CATERPILLAR®

3600 Marine Engine Application and Installation Guide

- Fresh Water Cooling
- Sea Water Cooling

LEKM8465 8-98

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Diesel Engine Systems - Fresh Water Cooling

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Operating Parameters

Basic operating parameters for the fresh water closed circuit engine cooling system are:

- 32°C (90°F) nominal water temperature to the aftercooler and oil cooler when using distillate or heavy fuel.
- 90°C (194°F) nominal water temperature to the cylinder block circuit on distillate and 93°C (199°F) on heavy fuel.
- 85°C (185°F) nominal oil to bearing temperature.

Marine engine ratings are based on 32°C (90°F) water to the aftercooler and 25°C (77°F) air to the turbocharger.

Marine engines which must operate in sea water temperatures greater than 26°C (79°F) will be allowed to operate without any power deration with water to the aftercooler and oil cooler of 38°C (100°F) maximum. Larger heat exchangers will be required to attain 38°C (100°F) aftercooler/oil cooler water temperatures when sea water temperatures exceed 26°C (79°F), but the benefits will be longer valve, exhaust manifold, and turbocharger life.

Consult the dealer or factory project engineer in those cases where aftercooler/oil cooler water temperatures are expected to exceed the 38°C (100°F) limit.

Basic System Configurations

Two basic closed circuit fresh water cooling systems are used — combined circuit and separate circuit.

The *combined circuit* configuration is also referred to as the single circuit fresh water system. It is typically used for marine and heavy fuel applications where a single heat exchanger is preferred. The aftercooler and oil cooler circuit is externally regulated (fluid inlet temperature control) to *32°C (90°F).* The system uses the aftercooler/oil cooler outlet water to cool a portion of the high temperature outlet water. The block coolant is contained on the engine. Only the water returning to the aftercooler/oil cooler pump requires a cooling source. This results in simple coolant piping installation. Refer to Figure 1 for a typical combined circuit flow diagram. An in-line engine is shown in Figure 2 and a vee engine in Figure 3. Figure 4 is a piping schematic for the combined circuit system. *(Refer to pages 33 through 36 for illustrations.)*

Figure 5, page 37, is a diagram for a two step inlet air temperature control system for continuous heavy fuel applications. See the *Heavy Fuel* section for further details.

The *separate circuit* cooling system shown in Figures 6, 7, and 8 is available for marine applications. It is normally used for keel cooled or radiator cooled installations to reduce the external cooling package size. *(Refer to pages 38-40 for illustrations.)*

Engine Coolant Flow Control

The correct coolant flows are provided by factory installed orifices combined with external circuit resistance (set at each site). The orifices are sized to provide proper flow splits and pressure levels to engine components (aftercooler, oil cooler, cylinder block, cylinder heads, and turbochargers). The external resistance setting is critical. It establishes total circuit flow by balancing total circuit losses with pump performance curves. Set it with an adjustable, lockable valve or orifice in customer piping. Measure external circuit resistance with blocked open regulators to assure all flow is passing through the external circuit. *The valve used to set the resistance must not use elastomer seat material.*

Typical factory and customer orifice locations are shown in Figure 1 for a combined system and Figure 6 for a separate circuit system.

Temperature Regulation

Inlet control temperature regulators are used on the jacket water and aftercooler/oil cooler (AC/OC) coolant and lube oil circuits. The standard regulator characteristics are shown below. Some marine societies require coolant temperature regulators to have a manual override capability. In these cases the standard Caterpillar regulator is not acceptable and another supplier must be used.

	Start-Open Temp °C (°F)	Full-Open Temp °C (°F)	Nominal Temp °C (°F)
AC/OC Circuit*:			
Distillate and Heavy Fuel	27 (81)	37 (99)	32 (90)
Two Step Control (at low load)			75 (167)
JW Circuit**:			
Distillate Fuel	85 (185)	95 (203)	90 (194)
Heavy Fuel	88 (190)	98 (208)	93 (199)
Lube Oil Circuit:	76 (169)	89 (192)	83 (181)

* Dual temperature control may be required on heavy fuel applications. See “Heavy Fuel” in the “Engine Systems” section of this guide.

** Minimum allowable inlet water temperature is 83°C (181°F) on distillate fuel and 85°C (185°F) on heavy fuel.

Heat recovery circuits usually require an external regulator to prevent over-cooling the engine. If the heat recovery circuit uses less than 30% of the available jacket water heat load, then an external regulator is not required. If used, the heat recovery regulator must have a start-to-open temperature 5°C (9°F) lower than the jacket water circuit regulator. See *Heat Recovery* within this section.

Regulator mounting location depends on the cooling system type and engine package configuration. If an expansion tank is mounted on an accessory module in front of the engine, the regulator may be mounted on the tank. See the table below for typical Caterpillar regulator mounting locations. Regulators supplied by other suppliers are usually mounted in the shipyard piping.

Water Pumps

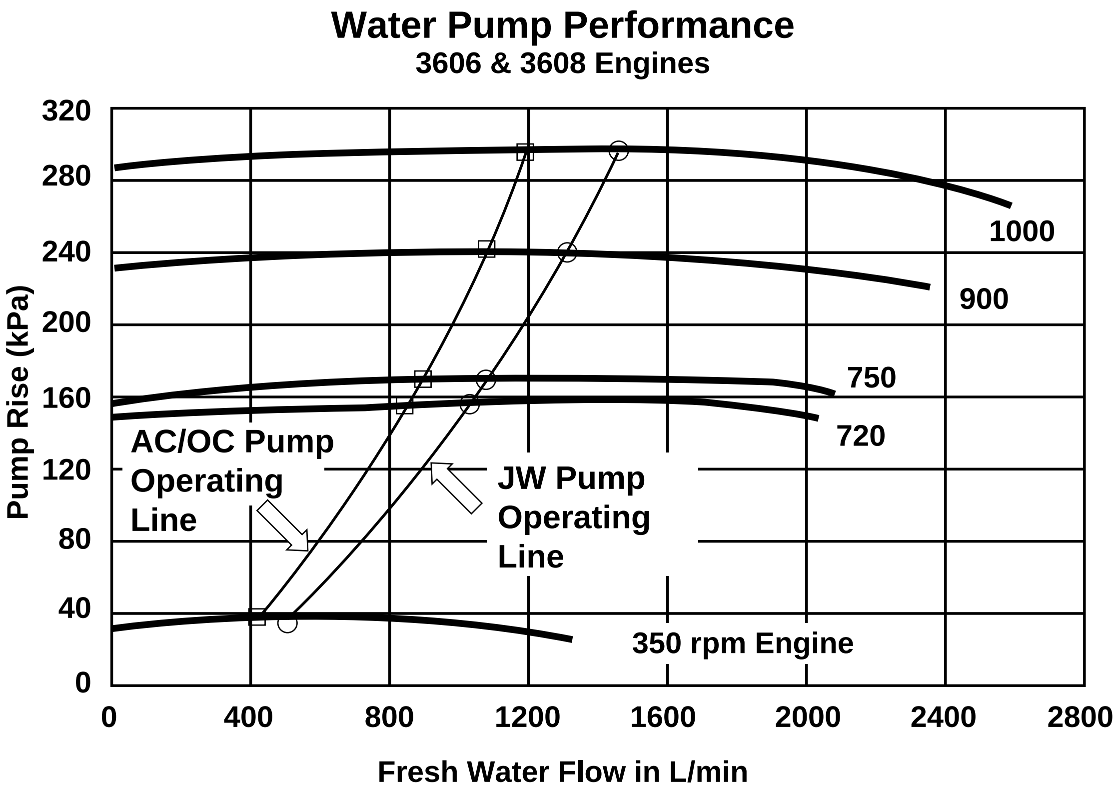
All engines have two engine driven fresh water pumps mounted on the front engine housing. The right hand pump (viewed from the flywheel end) supplies coolant to the cylinder block, cylinder heads, and turbocharger. The left hand pump supplies coolant to the aftercooler and oil coolers. Complete pump performance curves at various pressure heads are shown in Figure 9. An engine driven raw water pump is available and is gear driven off the front of the engine. See Figure 46 in the *Engine Performance* section for raw water pump power requirements.

Some applications will require standby pumps. Electrically driven standby pumps are shown in Figures 4 and 5 and are also included in the following description.

Standby Pumps

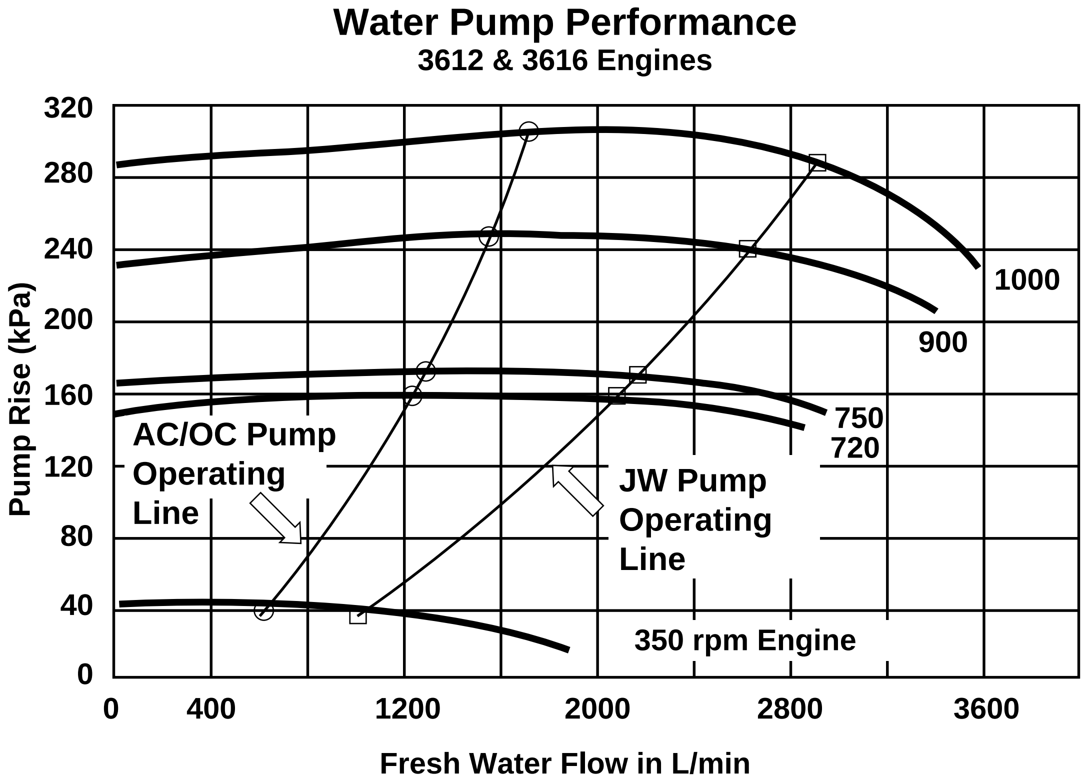
Typically an electric standby pump is required to parallel each engine driven pump for single engine marine propulsion applications to meet marine society requirements. Two fresh water pumps are required for standby, or emergency, service. One parallels the engine driven high temperature jacket water circuit. The other parallels the engine driven low temperature AC/OC circuit. Each external circuit must be isolated from the engine by check or shutoff valves.

Cooling System	Expansion Tank Location	JW Regulator Location	AC/OC Regulator Location	Oil Regulator Location
Combined	Module	Engine	Exp. Tank	Engine
Combined	Remote	Engine	Exp. Tank or Remote	Engine
Sep. Circuit	Module	Exp. Tank	Remote (in piping)	Engine
Sep. Circuit	Remote	Remote	Remote (in piping)	Engine



Water Pump Performance

3606 & 3608 Engines



Water Pump Performance

3612 & 3616 Engines

Figure 9

Install a water pressure low alarm contactor at the discharge of the engine driven pump to control the operation of the standby motor driven pump. The standby pump should start automatically if the engine driven pump discharge pressure falls below 120 kPa (17.4 psi). The control configuration should be arranged to operate only when the engine is running. Additionally, the contactor should be tied into the oil step function of the speed switch so that the standby pump can only operate above 75% of rated speed. This is because the engine driven pump pressure may be lower than the alarm set point at low engine speeds, but the pump pressure is still sufficient to cool the engine and the standby pump is not required.

Flow Requirements

Standby pump flow requirements must match the engine driven pump it is to replace. See the following table for pump requirements.

	AC/OC Pump @ 32°C				JW Pump @ 90°C			
	Flow L/min	gpm	Rise kPa	psi	Flow L/min	gpm	Rise kPa	psi
3606/3608:								
1000 rpm	1200	317	295	42.8	1460	385	295	42.8
900 rpm	1080	285	240	34.8	1315	347	240	34.8
750 rpm	900	238	170	24.7	1095	289	170	24.7
720 rpm	860	227	160	23.2	1050	277	160	23.2
3612/3616:								
1000 rpm	1730	457	305	44.3	2920	771	290	42.1
900 rpm	1560	412	245	35.6	2630	694	240	34.8
750 rpm	1300	343	170	24.7	2190	578	170	24.7
720 rpm	1250	330	160	23.2	2100	554	155	22.5

The recommended materials for the standby pumps are:
- Casing — Cast Iron
- Impeller — Bronze
- Shaft — Stainless Steel
- Seal — Mechanical

For emergency pump connection locations and sizes see Figure 4 (combined circuit).

Heat Rejection

Heat rejection to engine coolant comes from the cylinder block, cylinder heads, watercooled turbocharger turbine housing, aftercooler, and oil cooler. Watercooled manifolds are not used and there is no direct heat rejection from exhaust manifolds to the coolant. Jacket water heat rejection on 3600 Engines always refers to the sum of the block, head, and turbocharger.

Nominal values for heat rejection, coolant flows, and temperatures are shown in the *Engine Data* section. For the most current data always consult the TMI System.

Aftercooler Correction Factors

Heat rejection correction factors for the aftercooler can be calculated for various ambient air and cooling water temperatures (see Figure 10). A typical correction factor for 45°C ambient air and 32°C water to the aftercooler would be approximately 1.2 times the nominal aftercooler heat rejection valve in the Engine Data section of this guide.

Heat Rejection Tolerances

Coolant Flow = ±10%
Heat Rejection = ±10%

The tolerances account for engine-to-engine variation, test data accuracy, repeatability, and scatter. The heat rejection tolerance band does *not* account for on-site conditions such as ambient air temperature. Tolerance guidelines are as follows:

Heat Exchanger Tolerances

Base heat rejection capacity on the high side of the tolerance band, i.e., +8% to +10%. This tends to assure normal engine operating temperatures and compensates for unexpected fouling situations.

AfterCooler Heat Rejection
Correction Factors for Water and Ambient Air Temperature

NOTE: Applicable At or Near Rated Load Only.

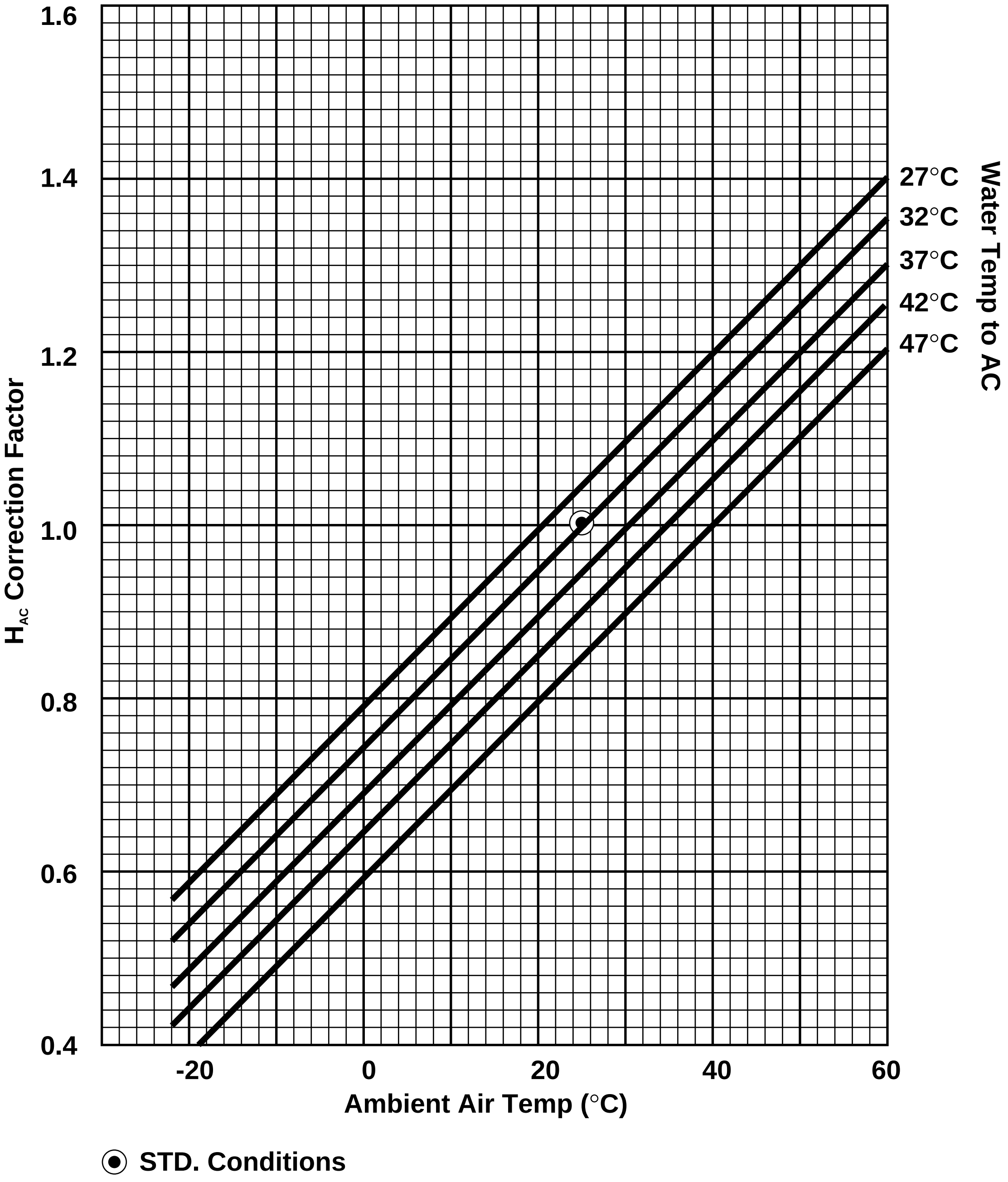


Figure 10

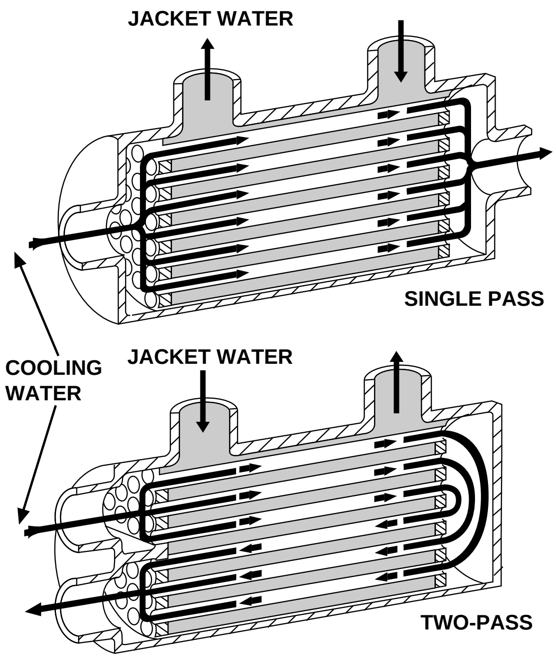
Heat Recovery Unit Tolerances
Assume recoverable heat available is at the lower end of the tolerance zone, i.e., -8% to -10%. This adjusts for the regulator control system characteristics and convection/radiation losses from the piping. See *Heat Recovery* in this section of the guide.

