52	0.22	152.0	40.0	18.8	6.60	2.20	0.91	40	2.52
45	2.84	0.28	5 in. (127 mm)	50.0	23.2	8.20	2.76	1.16	45	2.84
50	3.15	0.34	0.11	60.0	28.4	9.90	3.32	1.38	50	3.15
60	3.79	0.47	0.16	85.0	39.6	13.9	4.65	1.92	60	3.79
70	4.42	0.63	0.21	113.0	53.0	18.4	6.20	2.57	70	4.42
75	4.73	0.72	0.24	129.0	60.0	20.9	7.05	2.93	75	4.73
80	5.05	0.81	0.27	145.0	68.0	23.7	7.90	3.28	80	5.05
90	5.68	1.00	0.34	6 in. (152.4 mm)	84.0	29.4	9.80	4.08	90	5.68
100	6.31	1.22	0.41	0.17	102.0	35.8	12.0	4.96	100	6.31
125	7.89	1.85	0.63	0.26	7 in. (177.8 mm)	54.0	17.6	7.55	125	7.89
150	9.46	2.60	0.87	0.36	0.17	76.0	25.7	10.5	150	9.46
175	11.05	3.44	1.16	0.48	0.22	8 in. (203.2 mm)	34.0	14.1	175	11.05
200	12.62	4.40	1.48	0.61	0.28	0.15	43.1	17.8	200	12.62
225	14.20	5.45	1.85	0.77	0.35	0.19	54.3	22.3	225	14.20
250	15.77	6.70	2.25	0.94	0.43	0.24	65.5	27.1	250	15.77
275	17.35	7.95	2.70	1.10	0.51	0.27	9 in. (228.6 mm)	32.3	275	17.35
300	18.93	9.30	3.14	1.30	0.60	0.32	0.18	38.0	300	18.93
325	20.5	10.8	3.65	1.51	0.68	0.37	0.21	44.1	325	20.5
350	22.08	12.4	4.19	1.70	0.77	0.43	0.24	50.5	350	22.08
375	23.66	14.2	4.80	1.95	0.89	0.48	0.28	10 in. (254 mm)	375	23.66
400	25.24	16.0	5.40	2.20	1.01	0.55	0.31	0.19	400	25.24
425	26.81	17.9	6.10	2.47	1.14	0.61	0.35	0.21	425	26.81
450	28.39	19.8	6.70	2.74	1.26	0.68	0.38	0.23	450	28.39
475	29.97		7.40	2.82	1.46	0.75	0.42	0.26	475	29.97
500	31.55		8.10	2.90	1.54	0.82	0.46	0.28	500	31.55
750	47.32			7.09	3.23	1.76	0.98	0.59	750	47.32
1000	63.09			12.0	5.59	2.97	1.67	1.23	1000	63.09
1250	78.86				8.39	4.48	2.55	1.51	1250	78.86
1500	94.64				11.7	6.24	3.52	2.13	1500	94.64
1750	110.41					7.45	4.70	2.80	1750	110.41
2000	126.18					10.71	6.02	3.59	2000	126.18

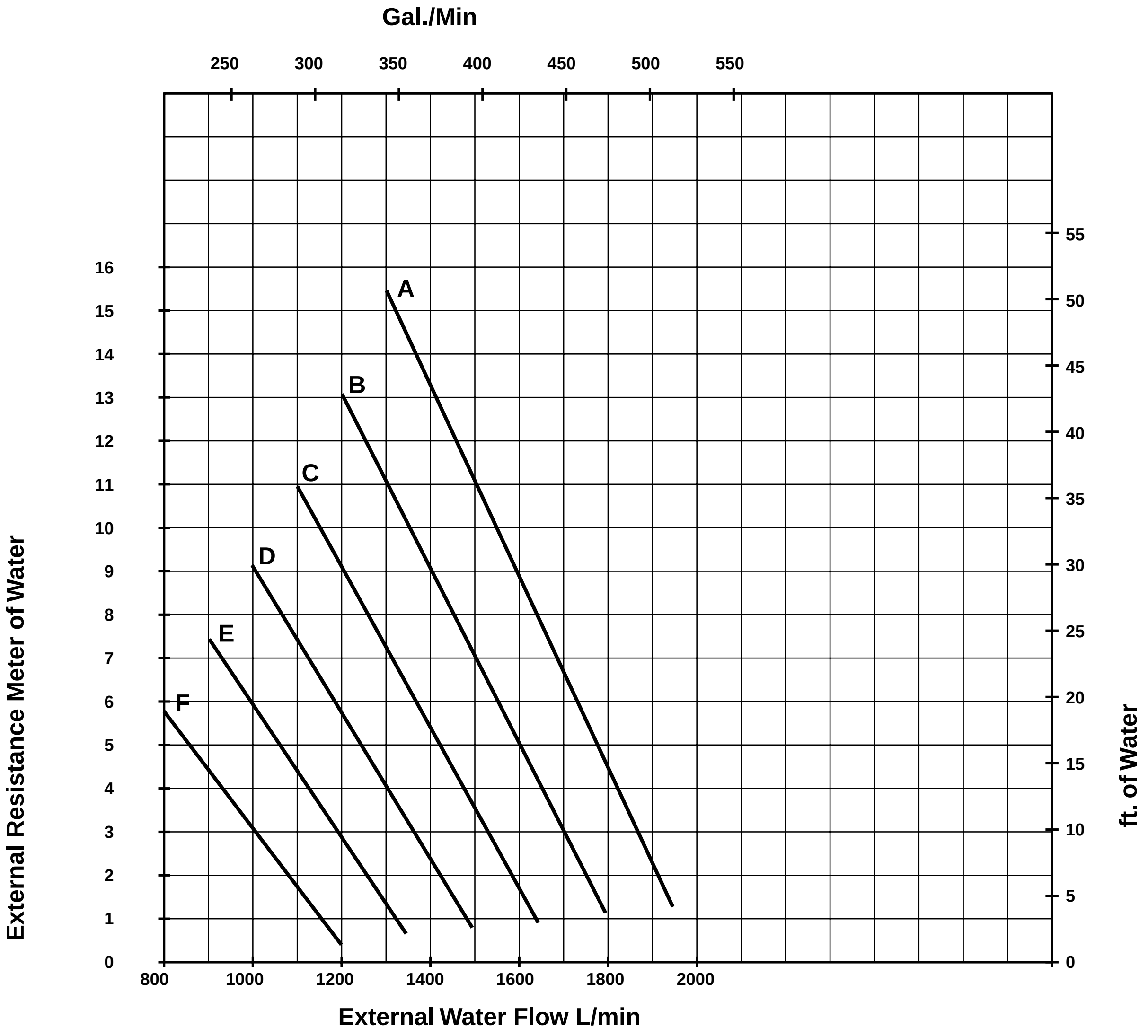
Table 7. Typical friction losses of water in pipe (old pipe). Nominal pipe diameter.



Example: The dotted line shows that the resistance of a 6-inch Standard Elbow is equivalent to approximately 16 feet of 6-inch Standard Pipe.

Note: For sudden enlargements or sudden contractions, use the smaller diameter, d, on the pipe size scale.

Figure 2. Resistance of valves and fittings to flow of fluids.



Jacket Water System Performance G3516 Low Speed

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 3. Pump curve.

Line Velocities

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. Table 8 can be used to calculate water velocity in a pipe or tube.

	(m/sec)	(ft/sec)
Pressurized Lines	4.5	15
Pressurized Thin-Wall Tubes	2.0-2.5	6.5-8
Suction Lines (Pump Inlet)	1.5	5
Low Velocity Deaeration Line	0.6	2

Table 8. Maximum water velocity.

Connections

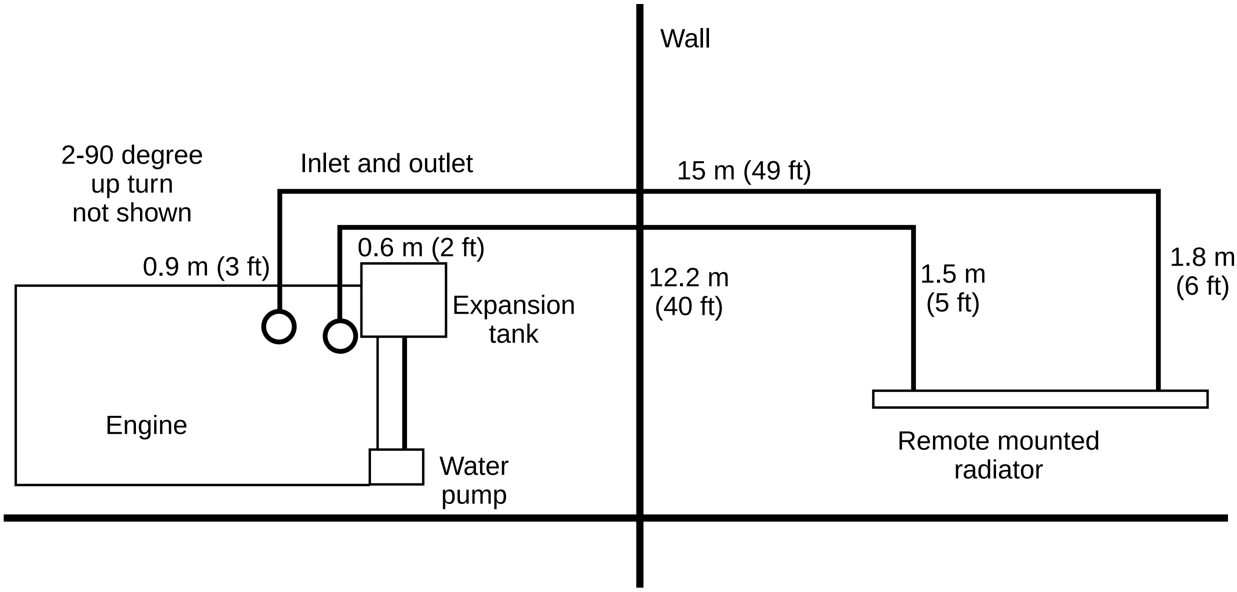
Use flexible connections for all connections to the engine (rubber hoses are not recommended). The positions of flexible connections and shut-off valves are important. Shut-off valves should be located to allow a flexible connection or engine repair without having to drain the entire cooling system. Orient the flex connector to take the maximum advantage of its flexibility. When selecting connectors, consider normal thermal expansion and maximum expected movement.

Material compatibility must also be evaluated. The internal surface must be compatible with the coolant used over the anticipated operating temperature and pressure ranges. The liner material must also be compatible with potential coolant contaminants, such as lube oil and system cleaning solutions. The outer cover must be compatible with its environment (temperature extremes, ozone, grease, oil, paint, etc.).

Example: Restriction Calculation

A G3516 Gas Engine running at 1200 rpm, requires a 1325 L/min (350 gpm) flow to provide cooling.

This could be the system design:



Components in the system:

Total straight length:	32 m (105 ft)
Standard 90° elbows:	6
Gate valve:	2

Utilizing Figure 2, Table 9a can be constructed to determine total effective straight length for various pipe diameters.

Effective straight length = straight length + 6 × Effective Elbow + 2 × Effective Value

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)	0.9 (3)	59.4 (195)
6	32 (105)	4.88 (16)	1.07 (3.5)	65 (214)
8	32 (105)	6.4 (21)	1.37 (4.5)	73.1 (240)

Table 9a. Example of determining total effective straight length.

Using Table 7 with the previously found equivalent length, the total restriction can be calculated as:
(Restriction/100 ft) × Equivalent Length.

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)	12.4	6.64 (21.8)
5	59.4 (195)	4.19	2.49 (8.17)
6	65 (214)	1.7	1.1 (3.6)
8	73.1 (240)	0.43	0.31 (1.03)

Table 9b. Example of determining total restriction.

