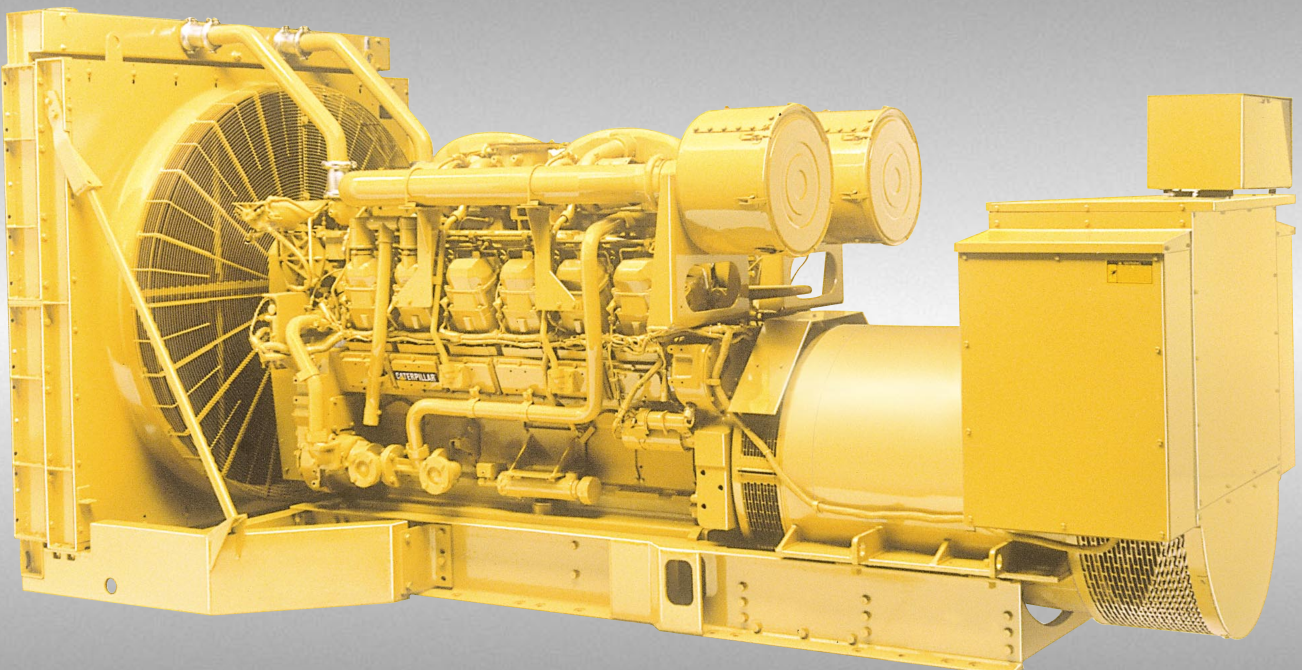
CATERPILLAR®

Generator Set Installation Fundamentals



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Product Information

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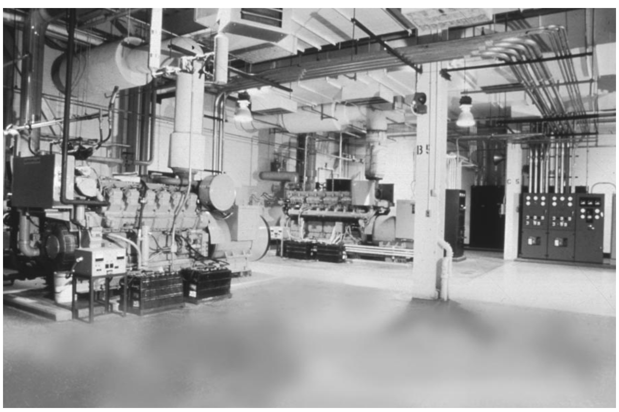
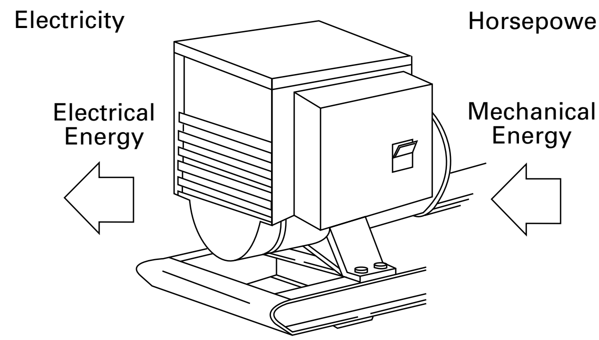
GENERATOR SET INSTALLATION FUNDAMENTALS

Proper generator set installation is crucial to ensuring the efficient, long, and dependable life of a system, as well as minimizing time spent on maintenance. System planning is the first step in achieving Cat performance and reliability. A system installation plan must address the product selected and the environment in which the product will operate. Before discussing installation, however, let's review some electrical power generation basics.



- **A generator set transforms chemical energy into electrical energy and heat.**
  - The engine converts an air-fuel mixture (chemical energy) into mechanical energy or power.
  - The generator then takes power from the engine and converts it into electrical energy kilowatts (kW).



Primary generator set systems and installation issues include:

- **Foundations**
- **Noise**
- **Air requirements**
- **Exhaust**
- **Emissions**
- **Cooling**
- **Heat recovery**
- **Fuel system**
- **Starting**
- **Engine governors**
- **Servicing**

FOUNDATIONS

Several basic foundations are suitable for generator sets. The foundation chosen will depend on the unit selected, as well as limitations imposed by the specific location and application.

Generator set foundations must:

- **Support** total wet weight of generator set, which includes accessory equipment and liquids (coolant, oil, and fuel)

- **Maintain alignment** between engine, generator, and accessory equipment
- **Isolate vibrations** of generator set from surrounding structures

Support

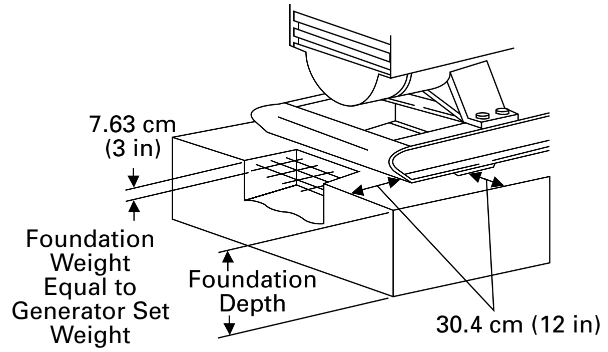
Mounting Surfaces

- Firm, level soil, gravel, or rock provides satisfactory support for single-bearing generator sets used in stationary or portable service. This support can be used where the weight-bearing capacity of the supporting material exceeds pressure exerted by the equipment package, and where alignment with external machinery is unimportant.
- Soil, such as fine clay, loose sand, or sand near the ground water level, is particularly unstable under dynamic loads and requires substantially larger foundations. Information concerning bearing capacity of soils at the site may be available from local sources and must comply with local building codes.
- Where support rails or mounting feet have insufficient bearing area, flotation pads can distribute the weight. The underside area and stiffness of the pad must be sufficient to support the equipment.
- Seasonal and weather changes adversely affect mounting surfaces. Soil changes considerably while freezing and thawing. To avoid movement from seasonal changes, extend foundations below the frost line.

Concrete Foundations

Massive concrete foundations are unnecessary for modern, multi-cylinder, medium-speed generator sets. Avoid excessively thick, heavy bases to minimize subfloor or soil loading. Bases should be only thick enough to prevent deflection and torque reaction, while retaining sufficient surface area for support.

CONCRETE FOUNDATION



FOUNDATIONS

Using Concrete Foundations

If a concrete foundation is required, minimum design guidelines are:

- Strength must support wet weight of units plus dynamic loads.
- Outside dimensions must exceed that of the generator set by a minimum of 1 ft (304.8 mm) on all sides.
- Depth must be sufficient to attain a minimum weight equal to generator set wet weight (if inertia block is specified for vibration control).

Foundation Design

- When effective vibration isolation equipment is used, floor concrete must only be deep enough to provide structural support of the static load.
- If isolators are not used, dynamic loads transmit to the facility floor and require it to support 125 percent of the generator wet weight.
- If generator sets are paralleled, possible out-of-phase paralleling and resulting torque reactions demand foundations that are able to withstand twice the wet weight of the generator set.

Estimate foundation depth that will accommodate generator set weight using the formula:

$$FD = \frac{W}{D \times B \times L}$$

FD = foundation depth in meters (feet)
W = total weight of generator set in kilograms (pounds)
D = density of concrete in kg/m^3 (lb/ft^3) (2402.8 kg/m^3, 150 lb/ft^3)
B = foundation width in meters (feet)
L = foundation length in meters (feet)

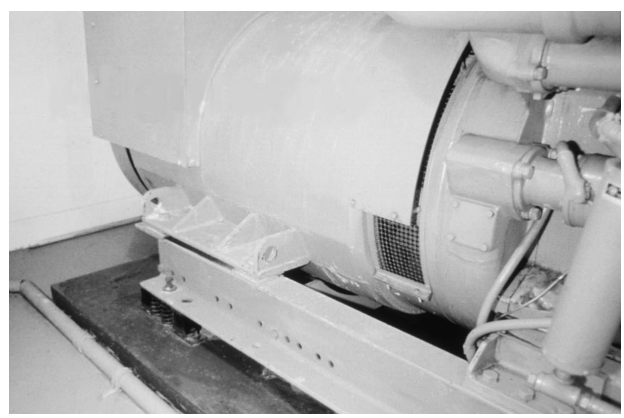
Bases

There are important factors to consider when selecting the type of base to be used because the different types of bases are designed to accommodate various needs.

Fabricated Bases

Engines with close-coupled, single-bearing generators maintain alignment by mounting rails or modest bases. They are commonly supported by fabricated bases. These bases are used to provide:

- Ease of relocation
- Ease of installation
- Isolation from a flexing foundation

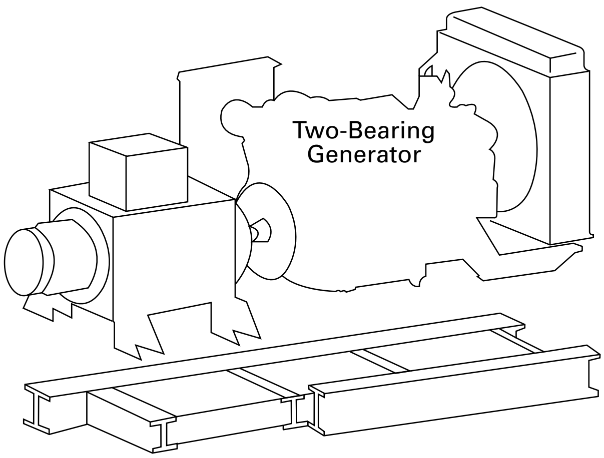


Heavy-Duty Fabricated Base

Two-bearing generators, generators driven from either end of the engine, tandem generators, or tandem engines require substantial boxed bases. They must incorporate sufficient strength and rigidity to:

- Resist outside bending forces imposed on the engine block, couplings, and generator frame during transportation
- Limit torsional and bending movement caused by torque reactions
- Prevent resonant vibration
- Provide alignment

FOUNDATIONS

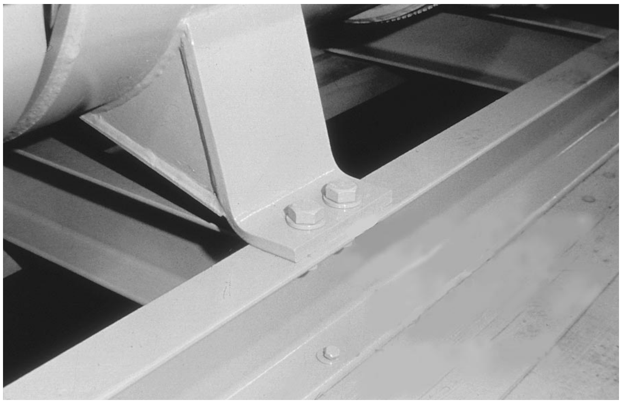


Structurally Rigid Base

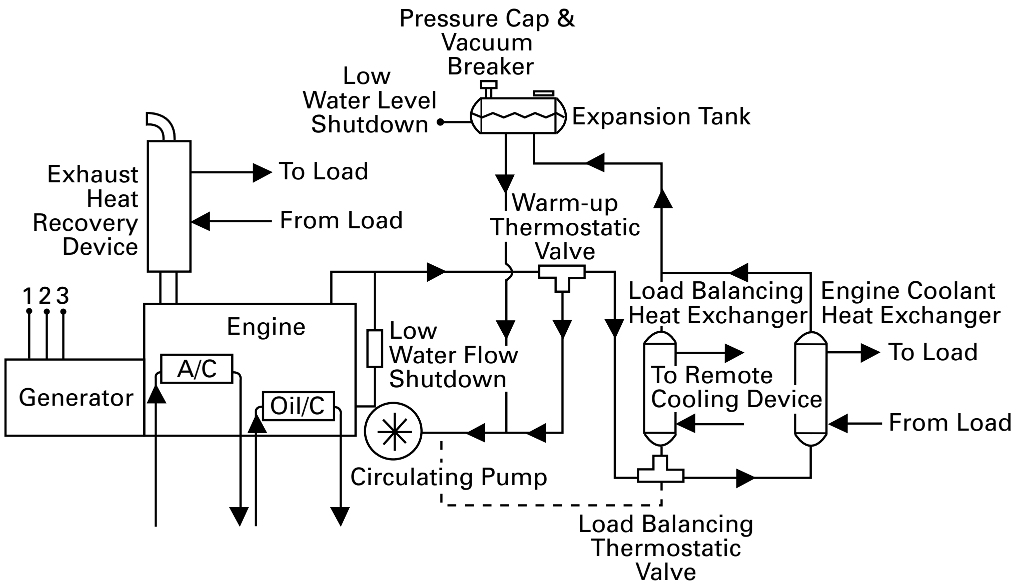
Thermal Expansion

Due to thermal expansion, engines may lengthen 2.3 mm (0.09 in) from cold to operating temperature. This growth must not be restrained.

- On single-bearing and most two-bearing generators, no close clearance dowels or ground body bolts may be used to limit thermal growth.
- For single-bearing generators requiring extremely close alignment, use a ground body bolt at the flywheel end on one side of the engine. No other restraint is permitted.
- Mounting feet of two-bearing generators can be doweled without harm. Slight expansion within the generator is absorbed in the generator coupling.

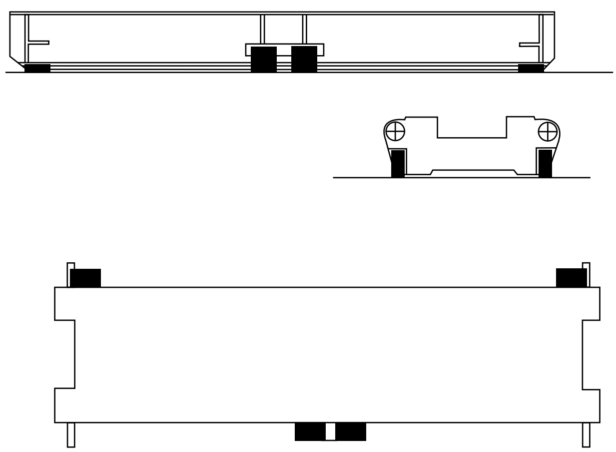


HIGH TEMPERATURE WATER SYSTEM



FOUNDATIONS

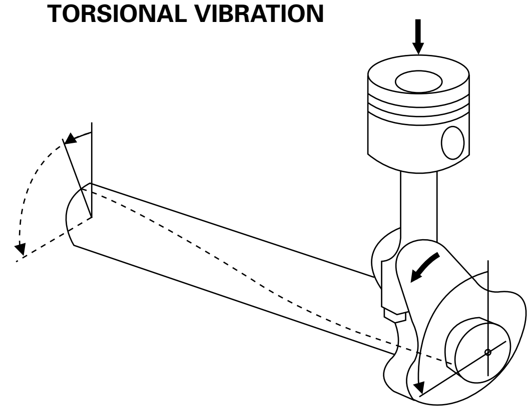
Three-point Suspension
On a long train of equipment such as a tandem arrangement, a very rigid steel base with a three-point suspension is recommended. The three-point suspension ensures uniform support and factory alignment, even on an uneven surface.



Vibration

Reciprocating engines will vibrate. Whether slight or severe, the vibration will be perceptable either as noise, a vibration, or both. Sometimes the vibration will be intense enough to be detrimental to the engine itself, to ancillary equipment and/or to the actual building.

TORSIONAL VIBRATION



Engine vibrations are produced and maintained by regular, periodic driving forces set up by unbalanced moving masses. These are called **forced vibrations**.

Free vibrations have no driving force. When set in motion such vibrations, if undamped, would continue indefinitely with constant amplitude and natural frequency.

If the frequency of a forced vibration is the same as the natural frequency of free vibrations, excessive vibration results. This is called **resonance** and can cause serious problems.

FOUNDATIONS

Engine vibration may be of the following types and causes:

1. Linear vibration — vertical and/or horizontal inertia forces due to lack of balance in reciprocating or rotating machinery.
2. Torque reaction — not a vibratory force, but may excite vibration.
3. Torsional vibration of shafting — occurs in any rotating mass elastic system (two or more masses connected by an elastic shaft) where periodic forces are present. Where these forces recur near the natural frequency of torsional vibration, resonance may develop and cause dangerous stress.
4. Axial vibration of shafting — when torques are applied to a crankshaft, it is alternately shortened and lengthened. This could be troublesome if the natural axial frequency is near a torsional frequency.

When an engine and generator are to be assembled to each other, vibration studies and tests must be completed to assure satisfactory, trouble-free operation on the job site. With factory assembled generator sets, the responsibility is assumed by the manufacturer. In any case, wherever assembly takes place, someone must assure the integrity of the installation from a vibration standpoint.

Vibration Isolation

Generator sets need no isolation for protection from self-induced vibrations. However, isolation is required if:

1. Engine vibration must be separated from building structures
2. Vibrations from nearby equipment are transmitted to inoperative generator sets
3. System is supported on a flexible mounting surface, such as a trailer bed

Vibration isolators prevent the transmission of possibly damaging generator set vibration throughout a building. Noise is also reduced.

Generator Set Protection

Running units are rarely affected by exterior vibrations. Methods of isolation are the same for external or self-generated vibrations.
If an **idle engine** is located near heavy reciprocating equipment, vibration isolation must be specified to protect the idle engine. If subjected to repeated shocks or vibrations when idle, damage to the bearings, gears, etc. may result. This occurs because the protections provided by the lubricating oil are not available.

Another application requiring generator set protection involves **mobile units**. Isolation from a movable platform is desirable to:

- Reduce vibration
- Reduce noise
- Prevent torque loading on generator sets from flexing platforms or trailer beds
- Avoid bending of the generator set by movement of the sub-base

FOUNDATIONS

Vibration carried throughout an enclosure causes early failure of auxiliary equipment. Relays, switches, gauges, and piping are adversely affected.

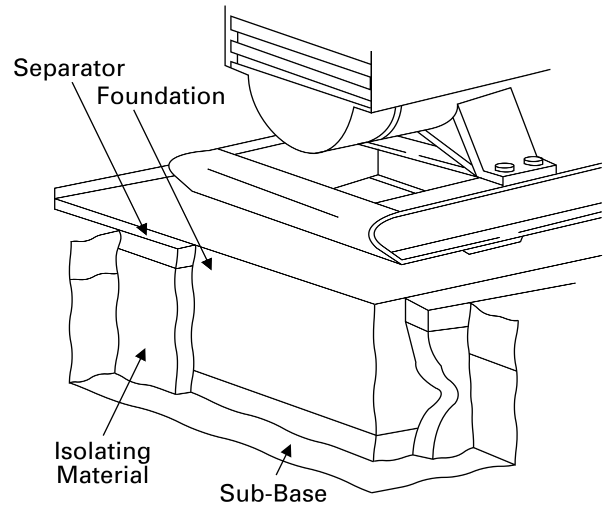
No Isolation Application

If no isolation is required, the generator set may rest directly on the mounting surface. Factory assembled units are dynamically balanced and theoretically there is no dynamic load. However, the surface must support 25 percent more than the static weight of the unit to withstand the torque and vibratory loads resulting from combustion forces and assembly tolerances. Unless the engine is a mobile unit or driving equipment which imposes side loads, no anchor bolting is required. Thin rubber or composition pads minimize the unit's tendency to creep or fret foundation surfaces.

Both bulk and fabricated isolators utilize static deflection. A basic vibration chart will describe the general effect deflection has on isolation. By using engine rpm as the nominal vibration frequency, magnitude of compression on isolating materials can be estimated.

Bulk Isolators

Bulk isolating materials are used between the foundations and supporting surface, but are not as foolproof as commercial types.



INERTIA BLOCK

Gravel or sand:

- Isolation of block foundations may be accomplished by 200 to 250 mm (8 to 10 in) in the bed of the foundation pit
- Can reduce engine vibration one-third to one-half

Note: The isolating value of gravel is somewhat greater than sand.

How they're used:

1. To minimize settling of the foundation, gravel or sand should be thoroughly tamped before pouring the concrete block.
2. The foundation pit should be made slightly longer and wider than the foundation block base.
3. A wooden form the size and shape of the foundation is placed on the gravel or sand bed for pouring the concrete.
4. After the form is removed, the isolating material is placed around foundation sides, completely isolating the foundation from surrounding earth.

FOUNDATIONS

Rubber, asphalt-impregnated felt, and fiberglass:
- Can also be used to isolate foundation block from subsoil
- Do not provide significant low frequency isolation

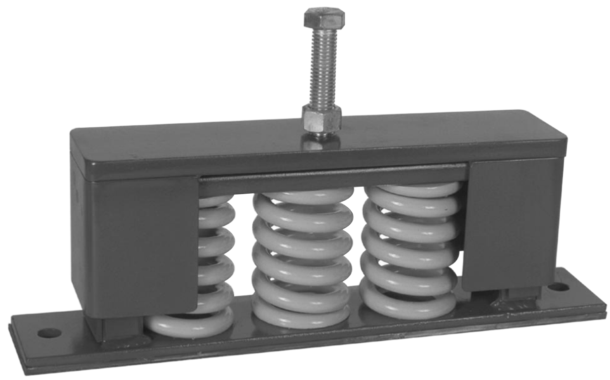
Cork:
- Is not effective with disturbing frequencies below 1800 cps
- If not kept dry, will rot
- Is seldom used with modern generator sets, but is used to separate engine foundations and surrounding floor because of resistance to oils, acids, or temperature changes between -18° and 93° C (0° and 200° F)

Commercial (Fabricated) Isolators

Several commercial isolators provide various degrees of isolation. Generally, the lower the natural frequency of the isolator, the greater the deflection and more effective the isolation. Weight of generator sets can be unequally balanced within the limits of the isolators. However, overloading will eliminate isolator benefits.

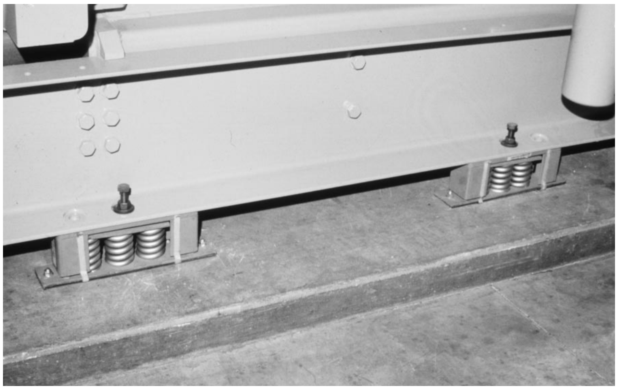
Rubber isolators:
- Are adequate for applications where vibration control is not severe
- Provide 90 percent isolation with careful selection
- Isolate noise created by transmission of vibratory forces
- Should not to be used with natural frequencies near engine exciting frequencies

Spring Isolators:
- Are the most effective isolator design, isolating over 96 percent of all vibrations
- Provide overall economy
- Permit mounting the generator set on a surface required to support only the static load



- As with direct mountings, no anchor bolting is usually required; however, when operating in parallel, vertical restraints are recommended
- Are available with snubbers for use when engines are side loaded or located on moving surfaces

Adding rubber plates beneath spring isolators blocks high frequency vibrations transmitted through the spring. These vibrations are not harmful but cause annoying noise.



FOUNDATIONS

Isolator Application

Commercial isolators are most effective when located under the generator mounting and engine front support.

To apply isolators, wet weight and center of gravity of the assembled unit must be established. Assuming engine and generator are assembled to a base, wet weight (WT) and assembled center of gravity can be calculated. A common reference is needed, usually the rear face of the flywheel housing. Because measurements are to both sides of the reference, one direction can be considered negative.

$$Wt(D) = We(D2) - Wg(D1) + Wr(D3)$$

$$D = \frac{We(D2) - Wg(D1) + Wr(D3)}{Wt}$$

where:

wet weight of:	distance from rear face block to C/G of:
Generator Set, Wt	D
Generator, Wg	D1
Engine, We	D2
Radiator, Wr	D3

If additional equipment is added, the process is repeated to determine a new center of gravity.

Having established the center of gravity for the total unit, loading on each pair of isolators (assuming two on each side) is determined by:

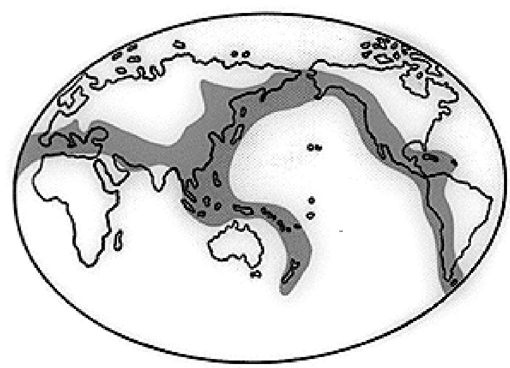
$$S1 = Wt \frac{B}{C} \qquad S2 = Wt \frac{A}{C}$$

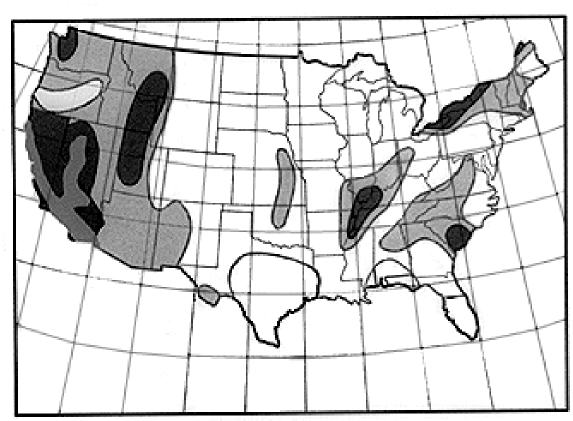
where:

A = distance from rear isolator to gen set C/G
B = distance from front isolator to gen set C/G
C = distance between front and rear isolators
S = load on each pair of isolators

Isolators are sized to have natural frequencies far removed from engine exciting frequencies. If these frequencies were similar, the entire unit would resonate. A vibration transmissibility chart depicts this condition, and also shows the significant improvement caused by decreasing the mounting natural frequency to allow a ratio increase above square root of 2, or 1.414.

Seismic Vibration





SEISMIC AREAS

- Zone 0 — no significant damage
- Zone 1 — minor damage
- Zone 2 — moderate damage
- Zone 3 — major damage
- Zone 4 — major faults

FOUNDATIONS

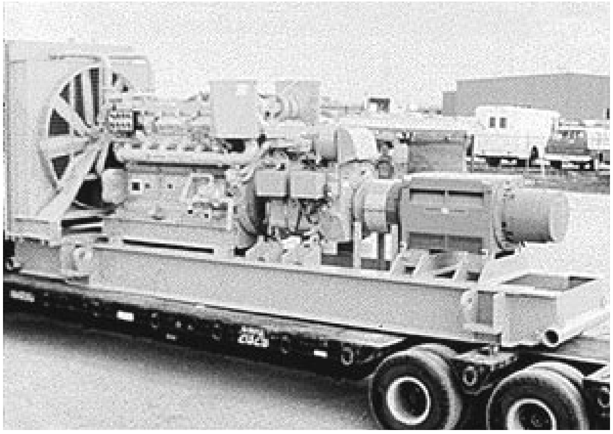
Seismic shocks are insufficient to harm generator sets resting on the floor. However, isolation devices, particularly spring isolators, amplify small movement generated by earthquakes to levels which would damage equipment. Special isolators incorporating seismic restraining or damping devices are available, but exact requirements must be reviewed by the isolator supplier. Isolators anticipating seismic shock are bolted to the equipment base and the floor. Positive stops are added to limit motion in all directions. Attached piping and auxiliary equipment supports must also tolerate relative movement.