Heat Exchanger

The Caterpillar shell and tube type heat exchangers provide compact, reliable, and cost effective cooling. Since heat exchanger tubes can be cleaned easily, raw water is usually routed through tubes and engine coolant through the shell. The flow in the raw water section is either single-pass or two-pass (see Figure 11). A two-pass type flows raw water twice through the exchanger; single-pass types use raw water only once. To provide maximum temperature differential and heat transfer in single-pass exchangers, the raw water flows opposite to coolant flow. The direction of flow is not important in two-pass exchangers.

If the raw water contains debris, use strainers to prevent tube plugging. In cases of extreme silt contamination or abrasive materials, consider a back-flush filter. Some raw water sources contain high levels of impurities or hardness which accelerate heat exchanger fouling. More frequent heat exchanger cleaning will be required if treatment is not practical.

Heat exchanger performance depends on raw water flow and temperature differential. Orifices or fixed valves must be used to limit raw water velocity and avoid tube erosion. Do not use temperature regulators in the raw water circuit. Engine jacket water is thermostatically controlled and additional controls add expense, cause restriction, and decrease reliability.



Heat Exchanger Types

Figure 11

Heat Exchanger Sizing
Combined Circuit:
The heat exchanger should be sized using a maximum coolant temperature at the AC/OC pump inlet of 38°C (100°F) for all Marine engines. The heat exchanger sizing must also consider the maximum expected ambient air temperature, maximum engine power (rack stop power), maximum expected raw water temperature, and 10% margin for a fouling and safety factor. Consult a project engineer if the vessel will operate in sea water temperatures greater than 32°C (90°F). It is impractical to purchase heat exchangers which are sized for less than a 6°C (11°F) differential between sea water and AC/OC water.

Separate Circuit:
There are two heat exchangers required for separate circuit cooling systems, one for the engine jacket water circuit and one for the AC/OC water circuit. The jacket water heat exchanger should be sized using a maximum coolant temperature at the jacket water pump inlet of 93°C (199°F) for heavy fuel engines, and 90°C (194°F) for distillate fuel engines. The jacket water heat exchanger sizing must also consider maximum engine power (rack stop power), maximum expected raw water temperature, and 10% margin for a fouling and safety factor.

The AC/OC heat exchanger should be sized using a maximum coolant temperature at the AC/OC pump inlet of 38°C (100°F) for all marine engines. The AC/OC heat exchanger sizing must also consider the maximum expected ambient air temperature, maximum engine power (rack stop power), maximum expected raw water temperature, and 10% margin for a fouling and safety factor. See the previous note on combined circuit heat exchanger sizing if sea water temperature is greater than 32°C (90°F).

Separate circuit cooling systems are most commonly used in applications where keel coolers or radiators are used as the heat exchangers, to keep the equipment size to a minimum.

Expansion Tanks

Caterpillar expansion tanks provide:
- Expansion volume for coolant
- Coolant level alarm
- Single filling location
- Pressure cap & vent
- Coolant sight gauge
- Deaeration chamber
- Thermostat mounting
- Drain
- Positive pump inlet pressure

Caterpillar offers two expansion tanks. The smaller tank has an expansion volume of 75 L (20 gal) and the larger tank has 245 L (65 gal). Calculations can determine if an auxiliary expansion tank is required.

Two tank arrangements can be provided by Caterpillar as follows:

Standard Volume Tank - For use with cooling systems whose total volume is up to 1500 L (400 gal), assuming a 4.4°C (40°F) fill water temperature.

High Volume Tank - For use with cooling systems whose total volume is up to 5700 L (1500 gal), assuming a 4.4°C (40°F) fill water temperature.

Figures 12 and 13 on page 13 show the two Caterpillar expansion tanks that are available.

Two possible methods of arranging the expansion tank in the cooling system are the full flow system and shunt type system. The most important point with either system is to ensure that air entrained in the coolant is removed to prevent pump cavitation and cavitation erosion of internal engine components. Deaeration of the coolant requires a low velocity area. In either case, locate the expansion tank to prevent vacuum formation. *The water level in the tank should be the highest point in the cooling circuit at any ship attitude.*

With the full flow system, the entire flow of coolant passes through the expansion tank via a regulator mounted on the tank. This allows air to be removed from the coolant because the tank has internal baffles that slow the water flow down to 0.6 m/sec (2 ft/sec). The full flow system provides a single fill point in both the combined and separate circuit systems. A make-up line between the two circuits is required on the separate circuit system (see Figure 6). The full flow system is usually used when the expansion tank is located near the front of the engine.

With the shunt type system, the expansion tank is connected to the cooling system by one smaller pipe that maintains a static head on the cooling system. Separate vent lines must be run from each system high point to the expansion tank to remove entrained air from the coolant. A deaerator chamber must also be installed at the coolant outlet from the engine. The deaerator removes entrained air from the coolant and a port in the top of the chamber is used to connect to the expansion tank. Figure 5 shows a shunt type cooling system used in a heavy fuel engine two step cooling system.

The shunt type system is used in applications where the expansion tank cannot be located near the front of the engine. In this case the expansion tank is mounted remotely (usually on the next deck up from the engine level), and only a few small connection lines to the tank are required for vents and the static head connection. This prevents the need for running large coolant pipes over long distances through the engine room. The coolant regulator is mounted separately from the expansion tank in a place convenient for the builder.

Expansion Tank Volume

Expansion tanks must provide adequate volume for coolant expansion plus reserve. Total cooling system volume must be known to determine the minimum acceptable expansion tank size. The total volume is the engine coolant volume plus the volume of all external (customer supplied) circuits. Volume data is shown in Figures 12 and 13 for the engine, full Caterpillar standard and high volume expansion tanks, tank piping and the Caterpillar supplied shell and tube heat exchanger.

The required expansion volume is calculated as follows:

Required Expansion Volume =
(Total System Volume) x
(Expansion Rate)

The expansion rate depends on the coolant mixture being used, and can be determined from the curves shown in Figure 14 on page 14.

Some installations will use the Caterpillar supplied heat exchanger and factory piping. In those cases, the volume of all external piping must be calculated. The minimum reserve capacity is determined from the following table:

Total External Circuit Volume	Minimum Reserve Capacity
≤ 50% of Engine Coolant Volume	10% of Total System Volume
60% of Engine Coolant Volume	9% of Total System Volume
70% of Engine Coolant Volume	8% of Total System Volume
80% of Engine Coolant Volume	7% of Total System Volume
90% of Engine Coolant Volume	6% of Total System Volume
≥ 100% of Engine Coolant Volume	5% of Total System Volume

The minimum acceptable expansion tank volume is:
Minimum Tank Volume = (Expansion Volume) + (Minimum Reserve Capacity)

Expansion Tank Standard Volume 75 L (20 gal)

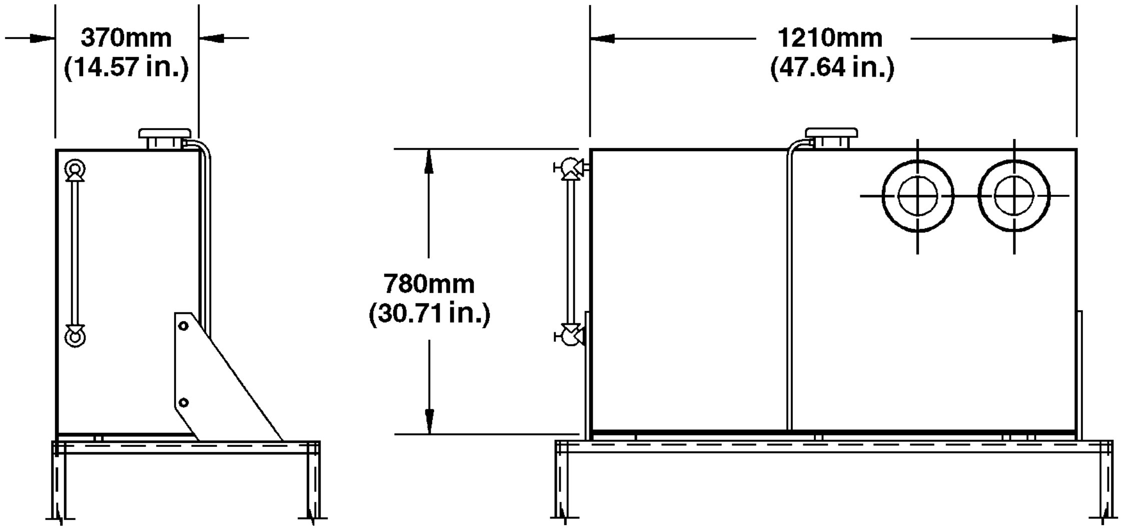


Figure 12

Expansion Tank High Volume 245 L (65 gal)

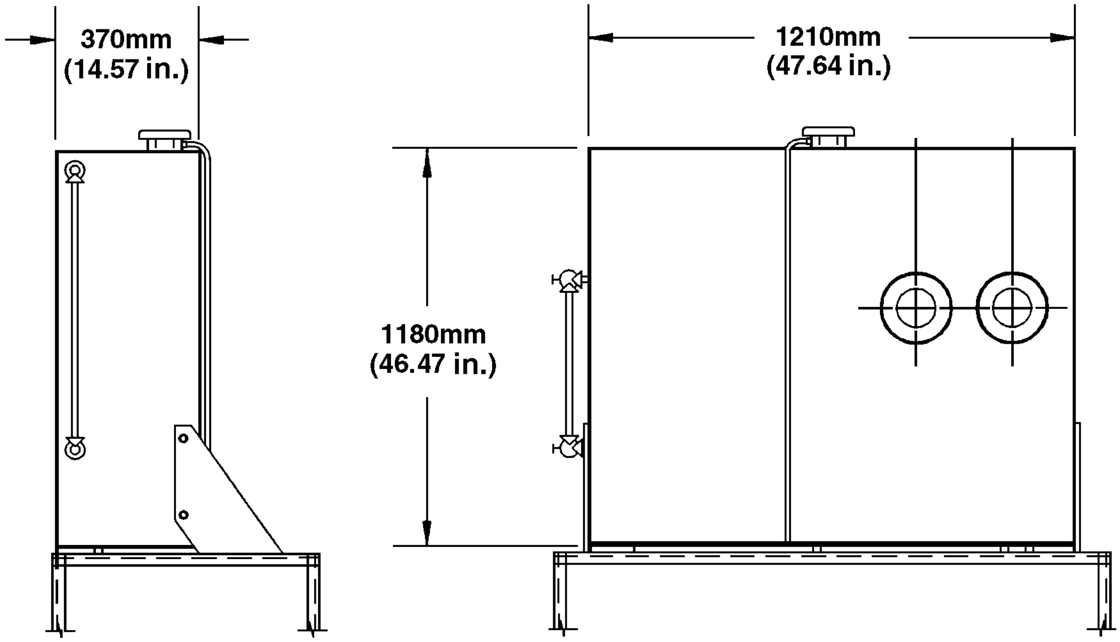


Figure 13

Engine	Engine Coolant Volume	Expansion Tank		Expansion Tank Piping	Heat Exchanger
		Standard Capacity	Increased Capacity		
		Liters (kg)			
3606	400 (400)	300 (300)	475 (475)	150 (150)	50 (50)
3608	530 (530)	300 (300)	475 (475)	150 (150)	50 (50)
3612	800 (800)	300 (300)	475 (475)	200 (200)	100 (100)
3616	1060 (1060)	300 (300)	475 (475)	200 (200)	100 (100)
Engine		U.S. Gallons (lb)			
3606	105 (875)	80 (667)	125 (1042)	40 (333)	15 (125)
3608	140 (1167)	80 (667)	125 (1042)	40 (333)	15 (125)
3612	210 (1751)	80 (667)	125 (1042)	55 (333)	30 (250)
3616	280 (2334)	80 (667)	125 (1042)	55 (333)	30 (250)

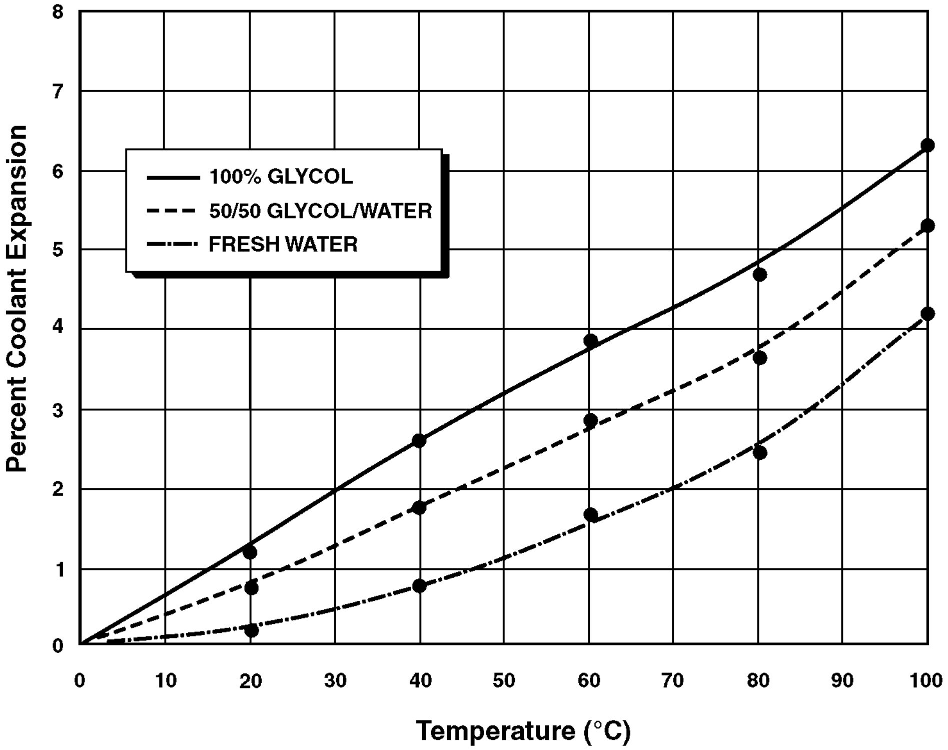


Figure 14

System Pressures

The following pressure limits apply to all 3600 Diesel Engines:

Water Pump Pressures:

Maximum Allowable Static Head	145 kPa	(15 m H_20)
Minimum AC/OC Pump Inlet (Dynamic)	-5 kPa	(-0.5 m H_20)
Minimum JW Pump Inlet (Dynamic)*	30 kPa	(3.0 m H_20)
Minimum Raw Water Pump Inlet (Dynamic)	-5 kPa	(-0.5 m H_20)

Maximum Operating Pressures:

Engine Cooling Circuits	500 kPa	(51 m H_20)
Caterpillar Expansion Tanks	150 kPa	(15.3 m H_20)
Caterpillar Heat Exchangers	1000 kPa	(102 m H_20)
Radiators/Non-Cat Heat Exchangers	(Contact Supplier)	

* Acceptable jacket water pump inlet pressures are achieved on combined cooling systems by maintaining the correct external circuit resistance.

External Circuit Resistance

The method used to set external circuit resistance depends on cooling system geometry.

Method No. 1: Used when the cooling circuit includes the Caterpillar expansion tank and regulators mounted on the front module assembly (full flow system). External pressure drop is measured from the engine outlet to the cold flow entrance at the regulator housing. Measure both pressures as close to the same elevation as possible (see Figure 15 and table at right).