Figure 3 gives 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.

Engine Design Configurations

Temperature Control

Thermostats

All internal combustion engines need to maintain a minimum operating temperature. If an engine is run continuously with an operating temperature that is too low, severe maintenance problems may arise. It is the function of the thermostat to control the minimum operating temperature of an engine. Each cooling system on an engine must have its own thermostat.

Since a thermostat controls the minimum operating temperature, the maximum temperature must be controlled by correct radiator or heat exchanger sizing. There are two basic methods for thermostatic control of minimum temperature in cooling systems: inlet regulated and outlet regulated.

Inlet Regulated

Inlet regulated cooling systems provide a constant temperature to the inlet jacket water, aftercooler, and/or oil cooler (see Figure 4). 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 bypass flow (hot water directly from engine) with cool water from a heat exchanging device, i.e. radiator, heat exchanger, etc.

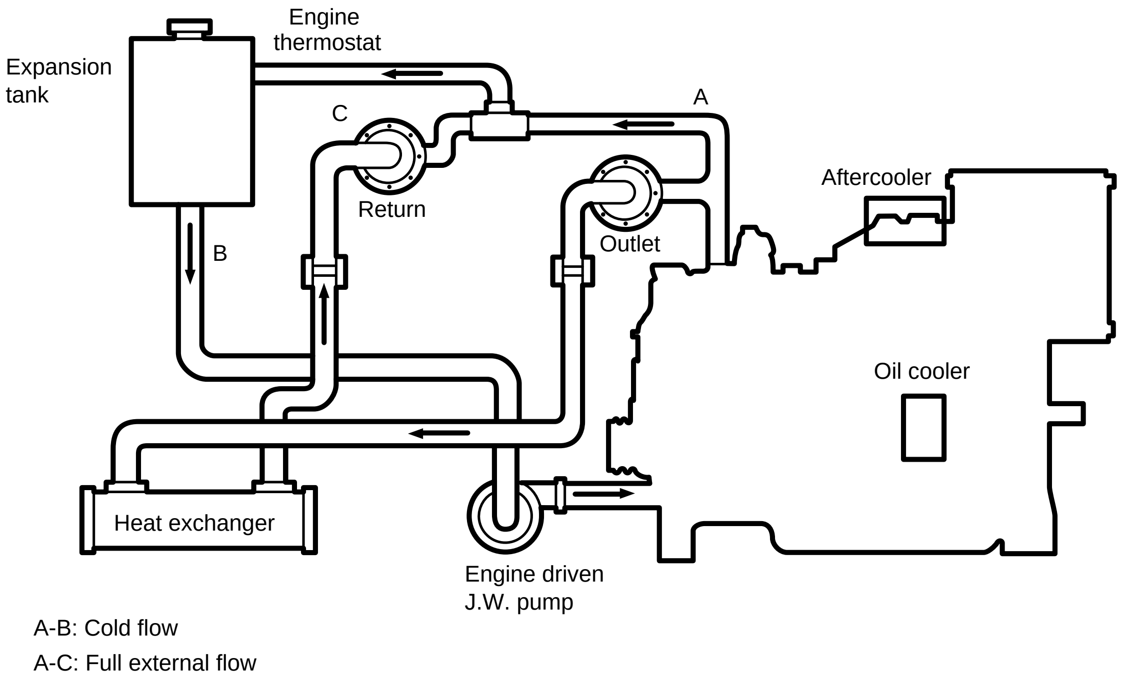


Figure 4. Inlet control.

A potential problem with inlet controlled cooling incorporating a radiator is that full pump pressure is imposed on the radiator core. This pressure usually exceeds the structural pressure of a solder tube radiator core. Therefore, inlet controlled systems are not often used with radiators. Inlet regulated cooling systems are most commonly seen in marine applications.

Outlet Regulated

Outlet regulated cooling systems provide a constant outlet temperature from the engine by regulating the flow between the bypass and cooling circuits (see Figure 5). 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. Note that all Caterpillar EPG radiator cooled systems use an outlet regulated cooling system.

Jacket Water

Water jackets in internal combustion engines consist of an outer casing surrounding the cylinders. The circulating coolant surrounds the cylinder bores and provides cooling for the cylinder heads.

Carefully sized coolant passages in the head aid in regulating the water flow and help to maintain uniform temperature throughout the block. Coolant surrounds the combustion chamber and spark plug bosses in the cylinder head.

Aftercooling

The air at the outlet of the turbocharger is at a higher temperature than the air at the inlet of the turbocharger. Some engines have an aftercooler to lower the temperature of turbocharger outlet air. Coolant is used in many aftercoolers to absorb the heat from the air. If the aftercooler core has dirt or oil in it, the coolant cannot absorb as much heat as it does normally. This can raise piston temperature and lower engine horsepower.

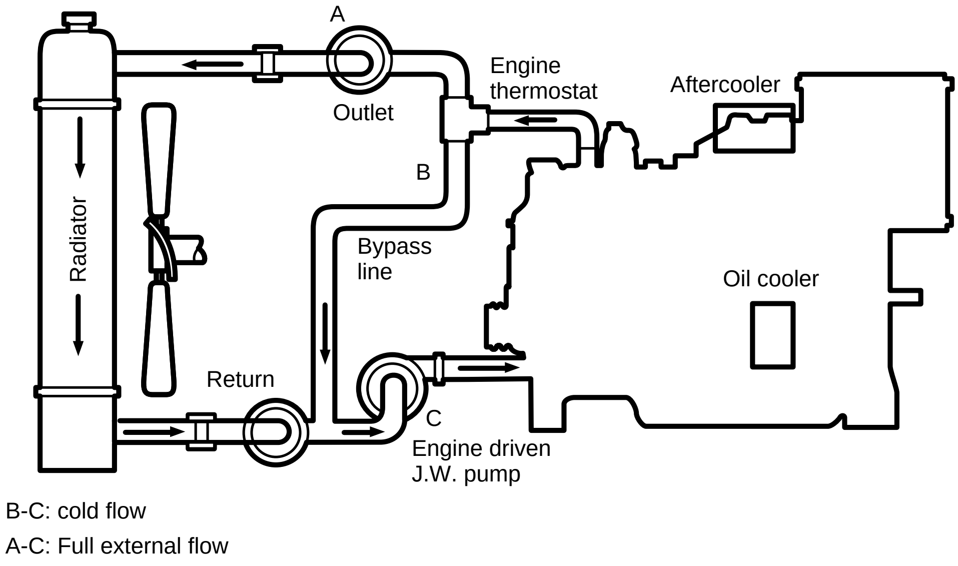
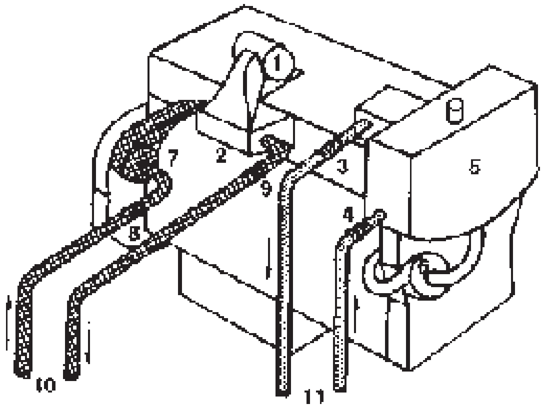


Figure 5. Outlet control.

Separate Circuit

As the name implies, the separate circuit aftercooler circuit, SCAC, provides water to the aftercooler from a source other than engine jacket water (see Figure 6). It is used to provide colder water to further reduce inlet manifold air temperatures.

The arrangement of the separate circuit aftercooled engine configuration provides a closed cooling circuit for the aftercooler coolant.



1. Turbocharger
2. Aftercooler, auxiliary water cooled
3. Jacket water outlet connection
4. Jacket water inlet connection
5. Expansion tank
6. Jacket water pump
7. Auxiliary water pump
8. Auxiliary water inlet connection
9. Auxiliary water outlet connection
10. Lines to aftercooler cooler
11. Line to jacket watercooler

Figure 6. Separate circuit aftercooled.

Aftercooler Condensation

With humid air and ambient temperatures above freezing, much of the water will be condensed in the aftercooler core. Provisions to remove the condensed water from the aftercooler core and piping must be included in the design. To address this need, a gas 3516 Low Emission Engine may produce up to 114 liters (30 gallons) of water a day.

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 drain 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.

Condensate traps should be installed in the intake piping close to the engine intake manifold. The design of a condensate trap is to quickly change direction of the air flow, usually by a minimum of 180°, and throw the heavier water droplets into a wall of the trap where they are collected and drained through a float valve. The condensate trap must be sized and designed so that its pressure drop is not excessive.

Air-To-Air Aftercooling (ATAAC)

Air-to-Air Aftercooling (ATAAC) can be used with turbocharged and aftercooled engines in areas where the lack of a 32°C (90°F) water source would otherwise preclude the use of full rated horsepower. This arrangement uses a dual-core radiator and fan. One section of this radiator is an air-to-air heat exchanger for the aftercooler circuit. Air piping must be fabricated to direct air from the turbocharger to the heat exchanger and return it to the engine.

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.

On low emission gas 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.

ATAAC Critical Design Criteria

The piping and heat exchanger core must be sized so the total pressure drop from the compressor outlet to the carburetor inlet is less than 38 mm (1.5 in.) of Hg. Install test fittings with pipe threads (1/4 in. recommended) 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.

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 be a corrosion resistant material.

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

The Air-to-Air Aftercooled engine configuration should not be used with low gas pressure arrangements. With this combination, a rather large volume of combustible air and gas mixture is flowing through the aftercooler core. If this mixture is ignited, damage may result to the aftercooler core.

Auxiliary Heat Sources

Exhaust

Heat recover mufflers economically recover about half the engine exhaust heat. Exhaust exit temperature above 177°C (350°F) helps eliminate condensation in ducting. Recoverable heat is obtained from TMI.

Lubricating Oil

When recovering heat from engines using high temperature cooling systems, it may be worthwhile to utilize heat rejected to lubricating oil. This heat can be applied to prehead boiler feed water, domestic hot water, or other low temperature requirements. Heat removed by lubricating oil from engines operating above 104°C (220°F) is always rejected to a cooling medium other than the jacket water. Heat rejection to the oil for Caterpillar Engines is approximately 0.14 kW/bkW (5.9 Btu/hp-min) for gas engines, 0.21 kW/bkW (9.1 Btu/hp-min) for diesel engines.

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 Caterpillar Engine. It is important to work with our experienced engineer and/or the local dealer when designing the best cooling system for each application. The following discussion lists some of the more common types of cooling systems.

There are two basic types of cooling systems, open and closed. Examples of each are given in Table 10.

Open System not recommended	Closed System
	Radiator
Cooling Tower (without heat exchanger)	Heat Exchanger
	Cooling Tower (with heat exchanger)
Spray Pond Body of Water	Evaporative Cooler

Table 10. Types of cooling systems.

Open System

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. Overheating may occur. 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

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.

Radiators

Radiator cooling is the most common type of closed cooling systems. Radiator cooling provides a closed, self-contained system that is both simple and practical for most installations.

Figure 7 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 to the bottom of the radiator and again is circulated through the engine by pump action. 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 deaerating of engine coolant. Extended systems using added coolant may require enlarged expansion tanks. 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.

The cooling system is designed to operate under a pressure of 27.6 to 48.3 kPa (4 to 7 psi) which results in a top tank temperature of 99°C (210°F). This limit prevents steam formation in the engine water jacket.

