CATERPILLAR®

Gas Engines Application and Installation Guide

G3600–G3300

- Air Intake System
- Exhaust Systems
- Engine Room Ventilation
- Crankcase Ventilation

LEKQ7250 Supersedes LEKQ2458

5-97

CATERPILLAR®

G3600 Air Intake System

Air Cleaners
- Precleaners

Ducting
- Air Intake Restrictions
- Cleanliness
- Flex Connections
- Turbocharger Loading
- Turbocharger Air Inlet Design

Air Cleaner Icing

Extreme Cold

Air Intake System

The air inlet system is responsible for providing the G3600 engine with cool clean air while minimizing the pressure drop to the turbocharger. A well-designed system should have accessibility for routine maintenance and inspection. The system should be located away from exhaust stacks (including engine exhaust stack), large concentrations of dirt, chemicals, industrial waste, or any other material that would not allow for cool clean air. If possible, the air around the inlet should be between 15° to 32°C (60° to 90°F).

Air Cleaners

Debris is the major source of engine wear. For this reason, air cleaners are necessary to remove debris from the incoming air. The air cleaners must be remote mounted and plumbed by the customer. They can be wall, floor, base or roof mounted *with the inlet facing downward.* Standard Caterpillar air cleaners consist of high efficiency dry paper elements packaged in low restriction weather proof housings. They remove 99.5% of AC fine dust, which is defined in Table 1. *Oil-bath and oil-soaked screen-type air cleaners are not acceptable. Filtration efficiency rarely exceeds 95%. There is the constant danger of improper servicing, resulting in even lower filtration efficiency or oil carryover into the engine air intake system.*

Particle Size (microns)	% Total Weight
0 – 5	39 ± 2
6 – 10	18 ± 3
11 – 20	16 ± 3
21 – 40	18 ± 3
41 – 80	9 ± 3

Table 1. AC fine dust particle specifications.

Clean filters cause little air restriction, thus the *initial* total air restriction through the filters and inlet ducting up to the turbocharger should not exceed 1.3 kPa (5 in. H_2O) of water column. See Air Intake Restriction.

Caution: *Under no circumstances should the engine be operated without air cleaners.*

Table 2 provides a guide for selecting air cleaners.

Engine	Standard Duty without Precleaner	Heavy Duty with Precleaner
G3606	1-Double Element Housing	1-Triple Element Housing
G3608	1-Double Element Housing	1-Triple Element Housing
G3612	1-Triple Element Housing (Dual Outlet)	2-Triple Element Housing
G3612	2-Double Element Housing	2-Triple Element Housing

Table 2. G3600 air cleaner selection guide.

If the air cleaner enclosure(s) are outside in the weather, a protective shield is recommended to prevent rain from being pulled into the cleaners/precleaners.

Precleaners

The addition of precleaners before the air cleaner extends the filter service periods. A flow restriction of 0.25 to 0.75 kPa (1-3 in. H_2O psi) is imposed by the precleaner, but it can prolong the life of the filter by three to seven times. Any application in an environment with heavy dust and debris is recommended to use a precleaner.

Ducting

Normally, combustion air must be ducted from outside the engine room. This is particularly true in high altitude operation where light air density is further affected by engine room temperature. *Air ducts should be located away from engine exhaust pipes, heating lines, or any other high temperature area.* If air ducting is not located properly, hot dirty air from the exhaust stack will be drawn in through the air intake.

Careful consideration of routing and support is required to account for overhead cranes used to service the engine. Adequate support for ducting is needed so that the weight of the duct is not borne by the air cleaner or the turbocharger.

It is important to keep flow restriction, or head loss, below 0.5 kPa (2 in. H_2O) in the air ducting. See *Air Intake Restriction* section. A short, straight ducting system is the best design. Abrupt transitions in the intake ducting increase head loss. When turns are needed, long radius bends far upstream of the turbochargers are recommended. The ducting should have welded seam piping or seamless piping to minimize the flow restriction. PVC piping is recommended because it is light-weight and will not rust. If ferrous material is necessary, it must be properly cleaned after fabrication and treated to prevent rust and scale from accumulating. Flanged connections with gaskets are preferred over threaded connections. Fasteners such as rivets should not be used. Ducting must withstand a *minimum* vacuum of 12.5 kPa (50 in. H_2O) for structural integrity. All piping should meet seismic requirements.

Air Intake Restriction

Because excessive vacuum on the inlet side of the turbocharger can result in reduced engine performance, the total air intake restriction should not exceed 3.7 kPa (15 in. H_2O) with **dirty** air cleaner elements and 1.3 kPa (5 in. H_2O) with initial **clean** elements. The duct head loss from the intake to the cleaner can only account for 0.5 kPa (2 in. H_2O) or less of the total loss. A higher head loss in the ducting will decrease filter life and efficiency. Head losses may be calculated with the following equations.