Method No. 2: Used when the cooling circuit includes a remote-mounted expansion tank and remote regulators (shunt type system). External pressure drop is measured from the engine outlet to the pump inlet. Make pressure measurements at the corresponding outlet and inlet elevations (see Figure 16).

rpm	ΔP (P_1-P_2) kPa (psi)
1000	90 (13)
900	73 (11)
750	51 (7.5)
720	47 (7)
Tolerance:	±10%

The above external resistance settings must be made with blocked-open regulators to assure full heat exchanger flow. Refer to Engine Data Sheet 50.5, "Cooling System Field Test".

A lockable plug valve is preferred for setting external resistance. A plate type orifice or other adjustable valve may be used, but it must not include an elastomer seal element.

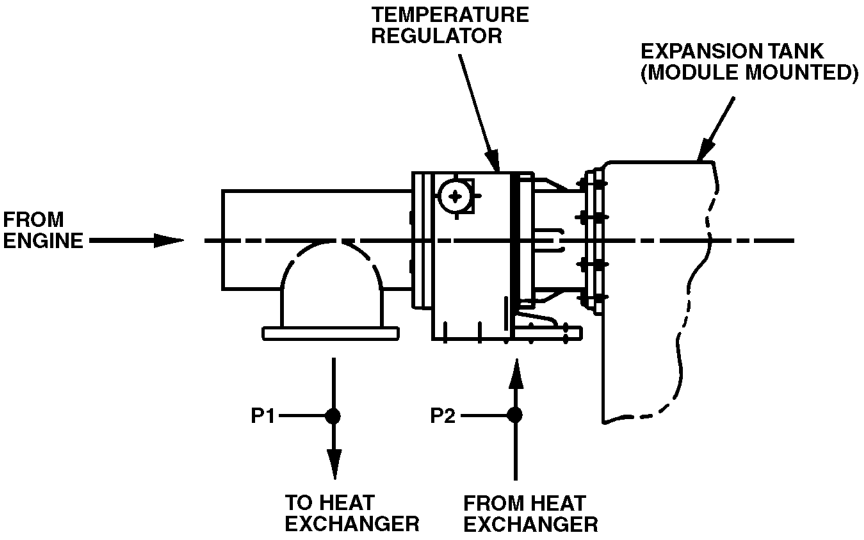
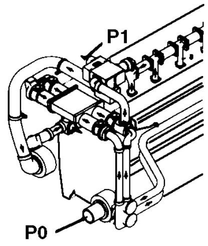


Figure 15

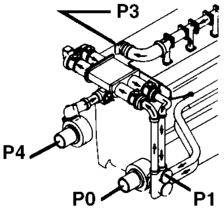
3606 and 3608 Combined Circuit

External Circuit Resistance, kPa (psi)



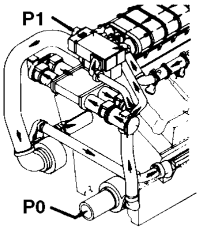
Engine Speed rpm	Low Temperature Circuit Δ P (P1-P2)	High Temperature Circuit Δ P (P3-P4)
1000	91 (13)	—
900	71 (10)	—
750	45 (6.5)	—
720	40 (5.8)	—
Tolerance:	± 10%	—

3606 and 3608 Separate Circuit



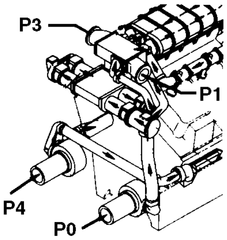
1000	104 (15)	99 (14)
900	84(12)	77 (11)
750	58 (8)	50 (7)
720	52 (7.5)	44 (6)
Tolerance:	± 10%	± 10%

3612 and 3616 Combined Circuit



1000	85 (12)	—
900	66 (9.6)	—
750	42 (6)	—
720	38 (5.5)	—
Tolerance:	± 10%	—

3612 and 3616 Separate Circuit



1000	85 (12)	103 (15)
900	66 (9.6)	81 (12)
750	42 (6)	52 (7.5)
720	38 (5.5)	47 (7)
Tolerance:	± 10%	± 10%

Figure 16

The correct circuit restriction must also be maintained for bypass flow. Systems including the module mounted expansion tank with Caterpillar regulators contain factory installed orifices to control bypass flow. For remote systems, set the external bypass restriction to 130% ±10% of the corresponding external restriction value for full heat exchanger flow. The restriction must be set before the circuit reaches regulator start-to-open temperature.

Keel Coolers

A keel cooler is an outboard heat exchanger attached to the submerged portion of a ship's hull. They are typically used in applications encountering muddy or silty cooling water.

Fabricated keel coolers use many shapes (pipe, tubing, channel, etc.). Material choice depends on the cooling water encountered. It must be compatible with the ship's hull materials to prevent galvanic corrosion.

Fabricated Cooler Performance and Sizing

This guide section may be used to determine keel cooler performance characteristics, including sizing, for 3600 Engines. Careful identification of application type, operating conditions, coolant temperature specifications, and acceptance limits must be emphasized for accurate analysis.

Application

The data may be used for the following:

- Determine keel cooler size (surface area) required for either a combined or separate circuit cooling system.
- Determine the performance capability, including the return to engine coolant temperature, for an existing keel cooler configuration.
- Predict *regulated* coolant temperatures at any engine operating conditions for a specific keel cooler configuration. This is an iterative process and requires temperature regulator characteristic curves (temperature vs stroke and flow split vs stroke) for the thermostats being used. Contact a Caterpillar Application Engineer for this analysis.

The general technique for analyzing keel cooler performance is based on establishing a unit heat rejection capacity factor in terms of kW/m^2 of surface area per °C temperature difference between coolant-to-engine and the raw water. This is determined from the curves in Figure 17 for a nominal (typical) set of conditions, and is referred to as the *baseline* performance. The baseline capacity is then adjusted for actual operating conditions using a set of correction factors. The corrections take into account fouling factors (raw water and coolant), use of antifreeze (% glycol) if applicable, and actual steel thickness of the heat transfer surface. Materials other than structural (mild) steel are not considered in this analysis.

For keel cooler sizing, the heat rejection capacity factor is used to calculate the total surface area required. This is based on acceptance criteria for the specific engine and application. Acceptance is normally based on coolant-to-engine temperature limits specified in the beginning of this *Cooling* section. After determining the required surface area, the structural members can be selected based on space limitations, availability, and total coolant flow. The cross sections selected (angle irons, channels, etc.) must provide flow conditions (velocity and turbulence) used in the capacity calculations and analysis. Flow losses (pressure drop) through the cooler must also be calculated to confirm an acceptable external circuit resistance.

To evaluate an existing keel cooler configuration (vessel repower, etc.), the heat rejection capacity factor is used to calculate the coolant-to-engine temperature. This calculation should be done assuming full keel cooler flow (thermostats fully open). If the resulting coolant temperature is *below* the maximum allowable limit, the keel cooler design is acceptable relative to heat rejection. Pressure drop through the cooler must also be calculated to determine if external circuit resistance is acceptable.

The curves and techniques in this section can also be applied to predict engine cooling system temperatures for specific operating conditions. This analysis procedure requires the determination of the equilibrium point at which the system flows — temperatures, engine heat rejection, keel cooler capacity, and thermostat temperature/flow characteristics are all balanced. Refer this iterative process to a Caterpillar Application Engineer.

Performance and Sizing Criteria

Keel cooler sizing must be based on the most critical set of operating conditions.

- For marine propulsion engines operating in a consistent type of raw water, the critical case will most likely be maximum engine power at rated vessel speed at maximum expected raw-water temperature. Examples would include ocean going ships, vessels limited to the Great Lakes, or large river tugs.
- For propulsion engines operating in multiple raw-water types, several cases may have to be evaluated to identify the critical situation. An example is an ocean-going vessel entering inland harbors via rivers, channels, etc.
- For marine auxiliary engines, the critical condition will most likely be maximum load, still water (ship anchored), and maximum raw-water temperature. If load demand varies significantly between anchored and *under-way* operation, both conditions must be evaluated.

The keel cooler design must meet the following criteria:

- Structural (mild) steel welded to ship's hull. *If raw water temperature exceeds 30°C, particularly in salt water, the use of packaged coolers made of corrosion resistant materials is recommended.*
- Engine coolant flowing from rear to front of the vessel (counter-flow). If this is not possible due to the hull design and piping limitations, or if an existing cooler with split flow types is being analyzed, contact a Caterpillar Application Engineer.
- No paint or protective coatings applied to heat transfer surfaces.

The engine coolant must meet the following:

- Water used must meet Caterpillar specifications.
- Conditioner must be used and maintained at proper concentration levels.
- Use of antifreeze (glycol) is acceptable.

Engine coolant flow through the cooler must meet the following:

- Flow velocity:

Maximum	2.5 m/sec	(8.2 ft/sec)
Minimum	0.5 m/sec	(1.65 ft/sec)
Design Point**	1.5 m/sec	(4.92 ft/sec)

- Turbulent flow (natural or induced)

** Rated engine speed with full flow through cooler (thermostats fully open)

Baseline Performance Conditions

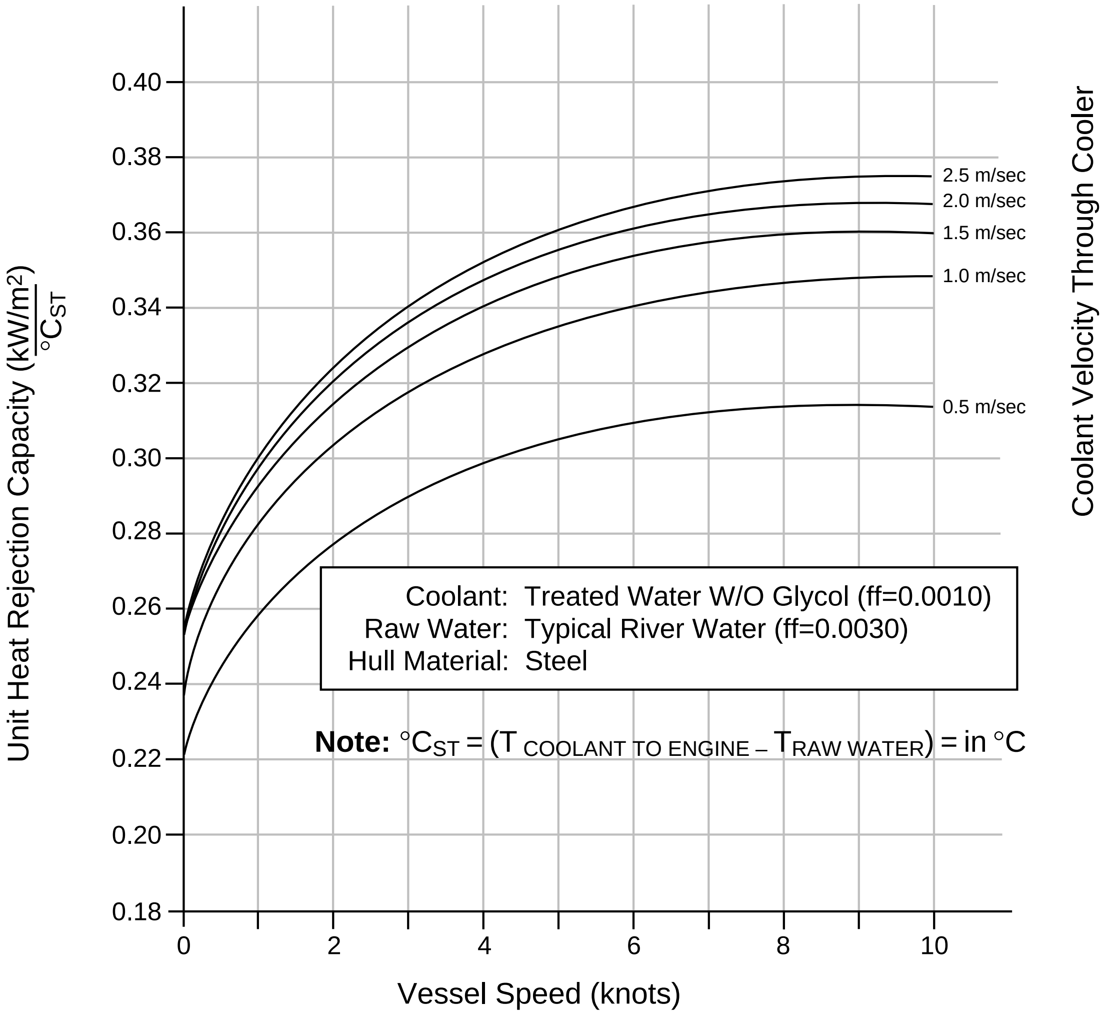
The baseline performance curves in Figure 17 are for the following conditions:

Engine Coolant:
Treated Fresh Water (no glycol)
Engine Coolant Fouling Factor:
0.0010 (no excessive hardness)
Raw Water Fouling Factor:
0.0030 (typical river water)
Steel Thickness:
6.35 mm (0.25 in)

Correction Factors

The *baseline* keel cooler performance (unit heat rejection capacity) obtained from Figure 17 must be adjusted to account for actual conditions. Correction factors (multipliers) required are shown in Figures 18 and 19.

Use of extremely hard water
Figure 18
Use of antifreeze (glycol)
Figure 18
Raw water fouling factors
Figure 18
Steel thickness (heat transfer surface)
Figure 19



Keel Cooler Performance & Sizing
Baseline Heat Rejection Capacity

Figure 17

Keel Cooler Performance Correction Factors

Correction Factors for Cooling System Water:

Water meets Caterpillar specifications	(baseline)1.00
Extremely hard water (>15 grains/gal)	0.90

Correction Factors for Antifreeze:

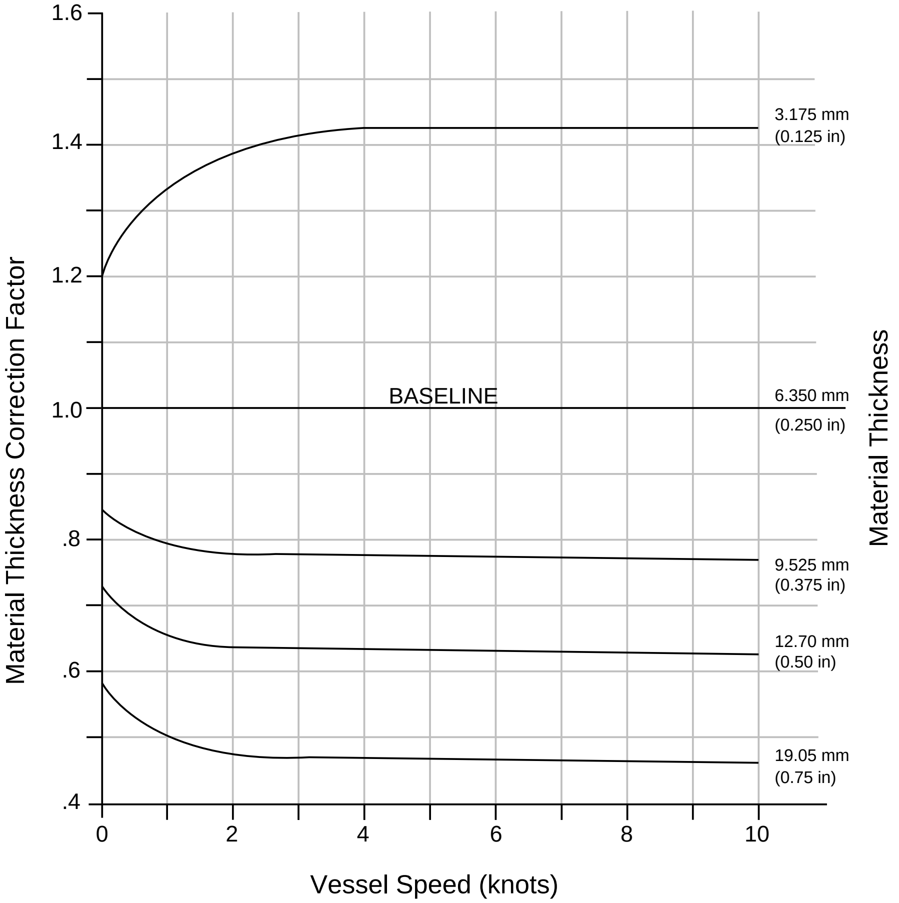
0% glycol	(baseline)1.00
10% glycol	0.97
20% glycol	0.94
30% glycol	0.91
40% glycol	0.88
50% glycol	0.85

Correction Factors for Raw-Water Type

Raw-Water Description	*Fouling Factor	Correction Factors @ Vessel Speed <2 knots	Correction Factors @ Vessel Speed >2 knots
River water (baseline)	0.0030	1.00	1.00
Open sea (ocean water)	0.0007	1.11	1.16
Great Lakes	0.0010	1.10	1.13
Chicago Canal	0.0060	0.88	0.85

* Fouling factor is shown here for reference only and is used to calculate the vessel speed correction factor.

Figure 18



Keel Cooler Performance & Sizing
Capacity Corrections for Material Thickness
(Structural Steel)

Figure 19

Worksheet

A worksheet for calculating keel cooler size (surface area) is shown on page 22. This worksheet applies to combined and separate circuit systems. A separate circuit system requires two worksheets: one for the low-temperature (aftercooler/ oil cooler) circuit, and one for the high temperature (jacket water) circuit.

Design/Installation Considerations

Large cross-sectional channels are often used for keel cooler passages. This can result in water velocities that are too slow for effective heat transfer. Inserts can be installed to create localized high water velocity or turbulence. An effective design for keel cooler inserts is a *ladder-like* device inserted through the full length of the keel cooler passages.