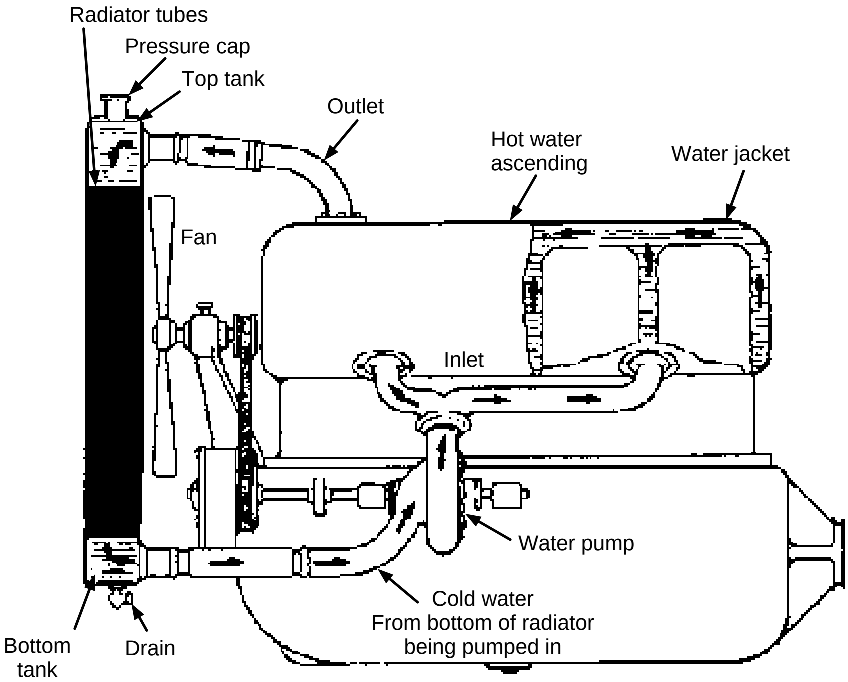


Figure 7. Schematic of typical radiator design.

Performance

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. The additional 10% will compensate for possible variations from published or calculated heat rejection rates, overload, and system deterioration. Even if the expected load is less than the engine rated power, size the radiator to match engine rated power.

- Correction factors to the observed ambient air temperature capability for the engine must not be overlooked. Altitude above sea level reduces the density of air and its ability to cool the radiator. A good correction factor is 1.38°C (2°F) deducted from the observed ambient temperature capability for each 305 m (1000 ft) above sea level. Consult the performance book for an exact correction factor.

- 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. The ambient temperature rise for different radiator locations is found in Table 11.

	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)	
Engine/generator in enclosure with internal muffler	9°C (16.2°F)	

Table 11. Estimated air to core rise.

- 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 prevent vibration and noise transmission.

- Position the radiator so prevailing winds do not act against the fan. One form of wind protection for radiators is a baffle located several feet from the radiator exhaust. Another method is to install an air duct outside the wall and mounting the air inlet or outlet vertically. Large radius bends and turning vanes prevent turbulence and excessive air flow restriction.

- It is important to make sure that the hot radiator air discharge is not recirculated to the air inlet. Figures 8A and B demonstrate this problem. Radiators must be arranged so that engine exhaust gases and/or crankcase ventilation gases are not drawn into the air inlet of the radiator (see Figure 8C).

- 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.

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

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

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

Speed

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

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

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

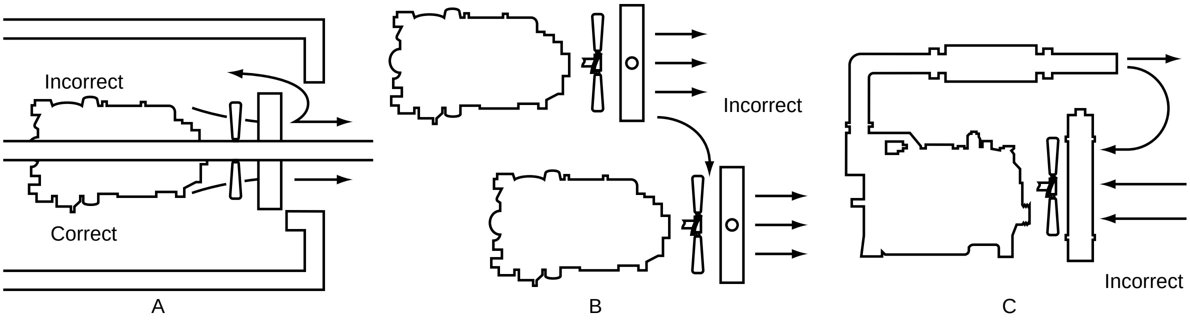


Figure 8. Radiator recirculation.

Temperature

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

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

$$\text{Radiator Ambient Capability} = \frac{99^\circ\text{C} - \text{Revised Coolant Temp.}}{\text{Coolant Temp.}}$$

$$\text{Radiator Ambient Capability} = \frac{210^\circ\text{R} - \text{Revised Coolant Temp.}}{\text{Coolant Temp.}}$$

Where:

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

Air Density = gm/cu•cm (lb/cu•in)
Air Flow = cu•m/min (cfm)
Coolant Temperature =

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

Original Radiator Temperature = the ambient air temperature that goes to the radiator
Assumptions:
Coolant Top Tank Temperature = 99°C (210°F)
Inlet to Outlet Radiator Temperature Change = 11.1°C (20°F)
Fan Horsepower = kW (hp)
Fan Speed = rpm
Static Pressure = mm (in) of 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 ambient temperature 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 flow, static pressure and fan 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.

Radiator System Pressure

Slight system pressure minimizes pump cavitation (voids in water) even at high altitude, and increases pump efficiency

For each 6.9 kPa (1 psi) of pressure, the boiling point is raised about 2°C (3°F).

Compared to pure water, alcohol/water mixes have a lower boiling point, while ethylene glycol mixes have a higher boiling point.

Ducting

Radiator ducting 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. 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 prevent recirculation and high room temperatures (see Figure 9). Some generator set packages have, as standard, radiator duct flanges for installation ease. The duct length is short and direct to minimize back-pressure, with total inlet and outlet restriction on the radiator fan less than 12.7 mm (0.5 in) of water.

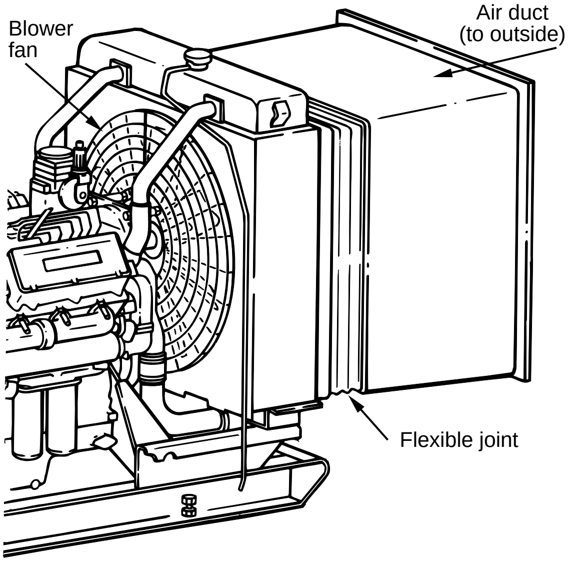


Figure 9. Ducting to the outside.

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 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. Give consideration to radiator design and larger piping. When distances separate the engine from the radiator, oversized piping may be required to minimize piping restriction.

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.

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.) (See Figure 10.)

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, an expansion tank must be used.

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.

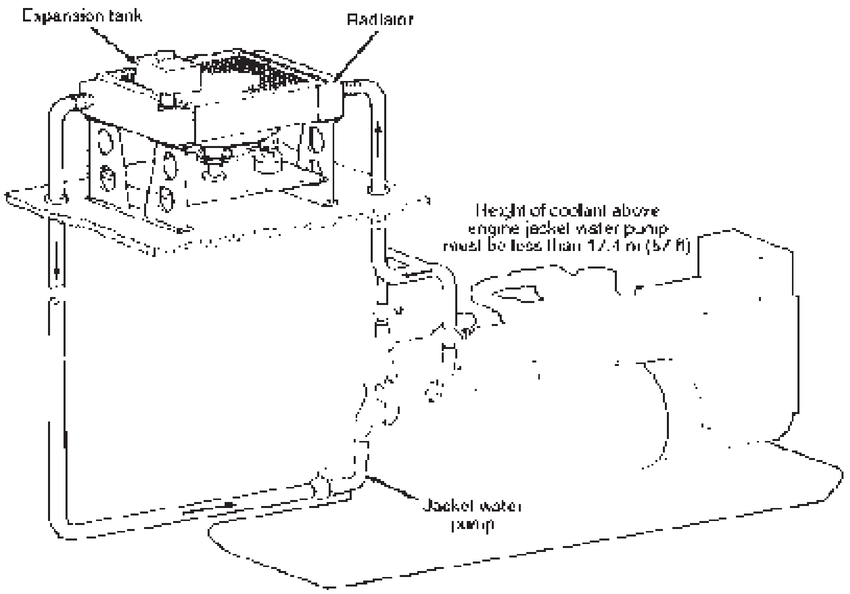


Figure 10. Remote mounted radiator.

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. If the radiator is mounted below the engine, do not use the radiator pressure cap. Remove the cap and seal the opening. This prevents untrained personnel from causing problems.

Vertical Remote

Vertical remote radiators are 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.

Booster Pumps

Booster pumps are utilized in conjunction with remote radiators which are usually applicable only for gas engines.

The function of the pump is to provide sufficient pressure for the coolant to reach the remote located radiator.

Fans

Radiator fans are belt driven from the crankshaft pulley. Fan air flow is dependent on:

- fan diameter
- number of blades
- blade shape
- blade rotation speed

Radiator and fan sizing charts should be consulted to ensure capacity and economic requirements are met.

Fan Power Demand

The fan included in Caterpillar radiator systems (typically) absorb 3-8% of the gross power output of the engine.

Fan Type

A radiator fan can be a blower or suction type. A blower fan, which forces air away from the engine, is usually a better choice for stationary engines, because it keeps the hot air from surrounding the engine. This type of fan also allows for easy disposal of hot air through a wall opening in an enclosed building installation. A suction fan, which pulls air toward the engine, is more effective in mobile equipment because of a vehicle's forward motion.

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 30-37% 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 127.1°C (260°F) outlet temperature. High temperature systems are further divided into solid water, water and steam, and ebullient steam systems.

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 shell and tube heat exchanger to transfer rejected engine heat to a secondary circuit, usually process water. An example system is illustrated in Figure 11. 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.

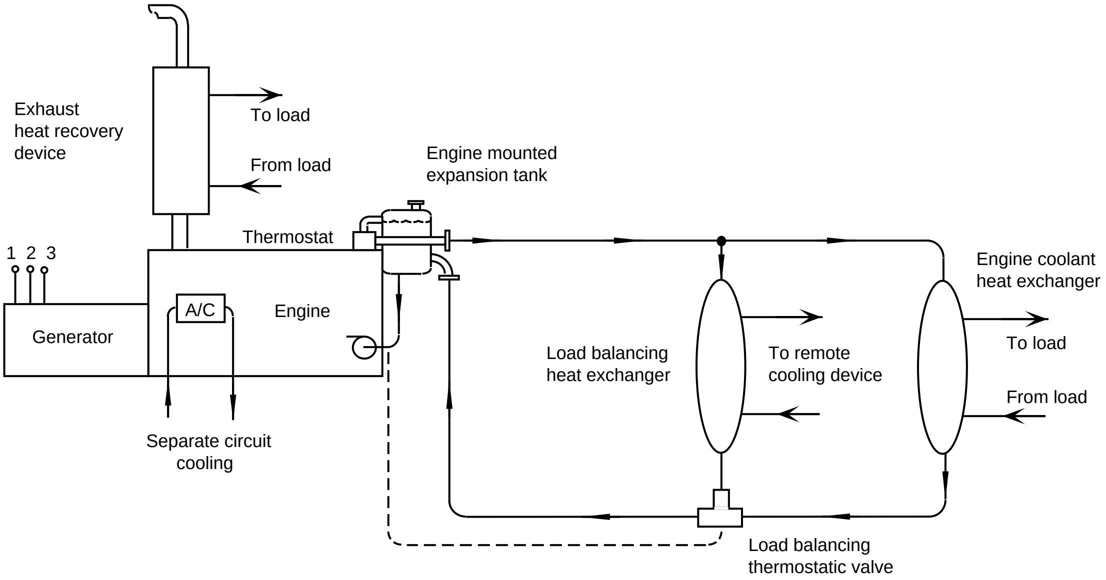


Figure 11. Standard temperature water system.