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

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

where,

P = Restriction (kPa, in. H_2O)

where,

1 psi = 0.0361 in. H_2O column
1 kPa = 6.3246 mm H_2O column

L = Total equivalent length of pipe (m, ft)

To obtain equivalent length of straight pipe for various elbows,

$$L_{(\text{standard elbow, bend radius = pipe dia.})} = \frac{33D}{X}$$

$$L_{(\text{long elbow, bend radius > 1.5 dia.})} = \frac{20D}{X}$$

$$L_{(\text{45 deg. elbow})} = \frac{15D}{X}$$

$$L_{(\text{square elbow})} = \frac{66D}{X}$$

where,

X = 1000 mm, or 12 in.

S = Density of air (kg/m^3, lb/ft^3)

where,

$$S(\text{kg/m}^3) = \frac{352.5}{\text{Air Temp} + 273°\text{C}}$$

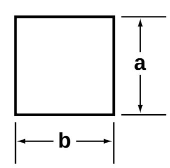
$$S(\text{lb/ft}^3) = \frac{39.6}{\text{Air Temp} + 460°\text{F}}$$

Q = Inlet air flow (m^3/min, cfm)

(Q may be found in TMI or the performance book)

D = Inside diameter of pipe (mm, in.)

For rectangular duct equivalent diameter,



$$D = \frac{(2 \times a \times b)}{a+b}$$

Cleanliness

An identifiable blanking plate should be installed ahead of the turbocharger to prevent debris from entering during initial installation of the unit. The plate should have a warning tag indicating it has to be removed prior to starting the engine. The Caterpillar supplied shipping cover can be used. Provisions should be made to inspect the ducting for cleanliness just prior to initial start up. If the piping is not clean, it must be cleaned before the engine is started at commissioning. This may require removal of the piping from its installed position.

Flex Connections

Flexible connections are required to isolate engine vibration and noise from the ducting system. The flex connection should be as close to the engine as practical. The flex engagement with the air intake duct should be a minimum of 50 mm (2 in.) and a maximum of 200 mm (8 in.). It is necessary to take appropriate measures to prevent heat from the exhaust piping from deteriorating the rubber flex connections.

Turbocharger Loading

Caution: *Turbocharger performance may be adversely affected if Caterpillar supplied air intake components are not used.* They are specially designed to provide the proper air flow pattern ahead of the turbocharger. The inlet elbow can be rotated in 30° increments. The turbocharger is designed to withstand a maximum moment of 294 N•m (217 ft-lb). Figures 1 and 2 show how the moment can be calculated.

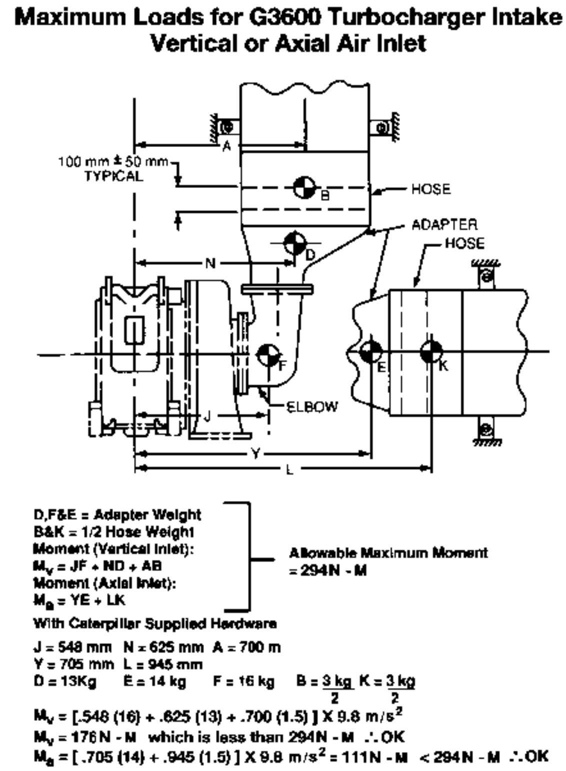


Figure 1.