Trailer Units

Lateral movement of the generator set must be minimized as the trailer is transported. This can be achieved simply by:

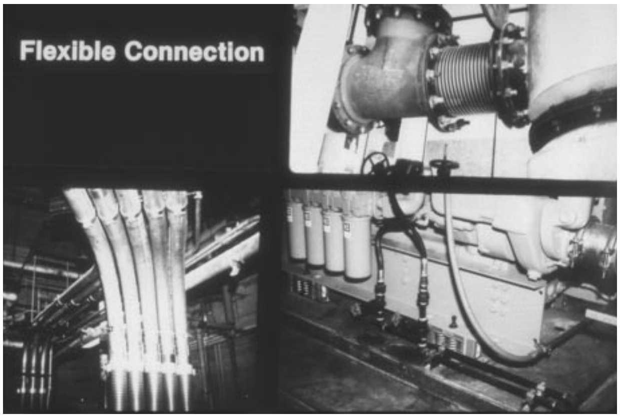
- Blocking the unit off the isolators during the move
- Using snubbers to confine vertical and horizontal movement

A spring-type isolator with the addition of thrust blocks will restrict lateral movement without interfering with spring function.



External Isolation

Piping connected to generator sets requires isolation, particularly when generator sets are mounted on spring isolators. Fuel and water lines, exhaust pipes, and conduit could otherwise transmit vibrations long distances.



- Isolator pipe hangers, if used, should have springs to attenuate low frequencies, and rubber or cork to minimize high frequency transmissions.
- To prevent buildup of resonant pipe vibrations, long support piping should run at unequal distances.

NOISE

Noise can be defined as all unwanted sounds. Noise can produce undesirable psychological effects on people and physical damage to the ears. Recognizing this, many governmental agencies around the world have established limits for various environments.

The physical effects of noise are measured by microphones that produce electrical signals directly proportional to sound pressures — the amplitude or strength of the sound pressure waves. This strength and the frequency of the waves are the only measurable properties of sound outside of the laboratory.

The human ear hears pressure levels that are about 100 000 times stronger than the lowest pressure it is actually affected by. For this reason, measuring instruments have extraordinary range and are scaled in decibels (dB). The decibel scale is logarithmic, which allows sound pressure to be measured in two- or three-digit numbers.

Sound Pressure Level (SPL) in dB =

$$20 \log_{10} \times \frac{\text{measured pressure}}{\text{reference pressure}}$$

The reference pressure is taken as: 20 µPa or 2×10^{-4} microbars = 0 dB.

The ear is more sensitive to high frequencies than low frequencies. To approximate the effect of sound on the average person, measurements are weighted according to frequencies corresponding to the sensitivity of the ear. The signal from the measuring microphone is fed to an amplifier, then to an attenuator, which is calibrated in decibels. The signal is then fed to one of four weighting networks, referred to as A, B, C, and D. The response of the network chosen modifies the input signal accordingly.

The most commonly used network is weighting A, and it is known as dB(A). It is often measured in relationship to time limit for exposure.

Permissible Noise Exposures

Duration of Daily Exposure (hours)	**Allowable Level** dB(A)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25	115

Noise Control

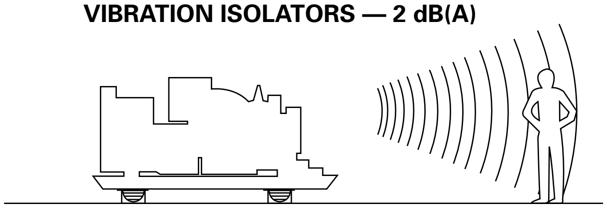
Mechanical

Many techniques for isolating generator set vibrations are applicable to mechanical noise isolation. Modest noise reductions result from attention to noise sources, i.e., reducing fan speeds, coating casting areas, and ducting air flows. But for attenuation over 10 dB(A), units must be totally isolated.

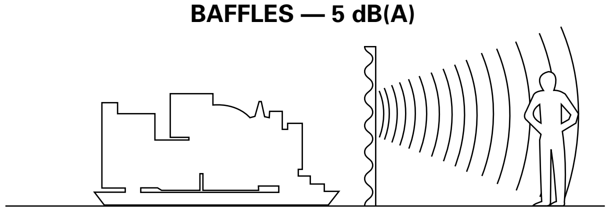
NOISE

A **2 dB(A) reduction** can be achieved by using vibration isolators under the generator set.

VIBRATION ISOLATORS — 2 dB(A)

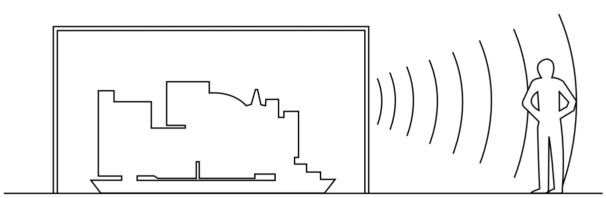


BAFFLES — 5 dB(A)

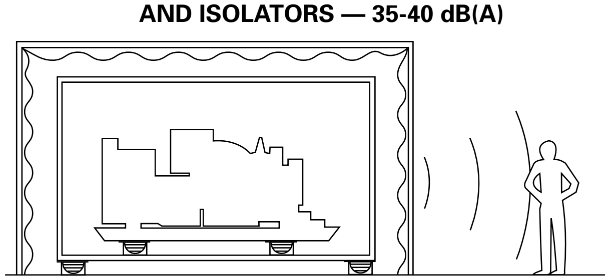


A **15 dB(A) reduction** is afforded with a rigid, sealed enclosure without openings; however, necessary openings for pipes, ventilation, and engine-driven radiator fans drastically reduce the degree of attenuation.

RIGID SEALED ENCLOSURE — 15-20 dB(A)



SOUND TREATED ENCLOSURES AND ISOLATORS — 35-40 dB(A)



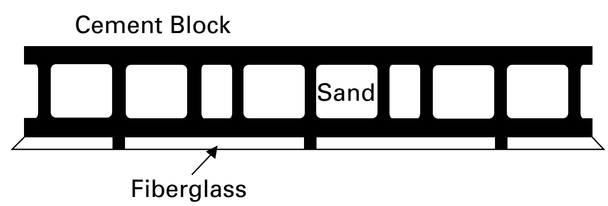
A **40 db(A) reduction** can result by using sealed, double-walled enclosures with absorption material and double mounting isolators.

Completely enclosed engines, however, are impractical due to openings required for pipes, ducts, and ventilation. Enclosures with numerous openings rarely attain over 20 dB(A) attenuation, even with double walls and isolators.

In an effort to achieve high attenuation, **radiator air flow** may be severely restricted. Reduced radiator cooling capabilities, however, should be anticipated.

A simple but effective method of reducing noise utilizes concrete blocks filled with sand to house the generator set. Materials with densities greater than 32 kg/m^3 (2 lb/ft^3) are good sound barriers. Filling voids with sand or even a thick coat of paint helps seal small cracks in the blocks and further reduces noise. However, the unit must also incorporate vibration isolation techniques.

ENGINE ROOM INSULATION



NOISE

Exhaust

Exhaust noise attenuation is commonly achieved with a silencer typically capable of reducing exhaust noise 15 dB(A) when measured 3.3 m (10 ft) perpendicular to the exhaust outlet. Because the number of cylinders and engine speeds create varied exhaust frequencies, specific effects of silencers must be predicted by the manufacturer.

Sound pressure level of site exhaust noise is determined by:

Sound Pressure Level, dB(A) =

Sound Pressure Level,
dB(A) - 10 x Log_{10} (3.1416 x CD^2)

where:

C = 2 for exhaust source adjacent to a flat surface, such as a horizontal exhaust pipe parallel to a flat roof

= 4 for exhaust source some distance from surrounding surfaces, such as a vertical exhaust stack some distance above a roof

D = Distance from exhaust noise source (m)

If the sound pressure level of a point source at some distance is known, the sound pressure level at a second distance can be calculated by:

$$SPL_2 = SPL_1 - 20 \times \log_{10} (D2/D1)$$

where:

SPL_1 = known sound pressure level, dB(A)
SPL_2 = desired sound pressure level, dB(A)
D1 = known distance, m (ft)
D2 = desired distance, m (ft)

AIR REQUIREMENTS

There are four air-related issues to consider in planning generator set installation.

- *Combustion air requirements*
- *Engine room ventilation*
- *Crankcase breathers*
- *Air filters*

Combustion Air Requirements

Diesel engines require approximately 0.09 m^3/min (3.2 cfm) of air per brake horsepower for combustion, or 17 lb of air for each pound of fuel. Volumetric (V) and mass (M) intake air flow have the following general relationships.

V (m^3/min) = .01486 x M (kg/hr)

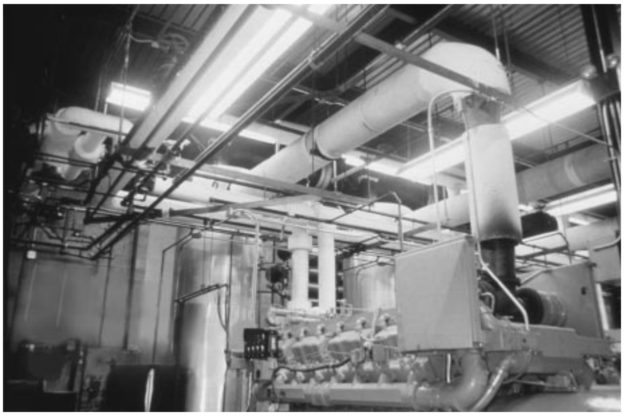
OR

V (cfm) = .2382 x M (lb/hr)

- Heavy fuel engines require about 40 percent greater inlet air flow than those burning distillate fuels.
- Gaseous fueled engines demand twice that of diesel.

Intake Location

Although normally obtained from air surrounding the engine, some circumstances require ducting combustion air from outside the engine room. This is particularly true in high altitude operations where light air densities are further affected by engine room temperatures.



- High intake air temperatures can adversely affect engine performance and raise exhaust temperatures, which may damage pistons, exhaust valves, and heads.
- Combustion air entering the engine air cleaners should ideally be less than 38° C (100° F).
- On some engine configurations, prolonged operation with extremely cold inlet air to the engine may require a boost control valve to limit intake air manifold pressure and resultant peak cylinder pressure.
- Cold air and altitudes above 2440 m (8000 ft) may cause overfueling when starting automatically, as some governors remain full open during acceleration to rated speed.

AIR REQUIREMENTS

Inlet Air Restriction

When ducting is necessary to obtain cooler or cleaner air, filters should remain on the engine. This prevents harmful dirt from leaking into ducting joints or remote filter housings.

- Fabricated ducting or fasteners such as rivets should not be used.
- Baffles incorporated in the duct prevent water from entering the engine.
- Design ducting to withstand a vacuum of 12.5 kPa (50 in. H_2O).
- If the filter must be remote mounted, piping at the turbocharger must encourage smooth air flow.

Filter Change	Duct Restriction (pipe size, # bends)	Filter Life
30"	2"	= 28"*
30"	15"	= 15"

*** 46% increased life**

- No duct weight should be imposed on the connection to the engine.
- Flexible connections are required to isolate engine vibration and noise from the ducting, and should be located as close as possible to the engine.
- Rubber flexible connections must be routed to avoid harmful heat from exhaust piping.
- Insulation can be used on inlet air ducting to reduce turbocharger noise and reduce heat transfer from the room to the combustion air.

Total inlet duct head loss (restriction) is generally less than 0.50 kPa (2 in. H_2O) column to maximize time between air filter replacements. As a general guide, ducting with a diameter equal to the standard air cleaner adapter can accommodate 7.6 m (25 ft) of straight pipe. Increasing this diameter 25.4 mm (1 in) will allow 19.8 m (65 ft) of straight pipe. Pipe bends are long radii, with flanged or welded joints to encourage low restriction. A flexible connection isolates engine vibration and noise, and allows easy filter servicing.

Saturated air with the dew point near freezing can cause icing and clogging of the air cleaner, with resulting performance loss. Procedures to avoid this condition include:

- Prewarming intake air
- Blow-in doors (with alarms) spring loaded to open at 12.5 kPa (50 in. H_2O) maximum
- Bypassing the cleaners (only in an emergency)

AIR REQUIREMENTS

Calculate duct head loss by:

$$P\ (\text{kPa}) = \frac{L \times S \times Q^2 \times 3.6 \times 10^6}{D^5}$$

$$P\ (\text{in. } H_2O) = \frac{L \times S \times Q^2}{187 \times D^5}$$

P = Restriction (kPa) (in. H_2O)
L = Length of pipe (m) (ft)
Q = Inlet air flow (m^3/min) (cfm)
D = Inside diameter of pipe (mm) (in)
in. H_2O = inches water column
kPa = 6.3246 x mm water column
psi = 0.0361 x inches water column

If duct is rectangular, $D = \frac{(2 \times a \times b)}{(a + b)}$

a and b = sides of duct (mm) (in)
S = Density of air (kg/m^3) (lb/ft^3)

$$S\ (kg/m^3) = \frac{352.05}{\text{Air Temperature} + 273.16^\circ\ C}$$

$$S\ (lb/ft^3) = \frac{39.6}{\text{Air Temperature} + 460^\circ\ F}$$

To obtain equivalent length of straight pipe for each long radius 90-degree bend:

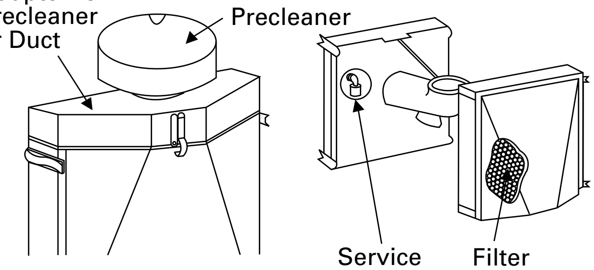
$L = 33 \times \frac{D}{X}$	**Standard Elbow (Radius equals pipe diameter)**
$L = 20 \times \frac{D}{X}$	**Long Elbow (Radius > 1.5 diameter)**
$L = 15 \times \frac{D}{X}$	**45-degree Elbow**
$L = 66 \times \frac{D}{X}$	**Square Elbow**
$L = 31$	**Flexible connection (1 = connector length)**

where X = 1000 mm or 12 in

The radius of 90-degree bends with radii 1-1/2 times the pipe diameter help to lower resistance.

Air Cleaners

Combustion air must be clean and cool. Engine-mounted, dry-type air cleaners are considerably more efficient than oil-bath types and remove 99.5 percent of AC fine dust.



- Clean filters offer little restriction so total air restriction, including ducting, should not exceed 1.2 kPa (5 in. H_2O) of water column.
- Air cleaner service indicators will signal a filter change when a restriction of 3.74 kPa (15 in. H_2O) develops.
- Ducting must have sufficient strength to withstand minimum restrictions of 12.5 kPa (50 in. H_2O), which is also the structural capability of the Caterpillar prime power air cleaner.

AC Dust (% total weight)

Micron Size	Fine	Coarse
0-5	39+/-2%	12+/-2%
5-10	18+/-3%	12+/-3%
11-20	16+/-3%	14+/-3%
21-40	18+/-3%	23+/-3%
41-80	9+/-3%	30+/-3%
81-200	0	9+/-3%

AIR REQUIREMENTS

Precleaners
Precleaners adapt to standard air cleaners to extend filter service periods.

- They impose 0.25 to 0.75 kPa (1 to 3 in. H_2O) added restrictions, but increase standard filter life about three times.
- Conventional precleaners approach 70 percent efficiency.
- Exhaust-augmented precleaners exhibit 92 percent efficiency, further extend filter element life and are maintenance free.

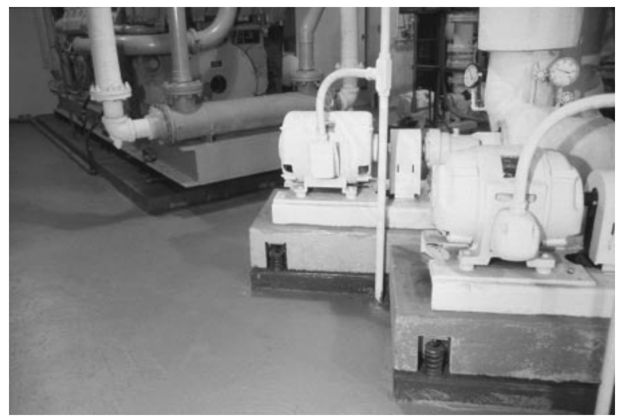
Heavy-duty air cleaners
Heavy-duty air cleaners provide the same protection as standard filters but allow further extension of filter change periods. Service periods are six to seven times that of standard air cleaners.

Ventilation

Six to 10 percent of fuel consumed by a diesel engine is lost as heat radiated to the surrounding air. In addition, heat from generator losses and exhaust piping can easily equal engine radiated heat. The resulting elevated temperatures in the engine room adversely affect maintenance personnel, switchgear, and generator set performance.

Engine room ventilation must provide an environment:

- Permitting machinery and equipment to function properly



- Where maintenance personnel can work comfortably and effectively

A 7° to 10° C (13° to 18° F) **temperature rise** is a reasonable target for engine rooms. However, in cold climates this may cause discomfort from the flow of cold air. Restrict flow only if engine combustion air is available and engine jacket water is adequately cooled.

Engine room ventilation can be estimated by the following formulas, assuming 38° C (100° F) ambient air temperature:

$$V\ (m^3/min) = \frac{H}{1.099 * 0.017 * dT} + \text{engine combustion air}$$

$$V\ (cfm) = \frac{H}{1.070 * 0.24 * dT} + \text{engine combustion air}$$

V = ventilating air
H = heat radiation; engine, generator, aux (kW) (Btu/min)
dT = permissible temperature rise in engine room (°C) (°F)

Density of air at:

40° C (104° F) = 1.099 kg/m³ (0.071 lb/ft³)

Specific heat of air at:

40° C (104° F) = 0.017 kW/(min•kg•°C)

0.24 Btu/(lb•°F)

AIR REQUIREMENTS

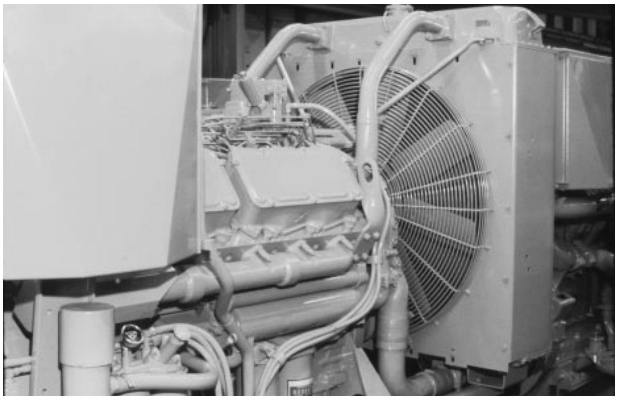
While engine room temperatures must be controlled, air velocities affect worker comfort. Typical air motion at various ambient conditions include:

Air Velocity

(fpm)	m/min	Conditions
50	15.2	Offices, seated worker
100	30.5	Factory, standing worker
150	45.7	Capture velocity, light dust
1300	396	Capture velocity, rain
200	61.0	Maximum continuous exposure
1-2000	305-610	Maximum intermittent exposure

Radiator Air

Installations utilizing remote or engine-mounted radiators may provide sufficient air flow for ventilation, but ventilation air flow requirements must be compared to radiator fan capabilities.



- Intake and exhaust ventilators may have movable or fixed louvers for weather protection.
- If movable, actuate by pneumatic, electric, or hydraulic motors; never depend on air pressure developed by the radiator fan to move the vanes.
- In cold climates, movable louvers can be arranged to provide circulation inside the room until jacket water temperatures reach 88° C (190° F).

Once jacket water temperatures reach 88° C (190° F), the radiator must be furnished with sufficient cooling air. Use a number of small ventilating fans rather than a single large unit. Selective fan operation compensates for varying ambient temperatures while maintaining engine room temperatures.

Increase air flow 10 percent for every 763 m (2500 ft) above sea level to maintain original cooling capability. Final ventilation calculations must use precise heat radiation of selected engine, generator, and power output.

Air Flow

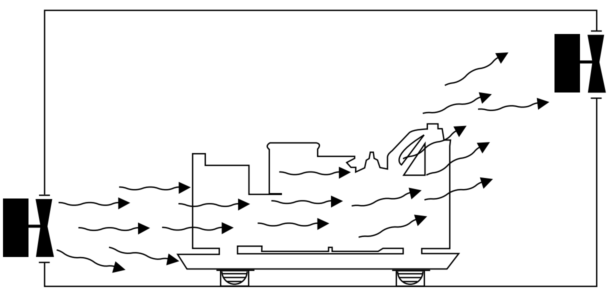
Ideally, clean, cool, dry air circulates around the switchgear, flows through the rear of the generator, across the engine, and discharges through the radiator. Cool air should always be available for the engine air cleaner.

- Locate room air intakes to provide maximum cooling air to the generator set.
- Multiple generator sets require additional openings and fans.

AIR REQUIREMENTS

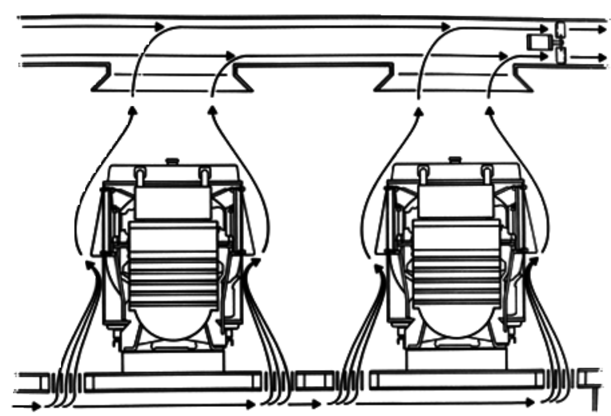
- Units not using radiators require a forced air draft.
- Openings for intake air should be low, near the rear of the engine; position outlets high on the opposite wall.

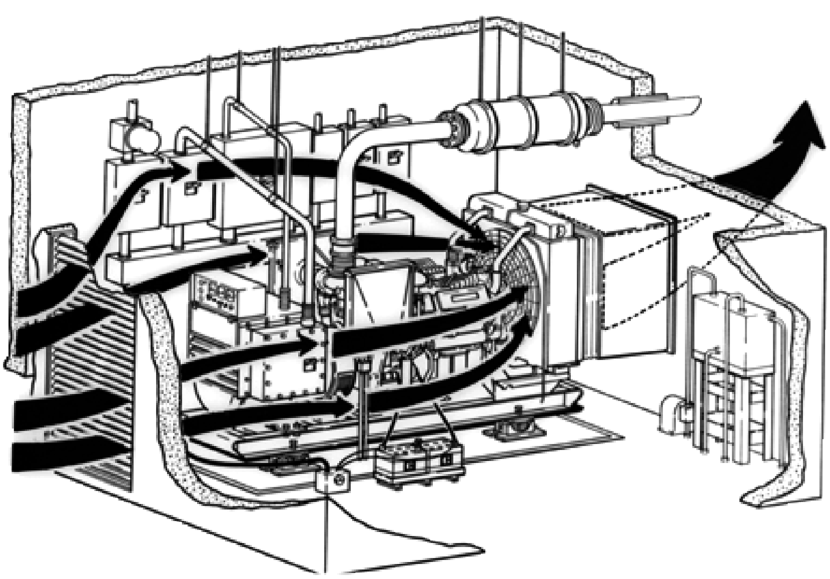
Horizontal Air Flow
Cool, dry, clean air should enter the engine room as close to the floor as possible using fans/ducts. Allow this air to flow across the engine room from the entry point across heat sources such as the engine, exposed exhaust, generator, etc.



- For best results, air should flow first across the generator then to both sides of the engine.
- If engine mounted radiators are not used, air discharge fans should be mounted or ducted at the highest point directly over the heat sources.
- Air inlet must circulate air between the engines.
- Inlets located at the end of the room will provide adequate ventilation only to the engine nearest the inlet.
- This technique will dissipate engine heat but a certain amount of heat will still radiate and heat the engine room.

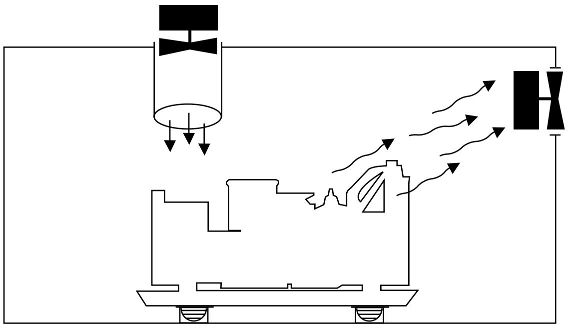
Air Curtains
Air curtains, totally enveloping the generator set, provide ventilation without exposing the equipment room to high air velocities. Radiated heat is removed with approximately half the air flow of a horizontal flow system.





AIR REQUIREMENTS

Vertical Air Flow
The least desirable ventilation system discharges outside air directly down on the engines with inlet fans.



- Exhaust fans should be mounted in the corners of the room.
- Because this system interferes with the natural rising of hot air, ducting should be used to prevent air from taking the shortest path out of the engine room and bypassing the engine.

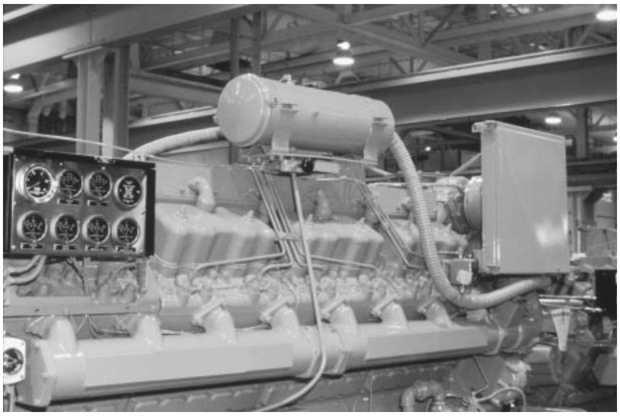
Crankcase Breathers

Firing pressure forces slight amounts of combustion gases past piston rings into the crankcase. Resulting crankcase pressure is relieved to maintain oil control and seal life by having crankcase breathers exhausting fumes at the rate of 0.028-0.042 m^3 (1-1.5 ft^3)/hp-hr.

Piping
- Pipe the breather outlet to an outdoor vent. Fumes are thus prevented from collecting in the equipment room, clogging engine intake air filters and radiator cores.
- Low operating hours of standby applications demand little of air filters, so fumes can discharge immediately in front of the filter. Do not bypass this air filter.
- Each engine's fumes disposal should have separate discharge pipes.
- Avoid low places allowing condensation to collect and block the fumes passage.
- Allowable crankcase pressure at full load is plus 0.25 kPa (1 in. H_2O).
- In unusually long runs of pipe, as in below-ground installations, or if forced to combine multiple engine breathers, increase pipe size to reduce backpressure.
- Excessive restrictions may require installation of a suction device in the line to aid ventilation. Flexible oil- and chemical-resistant tubing is connected (in a non-airtight manner) to the disposal tube so crankcase vacuum is less than 0.06 kPa (0.25 in. H_2O).

Breathers in Exhaust
NEVER incorporate the breather tube into the engine exhaust system. This can result in a buildup of deposits in the exhaust, and create excessive crankcase backpressure and a possible fire hazard.

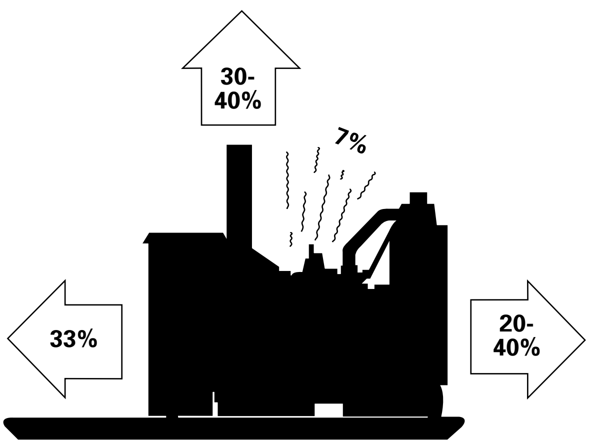
Filters
- In prime power applications where fumes cannot be disposed outside the engine room, special filters can be used to clean the crankcase fumes.



AIR REQUIREMENTS

EXHAUST

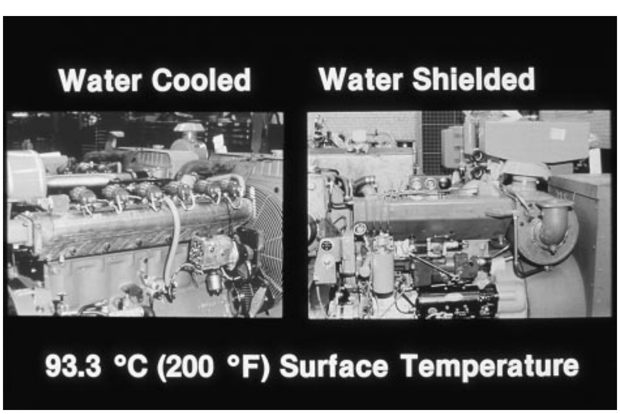
Exhaust systems collect exhaust gases from engine cylinders and discharge them quickly and silently. One purpose of the exhaust system is to minimize backpressure because exhaust gas restrictions cause horsepower losses and exhaust temperature increases.