Construct the ladder using rods [6 mm (1/4 in.) diameter] and flat bar (approximately the same shape, but 70% of the cross sectional area of the keel cooler flow passages). Use the same metal alloy as the hull and keel cooler. The flat bar cross pieces must not restrict flow. They should redirect the flow to avoid the laminar flow due to slow average velocity. Insert the ladder into the keel cooler flow passages and weld on end inlet and outlet manifolds.

Bypass Filters

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

Strainers

Full flow strainers are desirable. Size the strainer screens no larger than 1.6 mm (.063 in.) mesh. Connections must be no smaller than the recommended line size. A differential pressure gauge across the duplex strainer can be used to determine service periods.

Pressure drop across a strainer at maximum water flow must be considered as part of the system's external resistance. The strainer should have no more than 1 m (3 ft) H_2O restriction in clean condition.

Packaged Keel Coolers

Packaged keel coolers are purchased and bolted to the outside of a ship's hull. They are normally copper-nickel alloy and are initially toxic to marine growth, one of the more important advantages over fabricated keel coolers. The toxicity will decline with time, but the keel cooler can be partially restored by cleaning the heat transfer surfaces with a vinegar-salt solution. Another advantage of packaged keel coolers is their compactness and light weight compared to fabricated keel coolers. They can have less than 20% of the heat transfer surface of a fabricated cooler. Manufacturers publish sizing guidelines for specific conditions.

Never paint packaged keel coolers. Paint greatly reduces heat transfer.

Packaged keel coolers are rarely the same material as the ship's hull.*

If the piping is not the same material as the cooler, it must be electrically isolated from the hull metal and the ship's piping.

Keel Cooler Location

Locate the cooler in a protected area and low on the hull. The area immediately forward of the propellers is a region of high water velocity. It is high enough on the hull to be protected from grounding damage. The effects of sandblasting the cooler (from the propellers) during astern maneuvers must be considered.

---

*Coolers of aluminum alloy reduce the galvanic corrosion problems associated with dissimilar metals submerged in salt water, ie. aluminum and copper nickel.

KEEL COOLER SIZING WORKSHEET

GENERAL INFORMATION:

Project ____ Engine __________

Application ____

Fuel Type ____

Rated Power ____________________________ bkW Rated Speed ________ rpm

Cooling System Type (Combined or Separate) ________________________________

DESIGN-POINT CONDITIONS:

Engine Power ____________ bkW

Engine Speed ____________ rpm

Heat Rejection Data (from TMI):

- Jacket Water ____________ kW
- Oil Cooler ____________ kW
- Aftercooler ____________ kW

Vessel Speed ____________ knots

Maximum Expected Raw Water Temperature ____________ °C

Raw Water Type / Description ______________________________

CIRCUIT ANALYSIS INFORMATION:

Circuit Being Analyzed ___________________________________

Total Circuit Heat Rejection ____________ kW

Max Allowable Coolant-to-Engine Temp ____________ °C

Regulator (Thermostat) Part Number ____________________

- Start-to-Open Temperature ____________ °C
- Full-Open Temperature ____________ °C

Total Circuit Flow ____________ L/min

Coolant Velocity thru Keel Cooler ____________ m/sec

Max Allowable Circuit Resistance ____________ kPa

Coolant Water Type ____________________

Antifreeze Content (glycol) ____________ %

Steel Thickness of Heat Transfer Surface ____________ mm

CIRCUIT ANALYSIS INFORMATION:

Baseline Unit Heat Rejection Capacity (Figure 17) = ____________ (kW/sq m) / ° C

Total Correction Factor (see Figures 18 and 19):

Water Factor		Glycol Factor		Raw-Water Factor		Thickness Factor		
(______)	x	(______)	x	(______)	x	(______)	=	____________

Corrected Unit Heat Rejection Capacity:

Baseline Capacity		Total Correction Factor			
(________)	x	(________)	=	____________	(kW/sq m) / °C

Temperature Difference Calculation:

Coolant-to-Engine Temperature		Raw Water Temperature			
(_______) °C	-	(_______) °C	=	____________	°C

Unit Heat Rejection Capacity @ Design Temperatures:

Corrected Unit Capacity		Temperature Difference			
(________)	x	(________)	=	____________	kW/sq m

Total Surface Area Required:

Total Circuit Heat Rejection		Unit Capacity @ Design Temps			
(________)	/	(________)	=	____________	sq m

Keel Cooler Circuit Pumps

The engine driven water pump will normally circulate engine fresh water through the cooler. If the total external resistance cannot be held within limits, an auxiliary pump will be required.

Keel Cooler Venting

Proper venting of fabricated keel cooler channels is critical for good cooling system operation. Both ends of each channel section should have manual or automatic vent valves to remove air during initial system filling. This is important because the ship's trim can vary from vessel to vessel and air can be trapped if the channels are vented at only one end. If air gets trapped in the channel sections during initial fill, the expansion tank volume will drop dramatically when the engine is running because that air will be compressed by the pump pressure and coolant will take its place. This trapped air can also cause the external circuit resistance to be set improperly, which may result in poor coolant flow to the engine. Pump cavitation may also result from air trapped in the keel cooler.

Marine Gear Heat Rejection

Marine gears have an efficiency of about 97%. Approximate heat rejection to the marine gear cooling system is:

H = P x F

Where:

H = Marine Gear Heat Rejection, (kW)
P = Engine Power, (kW)
F = Gear Efficiency Loss, (0.03)

H = P x F x 42.41

Where:

H = Marine Gear Heat Rejection, (Btu/min)
P = Engine Power, (hp)
F = Gear Efficiency Loss, (0.03)

The gear manufacturer can supply actual heat rejection values as well as required cooling temperatures. Use the graphs previously presented to calculate the additional cooling area required for the marine gear.

Piping

Use black seamless pipe with connections fitted in the flow direction to minimize turbulence. *Do not use galvanized pipe.*

Cleanliness

All external pipe and water passages must be cleaned before initial engine operation. *Strainers are available from Caterpillar to be installed in pipes leading to externally added equipment.* They are available for 100 mm, 127 mm, and 152 mm (4 in., 5 in., and 6 in.) pipe sizes and all have 1.6 mm (1/16 in.) mesh size. *Install them on site prior to startup and remove after commissioning.*

Venting

Proper venting is required for all applications. Route vent lines to the expansion tank at an upward slope without dips. Avoid traps in customer supplied piping, but if this is not possible they must be vented. When it is not practical to route vent lines to a common point, use automatic air-release valves. The valves are suited for low velocity coolant areas such as expansion tanks. They may also be adapted to deaeration chambers. Locations must be selected to collect entrained air. Automatic air release valves are available in several styles. The heavy duty (cast iron body) style is recommended. In addition to the automatic venting feature, the valves usually have a *fast-vent* port available. Typically it is a pipe plug which can be removed or replaced by a ball valve, allowing venting during initial system fill.

Line Sizing

Water velocity guidelines are:

	Maximum Velocity 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

Connections

Cooling system weld flanges for customer connections are shown in Figures 20, 21, 22, and 23. *(Refer to pages 41-44 for illustrations.)*

Caterpillar flexible joint assemblies are available in the three pipe sizes used on cooling systems: 100 mm, 127 mm, and 152 mm (4 in., 5 in., and 6 in.).

Use flexible joints for all connections to the engine, but *do not use rubber hoses*. Minimize the length and weight of piping mounted on the engine. Place the flexible connection as close to the engine connection as possible, preferably right at the engine connection. This minimizes the stresses on the water pump housings caused by piping weight. Provide adequate pipe support on the hull side of system piping to minimize pipe movement and flex connection loading. Arrange flexible connections, check valves and shutoff valves as shown in Figure 4 when emergency cooling connections are used so that the engine can continue to operate with the standby pump. This is particularly important in single engine propulsion applications.

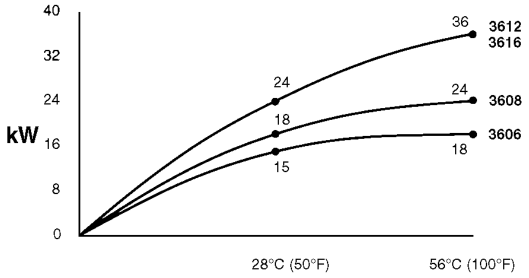
Orient the flex connector to take maximum advantage of its flexibility. Consider normal and maximum expected movement ranges when selecting connectors. Material compatibility must also be evaluated. The internal surface must be compatible with the coolant used over the anticipated operating temperature and pressure ranges. The liner material must also be compatible with potential coolant contaminants such as lube oil, fuel, and system cleaning solutions. The outer cover must be compatible with its environment — temperature extremes, ozone, grease, oil, paint, etc.

Jacket Water Heating System

Jacket water heating systems allow starting at ambient temperatures below 0°C (32°F). Heated water must enter the top of the cylinder block and exit from the bottom. This maintains a positive water pressure to the heater pump and avoids priming and cavitation problems. The jacket water heater and pump should automatically turn on when the engine is shutdown and automatically stop when the engine is started.

The Caterpillar system is a prepackaged shipped loose unit including:
- Circulating pump
- Electric water heater
- Control panel including controls for starting/stopping pump, high temperature shutdown, no flow shutdown, etc.
- Piping, valves and fittings are on the unit -- the customer must plumb the unit to the engine

A typical jacket water heating package is shown in Figure 24. *(Refer to page 45 for illustration).* The heating requirements for each engine is shown in Figure 25.



Coolant Temperature — Above Ambient

Figure 25

Water Treatment

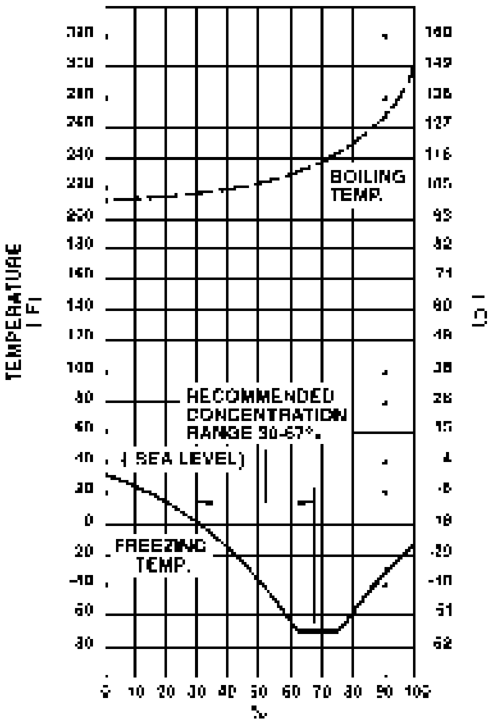
Caterpillar's water quality recommendations must be followed, particularly in closed cooling systems. Excessive *hardness* will cause deposits, fouling, and reduced cooling system component effectiveness. Water hardness is described in grains per gallon, one grain being equal to 17.1 parts per million (ppm) or mg/L, both expressed as calcium carbonate. Water containing up to 3.5 grains per gal (60 ppm) is considered soft and causes few deposits. Cooling system water must meet the following criteria:

Chloride (CL).......2.4 g/gal (40 ppm) max.
Sulfate (SO4).....5.9 g/gal (100 ppm) max.
Total
Hardness ....10.0 g/gal (170 ppm) max.
Total Solids......20.0 g/gal (340 ppm) max.
pH ....5.5 - 9.0

Water softened by removal of calcium and magnesium is acceptable. Corrosion inhibitors added to water maintain cleanliness, reduce scale and foaming, and provide pH control. With the addition of an inhibitor, maintain a pH of 8.5 to 10.

Exposing engine coolant to freezing ambient temperatures requires the use of antifreeze. Ethylene glycol is most common. The concentration required can be determined from Figure 26. Also refer to Form No. SEBD0970-01, *Coolant and Your Engine.*

Caterpillar recommends using a 50/50 mixture of glycol/water. Concentrations less than 30% require the addition of corrosion inhibitors to maintain cleanliness, reduce scale and foaming, and provide acidity and alkalinity (pH) control. The rust inhibitor must be compatible with the glycol mixture and not damage flexible connections, seals, or gaskets. Avoid sudden changes in coolant composition to minimize adverse effects on nonmetallic components.



COOLANT FREEZING AND BOILING TEMPERATURES
VS. ETHYLENE GLYCOL CONCENTRATION

Figure 26

Note: *Caterpillar antifreeze contains the proper amount of coolant conditioner. Do not use coolant conditioner elements or liquid coolant conditioners with Dowtherm 209 Full-Fill Coolant. Caterpillar inhibitors are compatible with ethylene glycol base antifreeze. Soluble oil or chromate solutions must not be used.*

Note: *Water treatment may be regulated by local codes when cooling water contacts domestic water supplies.*

Caterpillar's coolant additive is available in 19 L (5 gal) and 208 L (55 gal) containers: Part No's. 8C3680 and 5P2907 respectively. Caterpillar does not recommend additives from other suppliers. Caterpillar antifreeze is available in 3.8 L (1 gal) and 208 L (55 gal) containers: Part No's. 8C3684 and 8C3686 respectively.

System Monitoring

Make provisions for pressure and temperature differential measurements across major components. This allows accurate setup and performance documentation of the cooling system during the commissioning procedure. Future system problems or component deterioration (such as fouling) are easier to identify if basic data is available. It also provides information for relating *on-site* conditions to the original factory test.

Temperature and pressure measurement locations should give an accurate reading of fluid stream conditions. Preferred locations are in straight lengths of piping reasonably close to each system component. Avoid pressure measurements in bends, piping transition pieces, or turbulent regions. Self-sealing probe adapters are available in several sizes of male pipe threads and straight threads for O-ring ports. The adapters use a rubber seal allowing temperature or pressure to be measured without leakage. Probe diameters up to 3.2 mm (0.125 in.) may be used. The straight-threaded adapters are used on the engines with available ports. Pipe threaded adapters are more easily incorporated in the external customer supplied system. The adapters are an excellent alternative to permanently installed thermometers, thermocouples, and pressure gauges. They are not subject to breakage, fatigue failures, and gauge-to-gauge reading variations.

Serviceability

Access to heat exchangers is required for tube *rodding* (cleaning) or removal of the tube-bundle assembly. Engine water pumps should also be easy to remove. Remote water temperature regulators must be accessible, and appropriate isolation valves provided. Apply similar guidelines to heat recovery units, deaeration chambers, and other components requiring service.

System Design: Engine Data, Criteria and Guidelines

Design Forms:

Included in this section are forms for recording design input for both the combined (page 27) and separate circuit systems (page 28). See the *Engine Data* section of this guide for heat rejection and coolant flow values for both distillate and heavy fuel engines. Use Figure 10 to correct the AC/OC water and ambient air temperatures when different from standard conditions.