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.

An exhaust heat recovery device may be included 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 12 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.

A third variation on the standard temperature system is to incorporate the exhaust heat recovery device into the engine cooling loop, Figure 13. 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.

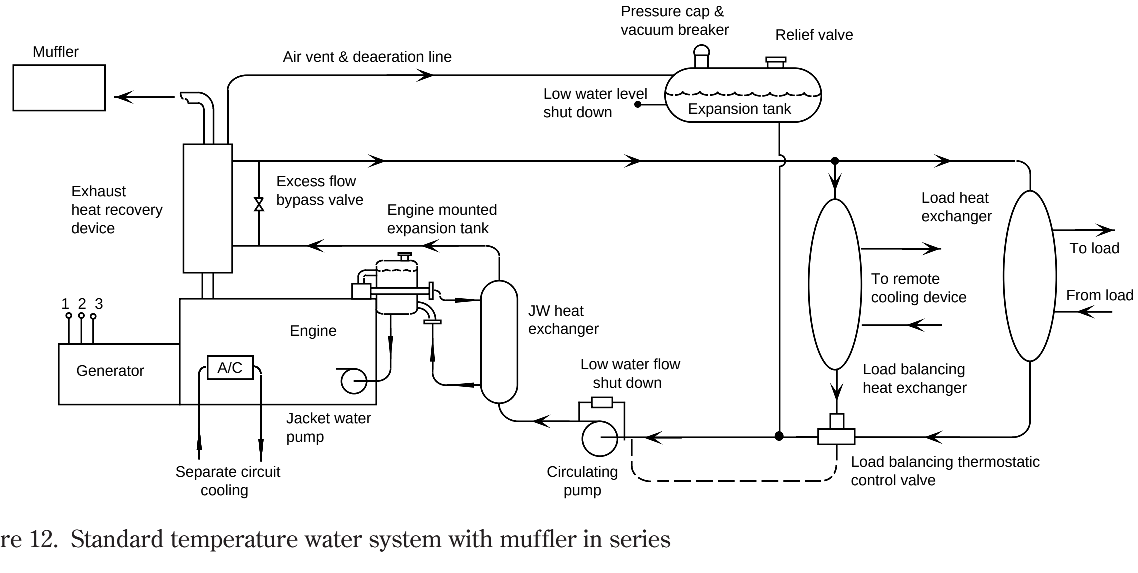


Figure 12. Standard temperature water system with muffler in series

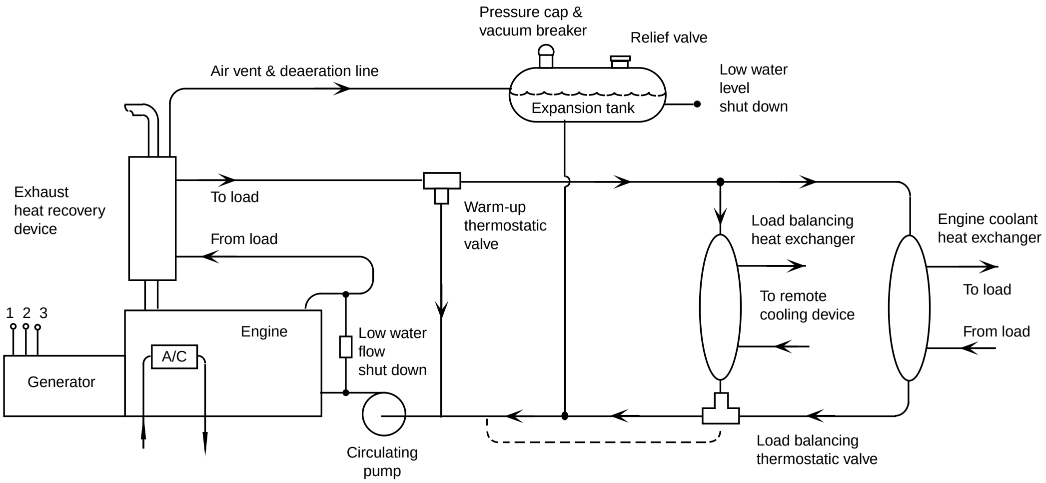


Figure 13. Standard temperature water system with the exhaust heat recovery device incorporated

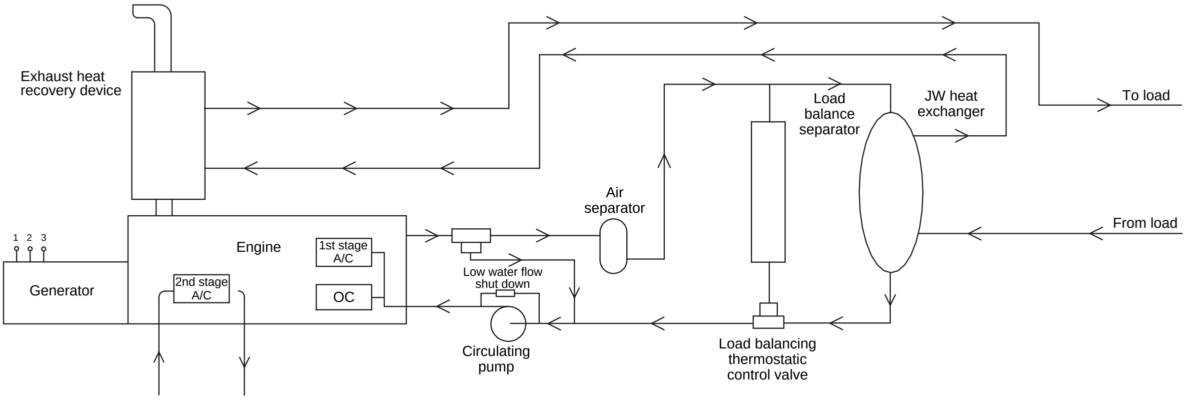


Figure 14. G3516B 50 Hz standard temperature combined heat and power system

Caterpillar G3516B 50 Hz packages with standard temperature heat recovery systems are available in the price list. This configuration is another variation of a heat recovery system. Figure 14 illustrates the design of this package. This package can be ordered with the jacket water heat recovery system only or with both the jacket water and exhaust heat recovery systems. This package is provided completely installed from the Caterpillar facility including all components and piping to recover heat from the jacket water and exhaust circuits.

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.

- Use only coolant or treated water in the engine cooling circuit.
- Incorporate 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.
- 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 27.6-34.5 kPa (4-5 psig) **above** the pressure at which steam forms. 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 systems include many of the same requirements as a standard temperature system, but there are some additional points which are important to take into account:

- 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 the cooling system.
- Proper water treatment is essential for successful system operation.
- 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 outlet 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 by using a low water flow shutdown device.
- 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.
- An external warm-up thermostat is required.
- 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.

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, 96.5 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 15 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. Once pressure builds to 96.5 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 89.6 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.

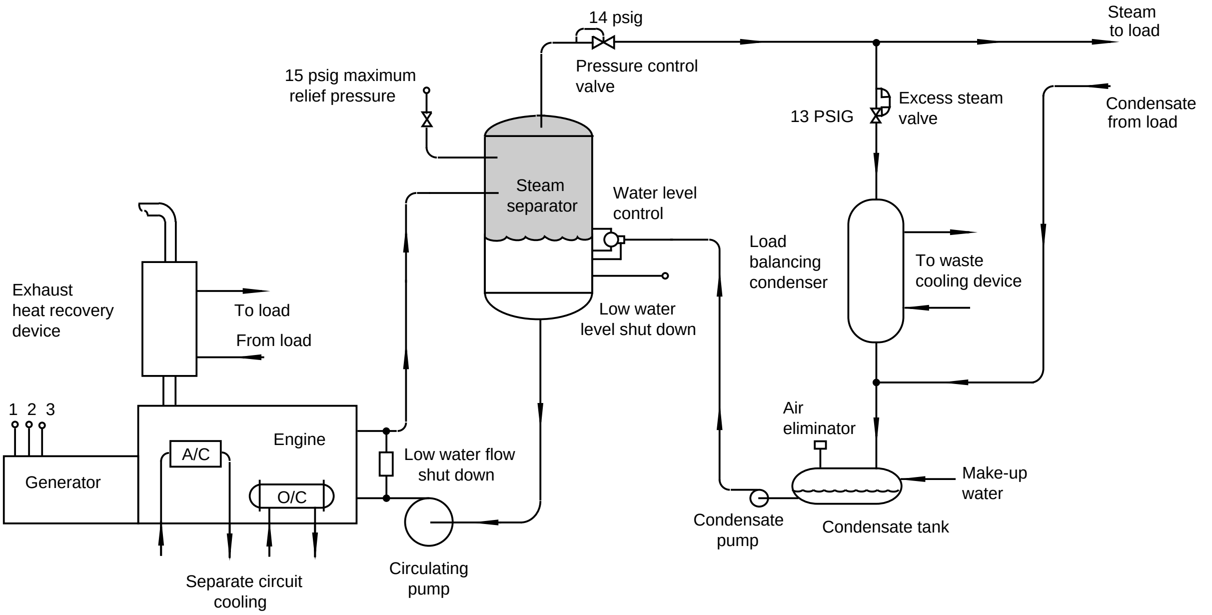


Figure 15. High temperature, water to steam system.

Critical Design Criteria for High Temperature Water-Steam

- 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.

- Pressure at the engine water jacket must be maintained between a minimum 55 kPa (8 psig) to a maximum of 197 kPa (28.5 psig). Maximum temperature at engine outlet must not exceed 126.7°C (260°F).

- 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.

Ebullient Cooling

The ebullient system utilizes heat of vaporization to remove heat from the engine. Steam is not collected within the engine, but moves through the water passages along with high temperature water by a change in coolant density as it gains heat. Therefore, a jacket water pump is not used. The water/steam mixture flows to a steam separator located above the engine. A temperature differential between engine-water-in and engine-water-out is usually 1.1-1.7°C (2-3°F). Correct flow requires careful design of pipes and lines. Because of critical design requirements, ebullient systems are not as popular as positive flow systems which incorporate a high temperature pump that forces steam flow through the engine.

Heat Exchanger

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.

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 (see Figure 16). 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.

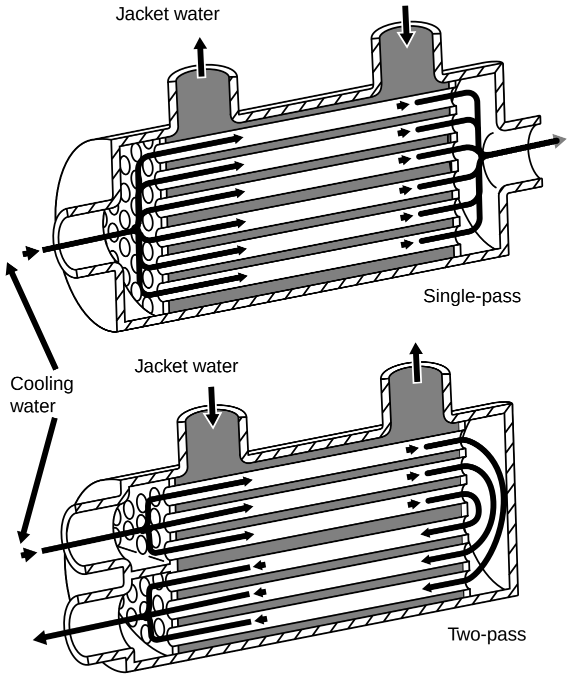


Figure 16. Heat exchanger, shell and tube type.