Components

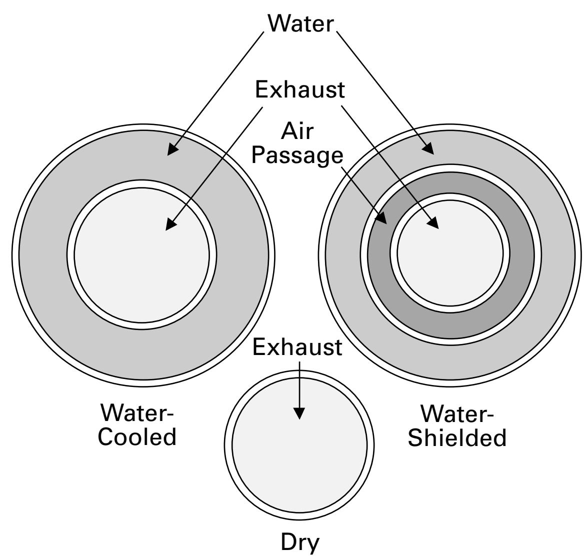
Engine exhaust manifolds collect exhaust gases from each cylinder and channel them into a single exhaust outlet. Several types of manifolds are available:

Dry manifolds are the most cost-effective, but least effective type of manifold for heat shielding. During engine operation, dry manifold surface temperatures can range from 430° to 480° C (800° to 980° F).



Watercooled manifolds' temperatures are considerably lower than those of dry manifolds. Surface temperatures reach only about 100° C (212° F) during operation.

Passages within watercooled manifolds allow engine jacket coolant to flow around the manifold removing heat otherwise carried by exhaust gases. Heat rejection to the jacket water will increase 20 to 40 percent, which requires a larger capacity cooling system. Loss of exhaust heat energy may affect turbocharger performance, causing engine deration and/or loss of altitude capability.



Water shielded manifolds have a fabricated auxiliary jacket or shield around the manifold. Engine jacket coolant circulates through the shield but does not come in direct contact with the manifold casting. This adds little heat to the engine cooling load and will not affect performance.

Exhaust System Design

Exhaust restrictions cause performance losses, particularly in fuel consumption and exhaust temperature.

EXHAUST

Restriction Criteria

- Pressure drop includes losses due to piping, muffler, and rain cap, and is measured in a straight length of pipe 3 to 5 diameters from the last transition change after the turbocharger outlet.
- Pressure drop across the exhaust system should not exceed 6.7 kPa (27 in. H_2O) of water for most Caterpillar engines.
- 3600 diesel gas engine performance will be adversely affected above 2.5 kPa (10 in. H_2O). Exceeding this limit on 3600s will increase fuel consumption approximately 0.8 percent per each 2.5 kPa (10 in. H_2O) of backpressure above the limit.
- Engines burning heavy fuel have an absolute backpressure limitation of 2.5 kPa (10 in. H_2O) to avoid excessive exhaust valve temperatures.

Calculate backpressure by:

$$P\ (\text{kPa}) = \frac{L \times S \times Q^2 \times 3.6 \times 10^6}{D^5} + Ps$$

$$P\ (\text{in. } H_2O) = \frac{L \times S \times Q^2}{187 \times D^5} + Ps$$

P = Backpressure (kPa) (in. H_2O)
L = Length of pipe (m) (ft)
Q = Exhaust gas flow (m^3/min) (cfm)
D = Inside diameter of pipe (mm) (in)
Ps = Pressure drop of silencer/raincap (kPa) (in. H_2O)
in. H_2O = Inches water column
kPa = 6.3246 x mm water column
psi = 0.0361 x inches water column
S = Specific weight of gas (kg/m^3) (lb/ft^3)

$$S\ (kg/m^3) = \frac{352.05}{\text{Exhaust Temperature} + 273.16^\circ\ C}$$

$$S\ (lb/ft^3) = \frac{39.6}{\text{Exhaust Temperature} + 460^\circ\ F}$$

To obtain equivalent length of straight pipe for each long radius 90-degree bend:

$L = 33 \times \frac{D}{X}$	**Standard Elbow**
$L = 20 \times \frac{D}{X}$	**Long Elbow (Radius > 1.5 diameter)**
$L = 15 \times \frac{D}{X}$	**45-degree Elbow**
$L = 66 \times \frac{D}{X}$	**Square Elbow**
$L = 31$	**Flexible connection (1 = connector length)**

where x = 1000 mm or 12 in

The radius of 90-degree bends with radii 1-1/2 times the pipe diameter help to lower resistance.

Exhaust gas mass flow can be calculated from the exhaust gas volumetric flow and the exhaust stack temperature.

Exhaust flow in:

$$kg/min = \frac{(\text{exhaust flow in } m^3/\text{min})\ (2078)}{\text{exhaust gas temperature in } ^\circ C + 273}$$

OR

Exhaust flow in:

$$lb/hr = \frac{(\text{exhaust flow in } m^3/\text{min})\ (2333)}{\text{exhaust gas temperature in } ^\circ F + 460}$$

Conversion to Standard Air flow (SCFM) = Actual CFM (ACFM)*

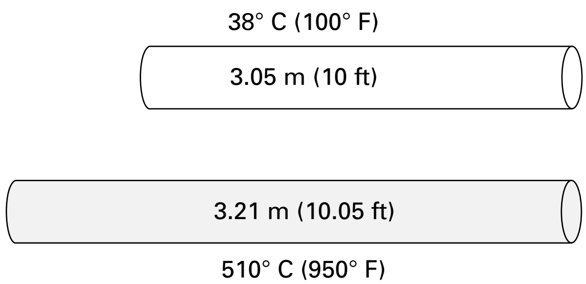
*** (density at actual temp/density at std temp)**

EXHAUST

EXHAUST

Thermal Growth

Thermal growth of exhaust piping must be planned to avoid excessive load on supporting structures.



- Steel exhaust pipe expands 1.13 mm/m/100° C (0.0076 in/ft/100° F) rise in exhaust temperature.
- A temperature rise from 38° to 510° C (100° to 950° F) will cause 16 mm (0.65 in) growth in 3.05 m (10 ft) length of pipe.

Exhaust Fittings

Exhaust pipes are isolated from the engine with flexible connections which have three primary functions:

Minimize exhaust piping weight on the engine
Engine exhaust components should not be more than 27 kPa (60 lb) of piping weight when the system is at operating temperature.

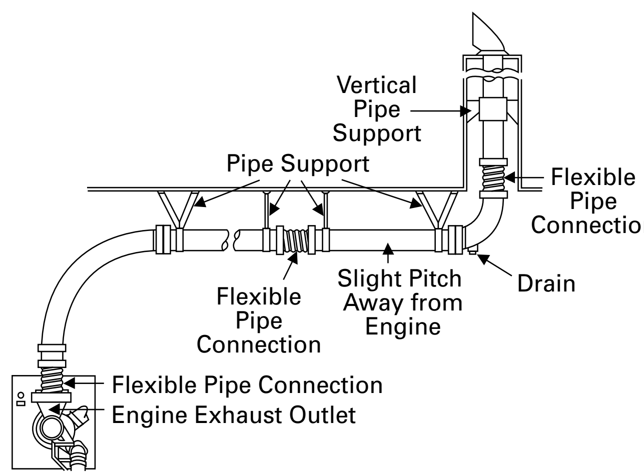
Isolation vibration
Flexible connections are needed to relieve exhaust components of excessive vibrational fatigue and prevent vibration transmission through the building.

Provide for movement of the engine and exhaust components
Movement between piping and engine is common and results from:

- Torque reactions when a generator set is mounted on spring-type isolators
- Expansion and contraction due to thermal changes. Pre-stretch the bellows during installation to allow it to operate near its free state at engine operating temperatures.

Piping Layout

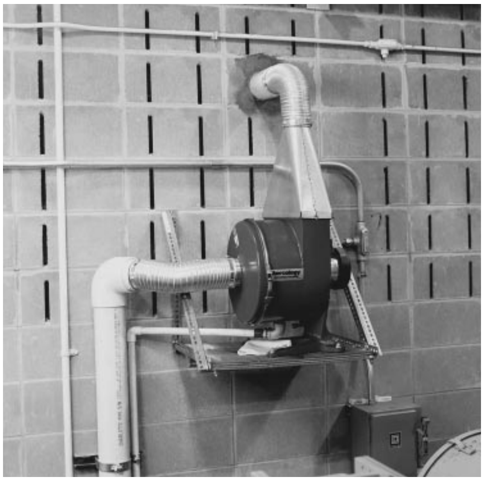
Physical characteristics of the equipment room determine exhaust system layouts.



- Thick-walled pipe provides long life while absorbing the shocks and noise of the combustion gases.
- Arrangements with minimum backpressures are favored, consistent with other requirements.

EXHAUST

- Support long runs of piping at unequal distances to minimize resonant vibrations.
- Pipes should be securely supported and rubber dampers or springs installed in the bracing to isolate vibrations, and routed to avoid interference with overhead service equipment.
- Long pipe runs need to be sectioned with **expansion joints**. Each section is fixed at one end and allowed to expand at the other. Supports are located to allow expansion away from the engine, avoid strains or distortions to connected components, and to allow equipment removal without additional support.
- Install lines with 229 mm (9 in) minimum **clearance** from combustible materials.
- Exhaust **thimbles** separate the exhaust pipe from walls or ceiling to provide mechanical and thermal isolation.
  - Single sleeve thimbles have diameters at least 305 mm (12 in) larger than the exhaust pipe.
  - Double thimbles (inner and outer sleeve) have outside diameter at least 152 mm (6 in) larger than the exhaust pipe.
- Long runs of exhaust piping require **traps** to drain moisture.
  - Traps installed at the lowest point of the line near the exhaust outlet prevent rainwater from reaching the silencer.
  - Slope exhaust lines from engine and silencer to the trap so condensation will drain.



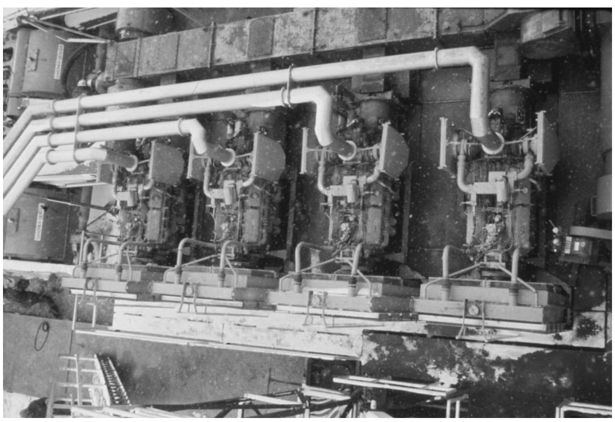
  - Traps may be built by inserting a vertical pipe down from a tee section in the line.
  - Including a short length of plastic pipe before the drain cock or removable plug will indicate drainage periods.

- Extended engine operation at loads less than 15 percent of rated may induce exhaust manifold **slobber**.
  - This black oily fluid does not necessarily indicate an engine problem and is not usually harmful to the engine, but can be unsightly and messy.

EXHAUST

- If extended periods of light loads are unavoidable, slobber can be minimized by operating the engine above 30 percent of rated power for at least ten minutes every four hours.

- Extend exhaust stacks to avoid **nuisance fumes and odors**.



- Pipe outlets cut at a 30- to 45-degree angle will reduce gas turbulence, and thus noise.
- Rain caps forced open by exhaust pressure will keep water from entering.

Insulation

Flexible pipe connections, when insulated, must expand and contract freely within the insulation. This generally requires a soft material or insulated sleeve to encase the connection.

Common Exhaust System

Although economically tempting, a common exhaust system for multiple installations is usually not acceptable.

- Combined exhaust systems with boilers or other engines allow operating engines to force exhaust gases into engines not operating.
- Every liter of diesel fuel burned provides about one liter of water in the exhaust.
- Spark ignited engines burning natural gas develop 1.6 kg of water for each cubic meter (1 lb/10 ft^3) of natural gas burned.
- This water vapor condenses in cold engines and quickly causes engine damage.
- Additionally, soot clogs turbochargers, aftercoolers, or air cleaner elements.
- Duct valves separating engine exhausts are also discouraged.
- High temperatures warp valve seats and soot deposits cause leakage.

Exhaust draft fans have been applied successfully in combined exhaust ducts, but must operate whenever exhaust is present. Separate exhaust systems assure expected engine performance and life.

Piping Outlet

Exhaust heat must be discharged without causing discomfort to personnel or hazards to buildings or equipment.

- Locate exhaust discharge away from ventilating air intakes to prevent reentry of offensive fumes and odors.
- Directing exhaust emissions in front of a radiator blower fan is acceptable; but avoid premature clogging of the radiator core by preventing exhaust passing through the radiator.

EXHAUST

Silencer

- Muffler placement greatly affects silencing ability. Locating it near the engine minimizes transmission of sound to the exhaust piping.

- Higher exhaust temperatures near the engine also reduces condensation and carbon buildup in the muffler; a drain removes condensation.
- At least 5 diameters of straight pipe upstream, and 2.5 diameters downstream are required to minimize turbulence and backpressure.

Both noise reduction and backpressure considerations are necessary when selecting a silencer. Engines using heavy fuel have greater exhaust flow than those burning conventional fuels, and silencer sizing must account for this increase.

Exhaust System Design Summary

- Locate the muffler near the engine; the transmission of sound through exhaust will be minimized.
- Provide a drain at the muffler's lowest point to relieve condensation.
- To prevent water from entering the system, vertical exhaust stacks require a bend or rain cap.
- Minimize potential system resonance by cutting the end of the exhaust pipe at a 45-degree angle.
- To prevent reentry of exhaust fumes into the building, exhaust pipes must be located away from air intakes.
- Use separate exhaust pipes for each engine.

EMISSIONS

Gaseous exhaust emissions of diesel engines are the lowest of modern internal combustion engines. Engine emissions are measured using a Horiba or Beckman gas analyzer, with equipment and data measurement techniques conforming to the U.S. Code of Federal Regulations, Title 40, Part 53 or 86. Caterpillar engines at rated load will not exceed:

Emission g/bhp-h	Diesel			Natural Gas	
	NA	TA	TA	Catalytic Converter	Low Emission
Nitrogen Oxide (NO_x)	12.0	15.0	19.0	1.2	2.0
Carbon Monoxide (CO)	3.5	2.0	1.5	1.0	1.7
Hydrocarbons (NMHC)	0.4	1.5	1.5	0.5	0.35

Nitrogen oxides are formed by decomposition and recombination of the molecular oxygen and nitrogen present in the combustion air.

- They consist primarily of nitric oxide and nitrogen dioxide.
- The designation of nitrogen dioxide signifies 1 or 2 oxygen atoms can be present in the molecule.
- Generally, over 90 percent of nitrogen dioxide in engine exhaust is in the form of nitric oxide.
- The nitric oxide gradually oxidizes to the more harmful nitrogen dioxide in the atmosphere.
- Nitrogen dioxide is a poisonous gas which, when combined with hydrocarbons in the presence of sunlight, forms smog and ozone.
- By convention, the nitrogen dioxide mass emissions (such as grams/hour) are usually reported as equivalent mass of nitrogen dioxide.

Nitrogen dioxide emissions in parts per million by volume can be approximated from the mass emission rate and the exhaust flow:

$$NO_x \text{ concentration} = 629 \times \frac{NO_x \text{ mass emissions}}{(\text{exhaust mass flow})}$$

where:

NO_x concentration is in parts per million (ppm)
NO_x mass emissions are in g/hr of equivalent NO_2
Exhaust flow is in kg/hr

Depending on configuration and rating, many engines emit considerably less emissions. Specific emission data is available from the engine supplier.

EMISSIONS

Carbon monoxide (CO) is poisonous and is formed by combustion that takes place with a shortage of oxygen. CO emissions in parts per million by volume is calculated by:

$$\text{CO concentration} = 1034 \times \frac{\text{CO mass emissions}}{\text{exhaust mass flow}}$$

where:
CO concentration is in parts per million (ppm)
CO mass emissions are in g/hr
Exhaust flow is in kg/hr

Carbon dioxide is not regulated in most areas but is considered a greenhouse gas. It is the result of combustion of all hydrocarbon fueled engines, including humans. Carbon dioxide is a function of engine efficiency, with high efficiency engines producing the lowest carbon dioxide.

Hydrocarbons (HC) consist of unburned fuel or lubricating oil, and can cause unpleasant odors and eye irritation. HC emissions in parts per million by volume is calculated by:

$$\text{HC concentration} = 2067 \times \frac{\text{HC mass emissions}}{\text{exhaust mass flow}}$$

where:
HC concentration is in parts per million (ppm)
HC mass emissions are in g/hr
Exhaust flow is in kg/hr

Particulates and sulfur dioxide levels are also sometimes required.

Particle emissions include unburned carbon (soot), soluble organic fraction (SOF), and sulfates.

- There is no universally accepted measuring method for non-truck application, so the level of particle emissions depends on the measuring method.
- Caterpillar has developed a correlation between smoke and particulate concentration which can be used to estimate particulate emissions.

Black smoke results from incomplete combustion and is the soot portion of particulates.

White smoke is caused by vaporized but unburned fuel passing through the engine, and usually occurs during startup of a cold engine.

The sulfur present in the fuel oxidizes primarily to **sulfur dioxide**, with less than two percent forming sulfate. The emission of sulfur dioxide depends only on the sulfur level of the fuel and the fuel consumption rate of the engine. Sulfur dioxide emissions are calculated by:

$$\text{Specific } SO_2 = (0.01998)\ (\text{BSFC})\ (\%\ \text{sulfur in fuel})$$

where:
Specific SO_2 is emissions in g/kW-hr
BSFC is Brake Specific Fuel Consumption in g/kW-hr
Percent sulfur in fuel is in percent by weight

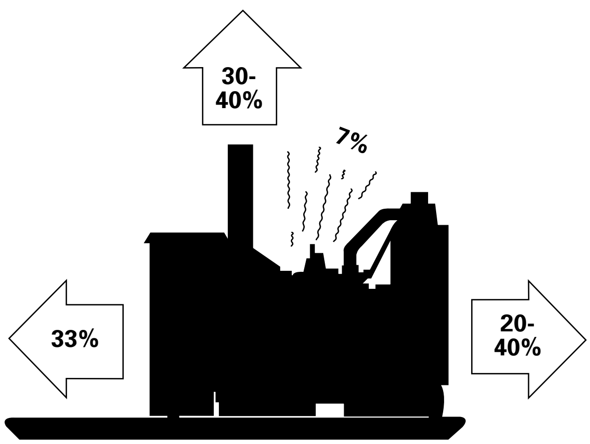
Aldehydes can cause eye and respiratory irritation, but levels are quite low for most engines.

Emission levels are affected by engine rating, speed, turbocharger, timing, fuel, and ambient conditions. Increased intake air temperature and higher altitudes increase nitrogen dioxide and particulate emissions.

COOLING

Heat Balance

Internal combustion engines produce heat as a by-product of combustion. Twenty to forty percent of fuel energy required for engine operation results in heat rejected to the jacket water, and must be totally removed by the engine's cooling system to assure dependable engine performance.



- The cooling system is comprised of the jacket water circuit and, depending on engine configuration, aftercooler, oil cooler, and fuel cooler circuits.
- A small percentage of heat is also rejected to the atmosphere, and is removed by engine room ventilation.

The distribution of input fuel to energy is approximately:

- 33% to useful work
- 30% to rejected work
- 30% to jacket water
- 7% to friction and radiation

Engine cooling systems must:

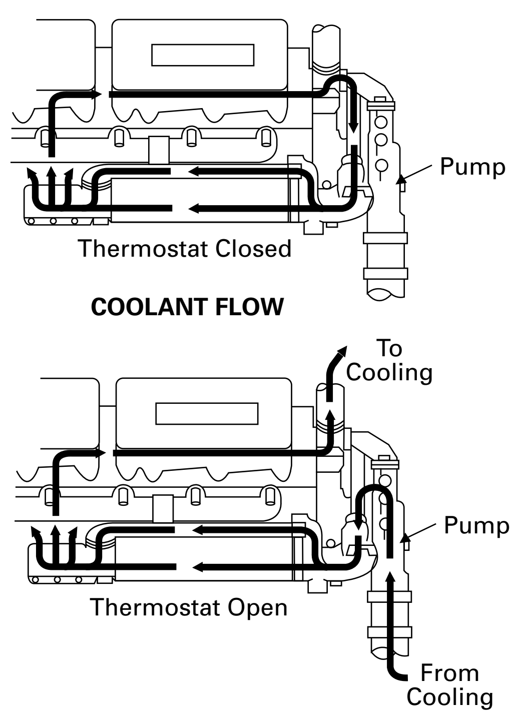
1. Cool jacket water at greatest engine load, highest ambient temperature, and altitude
2. Allow filling without air entrapment
3. Provide sufficient pressure head to discourage pump cavitation
4. Vent air introduced into the system by filling, leaks, and engine combustion

There are three primary areas to consider in engine cooling:

- Internal engine coolant flow
- Types of internal cooling systems
- Jacket water and separate circuit aftercooling

Internal Circuit

The engine thermostat controls minimum operating temperature of the engine. It permits efficient engine operation by disconnecting the external cooling system until jacket water temperature exceeds 79° C (174.2° F).



COOLING

- After the engine jacket water reaches approximately 80° C (176° F), the thermostat begins to open and allows circulation to the external cooling system.
- Never operate without thermostats when utilizing the normal 88° C (190° F) cooling system. Optional thermostats are available for applications requiring higher minimum operating temperatures.

Outlet regulated cooling systems provide a constant outlet temperature from the engine by regulating the flow between the bypass and cooling circuits. Usually applied with radiator cooled systems, the sensing bulb is placed in the outlet flow from the engine. Note that all Caterpillar EPG radiator cooled systems use an outlet regulated cooling system.

Inlet regulated cooling systems provide a constant temperature to the inlet jacket water, aftercooler, and/or oil cooler. This design is used to minimize overcooling when very cold or large cooling sources are involved. The sensing bulb of the thermostat is placed in the inlet flow to the engine. The thermostat then balances the bypass flow (hot water directly from engine) with cool water from a heat exchanging device.

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.

Types of Cooling

There are two basic types of cooling systems, one of which is an open system.

In an **open** system, untreated water is used to cool the engine. This cooling process can result in scale buildup, corrosion, and erosion in the internal cooling water passages, decreasing the cooling system's efficiency and endangering the engine's service life.

Caterpillar recommends a **closed** cooling system. In a closed system, cooling medium does not come into direct contact with air, but is cooled by a process of heat transfer, usually water or air (example — radiator).

Water Treatment

Prime consideration in closed cooling systems is to ensure no corrosion or scale forms at any point. Select the best quality water available, but **never use salt water**.

Usually water hardness is described in grains per gallon – one grain being equal to 17.1 parts per million (ppm), or in mg/L, both expressed as calcium carbonate. Water containing up to 3.5 grains per gallon (60 ppm) is considered soft and causes few deposits.

Usable water must have the following characteristics as defined by industry standard specification ASTM D4985:

pH	**5.5-9.0**
Chloride	**40 ppm** **2.4 grains/gal**
Sulfate	**100 ppm** **5.9 grains/gal**
Total Dissolved Solids	**340 ppm** **20.0 grains/gal**
Total Hardness	**170 ppm** **10.0 grains/gal**

COOLING

Water softened by removal of calcium and magnesium is acceptable.

- Never use water alone as a coolant. Coolant additives are required because water is corrosive at engine operating temperatures.
  - Corrosion inhibitors added to water or antifreeze solution maintain cleanliness, reduce scale and foaming, and provide pH control.
  - A 3 to 6 percent concentration of inhibitor is recommended to maintain a pH level of 8.5 to 10.
  - Soluble oil damages hoses, gaskets, and seals, and does not lubricate pump bearings, or protect from cavitation erosion. Avoid sudden changes in coolant composition to minimize failure of nonmetallic components.
  - Caterpillar cooling inhibitor is compatible with ethylene glycol and propylene glycol base antifreezes, but not with Dowtherm 209. With 30 percent glycol, no additional inhibitors are required.

Following are some main points of water treatment:

- To maintain constant protection, additives should be replenished every 250 operating hours.

- Because modern antifreezes contain considerable dissolved chemical solids to accommodate aluminum components, over-concentration needlessly reduces heat transfer and causes water pump seal leakage or failure.

Note: If cooling water contacts domestic water supplies, water treatment may be regulated by local codes.

- Engine cooling water for high temperature water systems is circulated within the engine water jacket at temperatures above 100° C (212° F).
  - High temperature solid water applications have the potential for steam to form.
  - Minerals in the water can precipitate during the heating process and form deposits within the cooling systems, restricting heat transfer and water circulation. The engine coolant must therefore be treated the same as boiler feed water.

The engine coolant (boiler water) is a mixture of feed water and resident water. It should not exceed the following maximum concentrations.

Silica concentration . . . . **150 ppm as silicon dioxide**

Total alkalinity. . . . . **700 ppm as calcium calcium carbonate**

Specific conductance . . . . **3500 microhms per cm (2680 ppm)**

pH **10.0-11.5**

In addition, the jacket water treatment should include:

- Maintenance to limit calcium carbonate equivalent of hydroxide alkalinity to 200-400 ppm
- A blend of dispersants to condition and suspend the precipitated solids
- Treatment of condensate return

COOLING

- Make-up water should not exceed the following maximum concentrations:

Iron	**0.1 ppm**
Copper	**0.05 ppm**
Total hardness	**0.3 ppm as calcium carbonate**

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

- Cooling towers supplying cooling water directly to turbocharger aftercoolers must also incorporate treatment.
  - A corrosion resistance core must be specified and raw water treated with corrosion inhibitors and protected from freezing.
  - Algae formation severely affects heat transfer rates and must also be controlled.

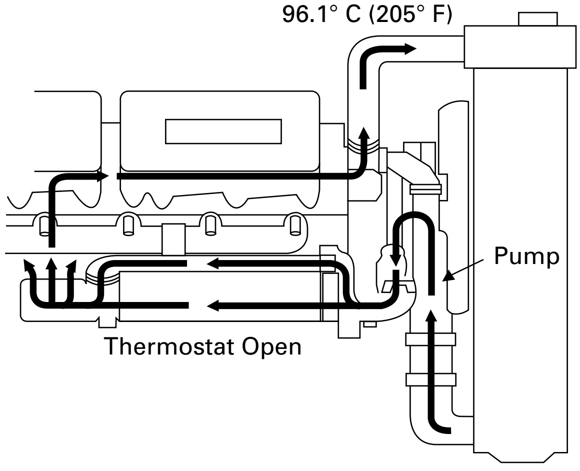
Antifreeze Protection
Exposing engine coolant to freezing temperatures requires addition of antifreeze. Ethylene glycol, Dowtherm 209 (sold at 20%), or Cat ELC (sold and recommended at 50%) are recommended to protect against freezing and inhibit corrosion. Borate-nitrite solutions such as Caterpillar Inhibitor or NALCO 2000 are compatible only with ethylene glycol and can replenish the original corrosion inhibitors in the antifreeze.

- The glycol concentration should exceed 30 percent to assure protection against corrosion and minimize water pump cavitation, but concentration above 60 percent will needlessly penalize heat transfer capabilities.
- Generally, a radiator derates 2 percent for each 10 percent of antifreeze concentration.
- Use of antifreeze year-round decreases radiator capabilities at least 3.3° C (6° F).

Radiator Cooling

Radiator cooling is the most common and reliable method used to cool engines. As with all cooling systems, radiators are usually sized 15 percent greater than the engine's maximum full load heat rejection. This allows for overload conditions and system deterioration.

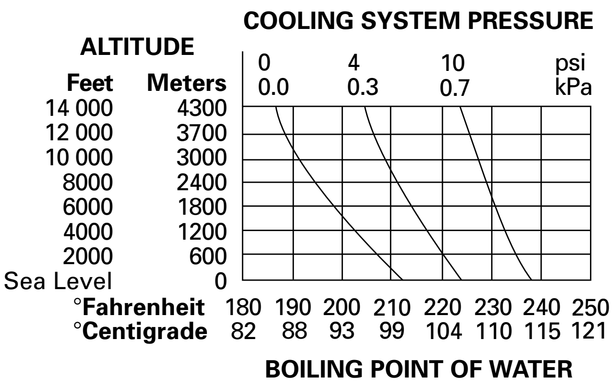
Temperature Differential
Most engines operate with water temperature differential (outlet minus inlet) of 5.5° to 8.3° C (10° to 15° F) maximum. Temperature limitation of water leaving the engine is determined by cooling system design. In standard systems operating with 27.6 to 48.2 kPa (4 to 7 psi) pressure caps, maximum top tank temperature is 99° C (210° F). This limit prevents steam formation in the engine water jacket. The drawing below illustrates the effect of system pressure on the boiling point of water at various altitudes.



COOLING

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). Elevations above 3048 m (10,000 ft) require higher rated pressure caps to avoid boiling.
- Additions of alcohol or other volatile antifreeze coolants lower the boiling point, while ethylene glycol solutions raise the boiling point.

Engine Mounted Radiator System Design

Jacket water flow is determined by engine heat rejection and allowable jacket water temperature rise.