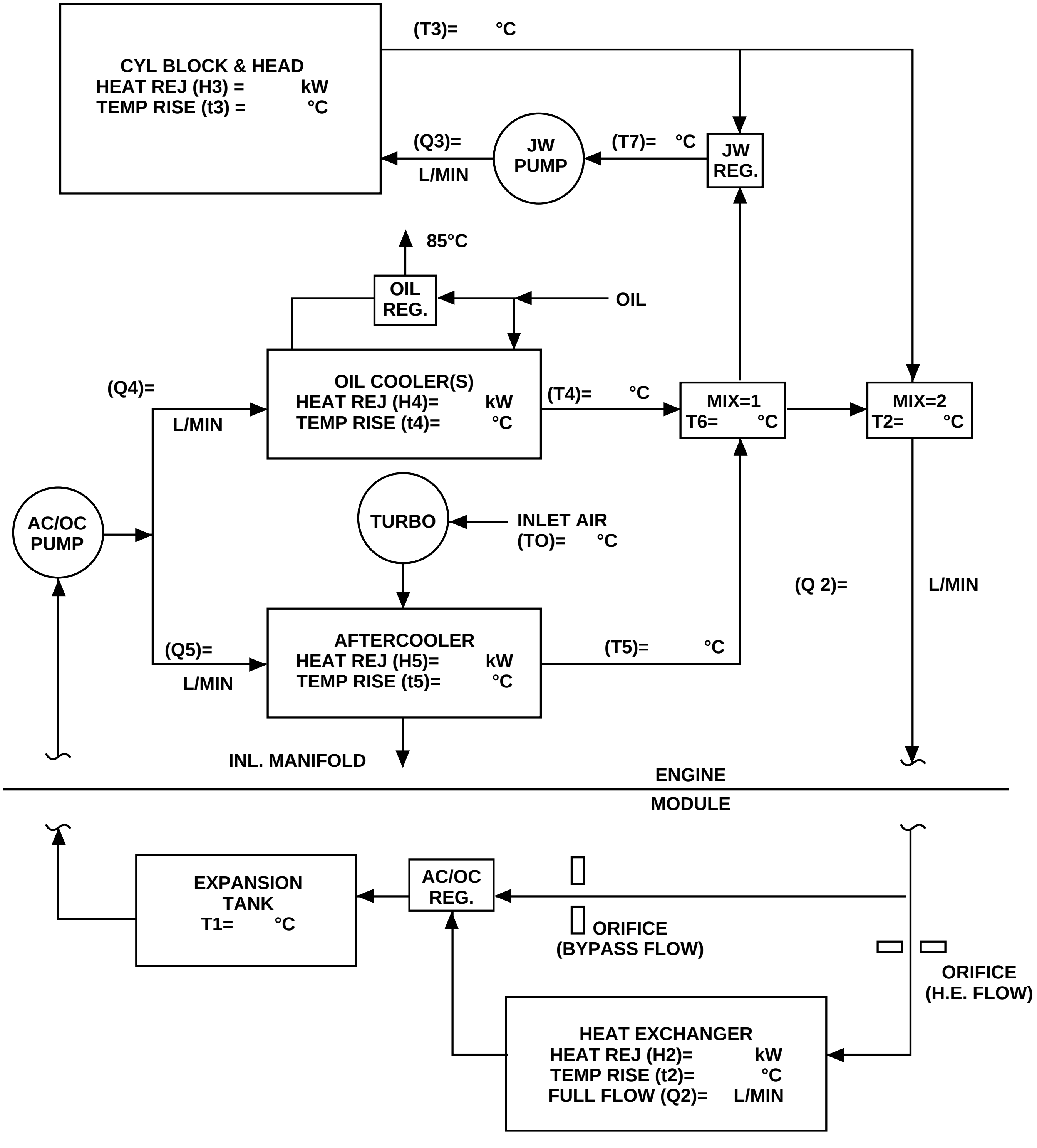
3600 Combined Cooling System

PROJECT: ____________________ **DATE:** __________

ENGINE: ____________________ **SPEED:** __________ **(RPM)**

APPLICATION: ____________________ **POWER:** __________ **(BKW)**

ALTITUDE: __________ **(M)** **COOLANT:** ____________________



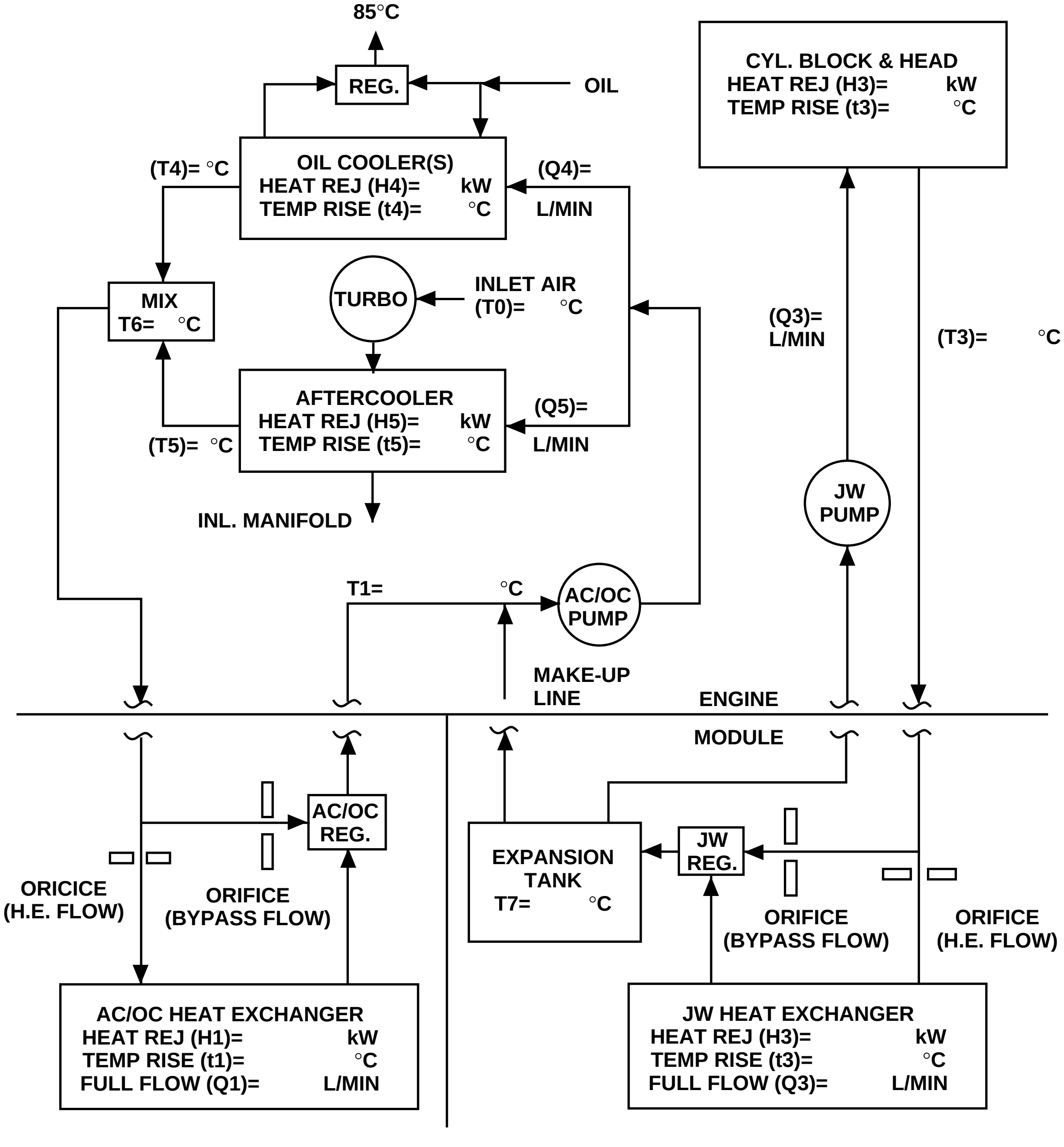
3600 Separate Circuit System

PROJECT: ______________________________ **DATE:** ____________

ENGINE: __________________________ **SPEED:** ______________ **(RPM)**

APPLICATION: ________________________ **POWER:** ______________ **(BKW)**

ALTITUDE: ____________ **(M)** **COOLANT:** ________________________



Heat Recovery

The 3600 Engines convert about 44% of their input fuel energy into mechanical power compared to 33% on older engines. The remaining input fuel energy transforms into heat from friction and combustion. It is carried from the engine by jacket water (including turbocharger cooling water), oil cooler water, aftercooler water, exhaust, surface radiation, and convection.

Heat recovery is a viable option with the 3600 Engine, but because of high overall thermal efficiency it must be given more deliberate consideration. Older engines have traditionally higher percentages of heat rejected to the exhaust and cooling systems, making heat recovery more desirable.

Heat recovery design best suited for any installation depends on many technical and economic considerations. However, the primary function of any design is to cool the engines. Engines must be adequately cooled even when heat recovery demand is low.

Due to the wide variety of uses for the heat recovered from a diesel engine, it is impractical to discuss specific systems in detail. Utilize design consultants or factory assistance when considering heat recovery.

The typical heat balance of 3600 Engines is shown in Figure 27.

Typical 3600 Heat Balance
ISO Conditions

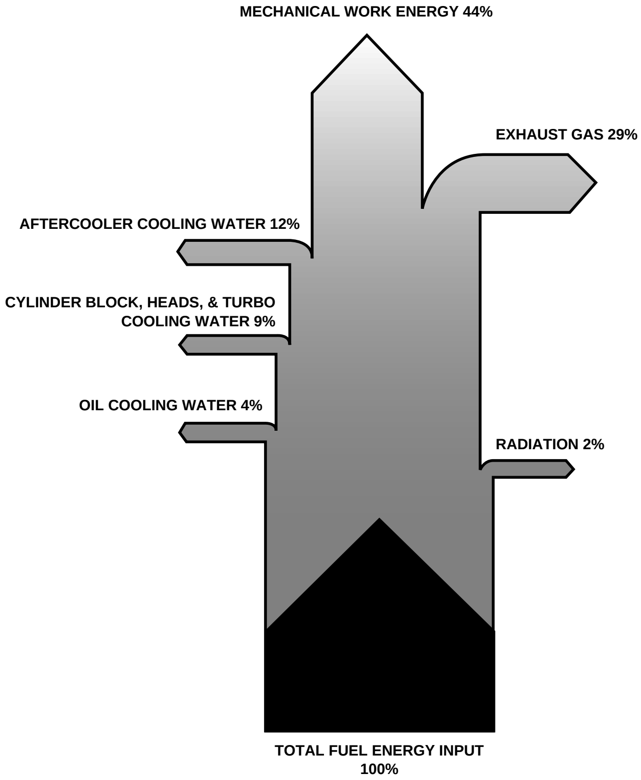


Figure 27

Heat rejection values for marine propulsion engines are included in the *Engine Data* section of this guide. The following data is included for all four engines at 750, 800, 900 and 1000 rpm.

- Jacket water heat rejection (includes turbo)
- Oil cooler heat rejection
- Aftercooler heat rejection
- Exhaust gas heat rejection using the lower fuel heating value
- Exhaust stack gas temperature
- Volume flow of the exhaust gas
- Coolant flow — jacket water and AC/OC water

Heat rejection for marine auxiliary engines is given in Form No. LEKX6559, the *Technical Data* section of the EPG A&I Guide.

When considering heat recovery for 3600 Engines review the cooling system parameters. The two cooling systems available are the combined circuit and separate circuit, and either system can use the high temperature jacket water circuit for heat recovery. Figure 28 shows a combined circuit cooling system and Figure 29 shows a separate circuit cooling system, both with heat recovery from the high temperature jacket water circuit. The flow restriction in the heat recovery circuit is critical because all of the cylinder block flow is directed to the heat recovery unit. Pressure measuring locations at the inlet and outlet connections of the engine are provided, but a factory project engineer should be consulted to determine the permissible pressure differential of the heat recovery system. Exhaust gas heat recovery is also available in either arrangement but details are not shown. If the heat recovery circuit uses less than 30% of the available jacket water heat load, then an external temperature regulator is not required. If a regulator is used it must be set 5°C (9°F) lower than the jacket water circuit regulator to prevent overcooling the engine. Install a full flow bypass valve to isolate the heat recovery circuit when not in use. A heat recovery unit bypass line may be required if the heat recovery unit cannot use the full amount of coolant flow.

Heat Balance

Typical heat balance calculations are illustrated in the following information. These are typical numbers only, meant to illustrate the calculations required. Values selected are from the Engine Data section of this guide. For the latest data use the TMI System.

Heat Balance Example

Use a 3606 Engine with a single circuit cooling system rated at 1730 kW (2320 bhp) at 900 rpm (using distillate fuel) as an example.

Heat Rejection Available
See *Technical Data* within the *Engine Data* section of this guide.

	kW	Btu/min
Block, head and turbocharger	373	21,212
Oil cooler water	185	10,521
Aftercooler water	402	22,877
Total water heat rejection at approx. 45°C (113°F)	**960**	**54,610**
Exhaust heat rejection	**1256**	**71,475**

$$\text{Total Fuel Energy Input} = \frac{\text{BSFC x kW x Qc}}{(1000\ \text{g/kg})(60\ \text{min/hr})(60\ \text{sec/min})}$$

Where Qc = LHV of Fuel = 42,780 kJ/kg (18,390 Btu/lb)

$$= \frac{195.5 \text{ x } 1730 \text{ x } 42{,}780}{3{,}600{,}000}$$

= 4,019 kW (228,710 Btu/min)

Practical Exhaust Heat Recovery, assuming 177°C (350°F) gas temperature after heat exchanger

$$Q\ (\text{available}) = \dot{m} c_p\, \Delta T$$

Where: $\dot{m}$ = mass flow rate, kg/hr

c_p = specific heat of exhaust gas = $0.018\ \frac{\text{kW - min}}{\text{kg - °C}}$

ΔT = exhaust temp drop through heat recovery, °C

The exhaust gas mass flow rate is obtained by multiplying the volumetric flow rate (372.1 m^3/min in this example) by the density. See the conversion formula in the *Exhaust* section.

Q (available) = .018 x 11,439 x (403-177) x 1/60
Q (available) = 776 kW (44,160 Btu/min)

Note: This example does not consider the heat of vaporization of water, a product of combustion and not usually retrievable.

$$n = \text{Thermal efficiency} = \frac{\text{Brake kW}}{\text{Fuel kW}} = \frac{1730}{4019} = 43.0\%$$

$$\text{Jacket Rejection} = \frac{373}{4019} = 9.3\%$$

Heat Balance (continued)

Oil Cooler = $\frac{185}{4019}$ = 4.6%

Aftercooler = $\frac{402}{4019}$ = 10.0%

Exhaust = $\frac{1256}{4019}$ = 31.3%

Radiation = $\frac{73}{4019}$ = 1.8%

100%

Available Heat Recovery

Using high temperature jacket water circuit and exhaust gas

$Q = Q_j + Q_{ex}$

Q (Available) = 373 + 776

Q (Available) = 1149 kW (65,386 Btu/min)

n (Available) = .43 + $\frac{1149}{4019}$

n (Available) = 71.6%

3600 Combined Circuit Cooling
Typical System Schematic

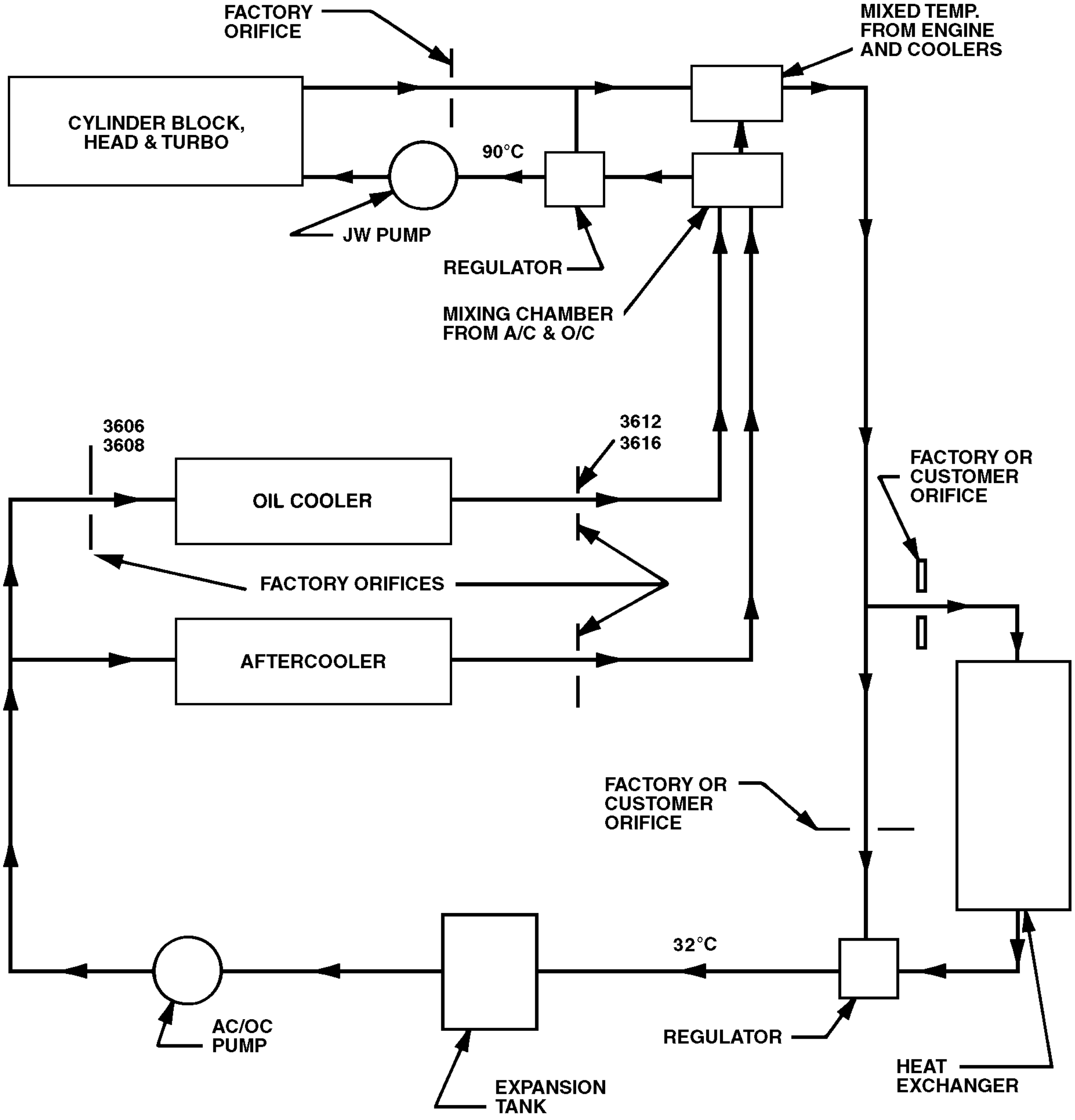
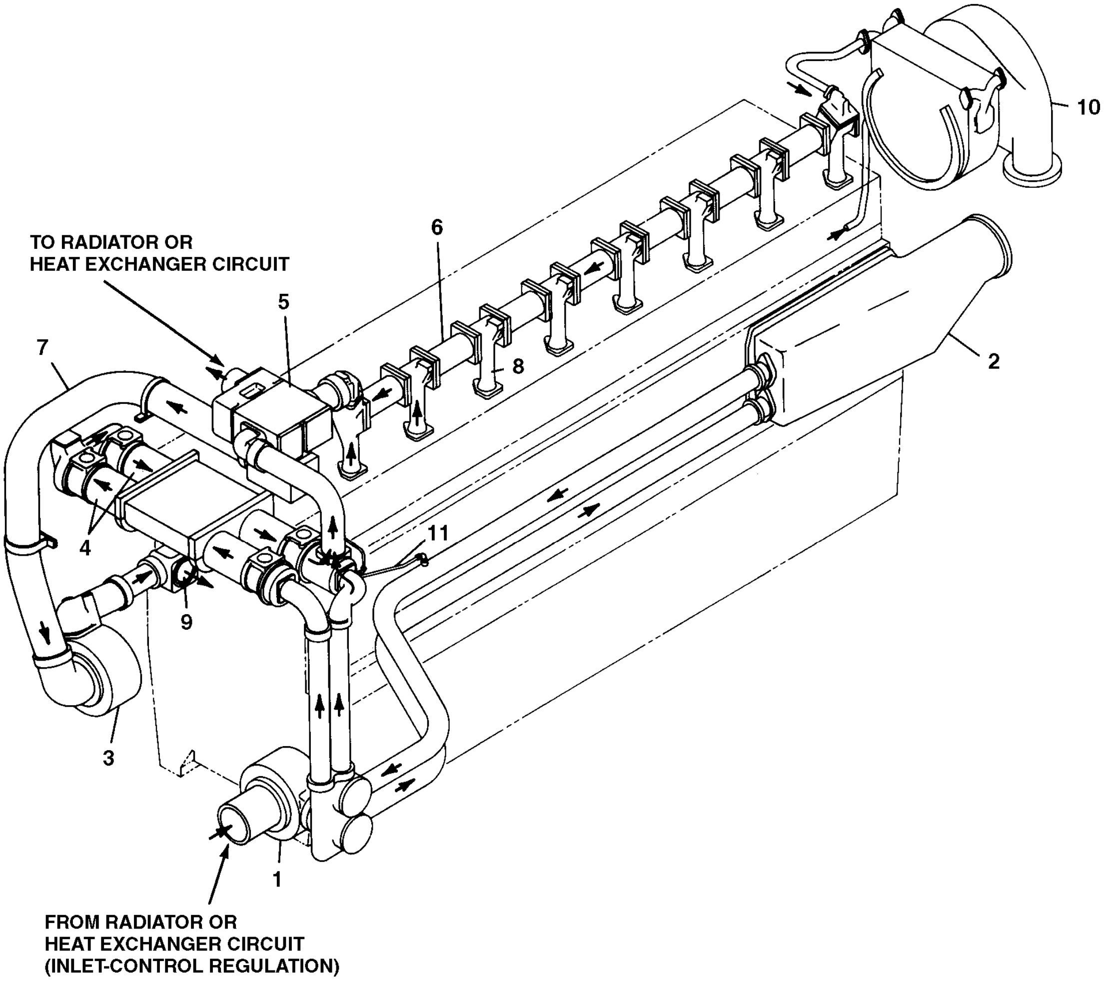