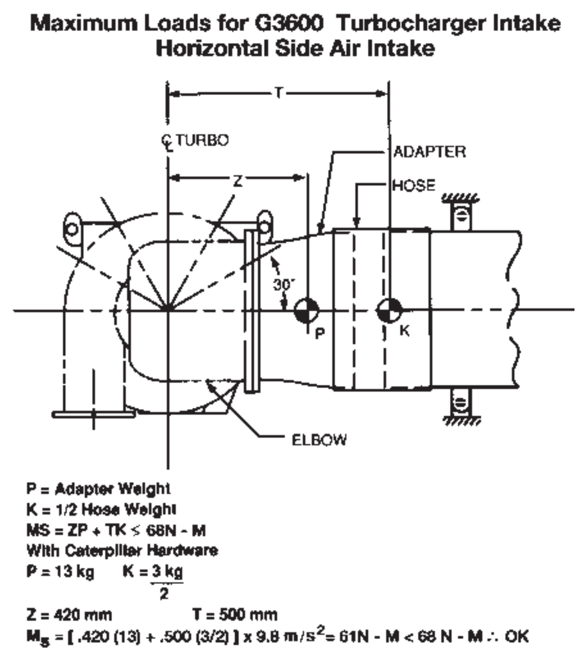


Figure 2.

Turbocharger Air Inlet Design

The piping to the turbocharger must be dimensioned to have approximately 4 in. of clearance from the turbocharger inlet adapter and also from the air cleaner housing adapter. The shipped loose rubber boot connectors should be used along with the shipped loose clamps. A quantity of 4 clamps should be used on each joint connection so that two clamp assemblies are on each end of the rubber joint connection. As a general rule, the piping to the turbocharger will encourage smooth air flows. Air striking the compressor wheel at an angle can result in pulsations, causing premature failure.

The following guidelines specify the allowable dimensions for two inlet design options which will minimize unfavorable flow conditions at the compressor inlet:

1. Air intake pipes that connect to the Caterpillar supplied 90° bend air intake elbow, Figure 3.

   a. A straight piece of pipe must be fitted in front of the Caterpillar supplied elbow.

   b. A minimum straight length, L, of ducting is required before the air intake elbow. L is at least 2 times the larger diameter of the straight ducting.

   c. An adapter may be used in front of the Caterpillar supplied elbow to make a flow area transition. The maximum flow area at 2-2 can be 1.3 times the flow area at 3-3. The flow area can not be less than that at 3-3. The adapter can have a rectangular cross section, or a transition from round to rectangular.

   d. Ducting must not have protruding edges that would create an orifice.

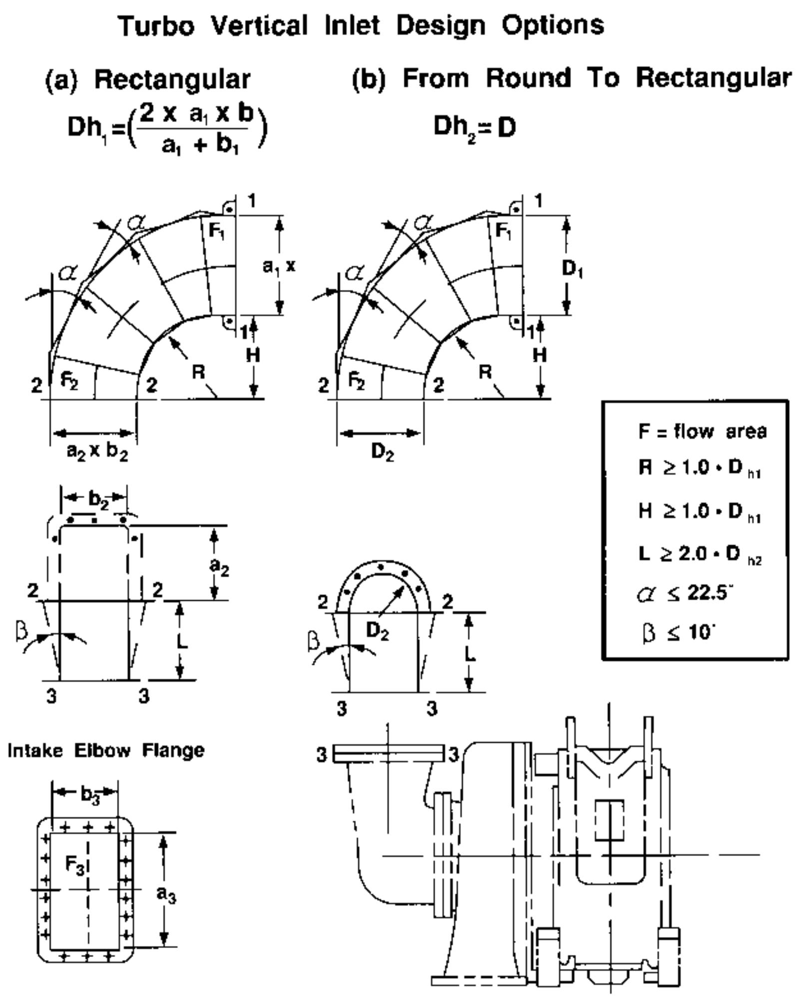


Figure 3.

e. Accelerated flow is expected to occur in a bend. When a bend is necessary the flow area should decrease at least 1.5 times, $F_1 > 1.5 \times F_2$. The bend can be designed as a circular arc or with sections of mitered pipe with 1) rectangular flow cross sections or 2) as a transition from round to rectangular cross section.