Plate Type

Another common type of heat exchanger is the plate type heat exchanger. 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.

The remaining section about heat exchangers will refer to the heat exchanger's coolant as "Raw or Treated Water" and the engine's coolant as "coolant".

The 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). Counter-flow heat exchangers can transfer more heat for a given surface area than Parallel-flow heat exchangers. Therefore most single-pass, shell/tube heat exchangers use Counter-flow.

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 capacity varies 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 12. The fouling factor relationship is:

$$\mathrm{FF} = \frac{1}{\text{U coolant}} = \frac{1}{\text{U clean core}}$$

Where:

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

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

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

Engine Coolant Temperature	**≤ 116°C (240°F)**	
Raw Water Temperature	**≤ 52°C (125°F)**	
	Raw Water Velocity	
Water Types	**≤ 0.9 m/s (3 ft/sec)**	**> 0.9 m/s (3 ft/sec)**
Sea Water	0.0005	0.0005
Brackish Water	0.002	0.001
Cooling Tower and Artificial Spray Pond: Treated Makeup 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

Table 12. Fouling factor chart for water.
Units are in hr-ft^2-°F/Btu
Note: 1 hr-ft^2-°F/Btu= .0545 hr-m^2-°C/kJ

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 17 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.

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.

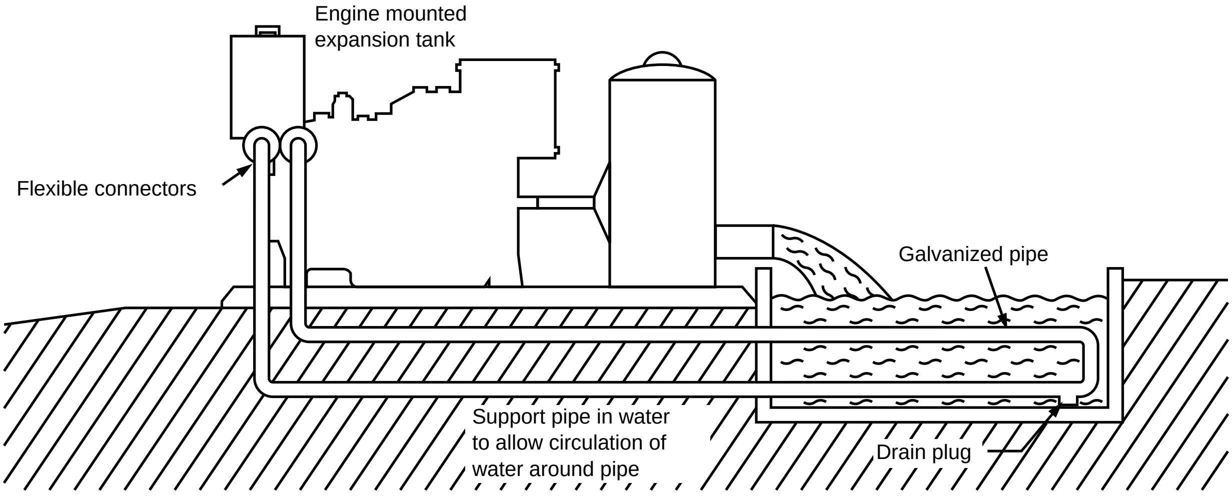


Figure 17. Submerged pipe cooling.

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 (i.e. 32°C (90°F) SCAC). In such cases, cooling towers are used when a large supply of cool water (i.e. a river, lake, cooling pond, etc.) 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 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: the open-type and the 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 Caterpillar Engines.

Closed Cooling Tower

Figure 18 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, Figure 19.

Cooling Tower Design Criteria

As a general 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.

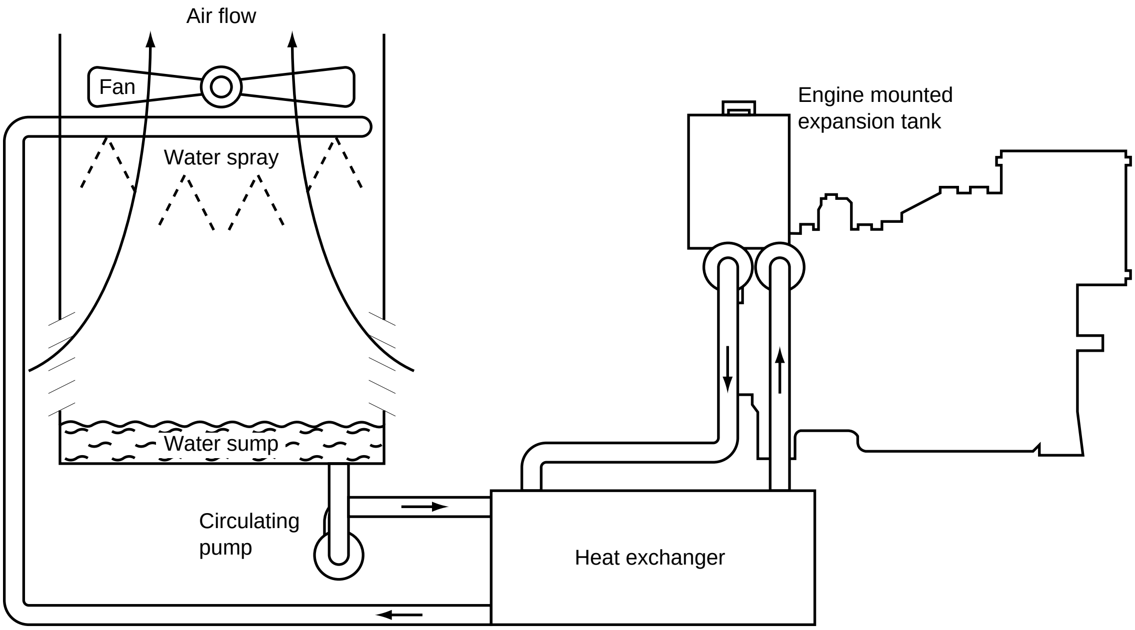


Figure 18. Closed cooling tower with externally mounted heat exchanger.

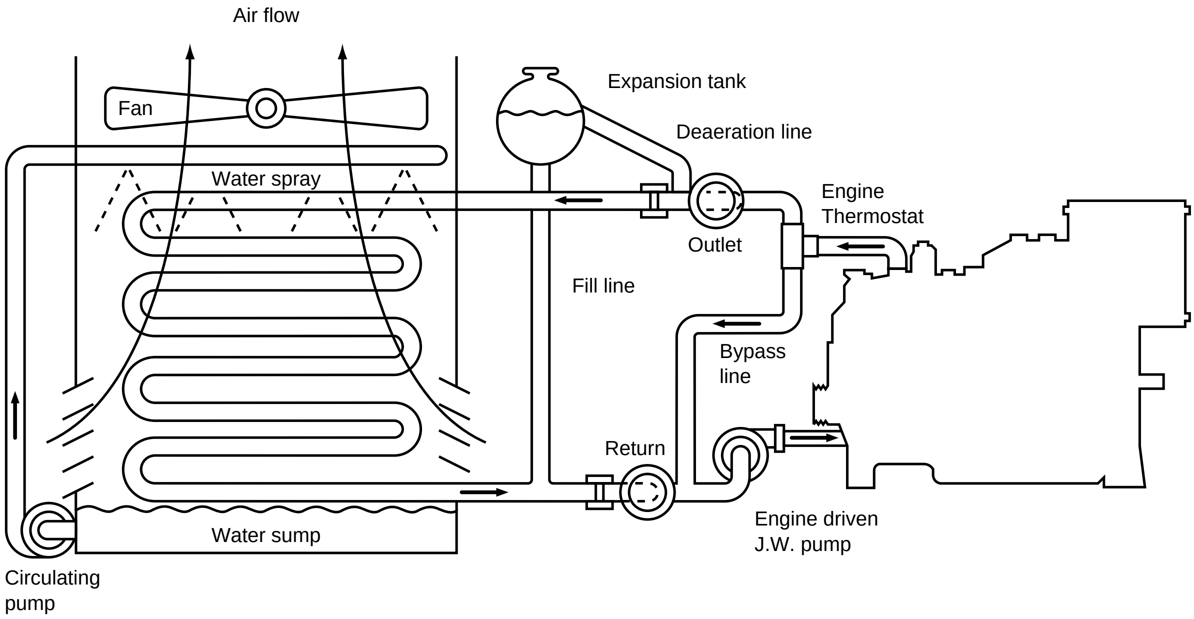


Figure 19. Closed loop cooling tower.

As with radiators, cooling towers are very sensitive to recirculation and the presence of other upwind cooling towers (see Figure 20). 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.

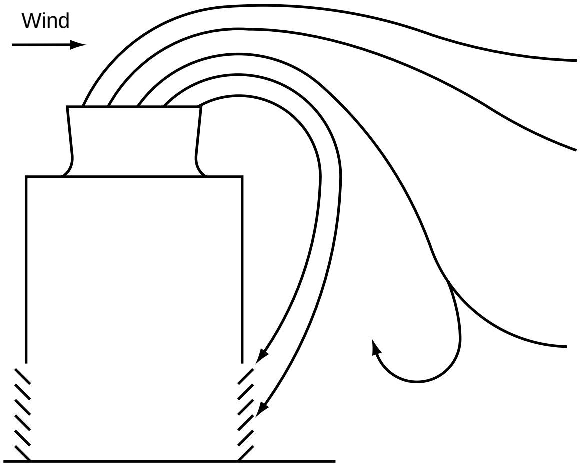


Figure 20. Tower recirculation due to wind.

Cooling System Design Considerations

Serviceability

Access to the heat exchanger is required for tube rodding (cleaning), plate scrubbing, or removal of the tube-bundle assembly. Engine water pumps must be easy to remove. Remote water temperature regulators should be accessible, and have appropriate isolation valves to allow servicing the engine without draining the entire system. Similar guidelines for radiators, heat recovery units, deaeration units, and other components requiring service or replacement apply.

Drain

Provisions must be made for adequate drainage and flushing of the cooling system.

Fill Rate

The Caterpillar engine mounted cooling circuits are designed to completely vent during the initial fill for fill rates up to 19.0 L/min (5 gpm). Vent lines are located such that the external cooling circuit will also be vented if the customer piping is installed level with, or below, the proper engine connecting points, and if no air traps are designed in the piping. Often vent valves are also part of the fill system. They provide air venting while preventing coolant from bypassing thermostat(s).

Piping Slope for Effective Venting

Piping carrying coolant from the engine to the radiator must have a continual upward slope. This is to allow any gases in the coolant to be separated from the coolant and vented in the radiator top tank.

Expansion Tanks

Heat exchangers, just like radiators, require expansion tanks. An expansion tank is an integral part of the engine cooling system and performs the following functions:

- Vent gases in the coolant
  - to reduce corrosion.
  - to prevent loss of coolant due to displacement by gases.
- Provide a positive head on the system pump
  - to prevent cavitation.
- Provide expansion volume
  - to prevent coolant loss when the coolant expands due to temperature change.
- 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.