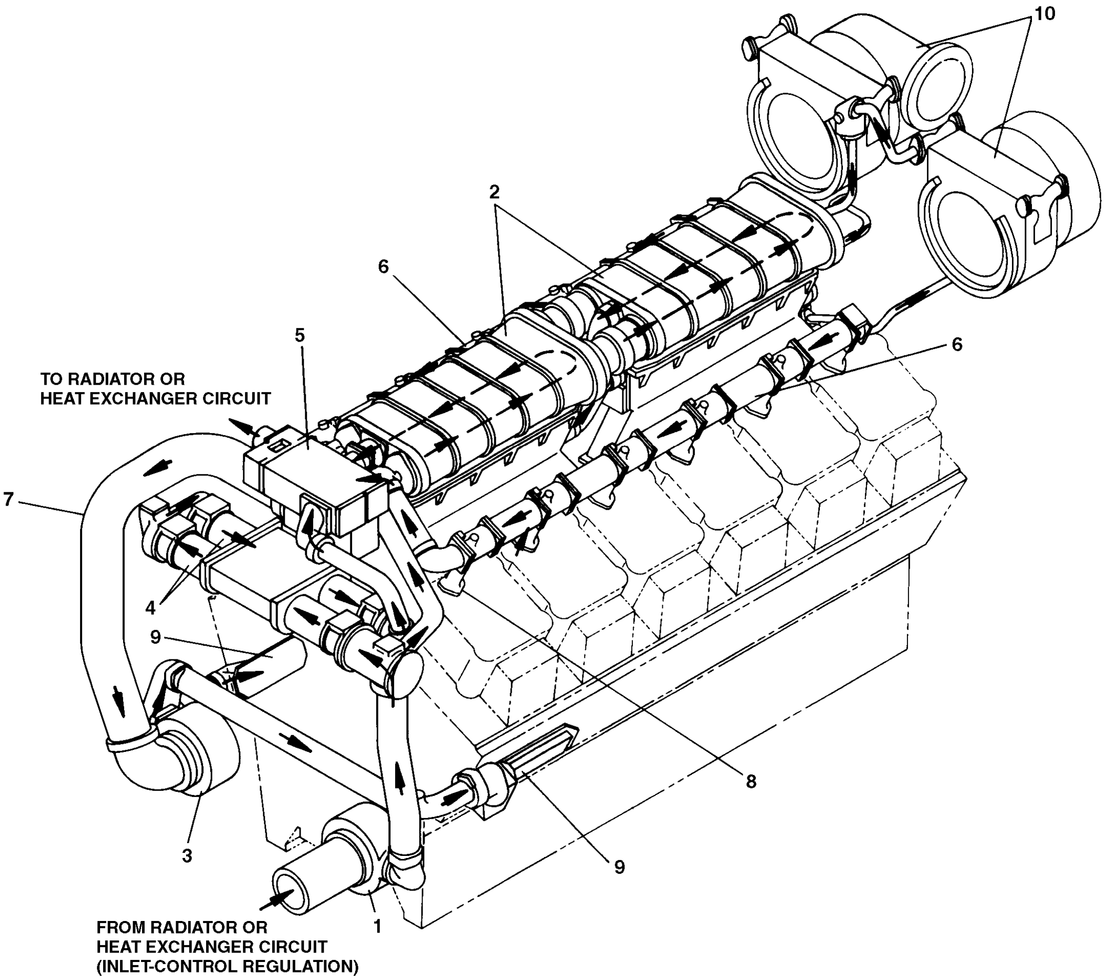
Figure 1



Typical 3606 and 3608
Combined Cooling Schematic

1. Aftercooler/Oil Cooler Pump
2. Aftercooler
3. Jacket Water Pump
4. Oil Coolers
5. Thermostat Housing (JW circuit)
6. Water Manifold
7. Jacket Water Pump Suction LIne
8. Water From Heads
9. Water To Block
10. Turbocharger
11. Vent Line

Figure 2

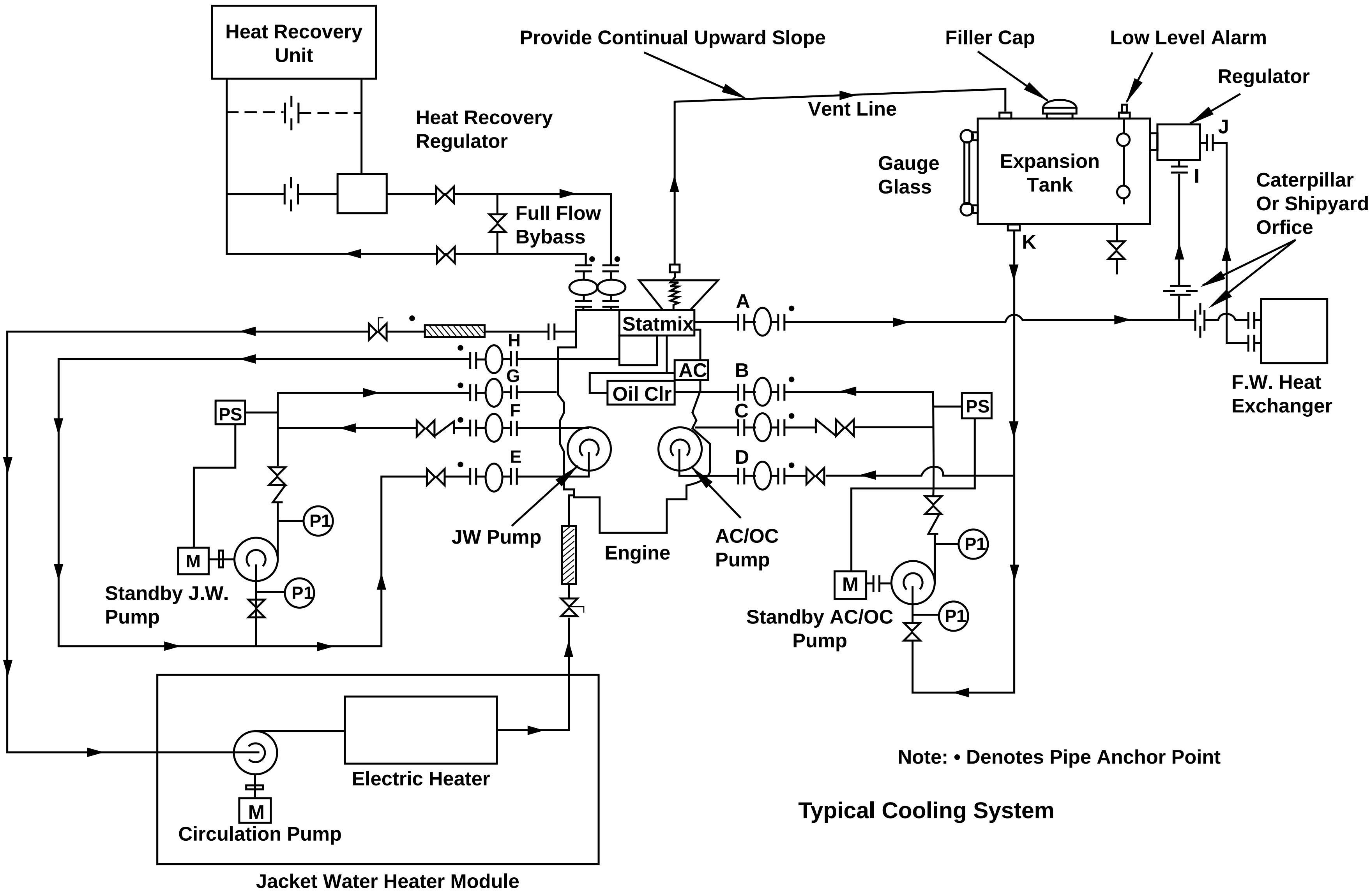


Typical 3612 and 3616
Combined Cooling Schematic

1. Aftercooler/Oil Cooler Pump	7. Jacket Water Pump Suction Line
2. Aftercoolers	8. Water From Heads
3. Jacket Water Pump	9. Water To Block
4. Oil Coolers (2) *	10. Turbochargers
5. Thermostat Housing (JW circuit)	
6. Water Manifold	

*** Three Coolers Required On Some Applications.**

Figure 3



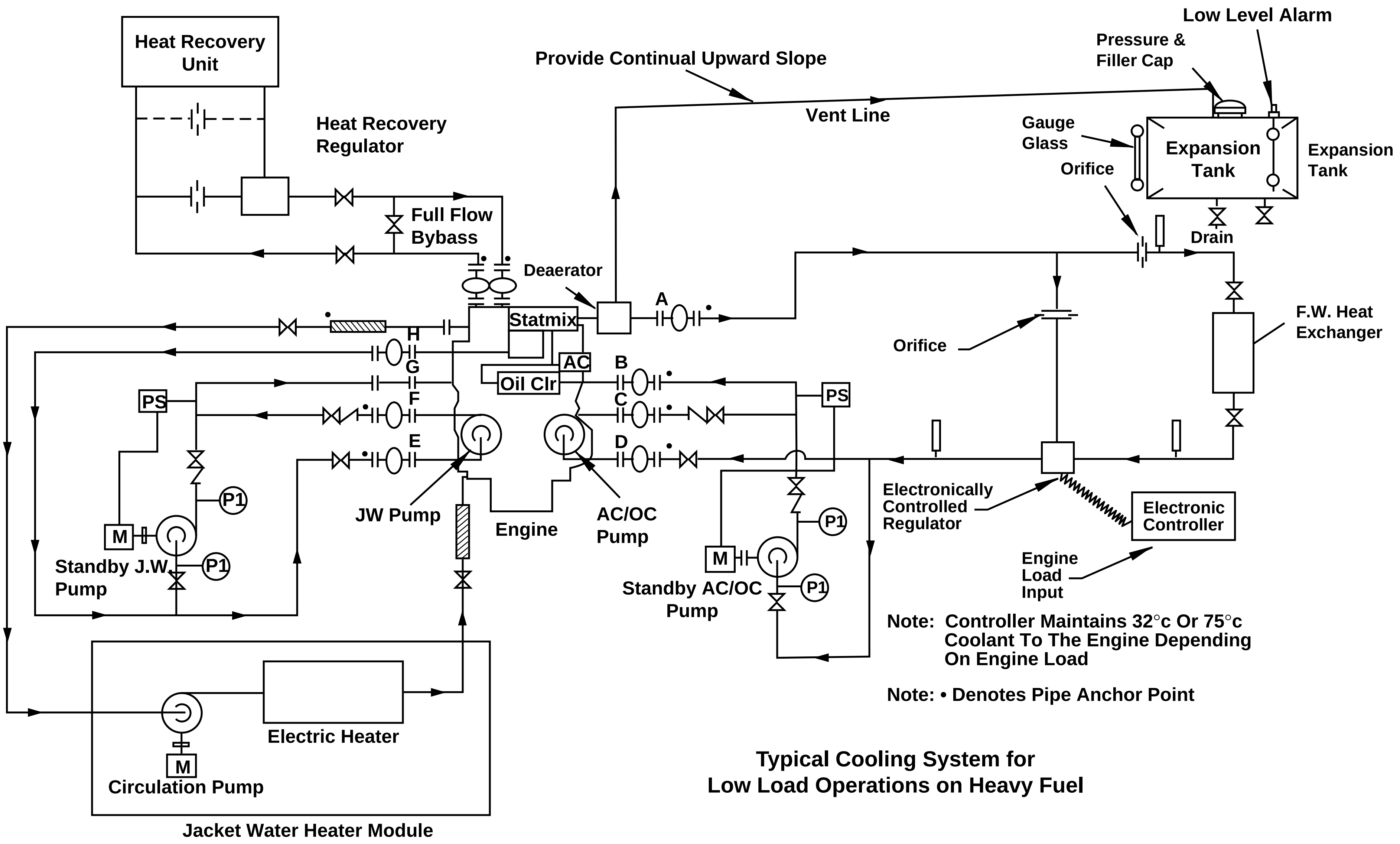
Note: • Denotes Pipe Anchor Point

Typical Cooling System

FLANGE TABLE

	WELD FLANGE I.D. - mm (in.)										
ENGINE	A	B	C	D	E	F	G	H	I	J	K
3606	143 (5.63)	110 (4.33)	110 (4.33)	171 (6.73)	171 (6.73)	110 (4.33)	110 (4.33)	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)
3608	143 (5.63)	110 (4.33)	110 (4.33)	171 (6.73)	171 (6.73)	110 (4.33)	110 (4.33)	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)
3612	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)
3616	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)

Figure 4



Note: Controller Maintains 32°c Or 75°c Coolant To The Engine Depending On Engine Load

Note: • Denotes Pipe Anchor Point

Typical Cooling System for
Low Load Operations on Heavy Fuel

FLANGE TABLE

	WELD FLANGE I.D. - MM (IN.)							
ENGINE	A	B	C	D	E	F	G	H
3606	143 (5.63)	110 (4.33)	110 (4.33)	171 (6.73)	171 (6.73)	110 (4.33)	110 (4.33)	143 (5.63)
3608	143 (5.63)	110 (4.33)	110 (4.33)	171 (6.73)	171 (6.73)	110 (4.33	110 (4.33)	143 (5.63)
3612	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)
3616	143 (5.63)	143 (5.63)	143 (5.63)	171 (6.73)	171 (6.73)	143 (5.63)	143 (5.63)	171 (6.73)