2. Air intake pipes that do not use the Caterpillar supplied 90° elbow, Figure 4.

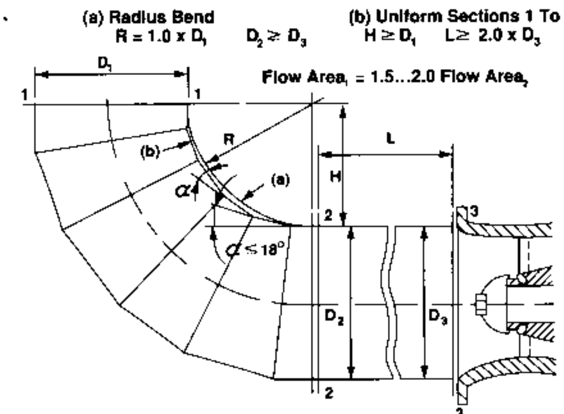


Figure 4.

a. A straight cylindrical pipe should be used in front of the compressor inlet flange. The pipe must have a length two times greater than its diameter at 3-3, $L > 2 \times D_3$.

b. A bend can be used in front of the straight pipe. The bend can be a circular arc or mitered pipe with round flow cross sections. Because accelerated flow is expected to occur in the bend, the flow area at 1-1 should decrease by 1.5 to 2 times at 2-2.

c. The bend radius R must be greater than or equal to the larger diameter D_1.

When ducting feeding two turbochargers is combined to form a single duct the same guidelines apply. In addition, a steadying zone of the length B is needed after the dividing joint B must be at least 5 times the larger diameter of the straight pipe at 2-2, see Figure 5. The transitions from sections 2-2 to 3-3 and from 1-1 to 2-2 will have many variations due to turbocharger hardware selected and installation site design. However, regardless of the transition selected, the steadying zone is always necessary.

Air Cleaner Icing

Air cleaner icing can occur in saturated air environments when the dew point of the ambient air is near freezing temperature. Small disturbances to the air such as the velocity and pressure changes at the air cleaner inlet reduce the moisture holding capacity of the air, resulting in moisture condensation and ice crystal formation. The ice buildup reduces the air flow area and increases the pressure differential across the air cleaner. Eventually, a plateau is reached where the pressure differential remains constant even though ice buildup may continue. Power loss and increased fuel consumption will result during these periods.

Several techniques may be used to overcome air cleaner icing. One solution is to heat the intake air slightly. It is not necessary to heat the air above freezing. The air requires only enough heating to be above the dew point temperature. Heat can be supplied to the air cleaner housing by several sources: ducting engine room air, ducting heated air from the exhaust piping, or electrical heating tape.

Extreme Cold

Heated engine room air may be required (for starting purposes only) in applications at very cold ambient temperature, -25°C (-13°F). This assumes combustion air is being drawn from outside the engine building and the engine is preconditioned with pre-heaters for metal, water and oil temperatures of 0°C (32°F). Admitting engine room air must be done without the possibility of allowing dirt or debris in the air inlet system of the engine.

CATERPILLAR®

G3500–G3300 Air Intake System

Air Cleaners
- Caterpillar Air Cleaners
- Precleaners
- Oil-Bath Cleaners
- Air Cleaner Selection

Ducting
- Air Intake Restrictions
- Flex Connections
- Turbocharger Loading
- Joining Two Turbochargers
- Cleanliness
- Intake Air Duct Insulation

Considerations for Low Pressure Gas
- Controlling Air Temperature
- Air to Gas Heat Exchanger

Air Cleaner Icing

Extreme Cold

Air Intake System

A well designed air intake system provides cool, clean air while minimizing pressure drop to the turbocharger. Normally this can be accomplished by using engine-mounted air cleaners. Some circumstances require ducting combustion air from outside the engine room. This is particularly true at high altitude and/or high ambient temperatures. Both can cause an engine to be derated.

Air Cleaners

Dirt is the major source of engine wear. It enters the engine by way of the inlet air. Any moving part is subjected to accelerated wear when dirt is contained in the inlet air.

Caterpillar Air Cleaners

The G3300, G3400 and G3500 Gas Engines all come standard with engine mounted air cleaners.