- Minimum temperature rise is desirable to reduce thermal stresses, but water flows are limited to reduce erosion and pump horsepower requirements.
- Watercooled exhaust manifolds increase heat rejection 15 percent over dry manifolds, and may affect turbocharger performance, causing power deaerations.
- Exact power ratings and configurations are necessary when calculating heat rejection.

$$\textbf{Flow (L/min)} = \frac{\textbf{Heat Rejection (kW)}}{\textbf{dT (°C) x Density (kg/L) x Specific Heat (kW-min/kg-°C)}}$$

$$\textbf{Flow (gal/min)} = \frac{\textbf{Heat Rejection (Btu/min)}}{\textbf{dT x Density (lb/gal) x Specific Heat (Btu/lb-°F)}}$$

Water flow rates in external cooling systems are calculated by:

	Pure Water	50/50 Glycol
Density kg/L at 80° C=	**0.98**	**1.03**
(lb/gal) at 175° F=	**8.1**	**8.6**
Specific Heat (kW-min/kg-°C)=	**.071**	**0.06**
(Btu/lb-°F)=	**1.0**	**0.85**

dT = Allowable temperature rise, °C, °F

- Piping and heat transfer equipment resist jacket water flow, causing an external pressure head which opposes the engine-driven pump.
  - Jacket water flow reduces as external head increases.
- To ensure adequate coolant flow, external head losses must be balanced against water pump capabilities.
  - Excessive external heads demand pumps with additional pressure capacity.
  - Friction head losses are a function of pipe size, number and type of fittings and valves used, coolant flow rate, and losses contributed by heat transfer devices.
  - After determining required coolant flow rate, pump performance establishes maximum allowable external head.

COOLING

- Coolant velocity is maintained to achieve optimum heat transfer without damage to system components by erosion.
  - Jacket water external circuit velocities of 0.6 to 2.5 m/s (2 to 8 fps) are acceptable.
  - Raw or sea water circuit velocities reduce to 0.6 to 1.9 m/s (2 to 6 fps).

Water Maximum Velocity	m/sec	ft/sec
pressurized lines	4.5	15
pressurized thin-wall tubes	2.5	8
suction lines (pump inlet)	1.5	5
low velocity deaeration line	0.8	2

- Radiators may contain orifices to limit coolant flow, so flow in engines with radiators may be less than in those without radiators.
  - Because published pump data reflects coolant flow without a radiator, auxiliary cooling equipment installed with standard radiators must anticipate flows lower than published.

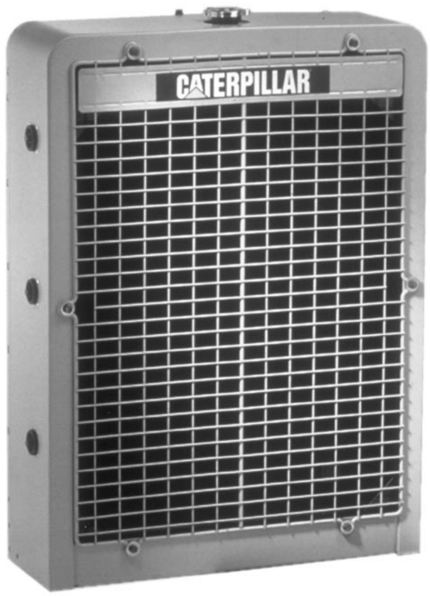
Pressure relationships:

- Pressure drop and velocity of liquids is calculated in EPG Designer, while both pressure drop and velocity are estimated in the Generator Set A&I Guide. For example, new 6-inch steel pipe carries 2270 lpm of water at 66° C (600 gpm at 150° F).
- If a high capacity pump is installed in series with the standard engine pump, total pressure head imposed on the engine pump inlet must be less than 1172 kPa (25 psi).
  - External system modifications may be necessary to prevent cavitation of the high capacity pump.
- Consult manufacturers' specification sheets for friction head loss through heat transfer devices.
  - Decrease resistance by minimizing number of bends.
  - Use long sweep elbows and gate-type valves.
- Suction head on the pump must not be significantly below atmospheric pressure.
- Inlet piping should have internal diameters at least the diameter of that furnished on the engine.
- Radiator bottom tank must have greater cross-sectional area than inlet piping.
  - Depending on the coating thickness, radiator capability will be reduced at least 3 percent.
- Coatings such as solder or paint are sometimes used to protect the copper fins of the radiator core from aggressive atmospheres.
- Altitude affects radiator sizing.
  - Increased air flow is required at higher altitudes to maintain cooling capabilities equivalent to sea level.
  - Reduce radiator performance 1.4° C per 305 m (2.5° F per 1000 ft) of elevation to compensate for lower air densities.

COOLING

Top Tank

Radiators normally have top tanks for filling, expansion, and deaerating of engine coolant. Extended systems using added coolant may require enlarged expansion tanks.



Installation

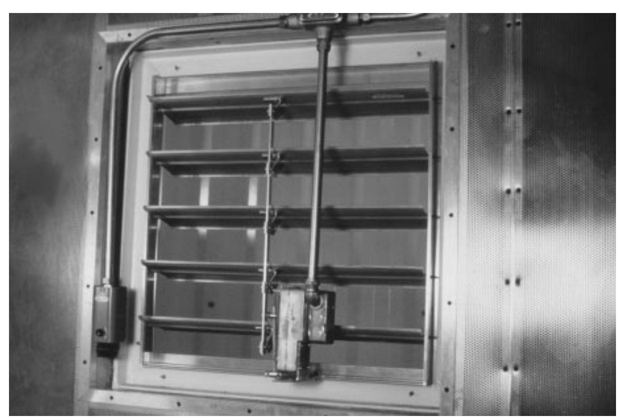
- When an engine-mounted radiator is used and the generator set is installed in a room, a blower fan and a radiator duct running to the outside can be used.
  - Ducts directing radiator air to the outside prevent recirculation and high equipment room temperatures.
  - Some generator set packages have standard radiator duct flanges for installation ease.
  - The duct length is short and direct to minimize backpressure, with total inlet and outlet restriction on the radiator fan being less than 6.35 kPa (0.25 in. H_2O).
  - Radiator ducting should be larger than the radiator core, with inlet air ducts 1.5 times greater than outlet ducts.

Restrictions

- When louvers are used, the duct size should be increased at least 25 percent due to louver assembly restrictions.
- If common window screening is used, the size of the opening may increase 40 percent.
- Solid walls perpendicular to fan air flow must not be closer than 2 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 within 150 mm (6 in) of the fan face.

Movable Louvers

If movable louvers are used, specify those which open in a positive manner. Pneumatic and electric-actuated louvers are satisfactory.



Louver Operation

- Louvers which open from the discharge pressure of the radiator fan are discouraged.
- Rain, ice, and snow can render them inoperative within a short time and result in engine overheating and shutdown.

COOLING

- Do not wait to activate the louvers until the engine warms up. In an emergency, the engine will be loaded immediately and require full air flow.
- Heat sensors needlessly complicate the system and their malfunction can reduce air flow to the engine and cause shutdown.
- Open louvers as soon as engine starts.
- Don’t use heat sensors.

Enclosures

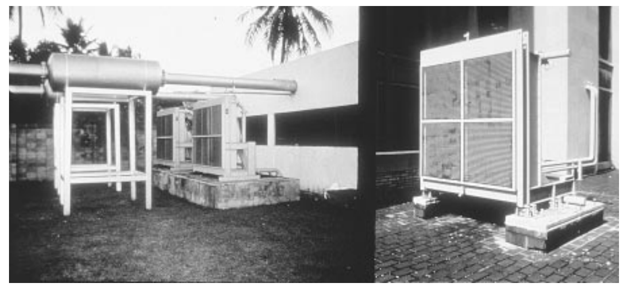
Enclosures trap radiated heat and direct it through the radiator decreasing cooling capabilities 8° to 10° C (14° to 18° F). Even with doors open, radiators can derate 5° to 7° C (9° to 13° F).

Remote Mounted Radiators

The radiator may be located some distance from the engine.

- Remote-mounted radiator systems add restriction to cooling water flow by additional piping.
- The standard engine coolant pump may be unable to provide adequate flow, so it may have to be replaced or boosted by an additional pump usually located in the engine return line. (The auxiliary pump operates whenever the engine is running.)
- Allowing engine warmup before pumping to remote radiator can cause the radiator core to fail due to thermal shock.
  - 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 water treatment to assure uninterrupted flow.

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 radiators nullify the effects of wind but may require protection from snow and ice.

Static Head

Static head is the maximum height the coolant water is raised.

- Large static heads are encountered where radiators or heat exchangers are located on the roof.
- Heights above 17.4 m (57 ft) cause leakage at the engine pump seals.
- Brace pipes at bends and use Marmon (or equal) clamps.

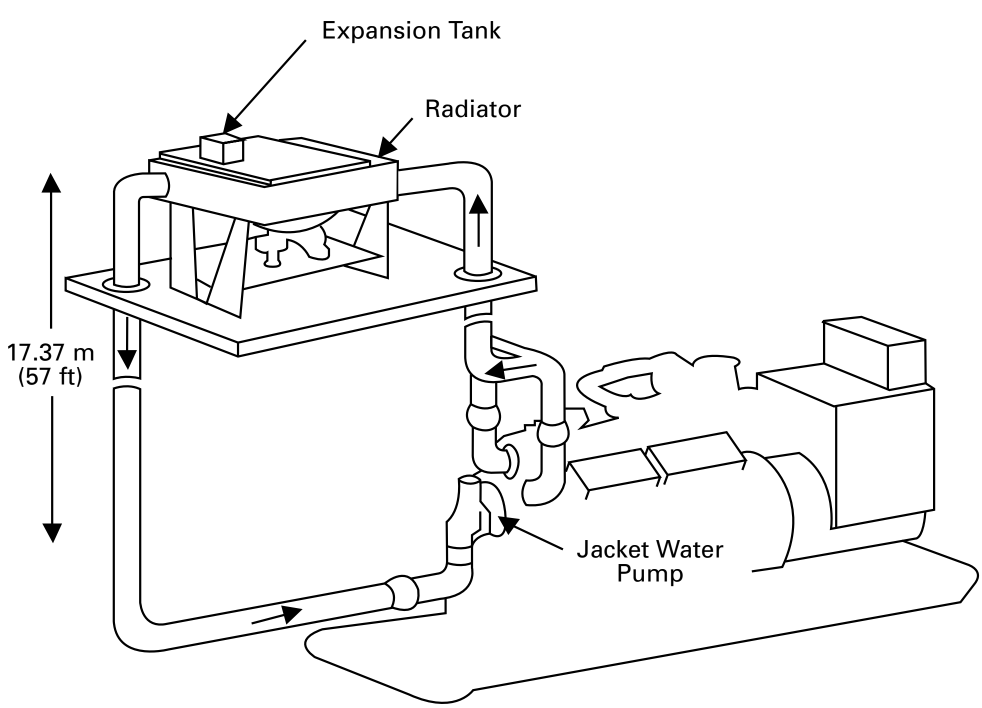
COOLING

- High static head and movement in long pipe runs cause straight clamped rubber hoses to leak. A separate external cooling system relieves the engine system from this pressure.
- Automatic make-up water controls and low water alarms are desirable in remote systems to avoid inattention.
- Radiators mounted level or above engine and connected with straight piping will avoid air traps.
- The engine outlet pipe, which dips below the engine, will trap air during initial fill or combustion gases which leak into the coolant.
- If piping dips are unavoidable, vent lines from each potential trap run to the radiator top tank.
- Vent lines must also slope up with no dips.

While preferable in installations involving multiple generator sets to provide separate cooling systems for each engine, using a single radiator is possible. Such designs must be analyzed by a cooling system engineer.

Location

- When selecting radiator location, consider fan noise.
  - Noise transmits through the air inlet as well as outlet.
  - Soft flexible joints between radiator and duct will reduce 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 set several feet from the exhaust.
  - Another method is to install an air duct outside the wall directing the air outlet (or inlet) vertically.



COOLING

Air Density

Air density, flow restrictions, and speed affect fan performance, possibly limiting radiator ambient temperature capabilities. Performance changes are estimated by these relationships:

Revised Static Pressure =

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

Revised Fan Horsepower =

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

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 speeds.

$$\text{Original Air Flow} \times \frac{\text{Revised Fan Speed}}{\text{Original Fan Speed}}$$

Revised Static Pressure =

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

Revised Fan Horsepower =

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

Temperature

Revised coolant temperature and radiator ambient capabilities are calculated as shown.

Revised Coolant Temperature =

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

Revised Coolant Temperature =

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

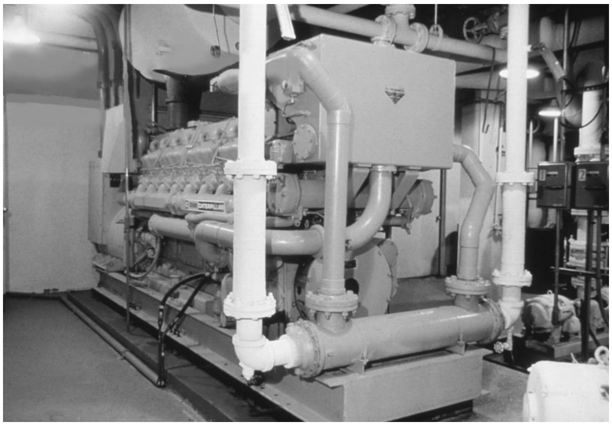
Radiator Ambient Capability =
Rad Top Tank, usually 99° C (210° F) - Revised Coolant Temperature

where:

Air Density = kg/cu cm (lb/cu in)
Air Flow = cu m/min (cfm)
Coolant Temperature =
$99° \text{ C } (210° \text{ F}) - \left(\frac{5.5}{2}\right) -$ **Original Radiator Ambient**
Assumptions:
Coolant Top Tank Temperature = 99° C (210° F)
Inlet to Outlet Radiator Temperature Change = 5.5° C (10° F)
Fan Horsepower = kW (hp)
Fan Speed = rpm
Static Pressure = mm (in) of H_2O

Heat Exchanger Cooling

A heat exchanger is sometimes used to cool the engine when ventilating air is limited or excessive static head on the engine must be avoided. Caterpillar exchangers are all shell and tube-type.



COOLING

COOLING

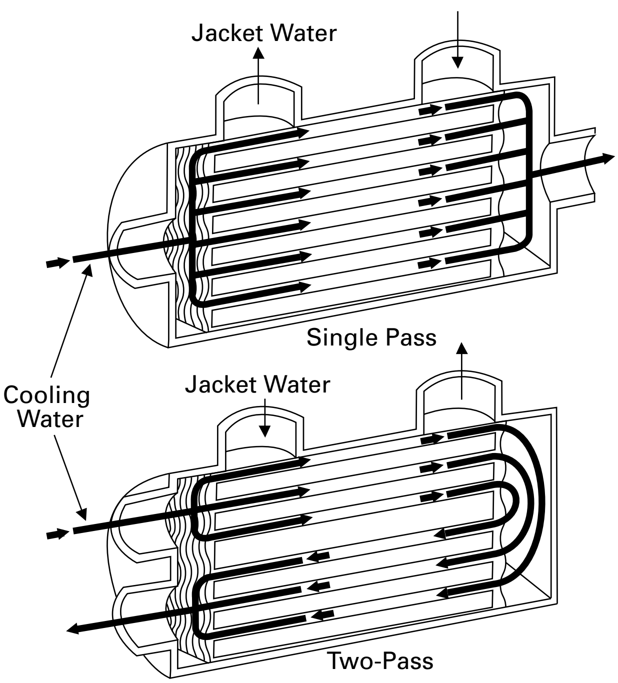
Advantages of heat exchangers include:

- No fan noise
- Reduced air flow requirement
- Minimum space requirement
- Less parasitic load, improving fuel consumption

The **disadvantages** of heat exchangers include:

- A separate cooling source
- A separate expansion tank
- An extra pump and plumbing
- Room ventilation

Design
Shell and tube heat exchangers are single- or two-pass. This refers to the flow in the raw water circuit of the exchanger.



HEAT EXCHANGER TYPES

- Multi-pass exchangers flow raw water through the exchanger two or more times. In multi-pass exchangers, relative direction of flow between jacket and cooling water is unimportant.
- Single-pass types use raw water only once. Raw water in single-pass exchangers flows through the exchanger opposite to coolant flow to provide maximum differential temperature and heat transfer. This results in improved heat exchanger performance.
- Heat exchanger performance depends on raw water flow and differential temperature.
  - To reduce tube erosion, flow of raw water through the tubes should not exceed 2.4 m/s (8 fps).
  - Minimum flow rate for good heat transfer design is 1.2 m/s (4 fps).
  - The heat exchanger must accommodate raw water temperature and flow needed to remove maximum engine heat rejection.
  - Thermostats are retained in the jacket water system to provide adequate low temperature control.
- Heat exchangers must accommodate heat rejection 10-15 percent greater than engine full load heat rejection, depending on fouling factors.
  - Standard Caterpillar exchangers incorporate a 0.001 hr-ft °F/Btu factor. Fouling factor affects heat transfer by the following relationship:

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

where:

FF = fouling factor, Btu/h ft °F/
U coolant = heat transfer coefficient of core with coolant, Btu/h ft^2 °F
U clean core = heat transfer coefficient of clean core, Btu/h ft^2 °F

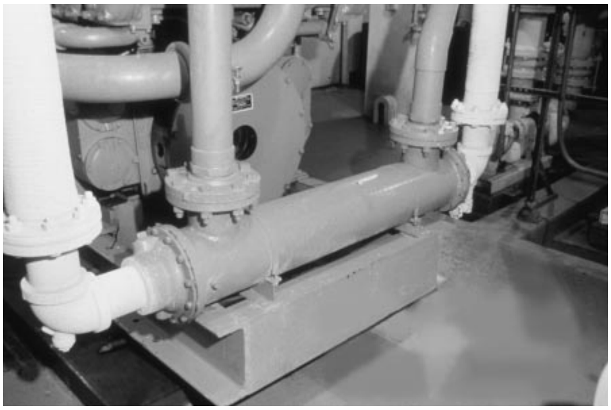
COOLING

COOLING

- Solenoid valves controlling cooling water are applied upstream of the heat exchanger.
- Since heat exchanger tubes can be cleaned more easily than the surrounding jacket, raw water usually is routed through tubes and engine coolant through the shell. Strainers prevent premature system fouling.
  - The exchanger is relieved of pressure when inoperative and raw water cannot be trapped in the tubes if the solenoid fails to open.
  - Water trapped during engine operation expands and can rupture the exchanger.
  - All solenoid valves include manual bypasses.
- Do not add temperature regulators in raw water supplies. Engine jacket water is thermostatically controlled and additional controls add expense, cause restriction, and decrease reliability.

Installation

- Always use flexible connections on water lines to prevent transmission of engine vibration to the heat exchanger.
- Limit total system volume by mounting the heat exchanger close to the engine.



Expansion Tanks

Unlike radiators, heat exchangers have no built-in provision for jacket water expansion. Surge (expansion) tanks must be included in heat exchanger systems. Factory-designed tanks are normally specified to assure proper performance of the total system.

Design

- Water expands about five percent between 0° and 100° C (32° and 212° F).
  - Expansion tanks should have capacity for at least 15 percent of system water volume for expansion, plus reserve.
  - Tanks vent to atmosphere or incorporate pressure caps to assure system pressure.
  - Tanks are located to prevent formation of a vacuum, a primary cause of cavitation on the suction side of the pump.

COOLING

- Deaerate jacket water to prevent formation of air pockets and minimize pump cavitation.
  - Entrained air encourages corrosion and erosion in the engine.
  - Coolant may be lost because air expands more than water when heated.
  - Entrained air is caused by air trapped during fill operations, combustion gases leaking (five percent per cu in displacement), leaks in piping (particularly on the inlet side of the pump), or low after-level in the expansion tank.
  - A low velocity area must be provided where deaeration can occur.
  - Entrained air separates from the water if the tank is sized and baffled to slow water flow to 0.6 m/s (2 fps).

If full flow is not directed to the expansion tank, a 10 mm (3/8 in) deaeration line to the expansion tank can be run from an enlarged cross-section of the return water line.

Expansion tanks are the highest point in the circuit. The heat exchanger mounts lower than coolant in the expansion tank, preferably several feet. Jacket water flows from engine outlet to heat exchanger, to expansion tank, and back to jacket water pump inlet. This purges air and creates positive pressure at the jacket water pump inlet. If the heat exchanger is remote mounted, locate in a minimum vibration area, with flexible fittings between heat exchanger and engine.

Cooling System Features

The various features of a cooling system ensure that the cooling system runs properly, in turn, aiding the performance of the entire generator set.

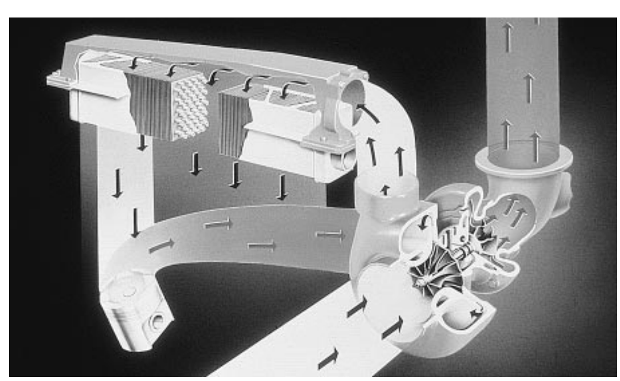
Hot Well
Hot well systems are used when static head exceeds 17.4 m (57 ft.), or a boost pump imposes excessive dynamic head. The auxiliary pump operates whenever the engine is running. Allowing engine warmup before engaging the pump can cause the radiator core to fail due to thermal shock.

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

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 suck air and that water level can be checked during shutdown.

Turbocharging
Turbocharging compresses combustion air charge, but this compression increases temperature, limiting the benefits of turbocharging. Lowering intake air temperature through jacket water aftercooling further increases the density of air for combustion.



COOLING

COOLING

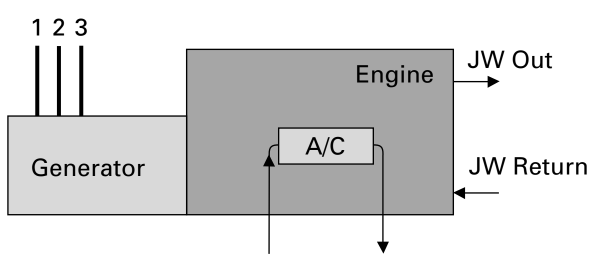
The resulting increase in oxygen allows more fuel to be burned, which produces greater engine power. Improved combustion can also lower:

- Brake Specific Fuel Consumption (BSFC)
- Exhaust temperature
- Certain exhaust emissions

Separate Circuit Aftercooling (SCAC)
Separate circuit aftercooling removes the aftercooler from the jacket water circuit and provides aftercooler cooling from an independent source. While jacket water temperature to aftercooler approaches 88° C (190° F), a separate source provides much cooler water, allowing air charge temperature to be further reduced, which improves engine performance.

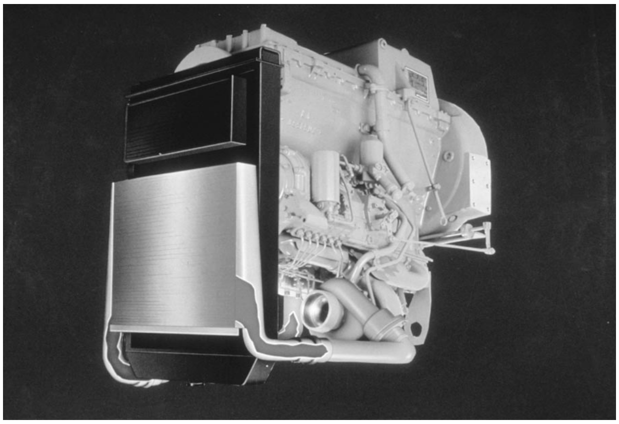
- SCAC is necessary on all turbocharged gas engines and high temperature jacket water systems used in heat recovery applications.
- A closed cooling circuit, such as a heat exchanger or radiator, is preferred to control water quality.
- If supplied from an open system, such as a cooling tower or pond, the aftercooler core and associated plumbing must be non-corrosive and cleanable.
- Cooling tower water should be treated with corrosion inhibitors and protected against freezing.
- Separate circuit aftercooling generally improves operating performance of all turbocharged engines, but gas engines MUST have a separate cooling source.
    - Cooling water temperature less than 54° C (130° F) is required to maintain proper (full) engine/generator power ratings and emission levels and to avoid detonation of the fuel mixture.
    - Split or dual core radiators will usually provide 54° C (130° F) coolant.
    - Lower water temperatures or air-to-air aftercooling will allow even greater performance.

SEPARATE CIRCUIT AFTERCOOLING (SCAC)



Inlet Temperature Range For Aftercooling:
32° C (90° F) to 54° C (130° F)

Air-to-Air AfterCooling (ATAAC)
ATAAC is an optional cooling medium used to achieve low charge air temperatures. The charge air is routed to the heat exchanger while ambient air driven by the radiator fan passes across the external surface. Aftercooler heat rejection, charge air flows, and piping restrictions require analysis to avoid compromising engine performance.



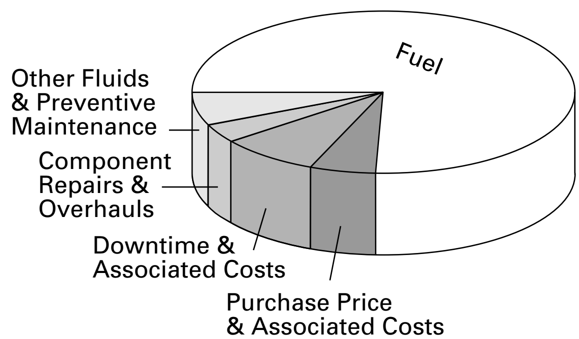
COOLING

HEAT RECOVERY

Recovery design for any installation depends on several technical and economic considerations. The primary function of any heat recovery system is to cool an engine or group of engines. Provisions must be made to ensure engines operate at correct temperatures, even when plant heat demands are small.

Fuel is the largest operating expense associated with a generator set.

GENERATOR SET OPERATING COSTS

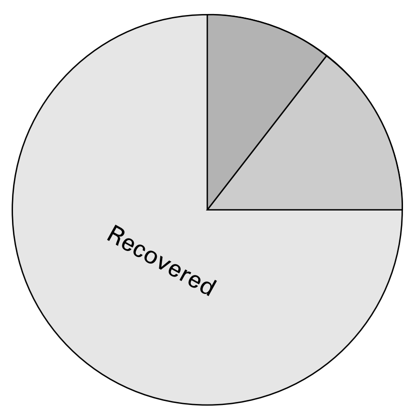


In typical prime power applications, fuel costs over a ten-year cycle can range from 75 to 85 percent of total operating costs. Therefore, in installations where heat can be recovered and used, it is possible to increase total energy output per dollar and yield significant savings.

Reciprocating engines convert about 30 to 37 percent of their input fuel energy into mechanical power. The remainder transforms into heat and is carried from the engine by jacket water, exhaust, and radiation.

- The 20 to 40 percent of generator set heat contained in jacket water can be totally recovered.
- About half of the 30 to 40 percent carried by the exhaust is economically recoverable.
- Total heat recovery results in fuel efficiencies approaching 80 percent.

USING HEAT RECOVERY



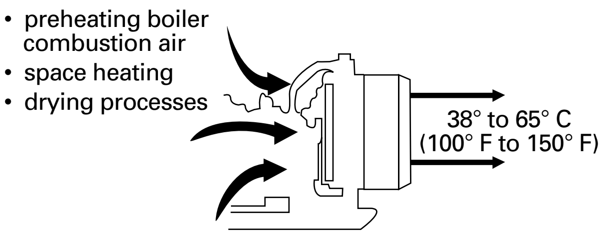
HEAT RECOVERY

Heat recovery may be as simple as utilizing heat from the engine radiator. Air passing through the radiator core of a loaded engine has a temperature of 38-65° C (100-150° F), and is suitable for:

- Drying
- Space heating
- Preheating boiler combustion air

Recovering radiator heat requires no modification of standard engine equipment, with overall efficiency approaching 60 percent.

TYPICAL HEAT RECOVERY APPLICATIONS



Types of Heat Recovery

Heat recovery methods are grouped as follows:

- Standard Temperature [93° C (200° F)]
- High Temperature [127° C (260° F)]
  - Solid Water [127° C, 137.4 kPa (260° F, 20 psi)]
  - Ebullient Steam [121° C, 103.4 kPa (250° F, 15 psi)]

Standard Temperature Heat Recovery

This approach uses a shell and tube heat exchanger to transfer the heat of normal jacket water [temperatures about 93° C (200° F)] to a secondary circuit — usually water.

The typical heat recovery system involving standard temperature jacket water includes standard engine equipment. Plant hot water is taken from the secondary side of the heat exchanger. After warmup, the regulator allows flow to the plant load heat exchanger.

Expansion Tank Location

Ideally, all flow passes through the expansion tank to promote deaeration.

The added external head of the extended jacket water circuit may exceed the allowable head on the engine mounted pump, so an auxiliary pump may be necessary.