The expansion tank must meet the following guidelines:

- The expansion tank must be the highest point in the system. If the attachment expansion tank is not the highest point of the system, an auxiliary expansion tank will be required. The additional added static resistance provided by the auxiliary expansion tank may raise the system pressure above the limit for the attachment expansion tank. The auxiliary expansion tank is added cost and may make the attachment expansion tank redundant. Those installations may be more successfully designed with a remote expansion tank instead of the attachment expansion tank.
- The maximum pressure capability is 96 kPa (14 psi). The maximum pressure limitation will prohibit the attachment expansion tank from many high temperature applications.
- The size of the expansion tank should be at least 15% of the total system water 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 pressure and prevent boiling of the coolant.
- The tank must provide deaeration and is usually the means of filling a system.

Attachment engine mounted radiators and most aftermarket-supplied 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.

Volume

An expansion tank's function, as the name implies, is to allow for thermal expansion of the coolant. Coolant expansion is a function of the coolant 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. Full-flow expansion tanks will require greater volume to perform the deaeration function.

Engines using high temperature cooling will need a larger volume to absorb after-boil that may occur on a hot shutdown. Closed accumulator-type tanks are not recommended since they cannot be designed to actively deaerate the coolant.

Deaeration

Air can be trapped in the cooling system at initial fill or enter through combustion leakage during operation. The cylinder head gasket design allows some continual escape of combustion gases into the cooling system. This air and gas must be vented from the system, or system deterioration and water pump cavitation will result.

Entrained combustion 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 (see Figure 21). If a centrifugal deaeration gas separator is not used, separation of gas from a liquid medium requires a low coolant velocity of 9.4 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. The deaeration flow is regulated by a 10 mm (3/8 in.) diameter orifice placed in the line. 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 (see Figure 22). 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.

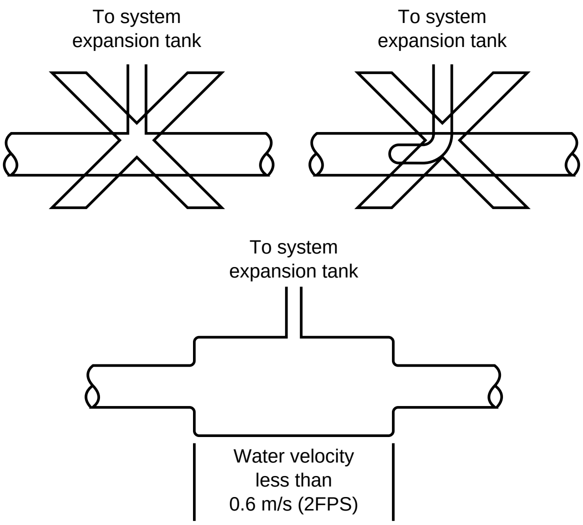


Figure 22. Diameter and water velocity.

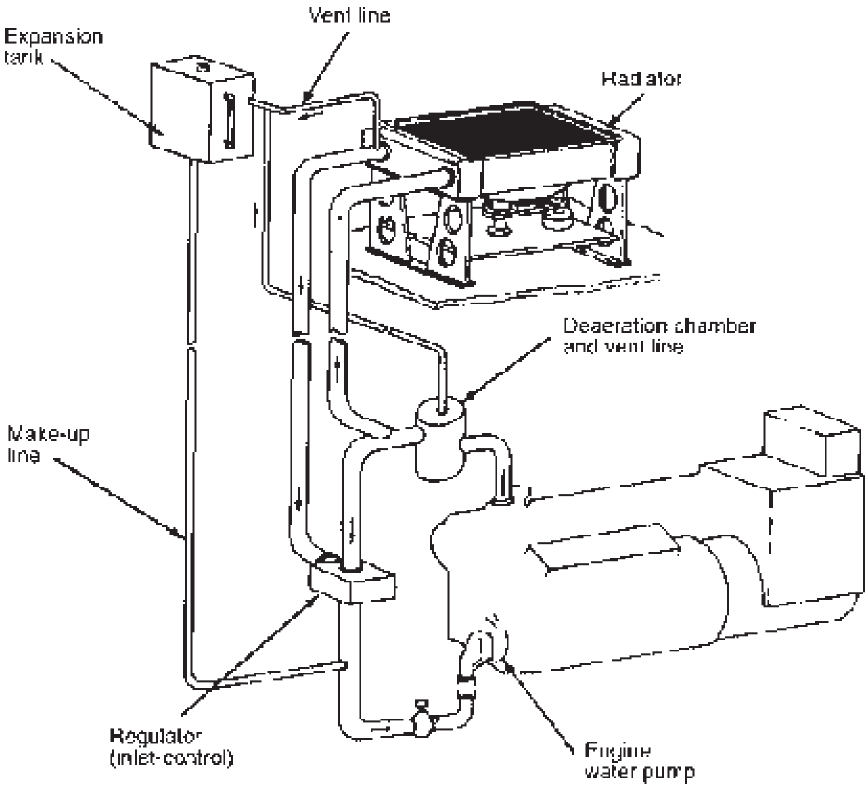


Figure 21. Deaeration.

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. A cooling system that will not purge itself on initial fill must have vent lines 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. An adequate vent line would be 6.3 mm dia. (0.25 in. dia.) 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, depending on the location.

Caution: The constant full level in the expansion tank must be above all piping. Vent high points of the engine to the expansion tank to allow a proper fill.

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 regulated or outlet regulated.

Inlet Regulated Systems

Inlet regulated 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 (see Figure 23). 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 resistance because of vent and

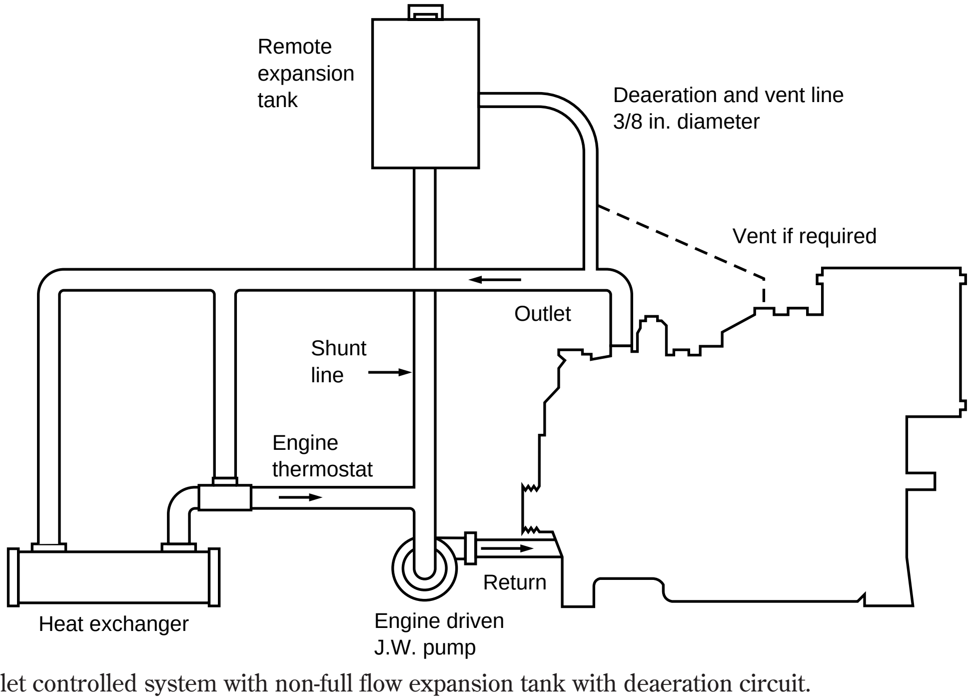


Figure 23. Inlet controlled system with non-full flow expansion tank with deaeration circuit.

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 (see Figure 4, page 15).

Outlet Regulated Systems

Outlet regulated systems differ from inlet regulated systems in the routing of the expansion tank connection. On an outlet regulated 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 sizes of the return line of the radiator provides minimum pressure loss. This means the expansion tank may be connected to either the outlet tank or anywhere in the return line to the pump (see Figures 24, 25 and 26). 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.

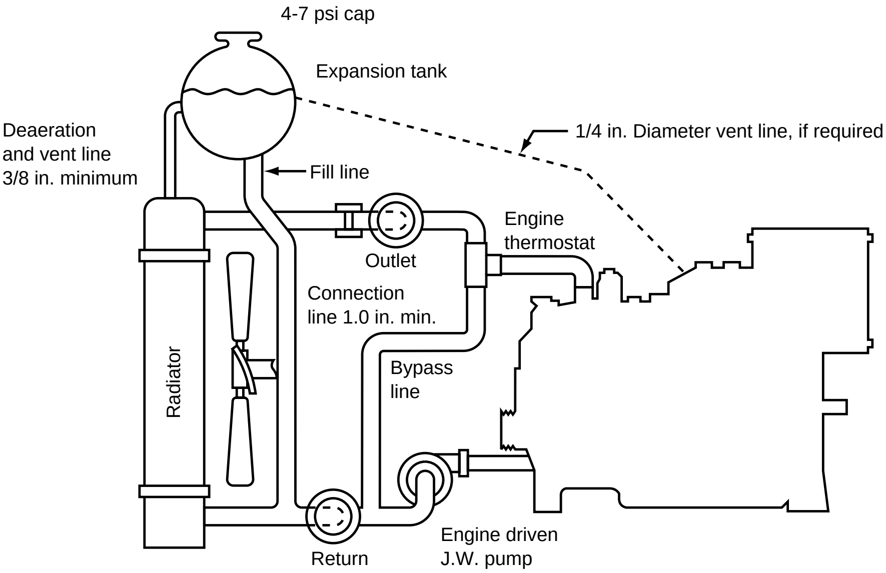


Figure 24. Outlet controlled with vertical radiator core.

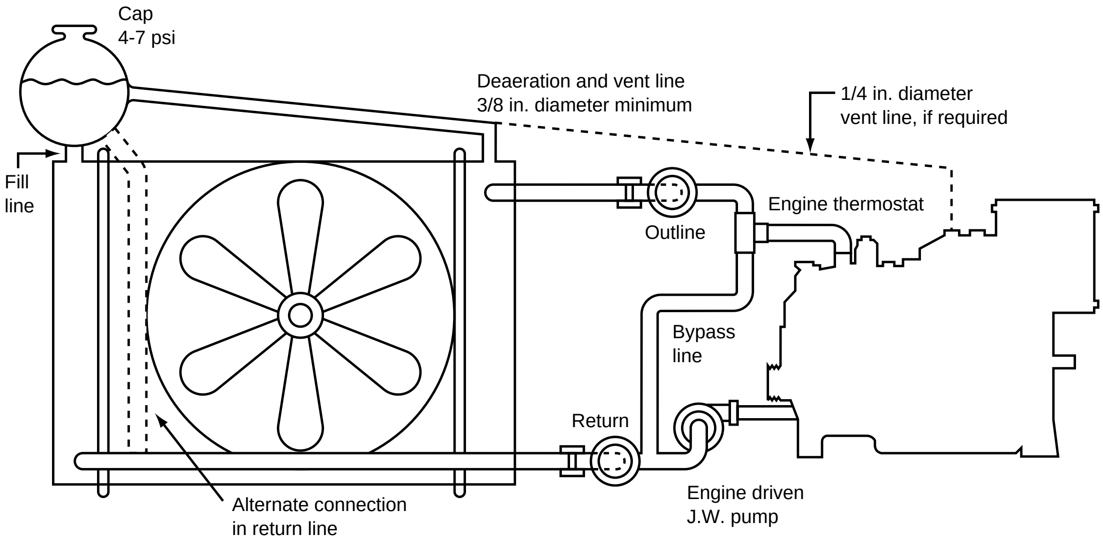


Figure 25. Outlet controlled with vertical cross flow radiator.