Figure 5

3600 Separate Circuit Cooling
Typical System Schematic

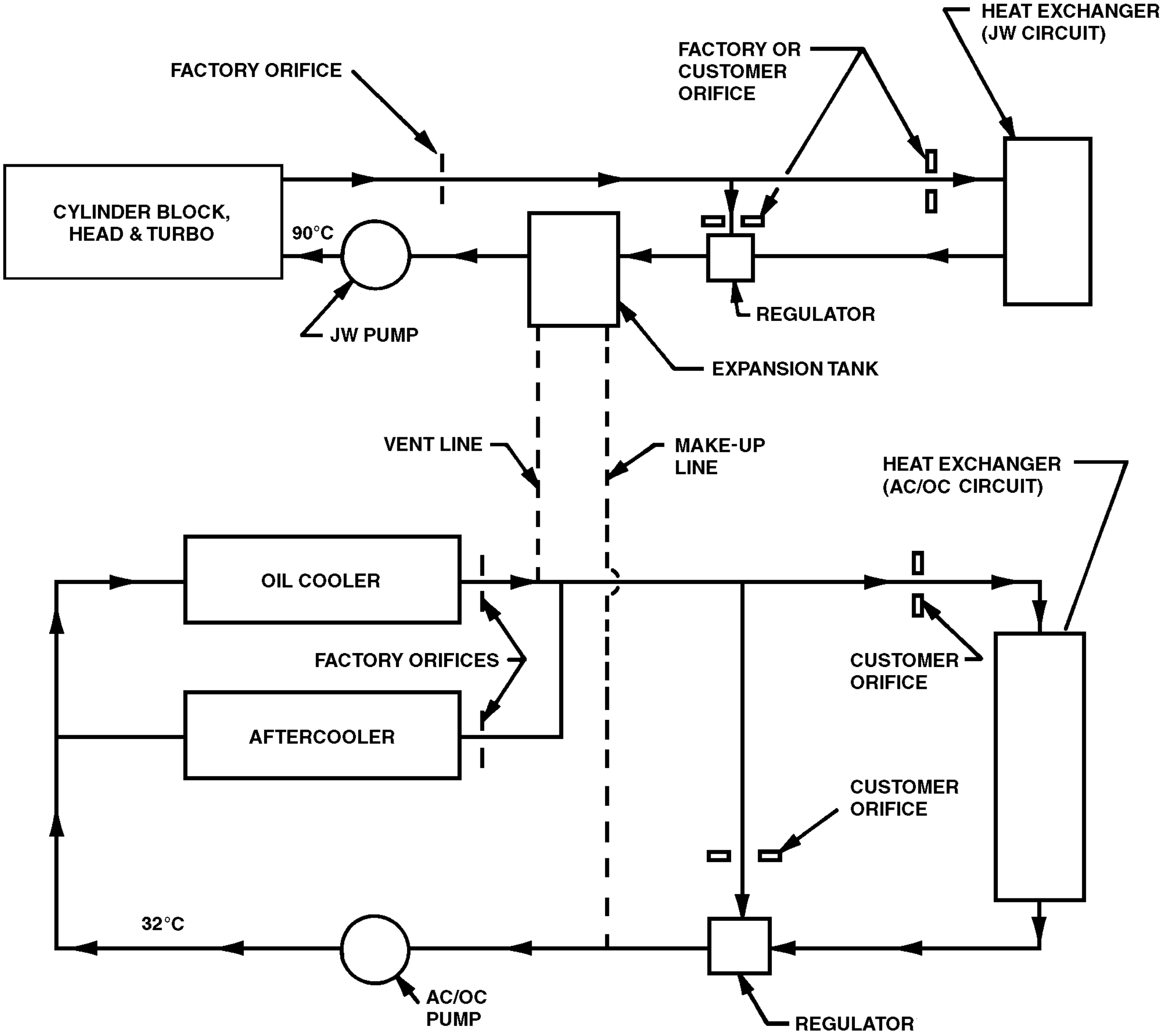
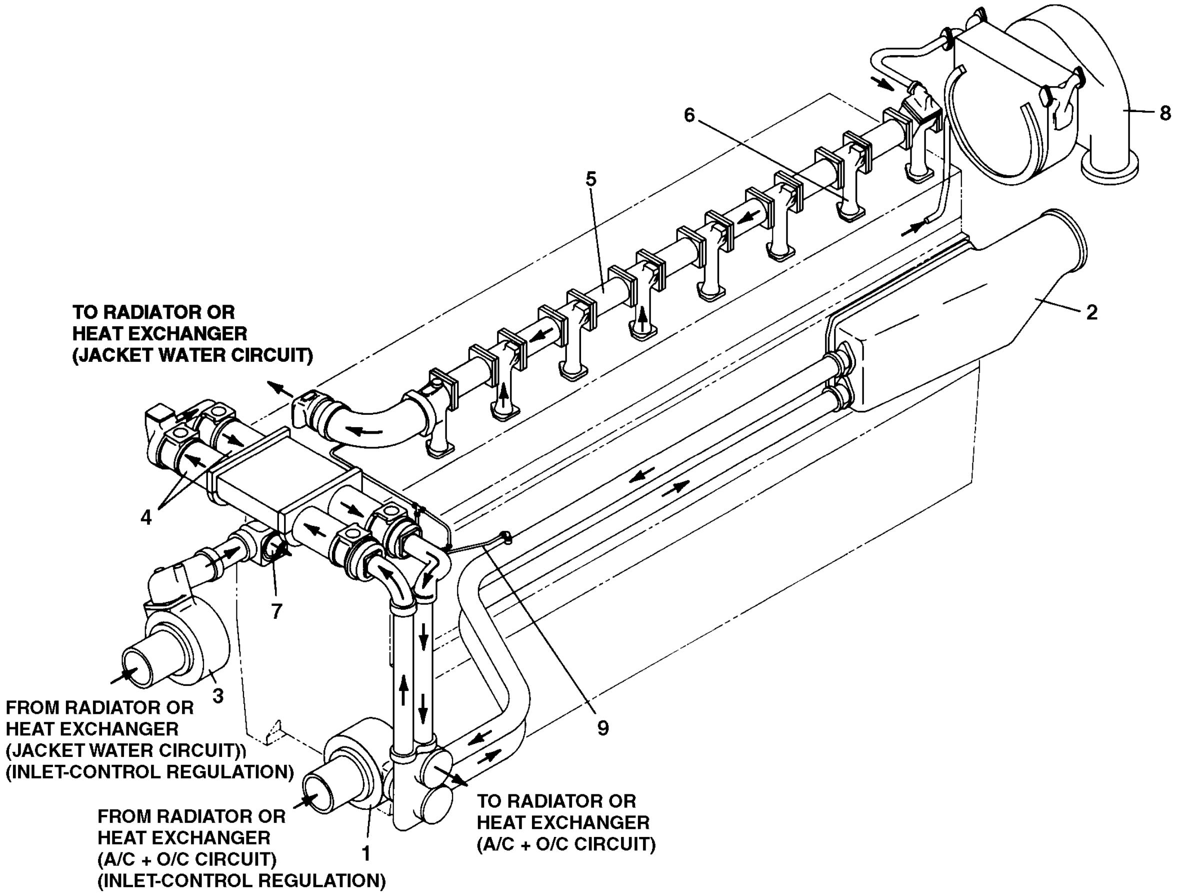


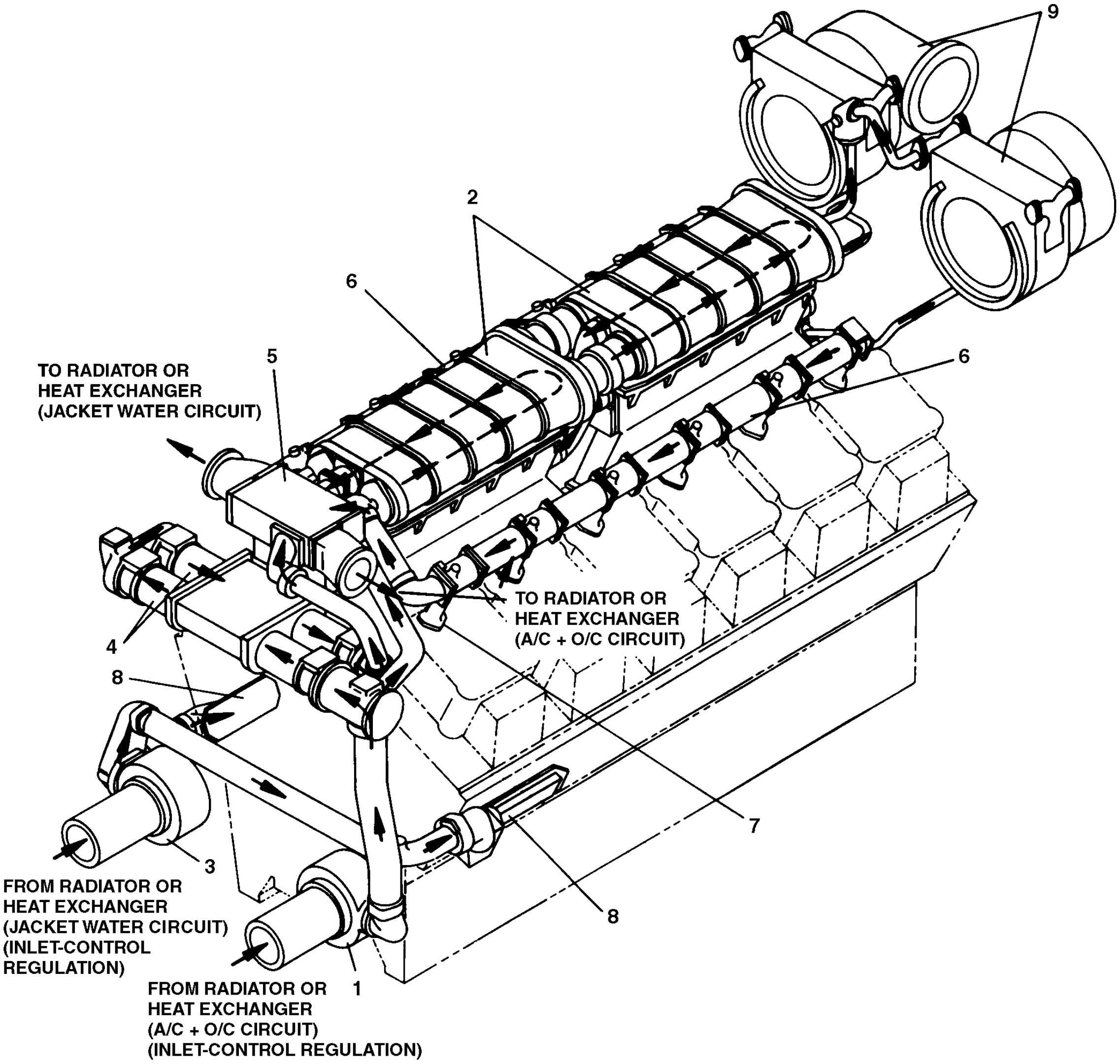
Figure 6



Typical 3606 and 3608
Separate Circuit Cooling Schematic

1. Aftercooler/Oil Cooler Pump
2. Aftercooler
3. Jacket Water Pump
4. Oil Coolers
5. Water Manifold
6. Water From Heads
7. Water To Block
8. Turbocharger
9. Vent Line

Figure 7



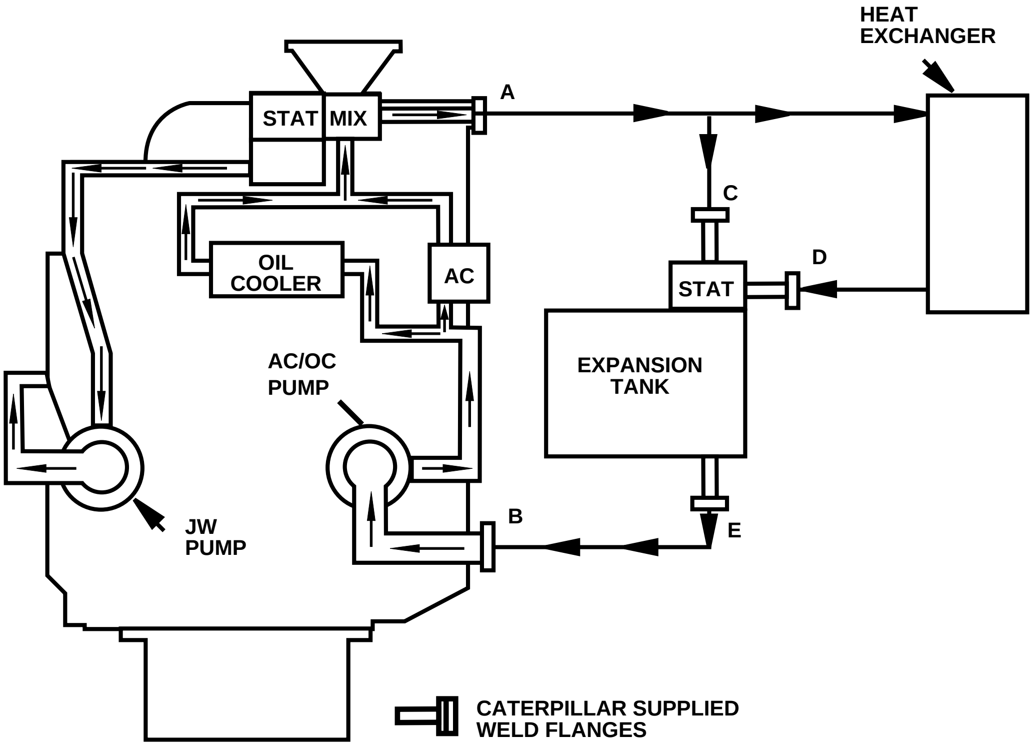
Typical 3612 and 3616
Separate Circuit Cooling Schematic

1. Aftercooler/Oil Cooler Pump
2. Aftercoolers
3. Jacket Water Pump
4. Oil Coolers (2) *
5. Outlet Housing
6. Water Manifold
7. Water From Heads
8. Water To Block
9. Turbochargers

* Three Coolers Required On Some Applications.

Figure 8

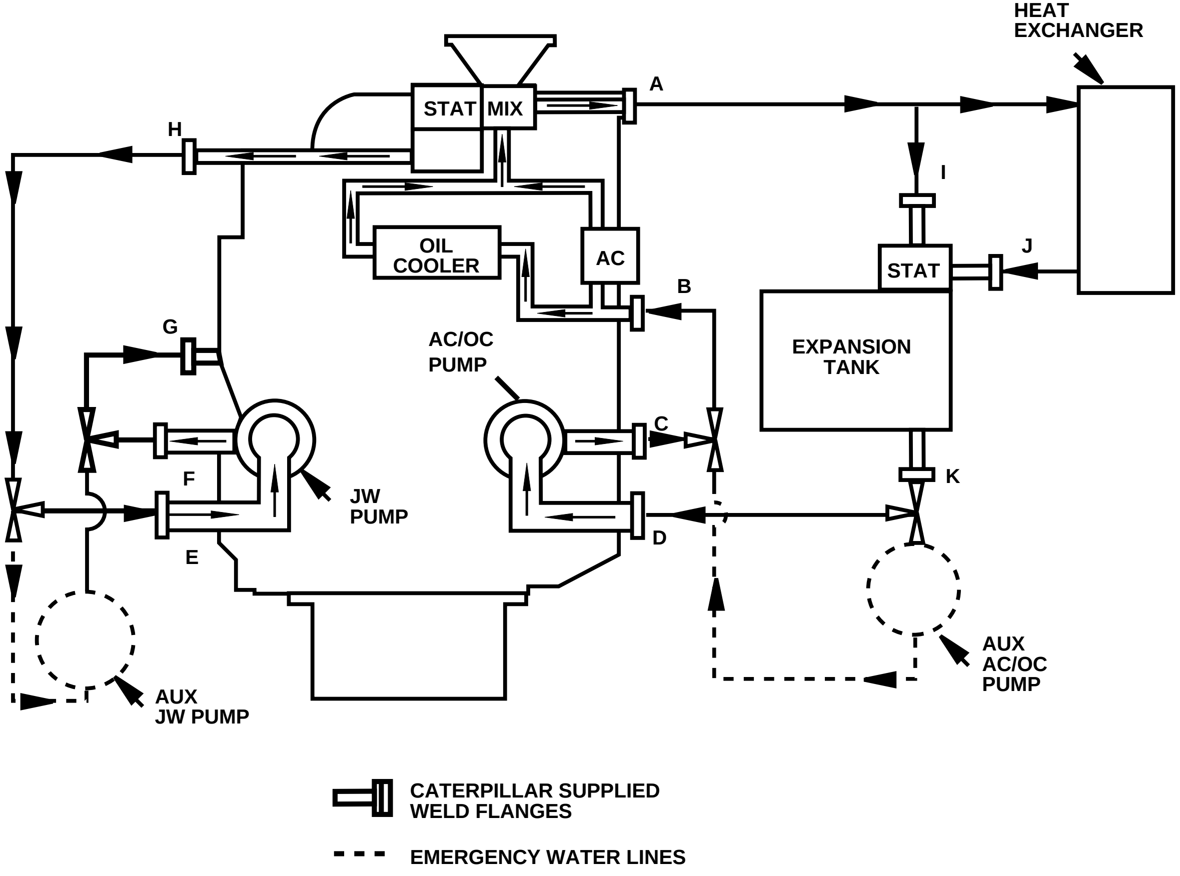
3600 Combined Circuit — Treated Water Cooling System
Customer Connections



Weld Flange ID — mm					
ENGINE	A	B	C	D	E
3606	143	171	143	143	171
3608	143	171	143	143	171
3612	143	171	143	143	171
3616	143	171	143	143	171

Figure 20

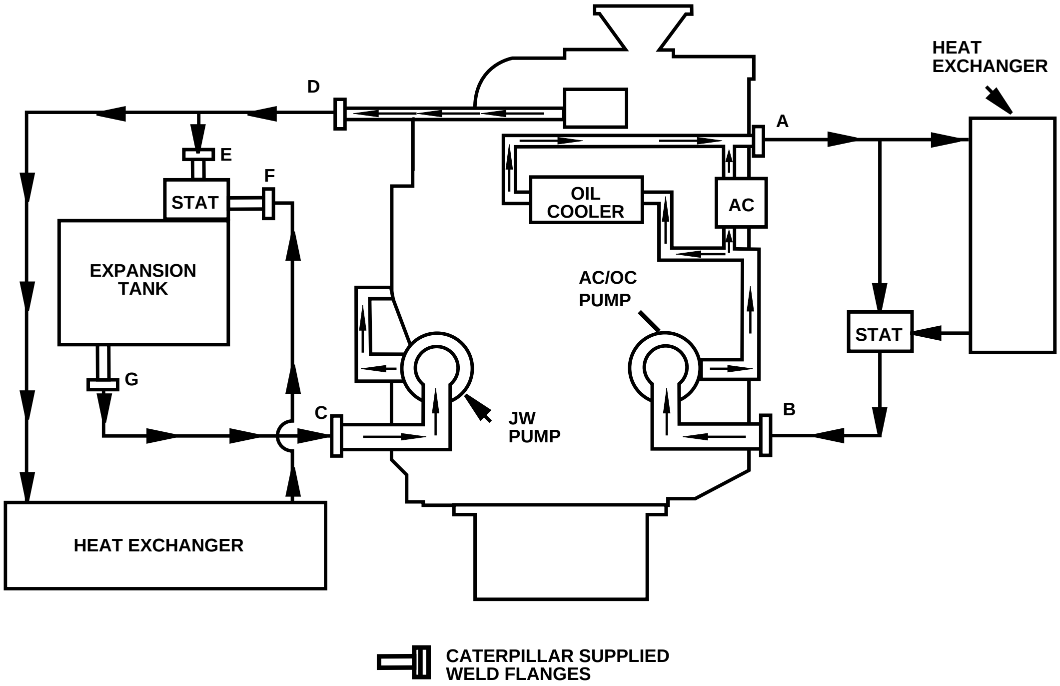
3600 Combined Circuit — Treated Water Cooling System with Auxiliary Pumps Customer Connections



Weld Flange ID — mm											
ENGINE	A	B	C	D	E	F	G	H	I	J	K
3606	143	110	110	171	171	110	110	143	143	143	171
3608	143	110	110	171	171	110	110	143	143	143	171
3612	143	143	143	171	171	143	143	171	143	143	171
3616	143	143	143	171	171	143	143	171	143	143	171