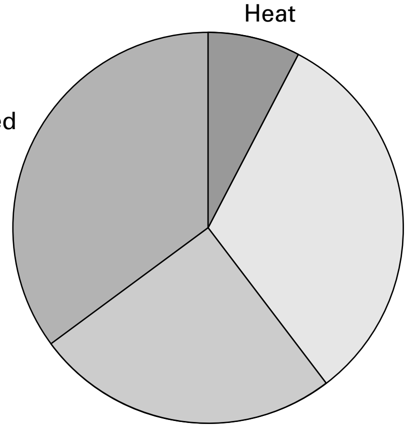
The amount of heat available is dependent on the mechanical load on the engine, so, in times when electrical loads are light but plant heat loads are high, an additional heating source (boiler) may be necessary. If heating loads are sometimes low when electrical loads are high, a load balancing heat exchanger should be incorporated.

HEAT RECOVERY

An exhaust heat recovery muffler may be added to the system as a separate water circuit or in series with the jacket water. As a separate heat source independent of the jacket water, the muffler water circuit can produce high temperature water or steam.

- The amount of heat available is highly dependent on engine load.
- Coolant must flow through the heat recovery device whenever the engine operates to avoid thermal shock.

Muffler Heat Recovery



Heat recovery mufflers economically recover about half the engine exhaust heat. Exhaust exit temperature above 149° C (300° F) discourages condensation in ducting. For each gallon of diesel fuel burned, a gallon of water is carried into the exhaust.

Recoverable heat data is obtained from the engine manufacturers but can be estimated by:

Q = CpM (T1-T2) where:

Q = Recoverable Heat (KJ/h)
Cp = Specific Heat
Diesel Engines – 1.081 KJ/kg per °C
Gas Engines – 1.170 KJ/kg per °C

T1 = Exhaust Gas Stack Temperature (°C)
T2 = Exhaust Gas Exit Temperature (°C)
M = Exhaust Mass Flow (kg/h)

$$M = \frac{M^3/\text{min} \times 60 \times 353.0}{T1\ (^\circ C) + 273^\circ\ C} \quad \text{OR}$$

Q = CpM (T1-T2) where:

Q = Recoverable Heat (Btu/hr)
Cp = Specific Heat
Diesel Engines – 0.258 Btu/lb per °F
Gas Engines – 0.279 Btu/lb per °F

T1 = Exhaust Gas Stack Temperature (°F)
T2 = Exhaust Gas Stack Temperature (°F)
M = Exhaust Mass Flow (lb/h)

$$M = \frac{\text{Exhaust Flow (cfm)} \times 60 \times 39.6}{T1\ (^\circ F) + 460^\circ\ F}$$

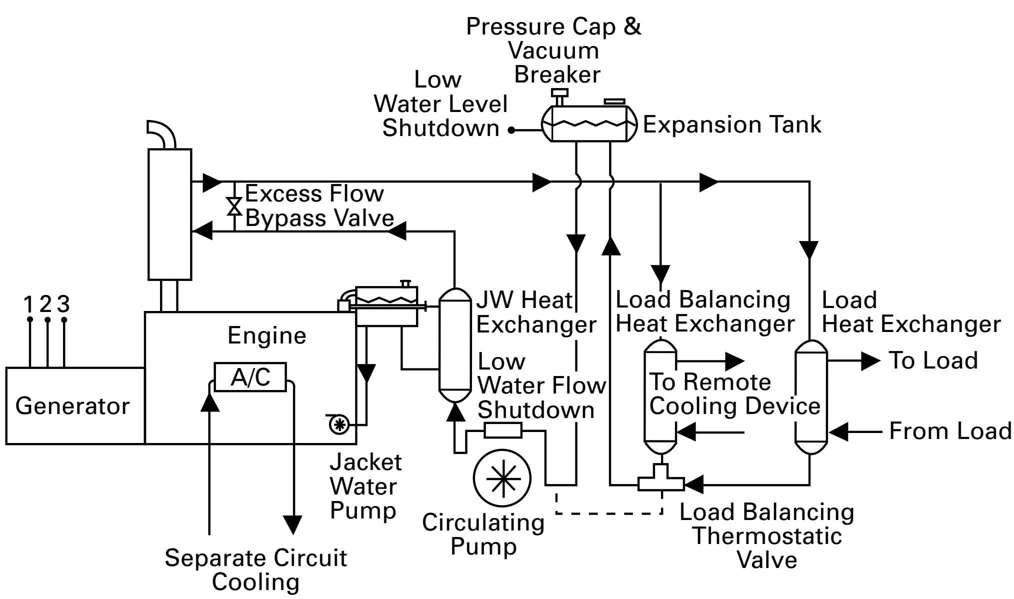
HEAT RECOVERY

HEAT RECOVERY

Muffler/Jacket Water in a Series
Placing the muffler in series with the secondary side of the jacket water heat exchanger adds the heat rejection of the two systems into a single source. The additional heat from the muffler demands a larger load balancing device than with the jacket water alone.

- Removal of engine thermostats and blocking water bypass prevents sudden thermal shock of coolant on hot muffler surfaces.
- An external regulator directs coolant back through the engine and the heat recovery muffler.
- When heat available from the engine and muffler exceeds plant heating requirements, an additional cooling source is added to the system to accommodate both jacket water and muffler heat.

STANDARD TEMPERATURE WATER SYSTEM
With Series Exhaust Heat Recovery



HEAT RECOVERY

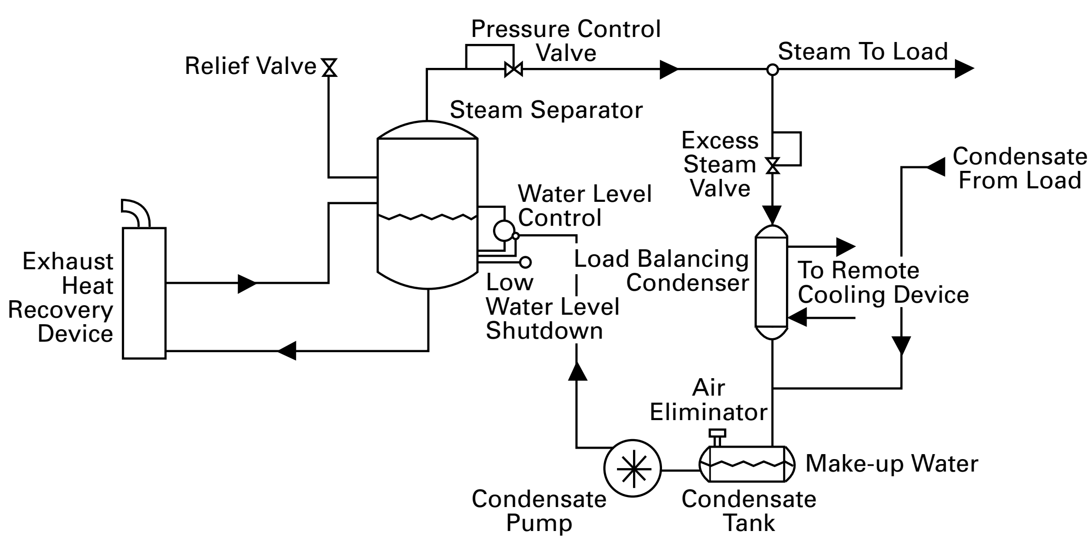
Water-Steam Circuit Heat Recovery System
The heat recovery muffler can be included in the system as a separate water-steam circuit for loads requiring high temperatures — in excess of 99° C (210° F).

In hospital applications, for example, absorption equipment may require 93° C (200° F) water, while sterilization equipment may require water-steam in excess of 99° C (210° F). The engine jacket water system could be used for the absorption equipment, and the exhaust heat recovery system for the sterilization equipment.

Here's how it works:

1. Water-steam flows through the exhaust heat recovery device to the steam separator.
2. Load demands determine valve pressures.
3. The pressure control valve regulates pressure within the steam separator.
   - The relief valve should be set at least 6.9 kPa (1 psig) above the pressure control valve setting.
   - The excess steam valve is set equal to or less than the pressure control valve setting.
4. As steam is absorbed by the load, it condenses to a liquid state, flows through the condensate tank, and is pumped back to the steam separator.
   - To avoid thermal shock on hot muffler surfaces, a low water flow shutdown device ensures constant coolant flow through the muffler.

SEPARATE CIRCUIT EXHAUST HEAT RECOVERY SYSTEM



HEAT RECOVERY

Design Criteria — Standard Temperature Heat Recovery Systems
Certain requirements are necessary for proper operation of a standard temperature heat recovery system. The following is not, however, an all-inclusive list. An engineer should be consulted for specific installations.

- The system must provide adequate coolant flow through the engine so the engine coolant temperature differential (outlet minus inlet) does not exceed 8.5° C (15° F).
- The expansion tank must be the highest point in BOTH the engine and load loop cooling systems. Locate the jacket water heat exchanger as near the engine as possible.
- Only treated water should be used 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 whenever the engine is operating to avoid thermal shock on hot muffler surfaces. This can be accomplished by using a low water flow shutdown device.

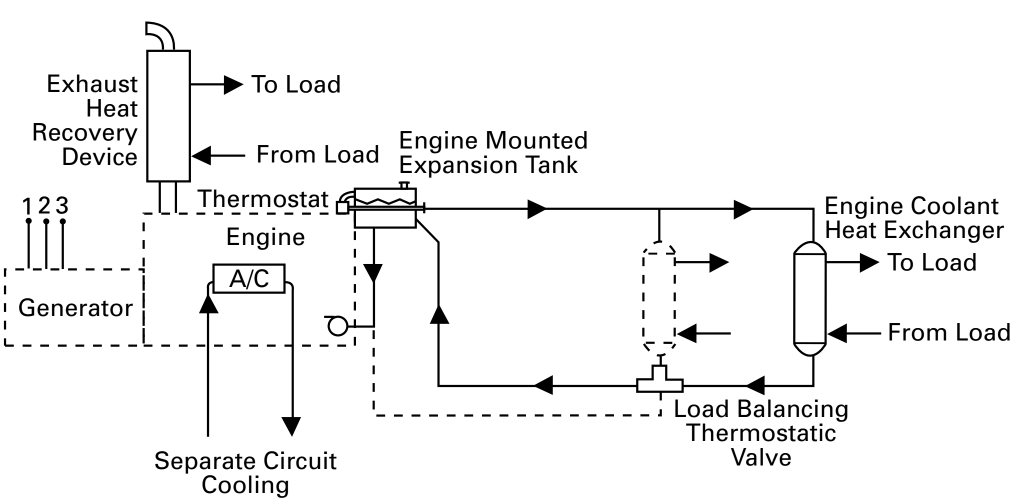
High Temperature Heat Recovery

Types of high temperature heat recovery systems include:

- Solid water system
- Ebullient system
- Water-steam system

High Temperature Heat Recovery System Design
Elevated jacket coolant temperatures [99° to 127° C (210° to 260° F)] recorded at engine outlet require higher system pressure to prevent flashing to steam. Operating pressures are normally 27.6 or 34.5 kPa (4 or 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 pressure in the expansion tank.

STANDARD TEMPERATURE WATER SYSTEM
Critical Design Criteria



HEAT RECOVERY

- For 127° C (260° F) water temperature, engine pressures are approximately 138 kPa (20 psig).
- Pumps suitable for elevated temperatures and pressures replace conventional engine jacket water pumps.
- High temperature engine operation requires separate cooling circuit for oil cooler and aftercooler.

Separate Circuit Oil Cooler/Aftercooler
To ensure proper cooling in all types of high temperature systems, the engine oil cooler (heat exchanger) and aftercooler require a cooling water circuit separate from the engine jacket water.

- A thermostat in the oil system controls lubricating oil temperature to prevent overcooling.
  - The thermostat begins to open at 82° C (180° F), and oil leaving the cooler should not exceed 88° C (190° F).
  - The maximum allowable coolant temperature to the oil cooler is 77° C (170° F).
- An external control valve is recommended to prevent oil gelling and ensure oil flow through the oil cooler.
  - The valve will bypass coolant to the radiator until the coolant reaches correct operating temperature.
- The standard water pump should be removed and replaced by a special high temperature pump.

Load Balancing Cooling Circuit
Below is a schematic of a load balancing remote radiator cooling circuit. There is no water flow through the load balancing heat exchanger when the load uses all the water/steam provided.

In cold environments, to prevent water from freezing in the heat exchanger, an external thermostatic control valve will bypass coolant to the radiator until the coolant reaches correct operating temperature.

Solid Water System
The function of this system is similar to a standard temperature water system, except elevated jacket water temperatures [99° to 127° C (210° to 260° F)] are used.

- The standard engine thermostat and bypass are removed and replaced by an external control (warm-up thermostatic valve).
- A pressure cap must be provided in the engine coolant circuit to assure a pressure of several kPa (psi) above the pressure at which steam forms.

HEAT RECOVERY

HEAT RECOVERY

- 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, pressure should be about 172 kPa (25 psi).

- The standard jacket water pump must be removed and replaced with one with high temperature and pressure capabilities.

Design Criteria — High Temperature Solid Water Systems

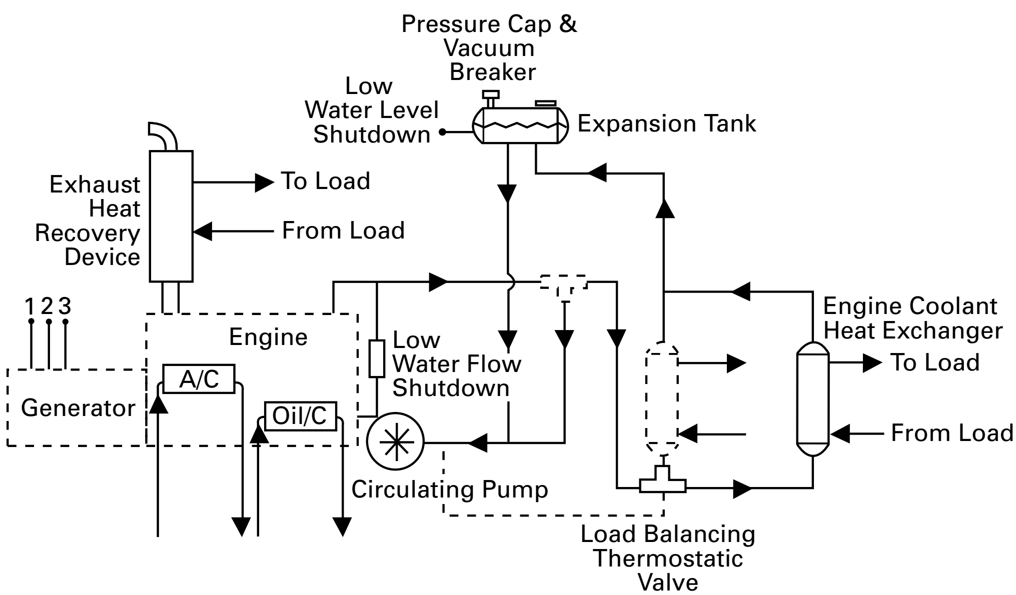
These design features are similar to those required for a standard temperature system. Check with a consulting engineer for a more comprehensive list.

- The system must provide adequate coolant flow through the engine so the engine coolant temperature differential (outlet minus inlet) does not exceed 8.5° C (15° F).
- The expansion tank must be the highest point in the cooling system. Locate the engine coolant heat exchanger as close to the engine as possible.
- Only treated water should be used in the 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 whenever the engine is operating to avoid thermal shock on hot muffler surfaces. This may be accomplished by using a low water flow shutdown device.

Unlike a standard temperature system, a high pressure system also requires:

- A pressure control for the engine coolant circuit.
- Water pumps suited for use with elevated temperatures and pressures
- Engine oil cooler and aftercooler with a cooling water circuit separate from engine jacket water

HIGH TEMPERATURE WATER SYSTEM
Critical Design Criteria



HEAT RECOVERY

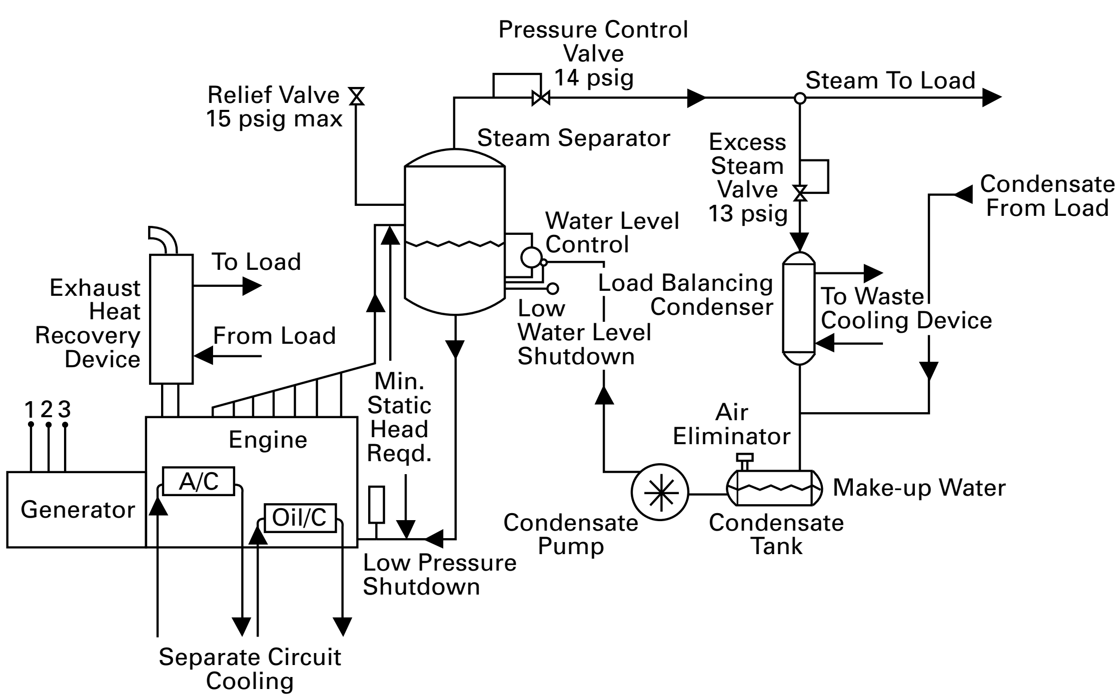
Ebullient System
"Heat of vaporization" removes rejected heat from the engine. A pound of water at atmospheric conditions of 101 kPa and 16° C (14.696 psia and 60° F) gains 1122.3 Btu [970.3+(212-60) = 1122.3] during vaporization. While ebullient installations are highly successful when properly applied, the difficulties involved in integrating the engine cooling system with the plant heating load discourage widespread acceptance.

- Steam is not collected within the engine but moves through the water passages mixed with high temperature water.
- Thermal action carries the mixture to a steam separator elevated above the engine.
- No jacket water pump is required with this system.
- While temperature differential between "water in" and "water out" is usually quite low [1.1° to 1.7° C (2° to 3° F)], flow is assured by change in coolant density as it gains engine heat.
- Formation of steam causes coolant to become lighter and creates a pressure differential between water inlet and outlet.

A variety of heat recovery arrangements are possible. The exhaust gas boiler, or muffler, and the steam separator can be combined into single "packaged" units — one package unit used for each engine. Other equipment combines exhaust gas boilers and steam separators in single units which may include a direct-fired section to eliminate the auxiliary boiler. Such units can each serve two engines, but to do so requires complex exhaust piping with a steam separator located above the engine.

Design Criteria — Ebullient Systems
- To avoid excessive boiling within the engine and the formation of steam pockets in water passages, engine coolant must be under a static head of at least 55 kPa (8 psi), but the combination of static and dynamic head must not exceed 197 kPa (28.5 psi).

EBULLIENT SYSTEM



HEAT RECOVERY

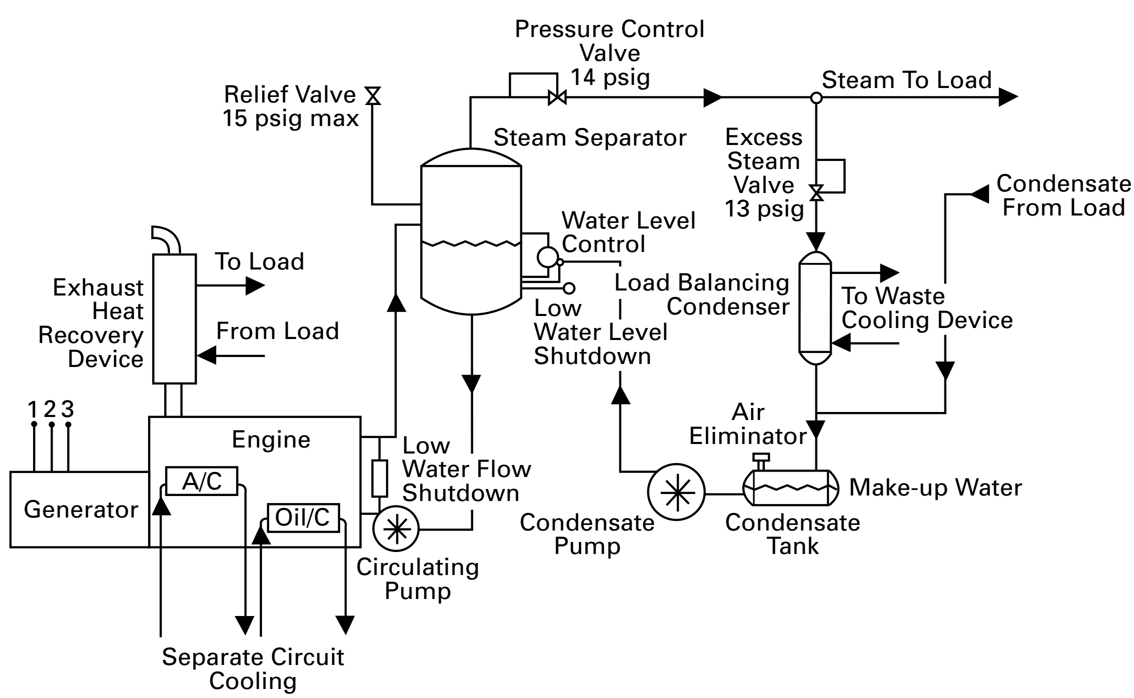
- The engine oil cooler and aftercooler require a separate water circuit from engine jacket water.
- The engine oil cooling system must be protected against a sudden loss of pressure.
  - Controls which limit a sudden pressure drop to 21 kPa (3 psi) must be located between the separator loads.
- Coolant piping between engine and steam separator must be installed so the flow of coolant (water and steam) will always be upward.
- Make-up water should be provided to compensate for any loss in the system.
  - This water should be treated and fed into the condensate tank.

Water-Steam System
The high temperature water-steam system is similar to the ebullient system with the addition of a circulating pump to assure positive flow. The circulating pump forces water through the cylinder block and heads to flush steam bubbles that may form in the engine.

Next the mixture flows to a steam separator. The steam separator is similar to the one used with the ebullient system, except it is sized for larger water flow.

The following pressures are representative values. The relief valve pressure 103 kPa (15 psi) is set by boiler codes. Pressure in the separator is controlled by the pressure control valve. Once the pressure builds to 97 kPa (14 psi), the control valve will allow steam to flow. The actual steam pressure in the load line is a function of load requirements. If the load is not consuming steam, the pressure in the steam line will increase. Once pressure reaches 90 kPa (13 psi), the excess steam valve will open to transfer engine heat to the waste cooling device (load balancing condenser). Install the excess steam valve downstream of the pressure control valve. If it is upstream, the pressure control valve may not function properly.

HIGH TEMPERATURE WATER-STEAM SYSTEM



HEAT RECOVERY

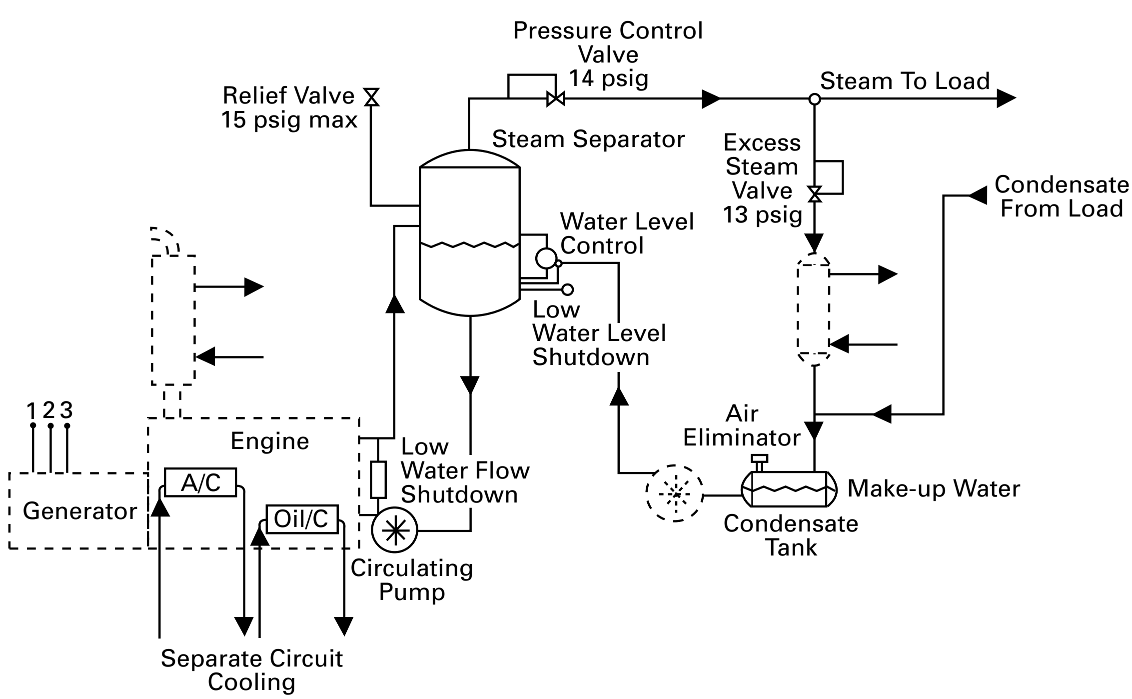
Design Criteria — Water Steam Systems
There are no elevation or static head requirements for the steam separator. Therefore, this system may be used in locations with limited overhead clearance.

- Pressure at the engine outlet must be maintained between a minimum of 55 kPa and a maximum of 197 kPa (8.0 to 28.5 psig).
- Maximum temperature at engine outlet must not exceed 127° C (260° F).
- A low water flow shutdown device is standard on high temperature cooling engines; it is a pressure differential switch located across the engine water jacket.
  - When the water flow rate slows or stops, a pressure drop across the engine block will shut down the engine.
- The pump should be running while the engine is operating, and the pump should continue to run for approximately five minutes after the engine is stopped.
- Proper water treatment care is essential for successful system operation.
- A low water level shutdown in the steam separator device is required and a low water level pre-alarm is also recommended. Low engine water level could cause engine overheating and more serious damage.

Lubricating Oil — an Auxiliary Heat Source
When recovering heat from engines using high temperature cooling systems, it may be worthwhile to use heat rejected to lubricating oil. This heat can be applied to preheat 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 7.9 Btu/kW-min (5.5 Btu/hp-min) for gas engines, 12.2 Btu/kW-min (8.5 Btu/hp-min) for diesel engines.

HIGH TEMPERATURE WATER-STEAM SYSTEM
Critical Design Criteria



FUEL SYSTEM

The main areas of consideration in a discussion of fuel systems and fuels are:

- *Fuel tanks, main and auxiliary*
- *Fuel coolers*
- *Fuel filters*
- *Types of fuels*
- *Gas engines*

Fuel Tanks

Main tanks are large tanks where fuel is stored. The fuel is transferred from the main tanks to smaller auxiliary tanks for ready access by the engine.

Bulk Storage

Fuel supply systems assure continuous and clean supplies of fuel. Bulk fuel is usually stored in large tanks and transferred to smaller tanks (day tanks) near engines by electric motor-driven pumps. Flexible nonmetallic lines routing fuel inside buildings should meet fire-resistant qualifications similar to U.S. Coast Guard Specification 56.60-25(c).

- National Fire Protection Association (NFPA) 37 further identifies fuel storage methods and quantities.

- The 1981 U.S. National Electric Code, Article 700, calls for on-site fuel supplies capable of operating the prime mover at full demand load for at least two hours.
- Fuel storage is one of the cheapest items for an installation. It is wise to provide too much rather than too little storage capacity.

Tank Material

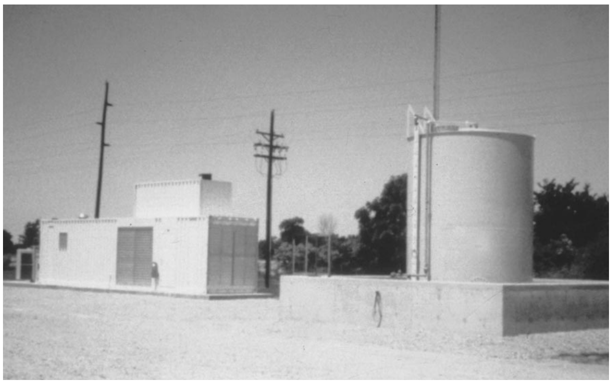
- Steel tanks are preferred, but black iron tanks and fittings are satisfactory.
- Avoid galvanized, aluminum or zinc-bearing fittings and tanks, because chemical reactions with fuel impurities will clog fuel filters.