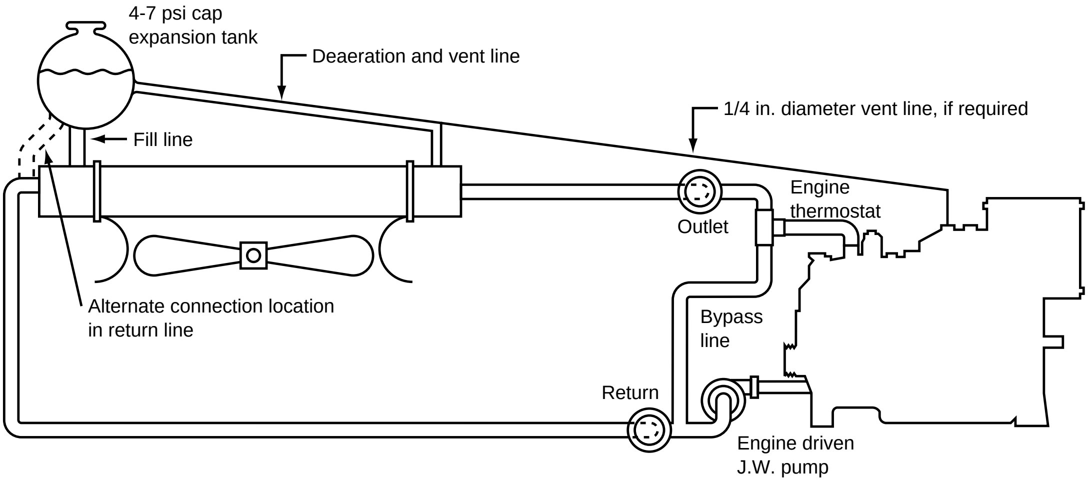


Figure 26. Outlet controlled with horizontal radiator.

Auxiliary Expansion Tank

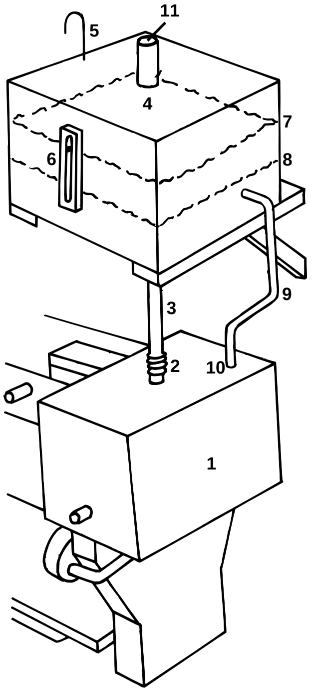
The function of the engine mounted expansion tank was covered earlier and is applicable for the engine's jacket water circuit. Caterpillar does not provide expansion tanks for the engines auxiliary water circuit (the aftercooler circuit). It can provide adequate expansion volume for only a modest amount 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 (see Figure 27) and is fabricated by the engine installer. 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 by allowed to rise by a continuous upward sloped standpipe 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.



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 27. Auxiliary expansion tank. Engine jacket water.

Aftercooler Circuit Auxiliary Expansion Tank

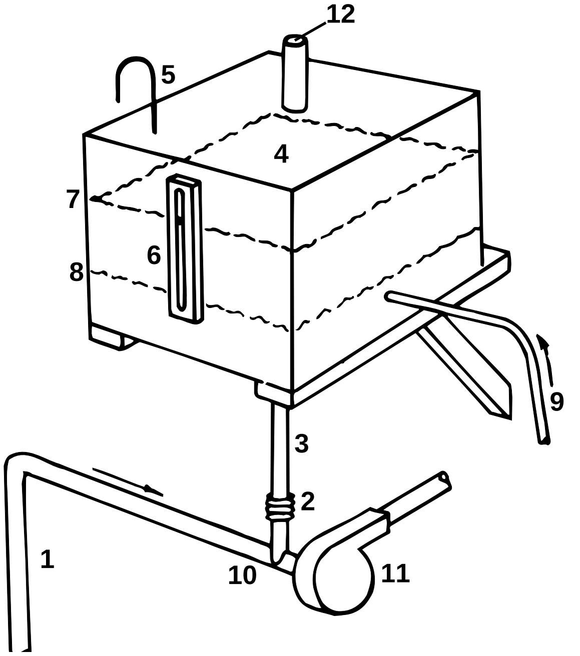
All closed fresh water aftercooler circuits require an expansion tank. The tank provides coolant expansion volume, allows system venting and provides a positive pressure on the inlet side of the circulating pump. The expansion tank must be the highest point in the aftercooler water circuit (see Figure 28).

This tank is a simple reservoir with the connecting pipe placed as close to the pump inlet as possible. The tank is 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 41, *Auxiliary Expansion Tank Sizing*, can be used to determine the minimum volume required.

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



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 28. Auxiliary expansion tank. Separate circuit aftercooler.

Auxiliary Expansion Tank Sizing, Engine Jacket Water (see Figure 27).

Engine Model ______________________ Rating ________ hp at ____________ rpm

1. Allowable external volume ________ L/gal, with engine mounted tank. (This value shown in Table 13, Column A, on page 42.)
2. Total volume of jacket water contained in external cooling circuit (not furnished as part of engine) _____ L/gal. See Table 14, page 42, 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 13, Column B ______________________________
   b. External volume Line 2 ____
   c. Multiply line a by 0.07 ____
   d. Multiply line b by 0.05 ____
   e. Total of lines c and d ____

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

For Separate Circuit Aftercooler, Figure 28:

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.)

Engine Model	Column A		Column B	
	Allowable External Volume With Engine Mounted Tank		Engine Jacket Water System Volume With Engine Mounted Tank	
	Liters	U.S. Gal	Liters	U.S. Gal
3116	0.0	0.0	28.0	7.5
3126	0.0	0.0	28.0	7.5
3208NA	7.5	2.0	47.3	12.5
3208T&TA	7.5	2.0	56.0	14.9
3304B	8.0	2.1	55.6	14.7
3306B	8.0	2.1	55.6	14.7
3176	0.0	0.0	45.0	12.0
3406C	38.0	10.0	94.5	23.6
3408B	53.0	14.0	142.0	37.5
3412	53.0	14.0	162.0	42.8
3508	243.0	64.0	285.0	75.3
3512	182.0	48.0	323.0	85.3
3516	122.0	32.0	384.0	101.4
3606	365.0	95.0	745.0	195.0
3608	210.0	55.0	875.0	230.0
3612	550.0	145.0	1145.0	300.0
3616	260.0	65.0	1405.0	370.0
3606	4710.0	1245.0		
3608	4550.0	1200.0		
3612	4890.0	1290.0		
3616	4600.0	1210.0		

Table 13. Cooling system volumetric data.

Nominal Size		Actual I.D.		Actual O.D.		ft/gal	m/L	ft/cu ft	m/cu m
in.	mm	in.	mm	in.	mm				
.125	3.18	.270	6.86	.405	10.29	336.000	27.000	2513.000	27.049
.250	6.35	.364	9.25	.540	13.72	185.000	16.100	1383.000	14.886
.375	9.53	.494	12.55	.675	17.15	100.400	8.300	751.000	8.083
.500	12.70	.623	15.82	.840	21.34	63.100	5.000	472.000	5.080
.750	19.05	.824	20.93	1.050	26.68	36.100	2.900	271.000	2.917
1.000	25.40	1.048	26.62	1.315	33.40	22.300	1.900	166.800	1.795
1.250	31.75	1.380	35.05	1.660	42.16	12.850	1.030	96.100	1.034
1.500	38.10	1.610	40.89	1.900	48.26	9.440	.760	70.600	760.000
2.000	50.80	2.067	52.25	2.375	60.33	5.730	.460	42.900	462.000
2.500	63.50	2.468	62.69	2.875	73.02	4.020	.320	30.100	324.000
3.000	76.20	3.067	77.90	3.500	88.90	2.600	.210	19.500	210.000
3.500	88.90	3.548	90.12	4.000	101.60	1.940	.160	14.510	156.000
4.000	101.60	4.026	102.26	4.500	114.30	1.510	.120	11.300	122.000
4.500	114.30	4.508	114.50	5.000	127.00	1.205	.097	9.010	97.000
5.000	127.00	5.045	128.14	5.563	141.30	.961	.077	7.190	77.000
6.000	152.40	6.065	154.00	6.625	168.28	.666	.054	4.980	54.000
7.000	177.80	7.023	178.38	7.625	193.66	.496	.040	3.710	40.000
8.000	203.20	7.982	202.74	8.625	219.08	.384	.031	2.870	31.000
9.000	228.60	8.937	227.00	9.625	244.48	.307	.025	2.300	25.000
10.000	254.00	10.019	254.50	10.750	273.05	.244	.020	1.825	19.600
12.000	304.80	12.000	304.80	12.750	323.85	.204	.160	1.526	16.400

Table 14. Volume per length of standard iron pipe.

Installation of Auxiliary Expansion Tank

When installing an auxiliary expansion tank, separately support and isolate the auxiliary tank against vibration from the engine mounted tank with flexible tank mounting and connections.

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. Typically, this is done by installing a vent line from that point to the aftercooler circuit expansion tank. Vent line size of 6.3 mm (0.25 in.) 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 leakage into 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 enter the cooling system, introducing bubbles and foam.

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 by either 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 head exceeds 10 m (33 ft) or a boost pump imposes excessive dynamic head (see Figure 29).

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.

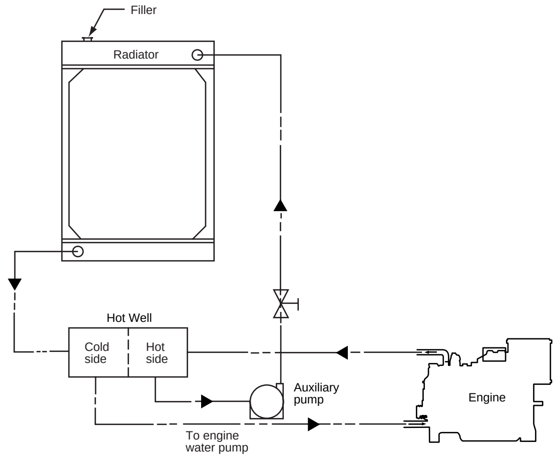


Figure 29. Hotwell system.

Mixing Tanks

A mixing tank accommodates total drainback of the remote cooling device and connecting piping. A baffle divides the tank into a hot and cold side, but is open sufficiently to assure full engine flow. Baffles are also used where water enters the tank to minimize aeration.

A tank sized for 110 percent of radiator and piping coolant ensures that pumps will not draw in air and that water levels can be checked during shutdown.

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 the required criteria (water flow, temperatures, pressures, etc.) for each engine while operating in all possible combinations with other units.

Cleanliness

All pipe and water passages, external to the engine must be cleaned before initial engine operation. There must be flow; any foreign material must be removed.

Strainers are recommended for installation in all pipes leading to externally added equipment. They are to be installed on the site prior to startup and removed after commissioning the unit.

Similar precautions must be taken when significant modifications are made to the external cooling circuit.

Coolant Considerations

Properties

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 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, select the best quality water available, but never use salt water.

Water hardness is usually described in parts per million, ppm (grains/gal), of calcium carbonate content. Water containing up to 60 parts per million (3.5 grains per gallon) is considered soft and causes few deposits.

Treated Water

Never use water alone as a coolant. Supplemental coolant additives are required because water is corrosive at engine operating temperatures. Corrosion inhibitors or antifreeze solution added to water maintains cleanliness, reduces scale and foaming, and provides pH control. A 3%-6% concentration of inhibitor is recommended to maintain a pH level of 8.5 to 10. Sudden changes in coolant composition should be avoided to minimize nonmetallic components failure.