Figure 21

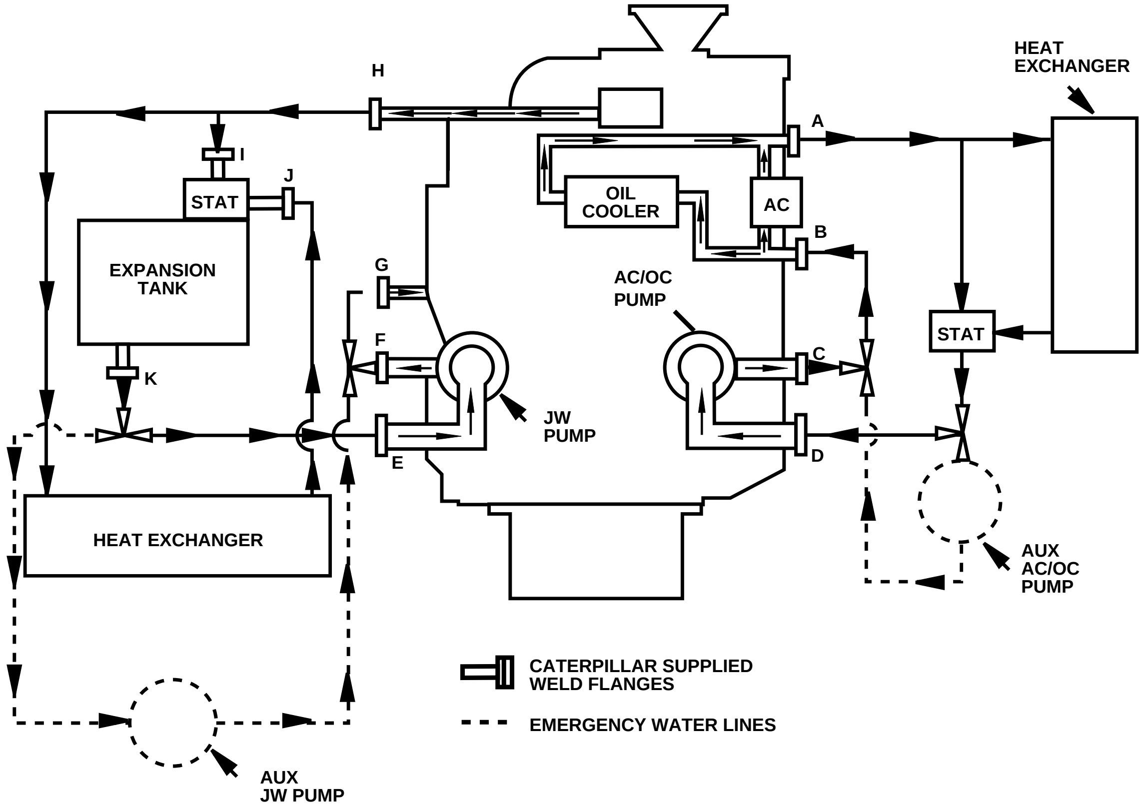
3600 Separate Circuit — Treated Water Cooling System Customer Connections



Weld Flange - mm							
Engine	A	B	C	D	E	F	G
3606	110	171	171	171	143	143	171
3608	110	171	171	171	143	143	171
3612	143	171	171	171	143	143	171
3616	143	171	171	171	143	143	171

Figure 22

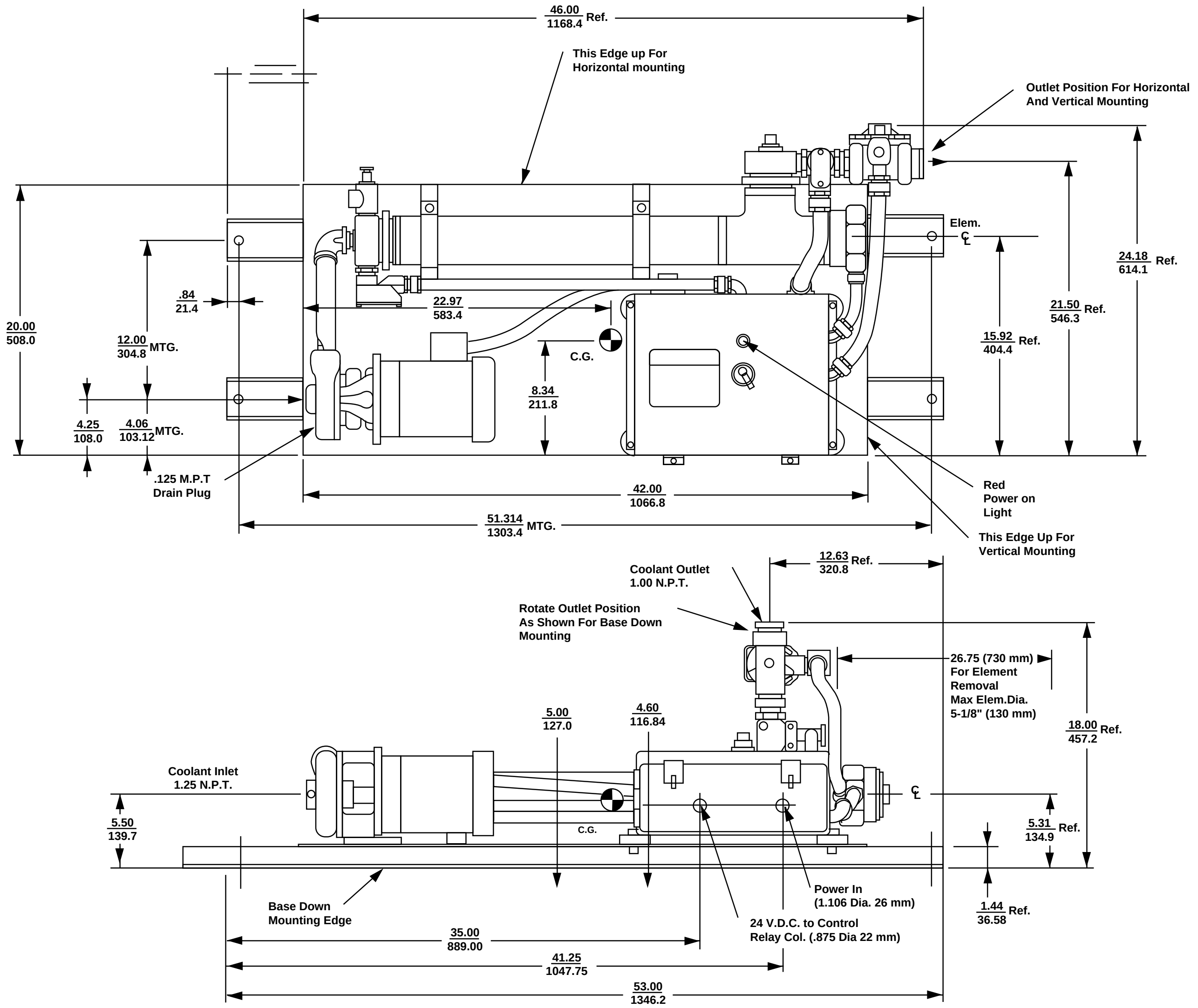
3600 Separate Circuit — Treated Water Cooling System With Auxiliary Pumps Customer Connections

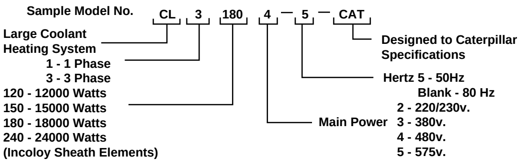


Weld Flange ID - mm

Engine	A	B	C	D	E	F	G	H	I	J	K
3606	110	110	110	171	171	110	110	143	143	143	171
3608	110	110	110	171	171	110	110	143	143	143	171
3612	143	143	143	171	171	143	143	143	143	143	171
3616	143	143	143	171	171	143	143	143	143	143	171

Figure 23





NOTES:

1. THE HEATING SYSTEM MUST BE MOUNTED IN THE PROPER POSITION TO ENSURE COMPLETE FILLING OF THE HEATING TANK. THE OUTLET MUST ALWAYS BE AT THE HIGHEST POINT OF THE INSTALLED SYSTEM. IF THE HEATING TANK IS NOT COMPLETELY FULL, PREMATURE ELEMENT FAILURE MAY RESULT.

2. COOLANT PUMP SUPPLY LINE MUST BE 1.25 NPT MIN.

PUMPING SPECIFICATIONS:

WARM WATER	LP.M. (GPM)	(HEAD IN METERS (FT)
15.6°C (50°F) 62M (25') SUCTION LIFT	0 (0)	195.7 (60)
26.6°C (80°F) 65.6M (20') SUCTION LIFT	37.8 (10)	180 (55)
37.8°C (100°F) 52.5M (16') SUCTION LIFT	75.7 (20)	147.5 (45)
48.9°C (120°F) 36.1M (11') SUCTION LIFT	113 (30)	131 (40)
60°C (140°F) 19.7M (6') SUCTION LIFT	151 (40)	98.4 (30)
82.2°C (180°F) 13.1M (4') POSITIVE SUCT.	169 (50)	85.6 (20)

3. THE COOLANT PRESSURE RELIEF VALVE IS ADJUSTABLE FROM 3.6-25.4 kPa COMPLETELY FULL, PREMATURE ELEMENT MAY RESULT. (25-175 P.S.I.) AND IS PRE-SET TO RELIEVE AT 10.9 kPa (75 P.S.I.) AND HAS AN .75 NPT OUTLET.

4. TOTAL SYSTEM WEIGHT 130 Kg (266 LBS.)

5. DIMENSIONS SHOWN AS $\frac{\text{INCHES}}{\text{mm}}$

KIM HOTSTART MFG. SPOKANE WA.

PROPRIETARY INFORMATION

Typical Jacket Water Heating System

Figure 24

3600 Combined Circuit Heat Recovery System
With Heat Recovery on Jacket Water Circuit

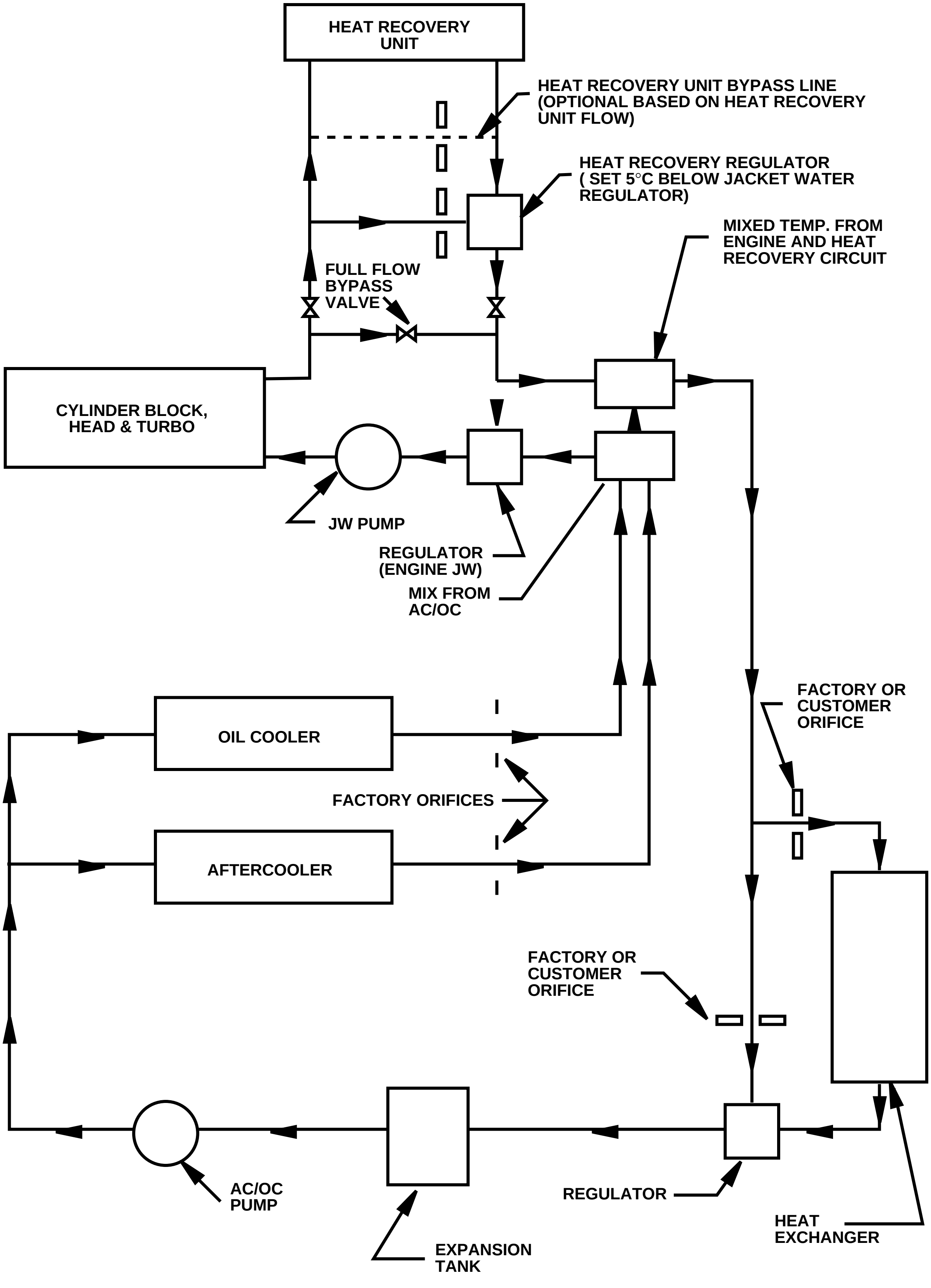


Figure 28

3600 Separate Circuit Heat Recovery System
With Heat Recovery on Jacket Water Circuit

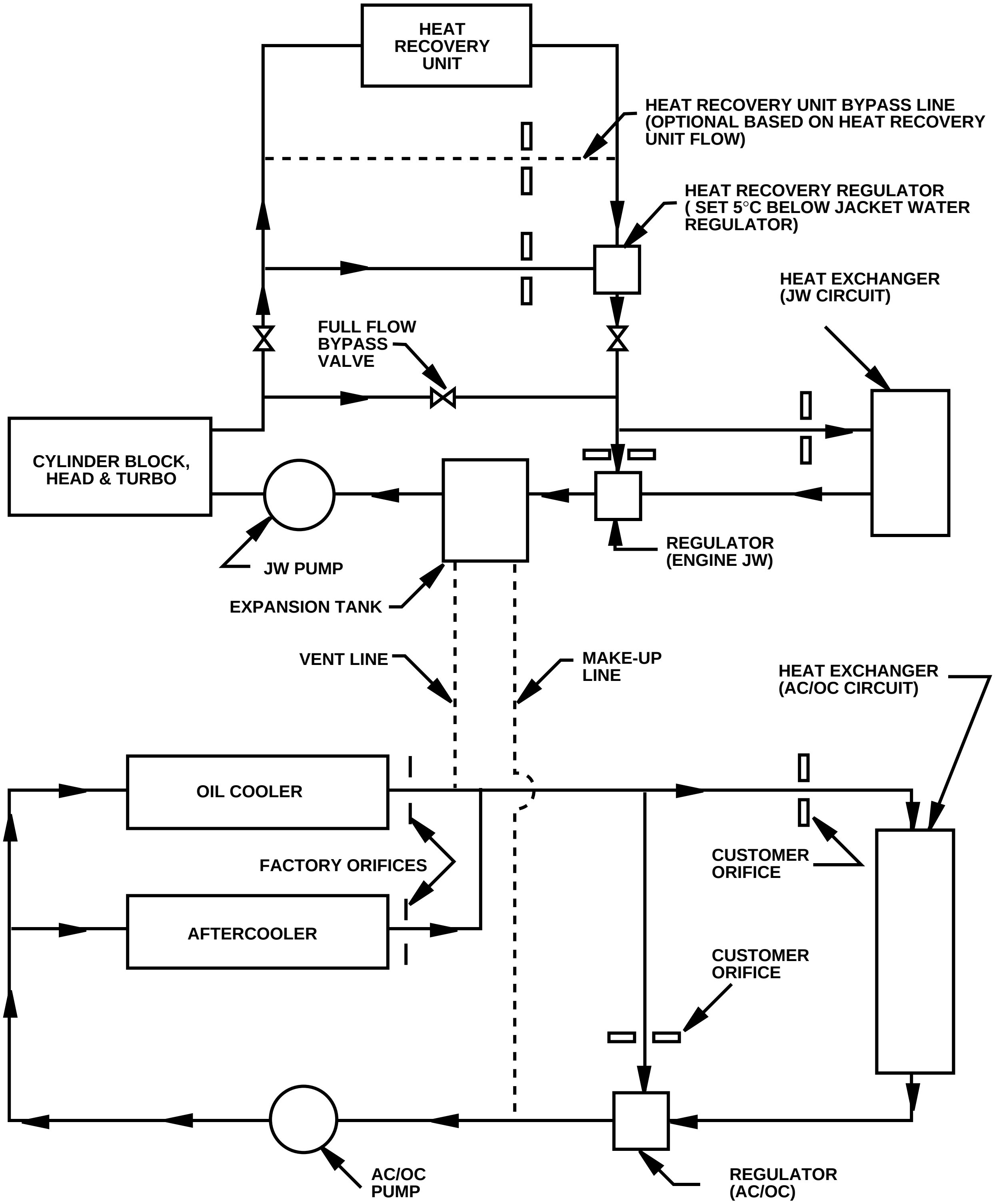


Figure 29