Tank Installation

Large capacity storage tanks allow bulk purchases and minimize dirt contamination. Maintaining full tanks reduces condensation, particularly if fuel is seldom used.

- Tanks may be above or below ground level, but high fuel level generally should not exceed the engine injector's height. This prevents possible fuel leakage into cylinders.
  - New and existing tanks must meet stringent corrosion protection and leak detection regulations.

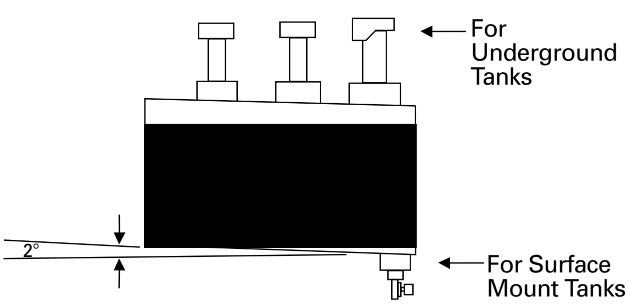
FUEL SYSTEM



- Above ground tanks provide accessibility, allowing for easy draining of impurities and reducing the danger of ground water contamination.
- Underground tanks allow the earth to work as an insulator, limiting radical temperature changes which can cause flow restrictions, condensation, and possible power loss.
- Regulations governing the installation and maintenance of both above and below ground fuel tanks may apply.

Tank Design

- Water and sediment are drawn periodically from the tank. Contaminants can be localized by rounding the tank bottom and tilting it about two degrees toward the drain.



- Consider ground settling when installing tanks so drain cocks remain low.
  - Avoid seasonal settling by burying tanks below frost lines.
  - Locate storage tank fill tubes for convenience and safety of filling operations.
- In underground tanks, remove water by pumping through a tube placed down the fill pipe.
- Vents relieve air pressure created by filling and prevent vacuum as fuel is consumed.

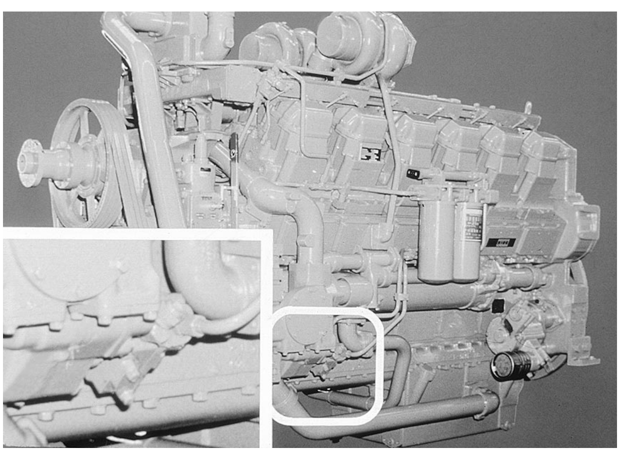
Tank Maintenance

- Water contamination of fuel during long-term storage encourages microorganism grout, forming a dark slime which:
  - Plugs filters
  - Deposits on tank walls and pipes
  - Swells rubber products that it contacts
- Sulfur compounds are natural antioxidants, so the low sulfur fuels (0.05 percent by weight) now available will degrade quicker in storage. Gums and varnishes will form which can plug fuel filters and injectors.
- Because microorganism growth occurs in the fuel/water layer, the tank should be designed to minimize this interface, and water bottoms should be drained regularly.
- Microbiocide additives, either water- or fuel-soluble, can be added to fresh fuel to inhibit microorganism growth. Consult your local fuel supplier for recommended additives.

FUEL SYSTEM

- In warm climates, large bulk storage diesel fuel requires full filtering every six months to one year.
  - Every two years fuel should be completely changed to remove water, scale, bacteria growth, oxidized gums/resins, and minimize filter clogging due to fuel separation into components such as asphaltenes.
- If it is necessary to store fuel longer, kerosene may be substituted for diesel fuel.
  - A simple engine power adjustment may be needed for this fuel's lower Btu content to achieve full rated power.

Pump Lift

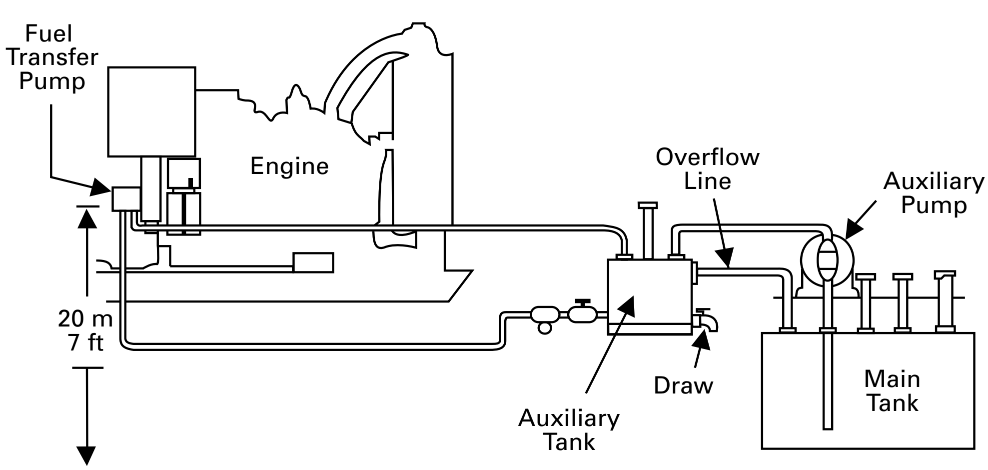


Cat engine-mounted transfer pumps are positive displacement gear-type or piston-type and have a prime and lift capacity of 2.0 m (7 ft) of diesel fuel. Pipe size, bends, and cold ambients limit this capacity.

Total System

If day tanks are not used, bulk tanks must provide a ready fuel supply to the engine-mounted transfer pump.

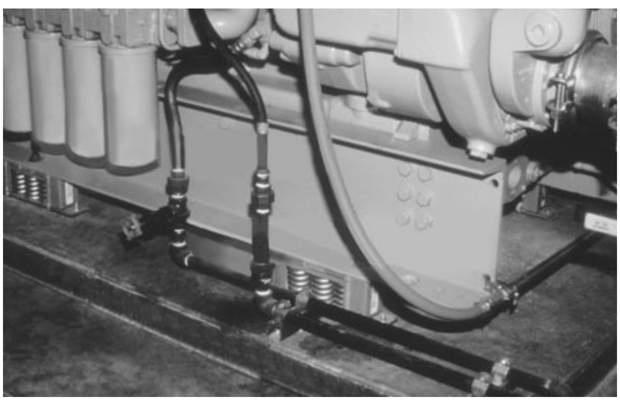
- Because the fuel shutoff function is normally accomplished in the engine fuel system, the supply line requires no additional shutoff to stop engine operation.
  - A shutoff in the supply line can cause a vacuum if activated prior to the engine coming to a complete stop, which, depending on the inertia of the system, can require several seconds.
  - If a separate supply line shutdown is required by specification, avoid hard starting problems by including a time delay for the solenoid.
- The return line enters the top of the tank without shutoff valves, allowing air to pass freely and prevent a vacuum in the fuel system.
  - No more than 60 kPa (8.7 psi) restriction is recommended in the return line.
  - Fuel suction lines remove fuel about 51 mm (2 in) above the tank bottom and tank end opposite the return line.



FUEL SYSTEM

- Piping and fittings should be sealed to prevent air and dirt contamination.
  - Air in the system causes hard starting and erratic engine operation.
- Joint cement affected by fuel should be avoided, and connection should be made without gaskets.
- Flexible fuel lines between fuel source (bulk storage or day tank) and engine fuel inlet and return will isolate vibration.

Fuel Lines



The delivery line carrying fuel to the fuel transfer pump, and the return line carrying excess fuel to the tank should be no smaller than engine fittings. If the fuel tank feeds multiple engines over 9.14 m (30 ft) from the tank, or temperatures are low, larger fuel supply and return lines ensure adequate flow. The overflow line from the day tank (or, if no day tank is used, the engine fuel return line) should be one size larger.

Auxiliary Tanks

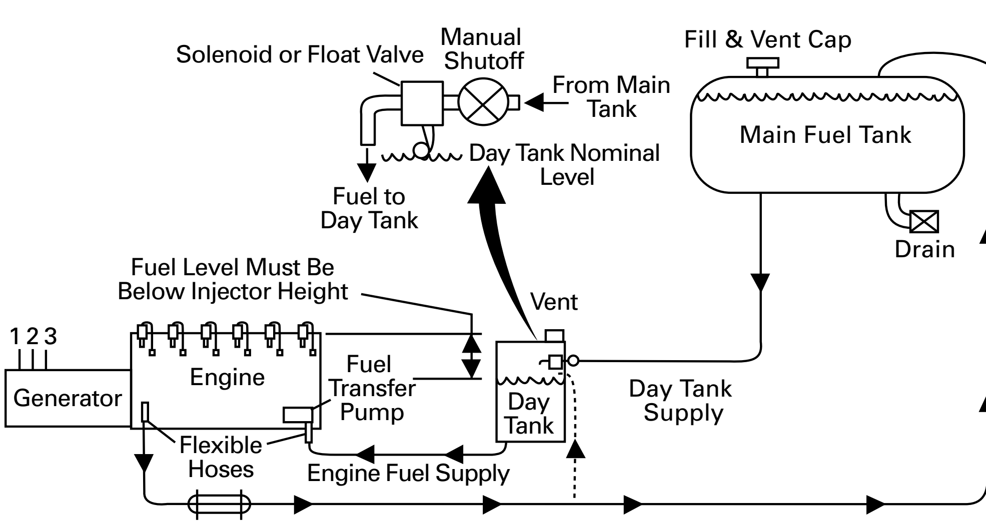
If the fuel tank is placed more than 2 m (7 ft) below the engine transfer pump, or more than 15 m (50 ft) from the pump, an auxiliary tank — or “day tank” — is desirable. While most engines have 9-12 ft lift capability, the 3208 and 3304 have a 7 ft limit.

Base Mounted Fuel Tanks

Base mounted day tanks are sometimes used to provide a convenient and close source of fuel with adequate capacity for four to eight hours of operation. While minimizing the floor space needed for fuel storage, the height of the engine will increase significantly with this option designed to ease maintenance.

If fuel must be located above the injectors, an **overhead mounting day tank** is recommended to avoid excessive pressures on the fuel system.

ELEVATED FUEL SUPPLY DESIGN



FUEL SYSTEM

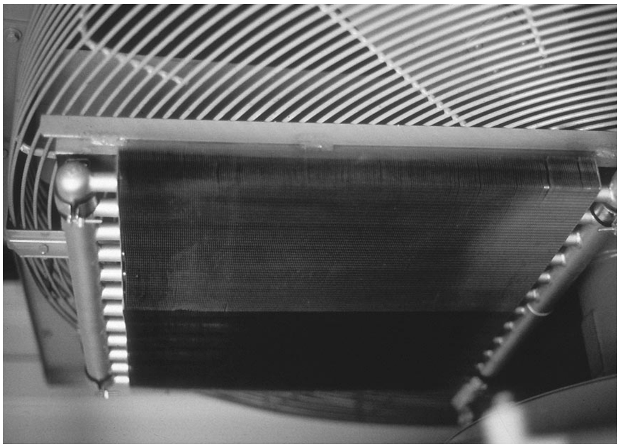
- A float valve or solenoid valve in this type of day tank regulates the fuel level to keep it below the level of the injectors.
- Fuel returning to the main tank will, because of its volume, aid with cooling, but returning to the day tank is permissible.
- If overhead mounting is unavoidable, as in NFPA Section 20 concerning fire pumps, include a 20.67 kPa (3 psi) differential check valve in the supply line and a 3.45 kPa (0.5 psi) differential check valve in the return line.

Coolers and Filters

By reducing the temperature of fuel and removing harmful particles, coolers and filters improve the quality of the fuel used by an engine.

Coolers

Engines incorporating unit fuel injectors transfer about 42.2 kJ (40 Btu) per minute per injector into the return fuel. If the fuel tank is insufficient to dissipate this heat, a cooling source must maintain fuel temperatures below 68° C (155° F). Heat also causes a volumetric change, resulting in a one percent power loss for each 6° C (10° F) above 38° C (100° F).



Auxiliary Cooling

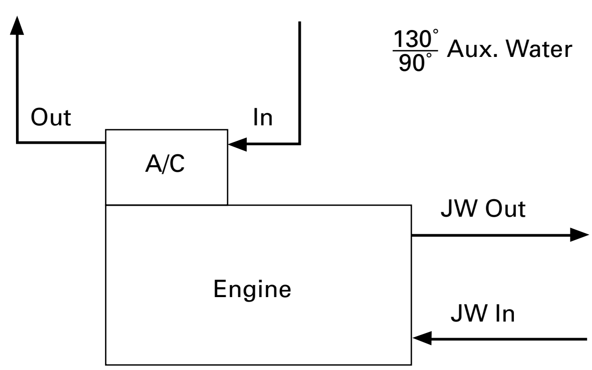
The air-fuel mixture a naturally aspirated engine can draw into its cylinders is limited by the engine's breathing characteristics and atmospheric conditions. Therefore, engine power output is limited.

Turbocharging is an efficient means of increasing air flow and power output. However, air compression by the turbocharger increases air temperature. An aftercooler between the turbocharger and intake manifold cools the compressed air. Acceptable temperature levels are achieved using a water source separate from engine jacket water.

Two temperature ranges are available:

- Water at a minimum of 32° C (90° F)
- Water at a minimum of 54° C (130° F)

SCAC



Filters

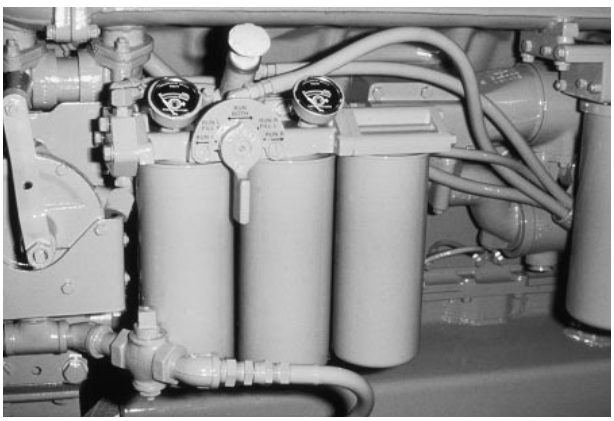
Clean fuel is necessary for dependable engine performance. Engine filters protect the fuel injection pumps and nozzles and should never be removed or bypassed.

Primary filters with 0.30 mm (0.012 in) screens extend engine filter and transfer pump life. Water and sediment traps can be included upstream of the transfer pump, but pump flow must not be restricted.

FUEL SYSTEM

Duplex filters for fuel and lubricating oil allow extended operation without interruption.

- The main and auxiliary filter systems allow changing either the main or auxiliary filter elements with the engine running under load.
- Generally, the same elements are used in both systems, and are capable of providing adequate filtration for at least 100 hours full load running time with reasonably clean fuel and oil.



- Use pressure gauges to determine when filters must be changed.
- Avoid mounting filters near the radiator fan, because a fuel or oil leak during replacement could create a fire hazard. (As either substance passes through the fan it can be atomized, and therefore easier to ignite.) Plus, coated radiator fins trap dirt which can diminish cooling capability.

Caterpillar Engines

Caterpillar engines operate efficiently with a variety of fuels. Generally, use the lowest priced distillate fuel which meets the requirements.

Diesel engines may require optional equipment to run on fuels as light as Jet-A, JP-5, and kerosene, and fuels with heavy distillates.

Clean fuels provide maximum service life and performance. Dirty fuels adversely affect combustion, filter life, injection system performance, startability, and component service life.

Requirements

Cetane Number Precombustion Chamber Direct Injection	 35 minimum 40 minimum
Viscosity	100 SUS at 38° C (100° F) max.
Pour Point	6° C (10° F) below ambient temp.
Cloud Point	not higher than ambient temp.
Sulfur	adjust oil change period for high sulfur fuel (greater than 0.5%)
Water and Sediment	0.1% maximum

Fuels meeting the above requirements include:

ASTM D396	No.1 and No. 2 fuels (burner fuels)
ASTM D975	No. 1 and No. 2-D diesel fuel oil
BS2869	Class A1, A2, B1, and B2 engine fuels
BS2869	Class C, C1, and C2 and class D burner fuels
DIN51601	Diesel fuel*
DIN51603	EL heating oil*

* These distillate fuels are also referred to as "gas oil," "35-second oil" (Redwood No. 1), or "diesel oil."

FUEL SYSTEM

FUEL SYSTEM

Other fuel categories requiring special treatment or blending when applying to modern engine designs include:

- Light residual fuel oil — ASTM D936-67 heavy, BSS2869 Class F, loosely referenced as "boiler fuel" or "1000-second oil"
- Heavy residual fuel oil — ASTM D936-67 No. 6, BSS2869 Class G, sometimes called "burner fuel oil" or "3500-second oil"

Aviation kerosene can be used as a fuel for Caterpillar diesel engines but some precautions must be taken. The following **aviation fuels** are defined by military, NATO, and commercial codes:

Name (military or commercial)	MIL-Spec ASTM SPEC	NATO Code	Comments
JP-4	MIL-T-5624	F-40	Aviation gasoline; NOT for use as Cat engine fuel
JP-5	MIL-T-5624	F-44	Aviation kerosene; acceptable Cat engine fuel; must control viscosity
JP-8	MIL-T-83133	F-34	Aviation kerosene; acceptable Cat engine fuel; must control viscosity
Jet A-1	ASTM D 1655	F-35	Commercial aviation kerosene; acceptable Cat engine fuel; must control viscosity
Jet A	ASTM D	1655	U.S.A. commercial aviation kerosene; acceptable Cat engine fuel; must control viscosity

FUEL SYSTEM

The **viscosity** of fuel is significant because the fuel serves as the lubricant for the fuel system components.

- If the viscosity of the fuel is lower than 1.4 cSt as supplied to the engine, excessive wear and scuffing, and seizure can occur.
- JP-5 fuel typically has a viscosity of 1.5 cSt measured at 40° C (the normal temperature used to evaluate a fuel).
- JP-8, Jet A-1 and Jet A have a viscosity of 1.2 cSt typically measured at the 40° C temperature, which is below the desired value for Cat engines.
  - To eliminate the problem of low viscosity of JP-8, Jet A-1, and Jet A kerosenes, the fuel can be supplied to the engine at a lower temperature to provide an increased fuel viscosity.
  - At a temperature less than 25° C (77° F), the fuel should have sufficient viscosity to properly lubricate the fuel system components.
  - The military fuel JP-8 does have a mandatory additive package (icing inhibitor, corrosion inhibitor, and static dissipator additive) which does increase the lubricity of the fuel. Jet A-1 may or may not have this additive package.
- Light fuels may out-produce rated power at factory settings, but adjustments to the engine fuel system are generally discouraged.
  - Fuel system component life may experience increased wear due to the low viscosity of the lighter fuel.
- The customer should order as heavy a distillate fuel as engine and temperature conditions permit.

NOTE: Caterpillar diesel engine fuel settings are based on 35-degree API (specific gravity) fuel. Fuel oil with a higher API (lower specific gravity) number reduces power output unless settings are corrected. When using heavier fuels, a corrected setting prevents power output above approved ratings.

Crude Oil Fuels
Crude oil, in some cases, is a practical and economic fuel for diesel engines. Crude oils are evaluated individually and special equipment may be needed to condition the fuel. Minimum guidelines have been established to determine the suitability of crudes.

Residuals

Residual fuel (which resembles tar and contains abrasive and corrosive substances) is composed of the remaining elements from crude oil after the crude has been refined into diesel fuel, gasoline, or lubricating oil.

After the more desirable products have been refined, residual fuel can be combined or diluted with a lighter fuel to produce a mixture that can flow. This mixture is called **blended or heavy fuel**. Heavy fuels tend to create more combustion chamber deposit formations which can cause increased cylinder and ring wear, particularly in smaller, higher speed engines.

- Blending may improve fuel density, but addition of alcohol (ethanol, methanol) or gasoline causes an explosive atmosphere in the tank and is not recommended.
- Cat 3500 and 3600 family engines can be modified to run on blended fuels, but extreme PREVENTIVE MEASURES MUST BE TAKEN, including following a thorough maintenance program and use of high quality fuel treatment equipment.

FUEL SYSTEM

Blended fuel can lower fuel cost, but there are often significant trade-offs. Fuel price must be weighed against:

- Fuel containment effects
- Reduced engine component life
- Higher maintenance and personnel costs
- Reduced warranty

Total Base Number

Most diesel fuels contain some degree of sulfur. Usually, heavy fuels have a higher sulfur content than distillates. Lubrication oils neutralize sulfur by-products, namely sulfuric acid, and thus retard corrosive engine damage.

TBN (Total Base Number) reflects the alkalinity number and is a measure of an oil's acid-neutralizing capacity.

- The higher the TBN, the more neutralizing capacity.
- When the fuel sulfur content exceeds 0.5 percent, special lubricating oil and more frequent oil changes are required to assure satisfactory engine/oil service life.

New oil TBN — Follow 1.25 line to line A which intersects at 25. This is the recommended TBN for 1.25 percent sulfur content.

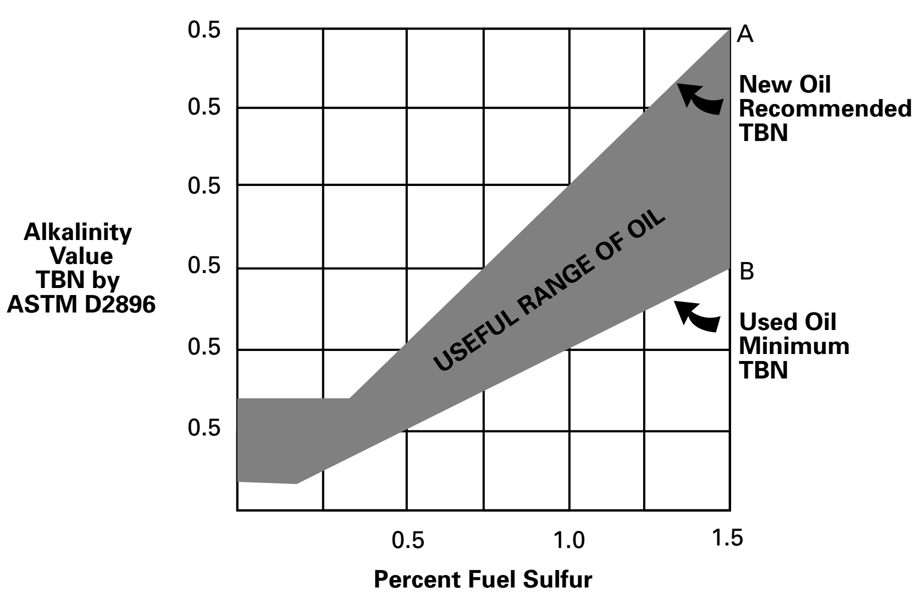
Used oil TBN — Follow 1.25 line up to line B which intersects at 12.5. At 12.5 TBN the oil should be changed.

Fuel Economics

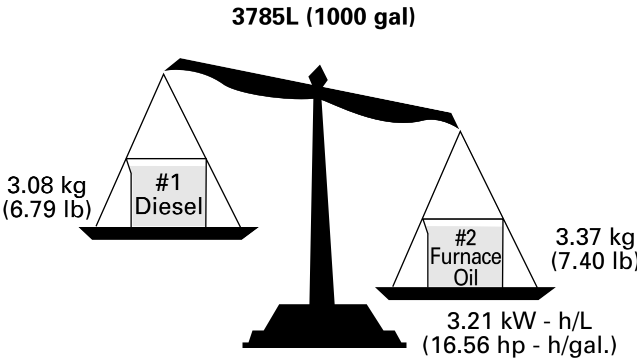
Heavier fuels generally provide more energy. Examining the economics (see the illustration provided) we can see that a gallon of No. 1 diesel fuel weighs 3.08 kg (6.79 lb) and will produce approximately 3.10 kW-h/L (15.78 hp-h/gal). The normal — and heavier — weight of No. 2 furnace oil is 3.37 kg (7.40 lb) and will produce approximately 3.21 kW-h/L (16.56 hp-h/gal).

Thus, for each 3785 L (1000 gal) of No. 2 furnace oil, you obtain an additional 582 kW/h (780 hp/h) — or a 4.9 percent gain. What's more, furnace oil is usually less expensive.

NEW OIL ALKALINITY VALUE REQUIRED FOR A STANDARD OIL CHANGE PERIOD WITH UP TO 1.5% FUEL SULFUR



FUEL SYSTEM



Since fuel consumption is the largest generator set operating expense, consider using a fuel which will provide the lowest cost per kW/h (hp/h) while delivering satisfactory performance.

Engine Configuration

To correctly determine which spark ignited engine configuration is required for a specific application, the following minimum information must be known:

- Horsepower required
- Gas pressure
- Type of fuel
- Type of cooling system
- Temperature of auxiliary cooling water
- Exhaust emission levels permitted

Gas Pressure

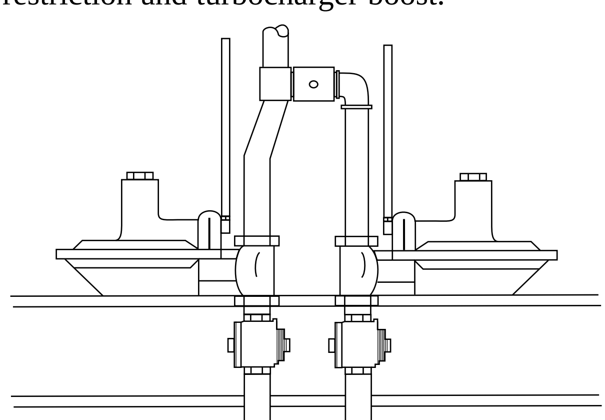
- Naturally Aspirated (NA) engines and turbocharged engines using optional low pressure equipment require minimum gas pressure of 13.8 kPa (2 psi) to the gas regulator.
- Standard turbocharged engine minimum requirements range from 82.7 kPa (12 psi) to 330 kPa (48 psi).
  - Lower values may be applicable only at low altitude installations where response to sudden load changes is not critical.
- Turbocharged engines require separate circuit aftercooling, so a 30° or 55° C (90° or 130° F) cooling source must be available.
- Operating with supply gas pressures slightly below the minimum values may be possible if the engine is not subjected to large load fluctuations.
- If the supply gas pressure to the regulator is below published limits, a low pressure conversion group should be used.

Gas Pressures Required		
Engine Models	**Pipeline**	**Digester Landfill**
3300 NA 3500 NA	14 kPa (2 psi)	Consult Factory
3306 TA	83 kPa (12 psi)	Consult Factory
3408 & 3412 TAs	138 kPa (20 psi)	138 kPa (20 psi)
3500 SITA L.E.	207 kPa (30 psi)	241 kPa (35 psi)
Low Pressure Conversion Gp.	14 kPa (2 psi)	Consult Factory

Note: minimum gas pressure must be adjusted for altitude.

Regulators

Regulator valves are positioned close to the carburetor for optimum gas pressure control. A balance line from regulator to air inlet manifold compensates for air cleaner restriction and turbocharger boost.



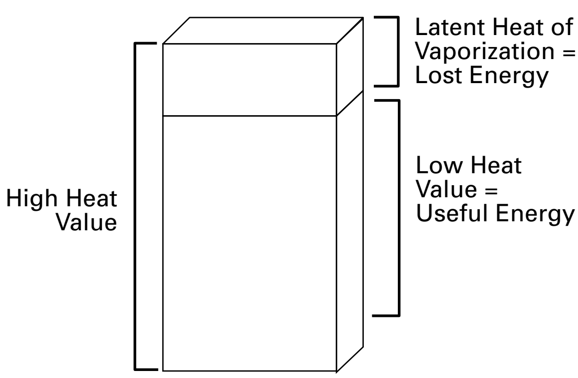
FUEL SYSTEM

FUEL SYSTEM

- Manual and solenoid valves are upstream (high pressure side) of the regulator to minimize restriction between regulator and carburetor.
- Regulators will withstand inrush of pressure gas when the valve is open.
- The upstream valve position slightly extends engine stopping time during normal shutdown.
- Emergency shutdown remains immediate by grounding magneto power and closing gas valves.
- Gas pipes cannot be used for electrical grounding.

Types of Fuel

A wide variety of gaseous fuels can be burned in Caterpillar gas engines. Various gases can back up the primary fuel. Addition of another regulator and change of carburetor may be necessary to accommodate a particular gas.



The **low heat value (LHV)** of a gas is the high heat value (HHV) less the heat used to vaporize the water formed by combustion. LHV is the figure Cat uses to express fuel consumption.

Power capabilities are calculated using LHV of the air-fuel mixture and not directly to the LHV of the fuel. Using fuels other than natural gas requires a recalculation of engine power capabilities.