Standard Caterpillar air cleaners consist of high efficiency, dry paper elements, packaged in low restriction weather proof housings. They remove 99.5% of AC fine dust. AC fine dust is defined as follows:

Particle Size (microns)	% Total Weight
0 – 5	39 ± 2
6 – 10	18 ± 3
11 – 20	16 ± 3
21 – 40	18 ± 3
41 – 80	9 ± 3

Precleaners

Precleaners extend filter service periods. They impose a 0.25-0.75 kPa (1-3 in. H_2O) additional restriction to the system, but can increase filter life from three to seven times. Precleaners are particularly helpful in applications where heavy amounts of dust will significantly reduce the life of a standard air filter.

Oil-Bath Air Cleaners

Oil-bath and oil-soaked screen-type air cleaners are not acceptable. Filtration efficiency rarely exceeds 95%. There is the constant danger of improper servicing, resulting in even lower filtration efficiency or oil carryover into the engine air intake system. Oil carryover can cause aftercooler plugging resulting in high inlet air temperatures and possibly detonation.

Caution: *Under no circumstances should the engines be operated without air cleaners.*

Air Cleaner Selection

Air cleaners on the G3300, G3400 and G3500 Gas Engines come as standard. No selection is necessary. Precleaners are offered as an attachment.

Ducting

When ducting is necessary to obtain cooler or cleaner air, the filters should remain on the engine to prevent harmful dirt from leaking into the engine through ducting joints. When air cleaners must be remote-mounted, it is extremely important that all joints be air tight to prevent ingestion of dirt.

Give careful attention to routing and support of air inlet ducting, especially on the larger engines, where overhead cranes are used to service the engines. Provide adequate support for duct work so that its weight is not borne by the air cleaner on engine-mounted air cleaners, or by the turbocharger on remote-mounted air cleaners.

Avoid abrupt transitions in the intake ducting to provide the smoothest possible air flow path. Keep total duct head loss (restriction) below 0.5 kPa (2 in. H_2O) for maximum filter life. Any additional restriction will reduce filter life. See the *Air Intake Restriction* section.

Design inlet ducting to withstand a minimum vacuum of 12.5 kPa (50 in. H_2O) for structural integrity.

If required, all piping must be designed and supported to meet seismic requirements.

Air Intake Restriction

Excessive vacuum on the inlet side of the turbocharger (or the air inlet on NA engines) can result in reduced engine performance.

Therefore, the air intake system's total restriction (including dirty filters, duct work, vents, etc.) is limited to a maximum of 3.8 kPa (15 in. H_2O). In order to maximize air filter life, it is important to keep the air inlet restriction caused by the remainder of the system to less than 1.3 kPa (5 in H_2O). Every additional restriction caused by the air inlet system subtracts from air filter life.

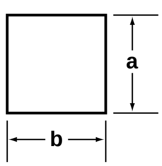
Calculate Duct Head Losses By:

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

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

P = Restriction (kPa), (in. H_2O)
psi = 0.0361 x in. water column
kPa = 6.3246 x mm water column
L = Total equivalent length of pipe (m) (ft)
Q = Inlet air flow (m^3/min), (cfm)-(found in TMI or performance book)
D = Inside diameter of pipe (mm), (in.)

If duct is rectangular



Then

$$D = \frac{(2 \times a \times b)}{a + b}$$

S = Density of air (kg/m^3), (lb/ft^3)

$$S\ (kg/m^3) = \frac{352.5}{\text{Air Temperature} + 273°C}$$

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

To obtain equivalent length of straight pipe for various elbows:

$L = \frac{33D}{X}$ Standard Elbow (Radius of elbow equals pipe diameter)

$L = \frac{20D}{X}$ Long Elbow (Radius > 1.5 Diameter)

$L = \frac{15D}{X}$ 45° Elbow

$L = \frac{66D}{X}$ Square Elbow

Where x = 1000 mm or 12 in.

As can be seen, if 90° bends are required, a radius of two times the pipe diameter helps to lower resistance.

Flex Connections

Flexible connections are required to isolate engine vibration and noise from the ducting system. The flex should be as close to the engine as practical. The flex engagement with the air intake duct should be a minimum of 50 mm (2 in.) and a maximum of 200 mm (8 in.). Care must be used to prevent exhaust piping heat from deteriorating rubber flex connections.

Turbocharger Loading

When remote-mounted air cleaners are used, turbocharger loading from the weight of the air inlet components becomes a concern. The turbochargers on G3300, G3400 and G3500 Engines are not designed to support any additional weight. Make the flexible connection directly to the turbocharger air inlet, as in Figure 5. All duct work to that point must be supported.