Caterpillar cooling inhibitor is compatible with ethylene glycol and propylene glycol base antifreezes but not with Dowtherm 209, or Cat Extended Life Coolant (ELC). With a 30% mixture of glycol containing corrosion inhibitors, no additional inhibitors are required. To maintain constant protection, additives should be replenished every 250 operating hours.

Caterpillar recommends the Extended Life Coolant for diesel engines, as it provides extended coolant service life, corrosion protection, extended water pump seal service life, and extended radiator service life. Caterpillar does not recommend Extended Life Coolant use in natural gas engines.

For conventional heavy duty cooling systems the antifreeze/coolant is recommended.

Note: If cooling water comes in contact with domestic water supplies, water treatment may be regulated by local codes.

Coolant/Antifreeze (Glycol)

Glycol in the coolant provides boil and feeze protection, prevents water pump cavitation, and reduces cylinder liner pitting. For optimum performance, Caterpillar recommends a 50/50 glycol/water coolant mixture.

Ethylene glycol is commonly used in heavy duty (HD) coolant/antifreezes. Propylene glycol is also common. Both ethylene glycol and propylene glycol have similar fluid properties in a 50/50 glycol/water mixture. Both ethylene glycol and propylene glycol provide similar heat transfer, freeze protection, corrosion control, and seal compatibility. The following charts define the temperature protection provided by the two types of glycol.

<table>
<tr><th colspan="3">Ethylene Glycol</th></tr>
<tr><th rowspan="2">Concentration
% Glycol/% Water</th><th colspan="2">Protection Against</th></tr>
<tr><th>Freezing</th><th>Boiling</th></tr>
<tr><td>50/50</td><td>–36°C (–33°F)</td><td>106°C (223°F)</td></tr>
<tr><td>60/40</td><td>–51°C (–60°F)</td><td>108°C (226°F)</td></tr>
</table>

<table>
<tr><th colspan="3">Propylene Glycol</th></tr>
<tr><th rowspan="2">Concentration
% Glycol/% Water</th><th colspan="2">Protection Against</th></tr>
<tr><th>Freezing</th><th>Boiling</th></tr>
<tr><td>50/50</td><td>–29°C (–20°F)</td><td>106°C (222°F)</td></tr>
</table>

Note: Do not use propylene glycol in concentrations that exceed 50 percent glycol because of propylene glycol's reduced heat transfer capability. Use ethylene glycol in conditions that require additional boil or freeze protection.

Exposing engine coolant to freezing temperatures requires addition of antifreeze. Ethylene glycol or Dowtherm 209 are recommended to protect against freezing and inhibit corrosion. Borate-nitrite solutions such as Caterpillar inhibitor are compatible only with ethylene glycol and can replenish the original corrosion inhibitors in the antifreeze.

Figure 30 defines the concentration of ethylene glycol required for system protection. It also describes the effect on coolant boiling temperature which reduces coolant afterboil. The concentration should exceed 30% to assure protection against corrosion, but above 60% will needlessly penalize heat transfer capabilities. Generally, a radiator derates 2% for each 10% of antifreeze concentration. Use of antifreeze year around decreases radiator capabilities at least 3.3°C (6°F).

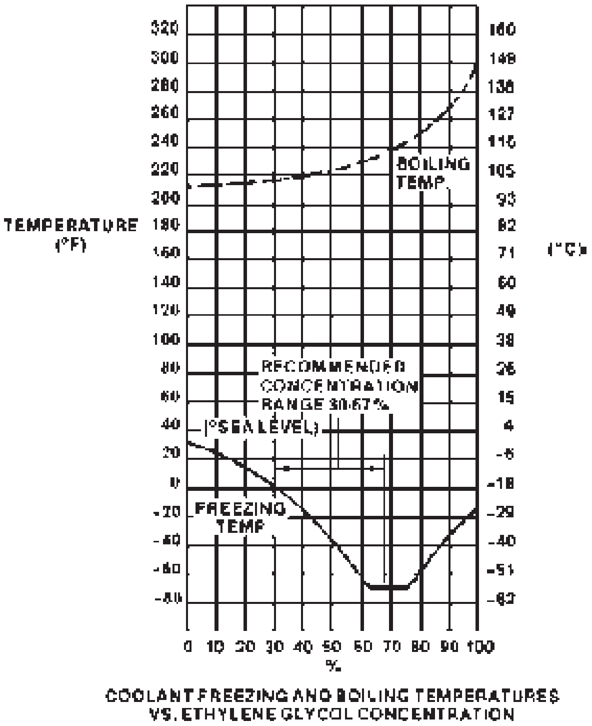


Figure 30. Ethylene Glycol concentration for protection.

Extended Life Coolant (ELC)

Caterpillar provides Extended Life Coolant (ELC) for use in heavy duty diesel engines and automotive engines. Caterpillar does not recommend Extended Life Coolant (ELC) for natural gas engines. The Caterpillar ELC anticorrosion package is totally different from conventional coolants. Caterpillar ELC is an ethylene glycol based coolant which contains organic acid corrosion inhibitors (which turn into carboxylates) and antifoaming agents. Caterpillar ELC has nitrites that serve as corrosion inhibitors that protect against cavitation corrosion. Caterpillar ELC also has TT (toly-triazole, a yellow (non ferrous) metal corrosion inhibitor). Caterpillar ELC has been formulated with the correct levels of additives to provide superior corrosion protection for all metals in diesel engine cooling systems.

Caterpillar ELC extends coolant service life to 6000 Service Hours or Four Years. Caterpillar ELC does not require frequent additions of supplemental coolant additives, SCA. A "one time only" coolant Extender is the only maintenance addition required. The Extender should be added to the cooling system at 3000 Service Hours or Two Years.

Caterpillar ELC is available Premixed with distilled water in a 50/50 concentration. The Premixed ELC provides freeze protection to –36°C (–33°F). The Premixed ELC is recommended for initial fill and for topping off the cooling system. ELC Concentrate is available to lower the freezing point to –51°C (–60°F) for Arctic conditions. ELC Concentrate should be used to adjust the coolant freeze point as required where Caterpillar ELC Premixed freeze protection is not acceptable.

Contact your Caterpillar dealer for part numbers and available container sizes.

Note: The Caterpillar EC-1. Specification is an industry standard developed by Caterpillar. The EC-1 specification defines all of the performance requirements that an engine coolant must meet in order to be sold as an extended life coolant for Caterpillar engines. Caterpillar ELC meets the industry performance requirements of ASTM D4985 and D5345 for heavy duty low silicate coolant/antifreezes. Caterpillar ELC also meets the industry performance requirements of ASTM D3306 and D4656 for automotive applications.

Note: Do not mix ordinary ethylene glycol or propylene glycol mixtures with ELC. Completely flush system before converting from one to the other coolant.

Corrosion Resistance

The coolant must prevent the formation of rust and pits in the engine and other components. Since all water can cause corrosion, water alone is not a good coolant. Both distilled water and softened water are unacceptably corrosive when corrosion inhibitors are not added.

Always add Caterpillar's corrosion inhibitor, Cooling System Conditioner, or equivalent to the water antifreeze mixture at the time of the initial fill of the cooling system if the initial fill does not include it. (This is not necessary when using Caterpillar Antifreeze. The Caterpillar formula includes all necessary inhibitors for initial fill.) If water only is used (not recommended), it is extremely important that conditioner be added. Use 3P2044, 0.118 Ltr (quart), or 6V3542, (0,24 L) (1/2 pint), Cooling System Conditioner.

Because modern antifreezes contain considerable dissolved chemical solids to accommodate aluminum components, over-concentrations can reduce heat transfer and cause water pump seal leakage or failure.

Note: Do not over inhibit your cooling system or damage will result.

Chromate Corrosion Inhibitors

Chromate is another corrosion inhibitor. In general, special testing equipment must be utilized in order to measure the coolant consist. Inappropriate amounts of corrosion inhibitor can do harm to the system. These are being phased out of usage due to toxicity and environmental concerns.

Soluble Oil
Soluble oil is used as coolant lubricant for machine tooling at the Caterpillar plants. This is not to be used in the engines as it damages hoses, gaskets, seals, does not lubricate pump bearings, or protect from damage caused by cavitation erosion. OSHA bans the use of these and are being phased out of usage due to toxicity and environmental concerns.

Water Quality and Treatment — Standard Temperature

Usable water for cooling systems must meet the following criteria:

Chloride (CL)	40 ppm (2.4 grains/gal) Maximum
Sulfate ($S0_4$)	100 ppm (5.9 grains/gal) Maximum
Total Hardness	170 ppm (10 grains/gal) Maximum
Total Solids	340 ppm (20 grains/gal) Maximum
pH	5.5-9.0

Water softened by removal of calcium and magnesium is acceptable.

Water Quality and Treatment — High Temperature

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. The coolant specifications published above and in the Caterpillar 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 is too high to be tolerated by the system. There are many types of water treatment. Softening, Evaporation, Deaeration and Ion exchange are typically the 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 micromho 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 $CaCO_3$ 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 Caterpillar 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 micromhos/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 a 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 overly so 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.
To emphasize again, scale formation is cumulative and the successful method of avoiding scale problems is to not permit conditions for 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. We have reasonable confidence

that operators who adhere to these guidelines will have years of deposit-free and scale-free performance from their Caterpillar Engines.

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

System Pressure

Slight system pressure minimizes pump cavitation (voids in water) even at high altitude, and increases pump efficiency.

- For each 6.9 kPa (1.0 psi) of pressure, the boiling point is raised about 2°C (3°F) (see Figure 31). Elevations above 3048 m (10,000 ft) require higher rated pressure caps to avoid boiling.

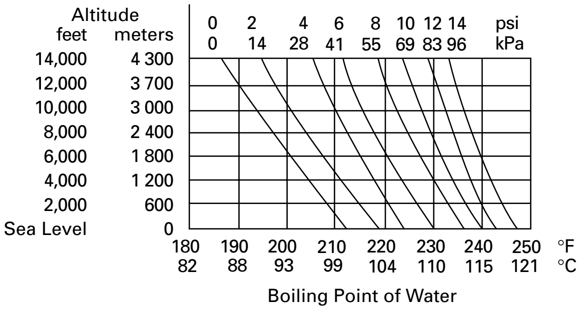


Figure 31. Cooling system pressure.

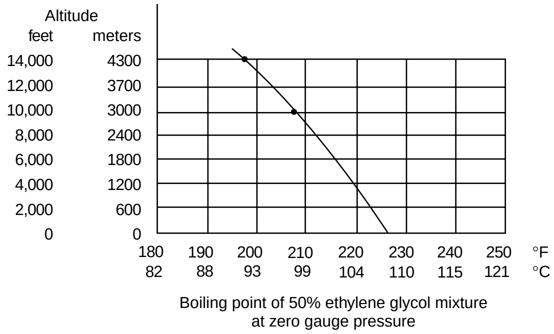


Figure 32. Cooling system pressure.

Coolant Testing

The coolant should be maintained throughout the life of the application. Dealers have available laboratory testing services which can measure not only the glycol levels but also the main corrosion inhibiting additives, as well as contaminants. Caterpillar recommends additives be kept within certain ranges depending on the type of coolant as well as the application. If regular coolant is being used, a prescribed dose of Supplemental Coolant Additive or SCA is usually added at 250 hour intervals which recharges the corrosion inhibitors in the form of nitrates, nitrites, borates, and silicates. If ELC (Extended Life Coolant) is used, Caterpillar's Cooling System Conditioner is added which contains a carboxylate or organic acid corrosion inhibitor, nitrites, and other ingredients necessary to insure the coolant remains corrosion resistant. If boiler or ebullient 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 will 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.

Notes

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