Natural Gas

The recommended fuel for Cat SI engines is dry natural gas or “pipeline gas.” These commercial gases have less than 10 parts per million (ppm) of hydrogen sulfide. Any gas with a greater concentration should be evaluated to determine engine effects and required special maintenance practices.

- Natural gas is a mixture of gases composed mostly of methane with varying percentages of methane, propane, butane, and small amounts of helium, carbon dioxide, and nitrogen.
- In its original state, natural gas is often referred to as field, well head, or wet gas.
- The designation “wet” or “dry” does not refer to water content, but to the presence or absence of liquid hydrocarbons such as butane or pentane.
  - Before distribution, the wet ends are removed to provide dry pipeline gas.

Natural Gas — Propane

- Propane is transported and stored in a liquid state, and converted to a vapor at the point of use.
  - Local codes may prohibit liquid propane storage within a building.
  - It is heavier than air, so good ventilation is necessary to prevent concentration in low areas.

FUEL SYSTEM

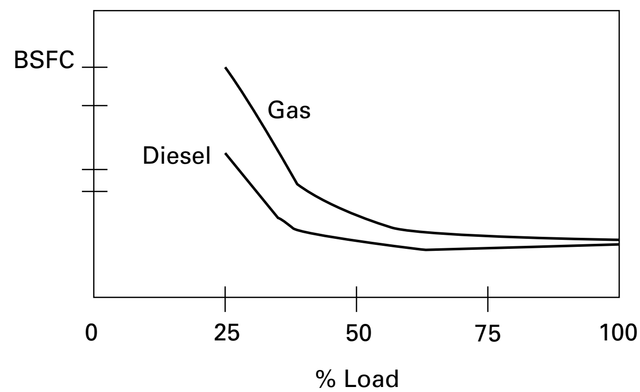
Alternative Fuels

- **Sweet gases** have low concentrations (below 10 ppm) of sulfur compounds, and can be used without treatment or changes to the engine.
- **Sour gas** generally refers to fuels containing high concentrations of sulfur compounds (above 10 ppm).
  - Fuels such as field, digester, bio-mass, and landfill gases usually fall into this category, and require special operating considerations.

Gas/Diesel Operating Efficiency

Performance characteristics of gas engines require consideration when analyzing operating costs. The Brake Specific Fuel Consumption (BSFC) at part load is much higher than at full load. When compared to a diesel engine, this part load inefficiency is apparent.

FUEL EFFICIENCY VS. LOAD



For most efficient operation, gas engines should operate near full load.

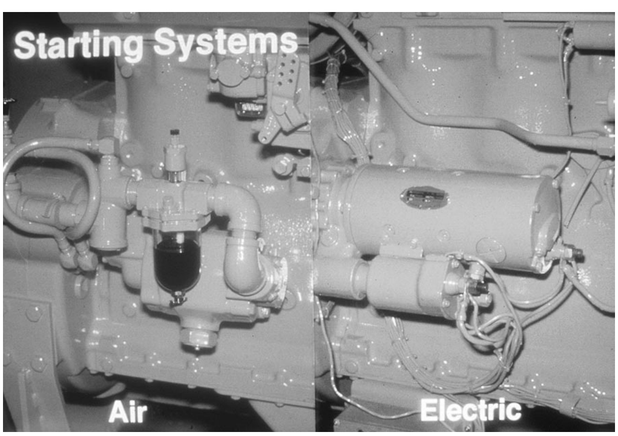
STARTING

Several starting mediums are available, but most common are electric (DC) and air. These mediums are both easily controlled and applied either manually or automatically.

Starting Basics

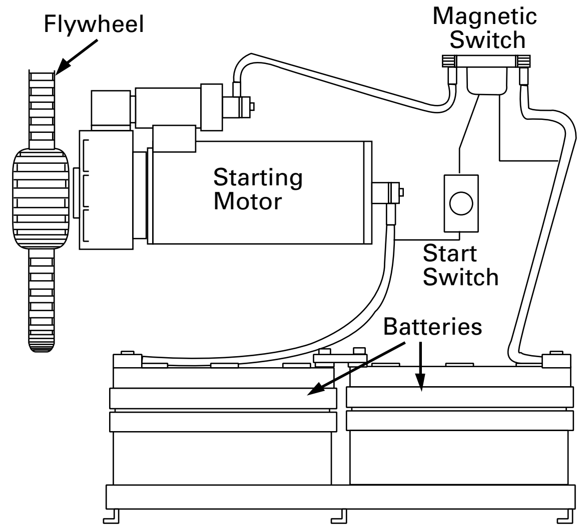
Startability of a diesel engine is affected primarily by ambient temperature and lubricating oil viscosity. The diesel relies on heat of compression (resulting from cranking time) to ignite fuel. When engines are cold, longer cranking periods are required to develop ignition temperatures.

Lubricating Oil
Heavy lubricating oil imposes the greatest load on the cranking motor. Oil type and temperature drastically alter viscosity. SAE 30 oil approaches the consistency of grease below 0° C (32° F).



Electric Starting

Electric motors utilize low voltage direct current and provide fast, convenient, pushbutton starting with lightweight, compact, engine-mounted components.



- Electric starting is generally 24-volt or 30- to 32-volt DC.
- A manual starting system includes a start switch, solenoid, and starting motor.
  - When the start switch is closed, the solenoid moves a pinion to engage with the flywheel ring gear.
  - After engagement, the main motor contacts close and the motor begins to crank.
  - The starting motor will continue to crank until the start switch is opened (usually by releasing the start button).

STARTING

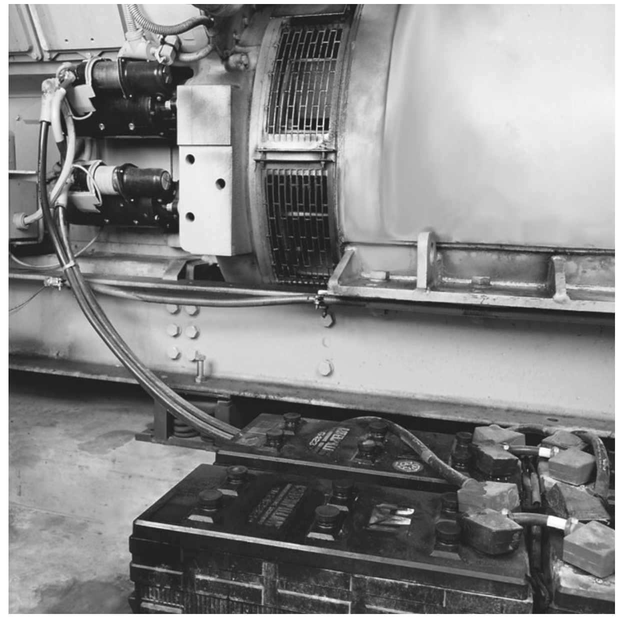
Batteries
Batteries provide sufficient power to crank engines fast and long enough to start.

- Lead-acid battery types are common, have high output capabilities and low cost.
- Nickel-cadmium batteries are costly, but have long shelf life and require minimum maintenance.
  - Nickel-cadmium types are designed for long life.

Battery Sizing
Low ambient temperatures drastically affect battery performance and charging efficiencies, as well as oil viscosity. High temperatures should also be avoided.

- Maintain 32° C (90° F) maximum temperature to assure rated output.
- High temperatures also decrease battery life.
- Ideally, temperatures surrounding the battery should not exceed 25° C (77° F). Battery life is roughly halved by a 10° C (17° F) rise in temperature; doubled if ambients are reduced 10° C.

Battery Location and Considerations
- To minimize voltage drops between the batteries and starting motor, place the batteries near the starting motor and connect with adequately sized cables.

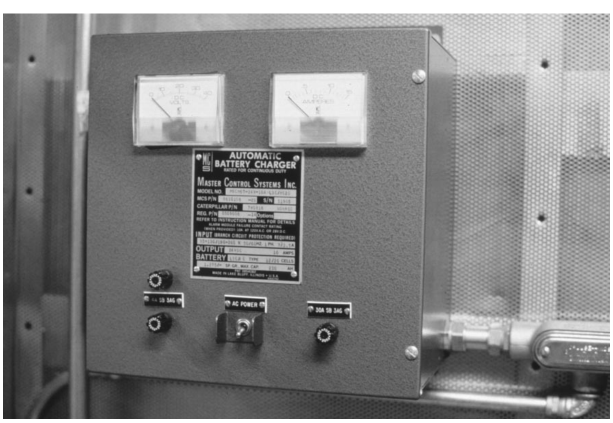


- Cables should be routed to avoid sharp bends and have sufficient play and support to minimize stress on the battery terminals.
- Locate cranking batteries for easy visual inspection and maintenance, away from flame or spark sources, and isolated from vibration.
- Mount level on nonconducting material and protect for splash and dirt.
- Disconnect battery charger when removing or connecting battery leads, as solid-state equipment (electronic governor, speed switches, etc.) can be harmed if subjected to the charger's full output.

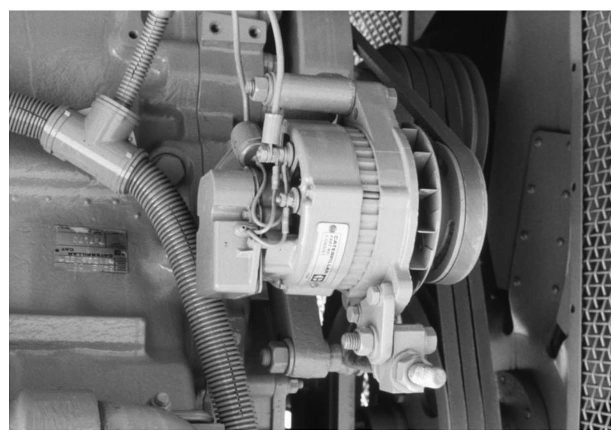
STARTING

Battery Chargers
Various chargers are available to replenish a battery.

- **Trickle chargers** are designed for continuous service on unloaded batteries and automatically shut down to milliampere current when batteries are fully charged.
- Overcharging shortens battery life and is recognized by excessive water losses.
  - Conventional lead-acid batteries require less than 59.2 ml (2 oz) make-up water during 30 hours of operation.



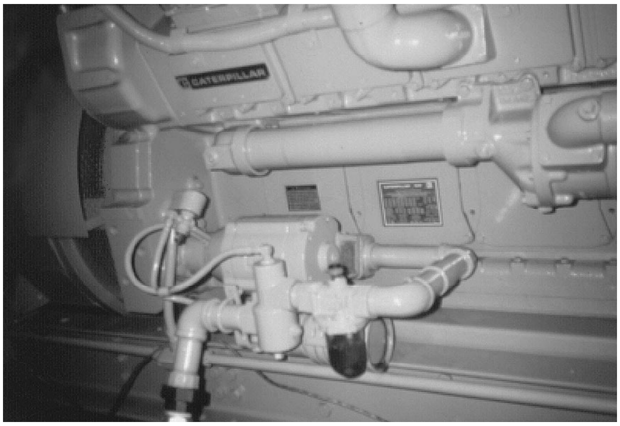
- **Float-equalize chargers** are more expensive than trickle chargers and are used in applications demanding maximum battery life.
  - These chargers include line and load regulation, and current limiting devices which permit continuous loads at rated output.
- Engine-driven generators or alternators can be used, but have the disadvantage of charging batteries only while the engine runs.
  - Where engine-driven alternators and battery chargers are both used, the disconnect relay is usually controlled to disconnect the battery charger during engine cranking and running.
- Chargers must be capable of limiting peak currents during cranking cycles, or have a relay to disconnect during cranking cycles.
  - If generator sets are subject to many starts, insufficient battery capacity could threaten dependability.
  - Charging alternators are not required for standby applications.



Air Starting

Manual or automatic air starting is highly reliable. It is generally applied where facilities have existing plant air, or where a combustible gas may be present in the atmosphere. Torque available from air motors accelerate the engine to twice the cranking speed in about half the time required by electric starters. Remote controls and automation, however, are more complex. Because the exhaust from the air starter is very loud, an air silencer may be appropriate.

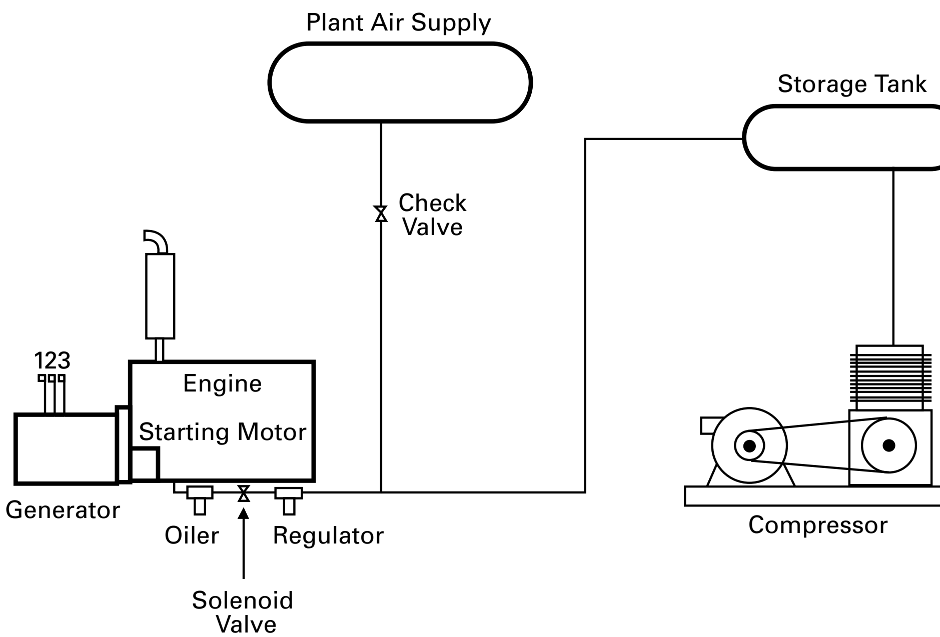
STARTING



An air starting system includes:

- Air starting motor
- Air storage tank
- Starting solenoid valve
- Pressure regulator
- Oiler
- Optional air silencer
- Pressure air may originate from air receivers and plant air.
  - A check valve between plant air and receiver assures that failure of plant air will not deplete the backup supply.
  - The air compressors are driven by gasoline engines and electric motors wired to the emergency power source.
- Air motor supply pipes should be short and direct, and at least equal in size to the motor intake opening.
  - Black iron pipe is preferable, and it should be supported to avoid stresses on the compressor.
  - Flexible connections between motor and piping are required.
- Tandem or compound engines use two motors and two solenoid valves.
  - Valves are equal distance from their respective motors for coordinated motor engagement.
  - When a single solenoid controls air to both motors, piping between valve and each motor must be equal in length.

AIR STARTING SYSTEM



STARTING

- Deposits of an oil-water mixture accumulating in receiver and piping are removed by traps installed at intervals in the lines.
  - Lines slope toward these traps.
- The compressed air may freeze in low ambient temperatures as it expands through the motor.
  - Below 0° C (32° F), a dryer at the compressor outlet or a small quantity of alcohol in the air tank prevents freezing.
  - Consult the factory for recommendations below -18° C (0° F).

Air Pressure

Compressed air from a 758 to 1723 kPa (110 to 250 psi) source is regulated to 759 kPa (110 psi) and piped to the air motor. Higher supply air pressures may be utilized by plumbing regulators in series.

Air Receivers

Air receivers should meet ASME specifications and be equipped with a safety valve and gauge. Check safety valves frequently to guard against sticking.

Receivers are sized for a specified number of starts. Receiver size is estimated by:

$$Rc = \frac{Ns\ (Ar \times Ap)}{Rp - 724 \text{ or } 90}$$

where:

Rc = Receiver Capacity (m^3) (ft^3)
Ns = Number of Starts
Rp = Receiver Pressure (kPa) (psia)
Ar = Free Air Requirement per Start (m^3) (ft^3)
Ap = Atmospheric Pressure (kPa) (psia)
Minimum = (724 kPa) (90 psia)

Free Air

Quantity of free air required per start (Ar) depends on:

1. **Time required per start.** Time per start depends upon:
   - Engine model
   - Condition
   - Ambient air temperature
   - Oil viscosity
   - Fuel type
   - Condition of fuel system
   - Cranking speed

   Five to seven seconds is typical for diesel engines at 25° C (77° F), but restarts of hot engines normally take less than two seconds.

   Due to the time necessary to develop a combustible mixture in the intake manifold, natural gas engines usually exhibit starting times up to double that of a diesel.

2. **Free air consumption.** Free air consumption depends on the same variables as time required per start, and also on the pressure regulator setting.

STARTING

Engines equipped with a pneumatic oil prelubrication pump require an additional 0.03 m^3/s (1 cu ft/s) of air volume. Cat 3600 engines require a one- to five-minute prelube; all other models require 2-20 sec. Five- to seven-second starting (prelube is additional) is typical for engines operating at 25° C (77° F) ambient temperature.

3. Prompt manual or automatic air shutoff after engine starting

Air Starting Free Air Consumption m^3/s (cu ft/s) Required for Air Motor to Start Engine at 10° C (50° F)					
Model	Motors	Air Pressure to Motor kPag (psig)			Min. Tank Pressure kPag (psig)
		690 (100)	862 (125)	1034 (150)	
3304	1	0.16 (5.8)	0.20 (6.8)	0.21 (7.7)	242 (35)
3306	1	0.17 (5.9)	0.20 (6.8)	0.22 (7.8)	248 (36)
3406	1	0.18 (6.4)	0.21 (7.3)	0.24 (8.6)	276 (40)
3412	1	0.25 (9.0)	0.29 (10.3)	0.33 (11.8)	207 (30)
D379	1	0.26 (9.3)	0.30 (10.3)	0.36 (12.6)	207 (30)
D398	1	0.28 (9.8)	0.32 (11.4)	0.38 (13.3)	242 (35)
D399	1	0.30 (10.8)	0.34 (12.1)	0.40 (14.1)	345 (50)
3508	1	0.26 (9.3)	0.30 (10.8)	0.36 (12.6)	207 (30)
3512	1	0.28 (9.8)	0.32 (11.4)	0.38 (13.3)	242 (35)
3516	1	0.30 (10.5)	0.34 (12.1)	0.40 (14.1)	345 (50)
3606	1	0.38 (13.6)	0.46 (16.4)	0.54 (19.2)	690 (100)
3608	1	0.38 (13.6)	0.46 (16.4)	0.54 (19.2)	690 (100)
3612	2	0.76 (27.2)	0.92 (32.8)	1.08 (38.4)	690 (100)
3616	2	0.76 (27.2)	0.92 (32.8)	1.08 (38.4)	690 (100)

STARTING

Starting Aids

Starting aids for temperatures below 21° C (70° F) reduce cranking time and assure dependable starts.

Starting Aid Options

Jacket water heaters are used on both manual and automatic starting systems, but are essential for automatic starting below 21° C (70° F). Heaters precondition engines for quick starting and minimize the high wear of rough combustion, by maintaining jacket water temperature during shutdown periods. Dual heaters are used on large vee-type engines to ensure circulation.

Heaters thermostatically control jacket water temperature near 30° C (90° F) to promote fast starts. Higher temperatures accelerate aging of gaskets and rubber material.

Preheating engine combustion chambers improves fuel ignition. Precombustion chambered engines provide a resistance-type **glow plug** in each chamber to aid manual starts in cold weather. The plug tip reaches 980° C (1800° F) in approximately 30 seconds to vaporize injected fuel. Direct injection engines cannot accommodate glow plugs.

In a **flame start**, glow plugs project into the air inlet manifold and ignite a small amount of diesel fuel during manual starting. The flame is maintained until smooth idling conditions are achieved.

Ether starting aids are restricted to manual starting systems and are rarely used for generator sets. Ether is highly volatile, with its low ignition point. Introduced into the intake air, it ignites the mixture at low cylinder temperatures. High pressure capsules are the safest and most positive injection method. Ether injection should not be used on Cat 3600 engines.

Oil heaters are usually not recommended due to the danger of oil coking. If specified, heater skin temperatures should not exceed 150° C (300° F) and have maximum heat densities of 0.02 W/mm^2 (13 W/in^2).

Starting Requirements

Automatic Start-Stop
Automatic start-stop systems are primarily for unattended engines which must:

- Start automatically
- Pick up the load
- Operate the load
- Stop automatically when demand ceases

For example, a standby generator set must start automatically when utility power fails.

Caterpillar offers both electric and air powered systems.

STARTING

Ten-Second Start

Ten-second starting is often required either by application or local regulation. The National Fire Protection Association (NFPA) 99, Health Care Facilities 1996 Edition states, "generator set(s) shall have sufficient capacity to pick up the load and meet the minimum frequency and voltage stability requirements of the emergency system within ten seconds after the loss of normal power."

Caterpillar requirements for ten-second automatic starting include:

- Combustion air a minimum of 21° C (70° F)
- Jacket water heaters which maintain a minimum of 32° C (90° F) water temperature
- Fully charged batteries to provide 60 seconds of continuous cranking, or full air supply
- Readily available fuel

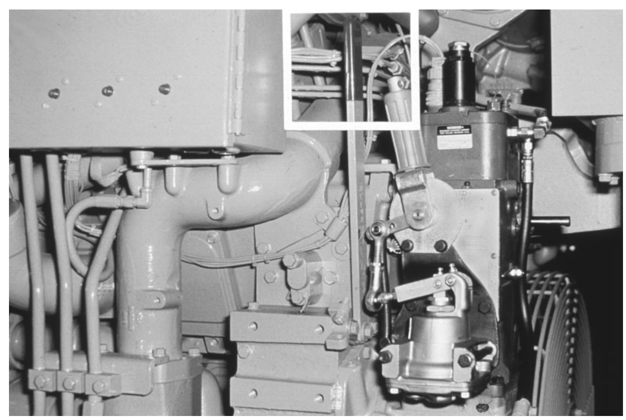
Engine Shutdown

Engine shutdowns result from either manually or automatically shutting off fuel, air, or both.

Depending on engine configuration, fuel shutdowns vary from a manual position on a governor control (shown) to an electro-mechanical shutoff control.

Automatic

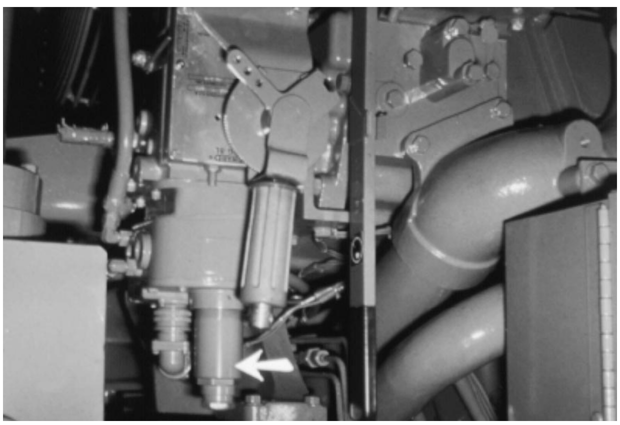
If automatic or remote shutdown is required, a solenoid shutoff is used on engines with mechanical, hydromechanical, or hydraulic governors. The solenoid shutoff operates by moving the fuel rack to the shutoff position. Either an energized-to-run or energized-to-shutdown system is available. For energized-to-run systems, an electrical signal must be present at the fuel solenoid for the engine to operate. When the signal is lost, the engine will shut down.



STARTING

For engines using electronic governors, the control panel signals the actuator to shut off the fuel. In some cases a solenoid shutoff is also used.

In either system, the engine may be shut down manually.



Engine Shutdown Devices
Caterpillar offers protection devices to prevent serious engine damage. Minimum protection for any generator set includes engine shutdown in the event of:

- Overspeed
- Low lubricating oil pressure
- High jacket water temperature

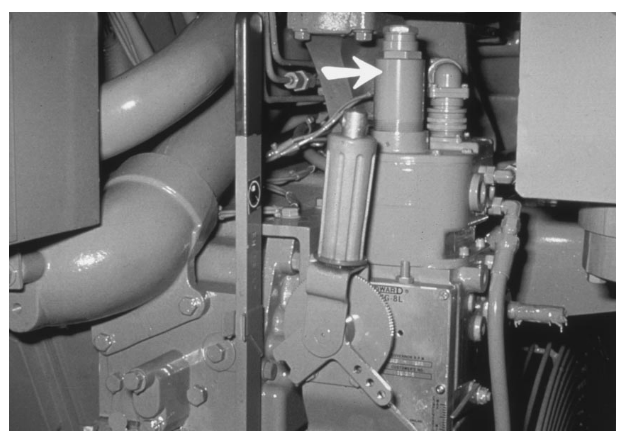
If the generator set is remotely started, overcrank protection is required.

- Indicators for engine water level and flow are recommended.
- Additional operating functions can be monitored with minor modifications.

Overspeed Shutdown
Engine overspeed can result from a governor malfunction or fuel rack sticking. With no overspeed protection, a diesel engine can rapidly accelerate to the point of destruction.

Inlet Air Shutdown
Engine overspeed can result from a seized fuel rack, or by the engine drawing in combustible gases which are sometimes present in the surrounding atmosphere — in oil or gas drilling operations, for example. If either of these conditions cause the engine to overspeed, a fuel shutoff system may be ineffective.

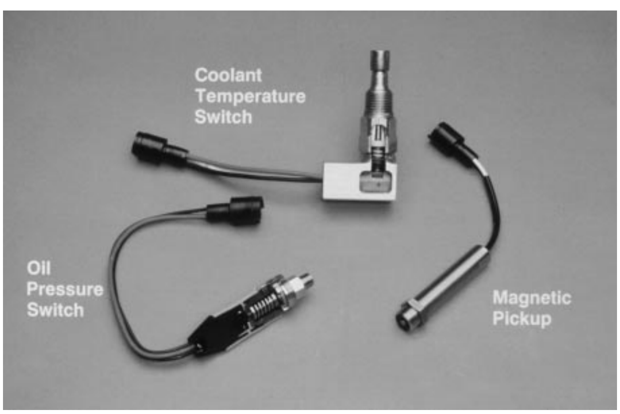
- A positive way to stop the engine is to shut off the air supply. An engine cannot operate without a source of combustion air.
- The air inlet shutdown is not recommended for routine shutdowns because there are some potential adverse mechanical effects on the engine.



STARTING

Conventional Switches
Conventional electro-mechanical control panels use switches and probes for monitoring engine conditions.

- Shown below is a Caterpillar two-wire type **coolant temperature switch**.
  - The two-wire system eliminates the need to ground through the case and provides greater reliability and accuracy.
  - To minimize electrical arcing, the switch utilizes snap action contacts activated by a miniature switch mechanism in lieu of butt-type contacts.
  - The temperature sensing element is a wax motor type, yielding excellent sensing accuracy.



- Low **oil pressure** can cause serious engine damage.
  - If pressure falls below a safe level, the **oil pressure switch** will activate an engine shutdown.
  - The oil pressure switch is also two-wire type with the same stable grounding characteristics.
  - It also includes the same self-cleaning contacts as the coolant switch.
- The **magnetic pick-up** measures engine speed and converts it to a digital pulse.
  - Generally Cat engines are shut down at 118 percent of rated speed.

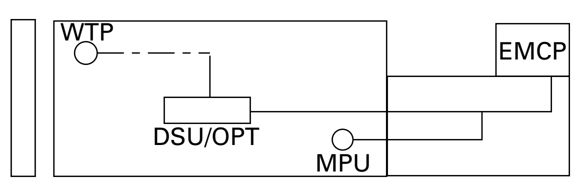
Electronic Modular Control Panel (EMCP) Monitoring System
The Caterpillar Electronic Modular Control Panel II (EMCP II), consisting of solid state microprocessor-based engine control modules, uses electronic transducers to monitor and digitally display engine conditions. Operating functions are monitored by three components:

- Jacket water transducer (water temperature probe)
- Oil pressure transducer
- Engine speed magnetic pickup

The oil pressure and water temperature transducers and the magnetic engine speed pickup send information directly to the engine control module. Transducers are industrial grade and environmentally sealed for reliability. They help eliminate additional jacket water and oil pressure temperature switches needed to activate alarm systems and gauges, and require significantly less wiring.

MONITORING SYSTEM

- Jacket Water Temperature Transducer
- Oil Pressure Transducer
- Engine Speed Magnetic Pick-Up
- DSU (Data Sending Unit)
- Single Wire Serial Data Link

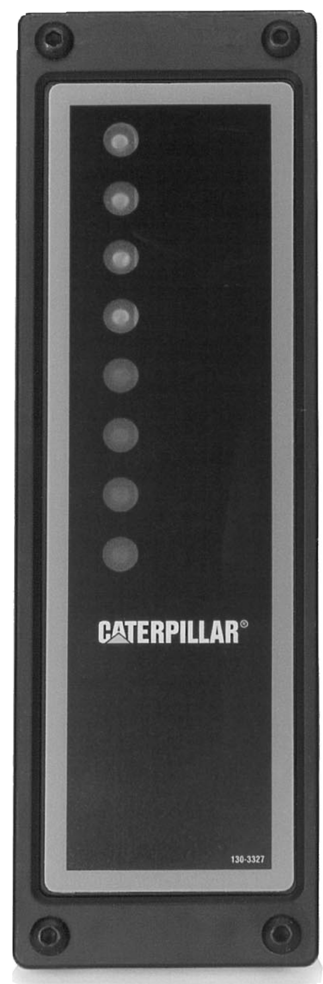


STARTING

Alarm Modules

Warning alarms and alarm modules are available to provide an audible and/or visual warning of engine conditions before they become severe enough to shut the engine down, or keep it from starting. This gives maintenance personnel time to remedy the condition.