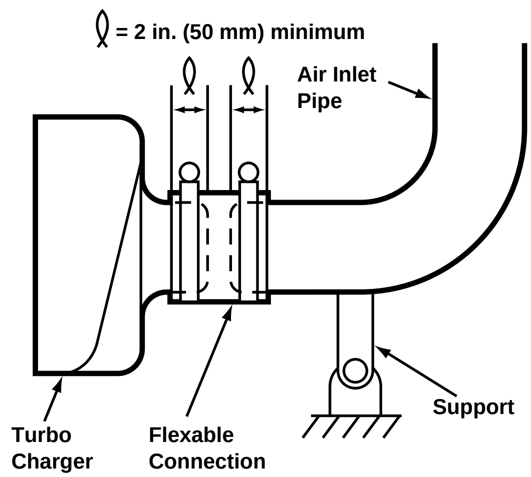


Figure 5.

Joining Two Turbochargers

When ductwork feeding two turbochargers is combined to form a single duct, a steadying zone of the length b > 5 x Dh must be provided after the dividing joint, see Figure 6. The flow area is:

$$F° = 1.0...2.0 \times F1 \text{ (or F2)}$$

The transitions from Sections 2-2 to 3-3 and from 1-1 to 2-2 will have many variations due to turbocharger hardware and installation site design. Regardless of the transition selected, the steadying zone must be provided.

Cleanliness

On remote-mounted air cleaners, the air intake ducting must be cleaned of all debris. Fabricated ducting or fasteners, such as rivets, should not be used. The ducting material must be designed such that prolonged operation will not result in debris coming loose and entering the turbocharger.

Install an identifiable blanking plate ahead of the turbocharger to prevent debris from entering during initial installation of the unit. Remove the plate prior to starting the engine.

Make provisions to inspect the ducting for cleanliness just prior to initial start-up.

Inlet Air Duct Insulation

Insulation may be needed on the intake ducting for remote mounted air cleaners. Insulation reduces turbocharger noise emitted into the engine room.

Considerations for Low Pressure Gas

Take special care when designing the air intake system for low pressure gas engines that do not have air-fuel ratio control. If the air and gas temperatures to the engine are not controlled, engine emissions and detonation margins can change. It is necessary to design a system that will prevent the variation in differential temperature (VΔT) between the gas and the air going to the carburetor from changing beyond the limits given in the following table.

	Emission Level		
Variation of VΔT	2.0 g NO_x/ hp-hr	1.5 g NO_x/ hp-hr	1.0 g NO_x/ hp-hr
Maximum Value of VΔT	± 5.5°C (10°F)	± 5.5°C (10°F)	± 3.3°C (6°F)

Where: ΔT = Temperature difference of inlet air and fuel gas
VΔT = |ΔT Condition 1 - ΔT Condition 2|

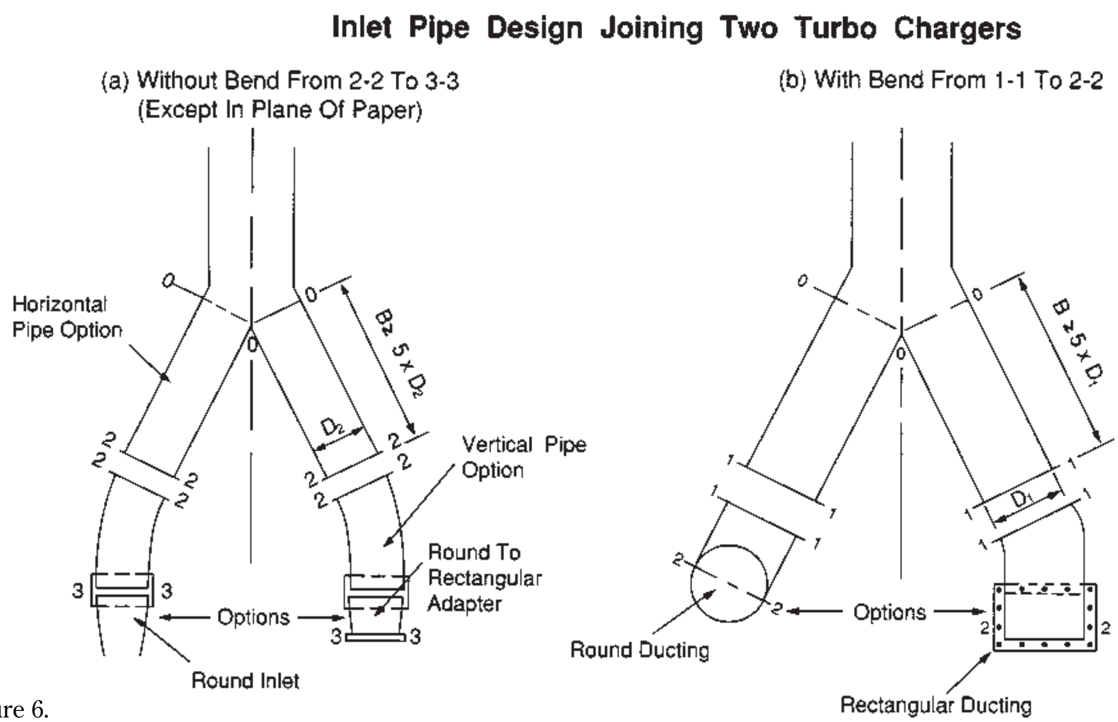


Figure 6.