The prime power alarm module shown satisfies NFPA 99 and NFPA 110. Also, remote annunciators are available which also satisfy NFPA 99 and NFPA 110.



ENGINE GOVERNORS

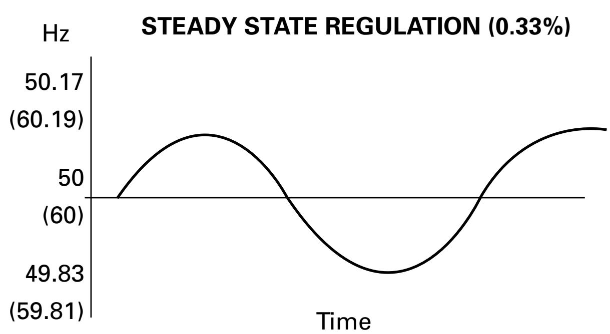
A governor controls engine speed (generator frequency). The main areas of engine governors to understand are:

- *Basic terms*
- *Types of governors*
- *Governor selection*

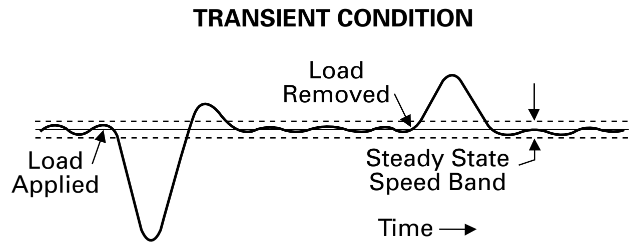
Basic Terms

A few terms must be understood in order to select the appropriate governor for a specific application. These terms are commonly encountered when specifying or analyzing governor and generator set performance.

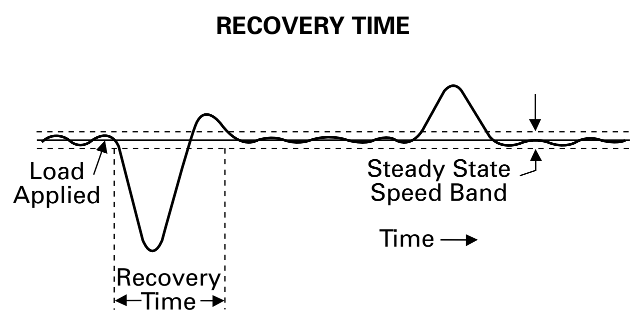
Speed band refers to the amount of variance from a set speed at any steady load. Caterpillar governors have a speed tolerance of +/- 0.33 percent while Woodward governors offer +/- 0.25 percent.



Transient speeds are temporary excursions from steady-state speed caused by sudden load changes.



Recovery time is the time of excursion from the steady-state speed band until returning and remaining within the band.

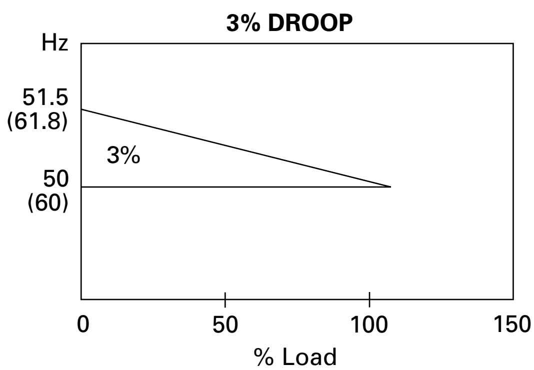


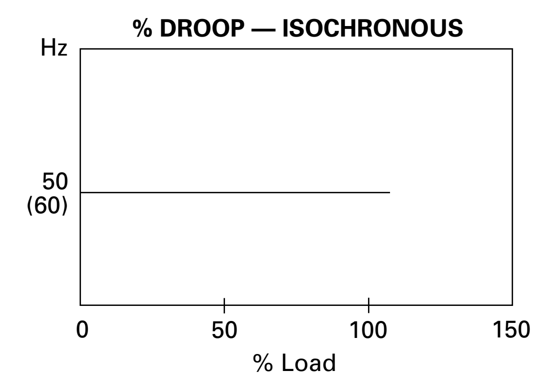
Droop, speed droop, and regulation are terms used interchangeably to describe the relationship of engine speed change from no load to full load in steady-state operation.

ENGINE GOVERNORS

Expressed as a percentage, droop is calculated by dividing the difference in speed between full rated load and no load by speed at rated load and multiplying the quotient by 100.

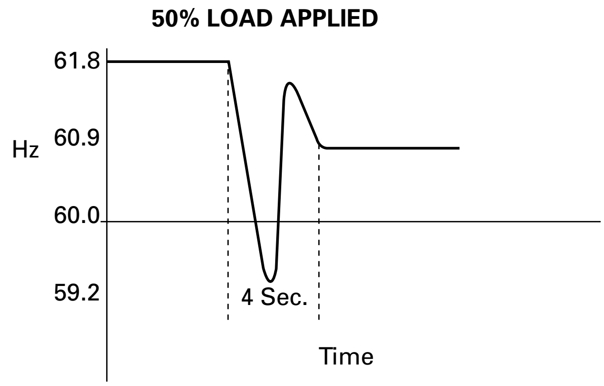
Example:
A generator set equipped with a three percent droop governor will operate at 60 Hz or 1800 rpm (50 Hz or 1500 rpm) at rated load (at half load — 60.9 Hz [50.75 Hz]). At no load the generator set frequency will increase no more than three percent to 61.8 Hz or 1854 rpm (51.5 Hz or 1545 rpm).





A generator equipped with a zero percent droop governor will operate at 60 Hz or 1800 rpm (50 Hz or 1500 rpm) at rated load and 60 Hz or 1800 rpm (50 Hz or 1500 rpm) at half load or no load.

Transient Response with Droop
The following graphic depicts a 60 Hz generator set equipped with a three percent droop governor. With no load, the generator



operates at 61.8 Hz (1854 rpm). When half load is applied, the frequency drops to approximately 59.2 Hz (1777 rpm). The governor senses this speed drop and adjusts the rack, delivering more fuel to the engine. This causes a momentary increase in generator frequency above 60.9 Hz (1827 rpm) before it levels off at 60.9 Hz (1827 rpm). Recovery time from when the load is applied until the frequency levels off at 60.9 Hz is four seconds. Governors are only one factor affecting transient speed and response. Greater influencers of the engine's recovery capabilities include:

- Size and type of load
- Engine configuration
- Type of generator voltage regulator
- Rotating inertia of motor load, engine, and generator

Governor Types

The following governors are noted in order of cost, simplicity, and power output. Cat recommends using the simplest governor which adequately satisfies the application.

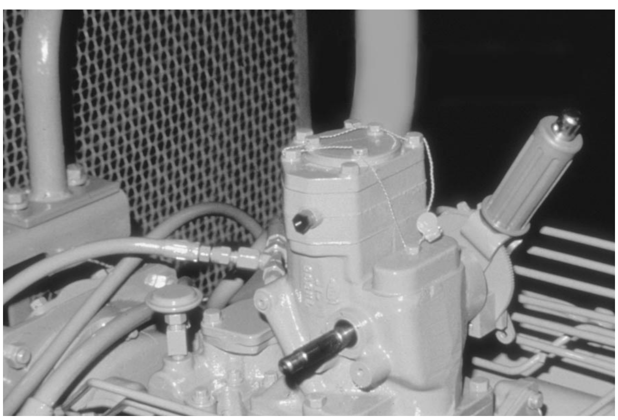
ENGINE GOVERNORS

Mechanical and Hydromechanical Governors

Although the exact design of a hydromechanical governor may vary, basically it is a mechanical governor assisted by a hydraulic servo valve.

Mechanical Governors

The simplest Cat governor is the mechanical type. It uses a ball head with flyweights for speed sensing. The mechanical governor develops sufficient force by flyweight action to move a fuel rack or carburetor control.



- The Caterpillar mechanical governor is a three percent fixed droop governor and features 0.33 percent steady-state regulation.
- Mechanical governors are adequate for manual paralleling and will share load within ten percent at any load point.

Hydromechanical Governors

As the force required to move the governor linkage and fuel injection pumps increases, the force developed by the governor must also increase. On a larger engine, instead of increasing the size of the mechanical governor, engine lubricating oil pressure is sometimes used to support the action of a mechanical control.

- Like Cat mechanical governors, Cat hydromechanical governors have nonadjustable three percent droop and are adequate for manual paralleling.
- Engine lubricating oil is used for lubrication and hydraulic power.
- They are used in most installations under 500 kW for spark ignited and 600 kW for diesel.
- They share load with paralleled units within +10 percent.

Speed Control

Caterpillar mechanical and hydromechanical governors have an optional governor control motor. The 24-volt direct current motor is used for speed control from remote locations.

Hydraulic Governors

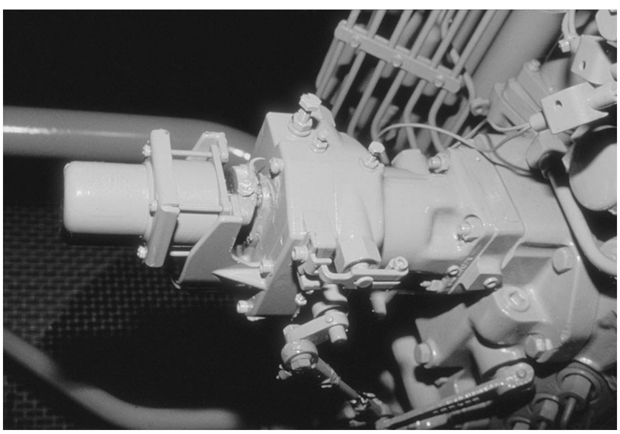
A hydraulic governor builds on the basic mechanical governor design, and develops additional work force. A control valve allows oil pressure to work directly on the terminal shaft through a power piston. No longer is the work force associated with the governor's speed-sensing mechanism.

- Depending on oil pressure and the area of the power piston, adequate force can be developed to control almost any size engine.
- The Woodward PSG, UG8D, and 3161 are hydraulic governors offered by Caterpillar.
- The governors have zero to ten percent adjustable droop and exhibit steady-state regulation of ± 0.25 percent.
- When adjusted to three percent droop, they share load with parallel units within five percent.
- These governors are applicable for single unit or manually paralleled multiple unit applications.

ENGINE GOVERNORS

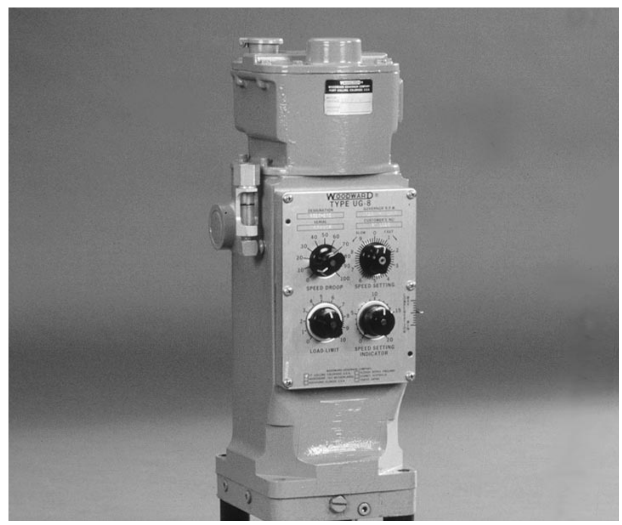
Woodward PSG Governors
The Woodward Pressure-Compensated Simple Governor (PSG) uses engine lubricating oil for a hydraulic medium and a self-contained pump, gear driven from the engine, to develop its work capacity. Generally it is adequate for generator sets up to 600 kW.

- The PSG has an externally adjustable droop control from zero percent (isochronous) to seven percent.
- Shares load with paralleled units within five percent. A 24- to 32-volt DC synchronizing motor for remote speed control is included with the basic governor.



Woodward UG8D Dial Governor
Two versions of the Woodward UG8D Dial Governor are available — one for single unit (non-parallel) operation and the other for multiple unit (parallel) operation. The single unit version is fast acting, providing excellent steady-state speed control and transient response to off speeds in startup and load rejection.

The paralleling version possesses dampening characteristics allowing it to perform well in parallel operations. It is slower acting, but retains excellent steady-state speed control and transient response. Both versions use a self-contained oil supply and gear driven pump. They are generally used on generator sets over 600 kW.



The Woodward UG8D has four external adjustments:

- Speed Droop — zero to ten percent, shares load within five percent
- Load Limit — provides movable stop which limits the amount of load the generator set will accept
- Speed Setting — manually adjusts engine speed (rpm)
- Speed Setting Indicator — indicates percent of travel of terminal shaft; the UG8D has remote speed control which operates on 110 VAC or 24-32 VDC

ENGINE GOVERNORS

Woodward 3161 Governor
The Woodward 3161 governor is completely interchangeable with the UG8D. These governors feature:

- A synchronizing motor for remote speed control
- Zero percent (isochronous) to ten percent droop
- External adjustability
- Synchronizing motor for remote speed control
- Adjustable load limit
- Use of an independent oil supply and pump which develops the output force necessary to control large engines

All hydraulic governors feature ± 0.25 percent steady-state regulation, load sharing within five percent, and are capable of single unit isochronous operation or manual paralleling.

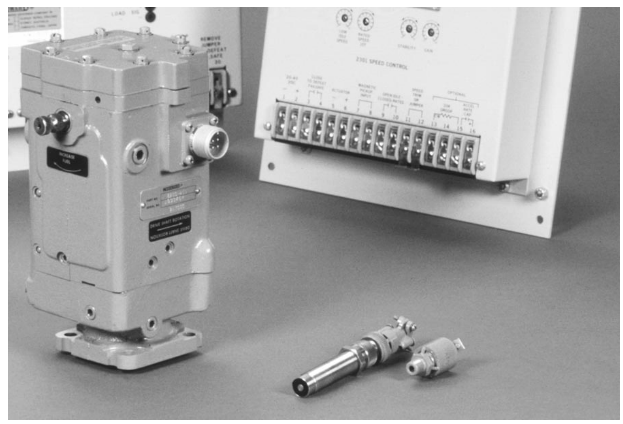
Electronic Governors
Electronic governors offer the greater capability and flexibility needed for complex control applications.

Advantages of electronic governing systems include:

- Automatic paralleling of multiple units
- Isochronous load sharing
- Fast response to load changes which minimizes speed changes and recovery time
- Flexibility with numerous options
- Excellent steady state frequency control
- Fail-safe speed sensing

Most electronic governing systems include:

- Electronic speed control assembly with optional load sharing control
- Actuating system (electronic or electronic hydraulic)
- Magnetic pickup
- Oil pressure switch (optional)



Operation

1. Engine speed is detected with the magnetic pickup which is located next to the flywheel ring gear. The magnetic pickup generates a voltage with frequency proportional to engine speed. This voltage travels to the electronic control assembly where it is compared to the adjusted governor setting
2. The control sends the appropriate signal (voltage) to the actuating system that converts the electrical input to a mechanical output which positions the engine fuel rack.
3. The oil pressure switch attaches to the engine and is electrically connected to the control assembly. When proper oil pressure is obtained, the switch signals to the control assembly to accelerate their engine to rated speed.

ENGINE GOVERNORS

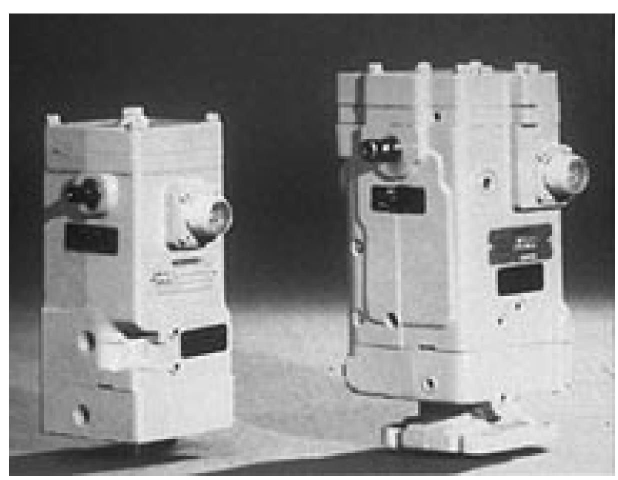
- All wiring should be isolated from AC power.
  - Low grade voltage lines, e.g., magnetic pickup, and oil pressure switch lines should be shielded and grounded because signals flowing through these wires are inherently weak.

Governing System
The Woodward 8290/1724 and 8290/Peak actuator is a completely electronic governing system. The 8290 identifies the control assembly and the 1724 identifies the electronic actuator. In contrast, the 8290/Peak uses an electrical motor to control a hydraulic servo valve which provides the mechanical power to move the fuel rack. Both systems as standard have zero speed droop and exhibit steady-state regulation of ± 0.25 percent.

- When load demand increases, requiring additional units in parallel, a load sensor may be added to the system for droop (zero to ten percent) — or isochronous — load sharing capabilities.
  - Units can share load within ± 0.5 percent.
- An SPM (Speed and Phase Matching) Synchronizer can be connected to the load sensor for a fully automatic system.

Woodward 2301 EG Actuators
The 2301 identifies the Woodward electronic control assembly. The electric/hydraulic actuator is either an EG3P, EG10P, or EG26P, and contains an engine driven oil pump to develop power to move the fuel mechanisms of larger engines.

- The EG3P has a maximum work capacity of 6.1 J (4.5 ft-lb).
- The EG10P has a maximum work capacity of 12.6 J (9.3 ft-lb).
- The EG26P has a maximum work capacity of 54 J (40 ft-lb).
  - The EG26P is an electrically controlled actuator with an integral backup mechanical governor. The actuator is used on units which must continue to function even when the electrical governor fails.



ENGINE GOVERNORS

Isochronous Load Sharing

There are two major reasons why electronic governing systems can share loads isochronously:

- The governor's reaction time to speed and load changes is very fast.
- When units are paralleled, auxiliary contacts controlled by the circuit breaker connect the controls through paralleling lines.

This allows the controls to continuously compare their real-time positions to each other.

Woodward 2301 Load Share/Speed Control

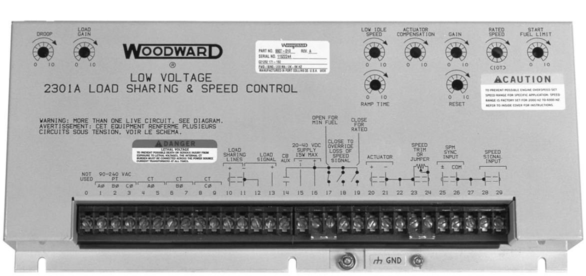
Governor characteristics are expanded when the 2301 Load Share/Speed Control Module replaces the standard/basic 2301 Speed Control. It adds:

- Isochronous load sharing capability
- Input for an SPM synchronizer (required in automatic paralleling applications)

Woodward 2301A Load Share/Speed Control Module

This system further extends the 2301's capability to include:

- Fuel limiting during engine startup
- Actuator compensation for increased stability
- Protection from voltage spikes and reverse polarity



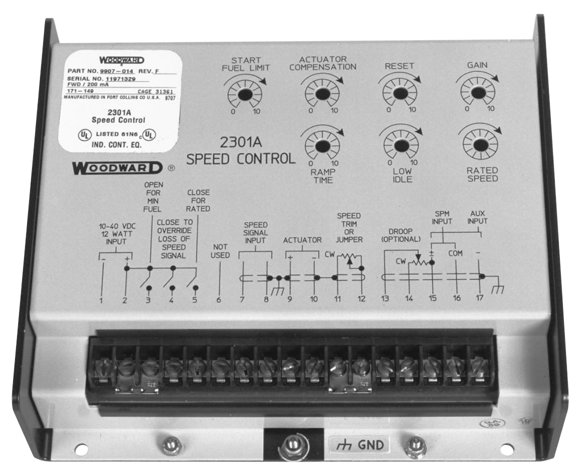
The starting fuel limit sets the maximum actuator position during engine cranking and is removed when the engine is running. This creates improved starting and minimizes smoke emissions from the engine. The actuator compensation allows the control to work on several different fuel systems.

Share/Speed Control Module

This electronic governor features zero percent (isochronous) to ten percent droop and includes:

- Magnetic speed pickup
- Control for parallel/nonparallel operation
- Hydraulic actuator using engine lubricating oil and internal pump

This system is applied where extreme frequency control is demanded or in automatic paralleling installations. Models include EG3P, EG10P, and EG26P, depending on work force required.



ENGINE GOVERNORS

ENGINE GOVERNORS

Caterpillar Electronic Control Module (ECM)
The Caterpillar Electronic Control Module (ECM) offers all the advantages of conventional electronic governors, plus enhanced capabilities to optimize engine performance. It is available on all Cat 3500B engines. The ECM combines traditional governing functions with real-time input from sensors monitoring:

- Coolant temperature
- Fuel pressure
- Oil pressure
- Atmospheric pressures
- Exhaust temperature
- Turbocharger inlet pressure
- Boost pressure
- Injection timing

This information allows the governor to continuously adjust to operating conditions.

- System includes:
  - Magnetic speed pickup
  - Fuel-air ratio control
  - Cold start programming
  - Independent oil pressure
  - Coolant temperature engine protection
  - Automatic altitude deration
- Allows custom programming to:
  - Improve fuel consumption
  - Minimize exhaust emissions
  - Improve transient response while minimizing over/undershoots
- Used where extreme frequency control is demanded or in automatic paralleling installations
- Shares load within five percent
- Droop is adjustable, zero percent (isochronous) to ten percent.

Selection
When selecting a governor, always use the simplest governor that will adequately satisfy the application. To review:

- A **mechanical governor** is used when the application requires:
  - Manual paralleling
  - Share load within ten percent
  - 0.33 percent steady-state regulation
  - Fixed droop of three percent

ENGINE GOVERNORS

- The **PSG governor** can be used to satisfy the following conditions:
  - Manual paralleling
  - Share load within five percent
  - 0.25 percent steady-state regulation
  - Adjustable droop zero to seven percent
  - Isochronous capability for single unit operation
- The criteria for using a UG8D governor is the same as for the PSG, except:
  - It produces more work force and is used with larger engines
  - It is available in two versions — one for single unit operation and one for parallel operation
- The criteria for using a **3161 governor** is similar to the UG8D, but:
  - It utilizes engine lubricating oil
  - It delivers better performance
  - Only one version is used for all applications
- An **electronic governor** is recommended if the following are critical:
  - Automatic paralleling
  - Isochronous load sharing
  - Improved response time

SERVICING

Optimum Performance

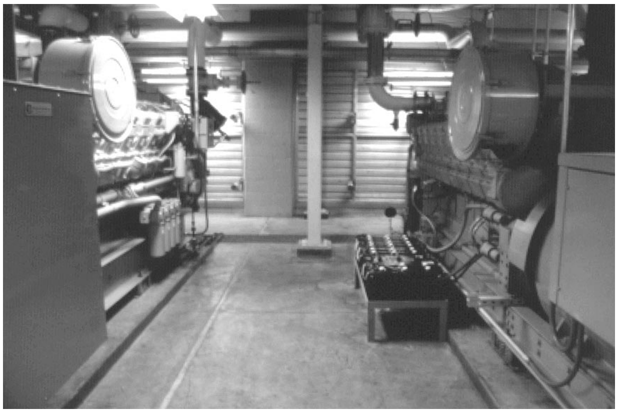
Two keys to optimum performance and long service life are:

- *Serviceability*
- *Preventive maintenance*

Adherence to proper generator set maintenance practices is critical to generator set reliability. Caterpillar publishes guidelines and service intervals for every engine and generator model. Reference should be made to these guidelines for specific maintenance practices. However, the installation must be designed for ease of servicing to ensure adequate maintenance.

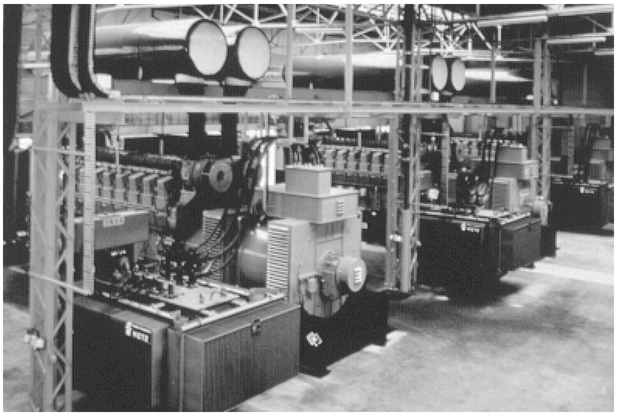
Location for Serviceability

A generator set should be positioned so service can be performed easily. Floor space must be adequate for both routine service and major engine repair.



- As a rule of thumb, the minimum amount of floor space between engines or a wall should be at least the width of the representative engine.
- Floor space at the front or back of the generator set must be adequate for engine removal or removal of any of its major components — either by forklift or crane.
- Camshaft or crankshaft removal on many engines requires an area at one end of the engine equal to the engine length.

Overhead clearance (between top of engine and ceiling or nearest obstruction) should permit the removal of cylinder heads, exhaust piping, etc. With larger engines adequate area should be provided to permit use of a chain hoist or overhead crane to remove heavier components.



Expansion
When determining the location of a generator set, future expansion should be considered. An installation should be designed so additional units can be added with minimum effort.

Preventive Maintenance

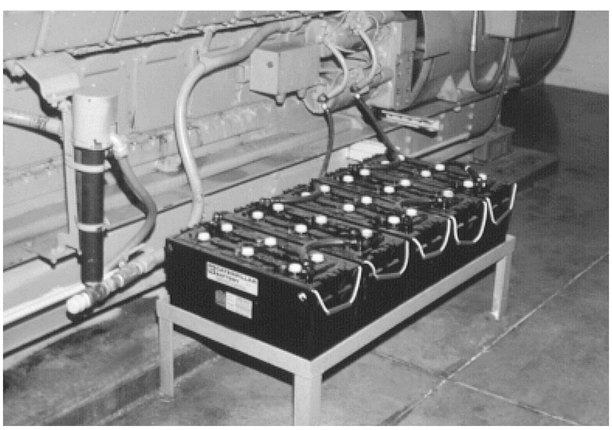
Inspection, test, and maintenance programs must be carefully planned and carried out on schedule. Poorly maintained equipment can be very unreliable. Load increases must be carefully monitored. Overloads, if sustained, can cause failure even though maintenance is good.

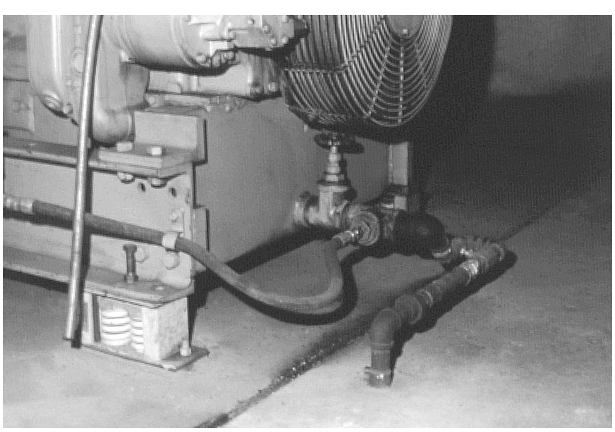
SERVICING

Preventive maintenance of generator sets will vary depending on configuration and usage. However, areas that require easy access include:

- Batteries
- Oil drain
- Oil filters
- Fuel filters
- Coolant
- Air cleaners

Batteries should be positioned so water can easily be added, and battery cables and terminals can be cleaned to assure good contact.

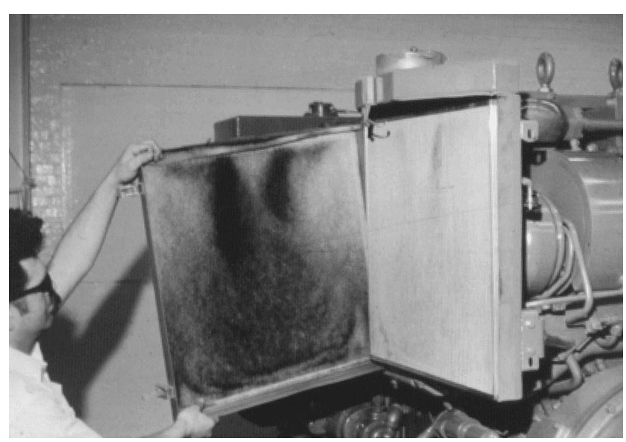




With an engine mounted radiator, sufficient area above the radiator is required to add **coolant**.

A remote-mounted radiator requires periodic **coolant level inspections** and convenient access is a must. Depending on the radiator location, a stairway or permanent ladder may be required.

Air filter replacement intervals will vary with engine usage. The area required to replace a filter will be determined by the filter size and location.



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