Carburetors used in Caterpillar Gas Engines meter fuel into incoming air on a volume-for-volume basis. If the density of either the air or the gas changes relative to the other, the air-fuel ratio of the engine will also change.

For example, if a G3516 LE, 11:1 CR, 32°C (90°F) A/C, LE engine is adjusted to produce 2 g NO_x at full load, the percent O_2 in the exhaust must be set to 8%, which results in an air-fuel ratio of 14.75 on a volume-for-volume basis.

If the engine is adjusted when the incoming air is 10°C (50°F) and the incoming gas 21°C (70°F),

$$\Delta T1 = 10°C - 21°C = -29°C$$
$$(\Delta T1 = 50°F - 70°F = -20°F)$$

If the air temperature is later increased to 32°C (90°F) and the gas temperature remained constant,

$$\Delta T2 = 32°C - 21°C = -7°C$$
$$(\Delta T2 = 90°F - 70°F = +20°F)$$

The VΔT would then become:

$$V\Delta T = |-7°FC - (-29°F)| = 22°C$$
$$(V\Delta T = |20°F - (-20°F)| = 40°F)$$

The density of the air would then decrease, resulting in a lower air-fuel ratio of 13.67. The lower air-fuel ratio would result in reducing the percent O_2 in the exhaust to 6.5%. Figure 7 shows how NO_x changes as a function of percent O_2 in the exhaust. The increased air temperature in our example would increase the NO_x emissions to 8.8 g NO_x/bhp-hr, an increase of 440%.

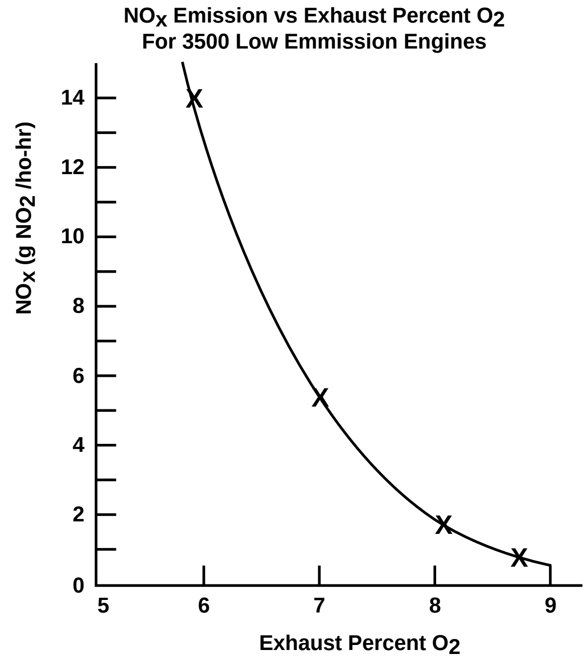


Figure 7.

High pressure gas engines are not affected by these changes to the extent low pressure gas engines are. This is because the supply gas temperature remains relatively constant at most installations and the thermostatically controlled aftercooler maintains a fairly constant air temperature to the carburetor. Since these two temperatures are not subject to large changes, the air-fuel ratio remains relatively constant.

There are two primary methods of controlling VΔT:

- If the gas temperature is expected to remain relatively constant, then the air temperature to the engine can be controlled to maintain a constant temperature to the engine.
- A gas-to-air heat exchanger can be used to make the temperatures of the incoming air and gas relatively the same, or close. If either the air or gas temperature changes, the other will follow.

Controlling Air Temperature

One method of controlling air supply temperature is to regulate the engine room temperature. However, this approach is not recommended. It is difficult to regulate an engine room to a temperature that is both comfortable to work in and high enough to provide a constant air temperature to the engine. For example, an installation expecting a 32°C (90°F) ambient temperature, will need to regulate the engine room to about 38°C (100°F) at all times. Also, engine rooms having large service doors that, at times, must be left open while the engines are running, will not maintain the air-fuel ratio while the doors are open.

The preferred method is to use duct work to supply a temperature regulated air supply to the engine, see Figure 8. This system uses jacket water to heat the air to the temperature set by the thermostat. If one intake system is used to supply temperature controlled air to multiple engines, provisions must be made to insure that heated water is sent to the heat exchanger when engines are running. If engine jacket water is used, the engine that the water is taken from must be running when any of the other engines are operating.

Air-to-Gas Heat Exchanger

If the use of duct work is not practical for a given installation, another option is to install a gas-to-air heat exchanger, see Figure 9. If done correctly, this system will prevent temperature changes in the gas or the air from affecting the air-fuel ratio. Design the system so the gas flows through the heat exchanger before entering the gas regulator. The pressure drop across the heat exchanger at full load must be added to the minimum gas supply pressure required by the engine. Design the heat exchanger to minimize both gas and air flow pressure drop while still providing enough heat transfer so that VΔT stays within the given limits.

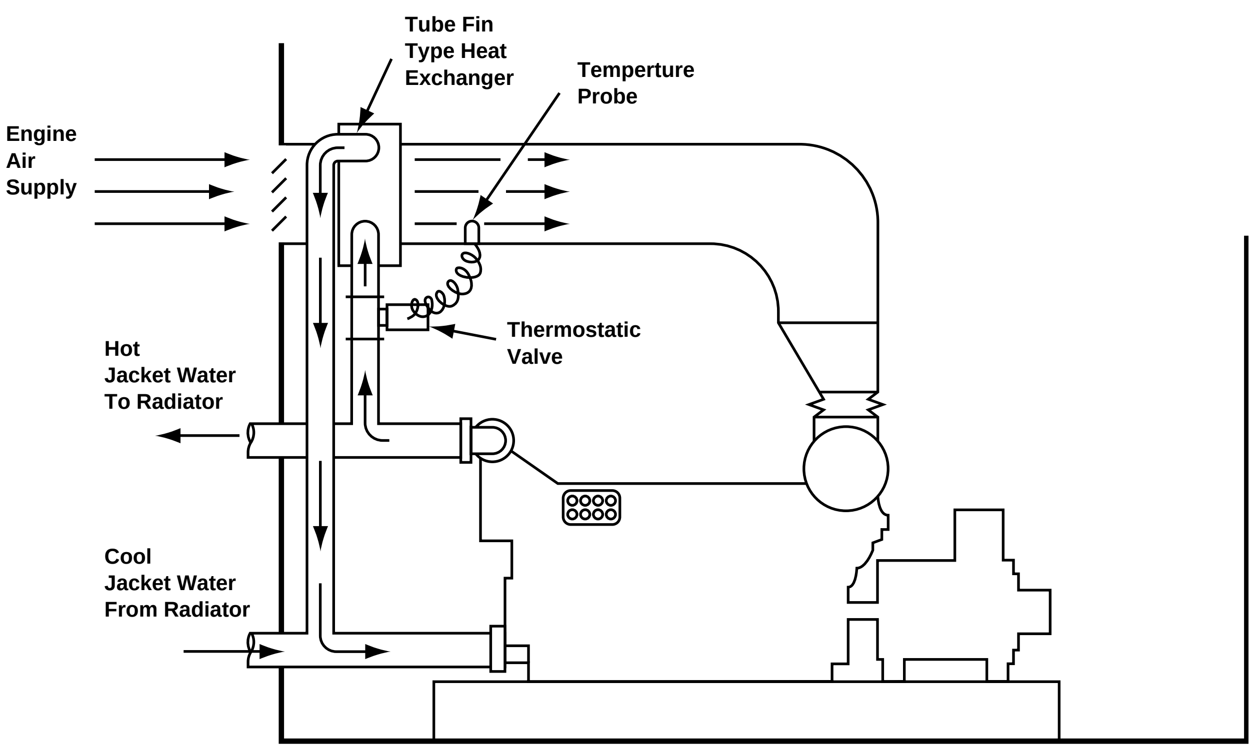


Figure 8.

Air Cleaner Icing

Air cleaner icing can occur in saturated air environments when the dew point of the ambient air is near freezing. Small disturbances to the air such as velocity and pressure changes at the air cleaner inlet reduce the moisture-holding capacity of the air. This results in moisture condensation and ice crystal formation. The ice buildup reduces the air flow area and increases the pressure differential across the air cleaner. Eventually, a plateau is reached where the pressure differential remains constant even though ice buildup may continue. Power loss and increased fuel consumption will result during these periods.

Several techniques may be used to overcome air cleaner icing. One solution is to heat the intake air slightly. It is not necessary to heat the air above freezing. The air requires only enough heat to be above the dew point. Heat can be supplied to the air cleaner housing by ducting engine room air. Heated air from the exhaust piping or muffler, or electrical heating tape may also be used.

Extreme Cold

Heated engine room air may be required (for starting purposes only) in applications at very cold ambients, -25°C (-13°F). This assumes combustion air is being drawn from outside the engine building, and the engine is preconditioned with pre-heaters for metal, water and oil temperatures of 0°C (32°F). Admitting engine room air must be done without the possibility of allowing dirt or debris into the air inlet system of the engine.

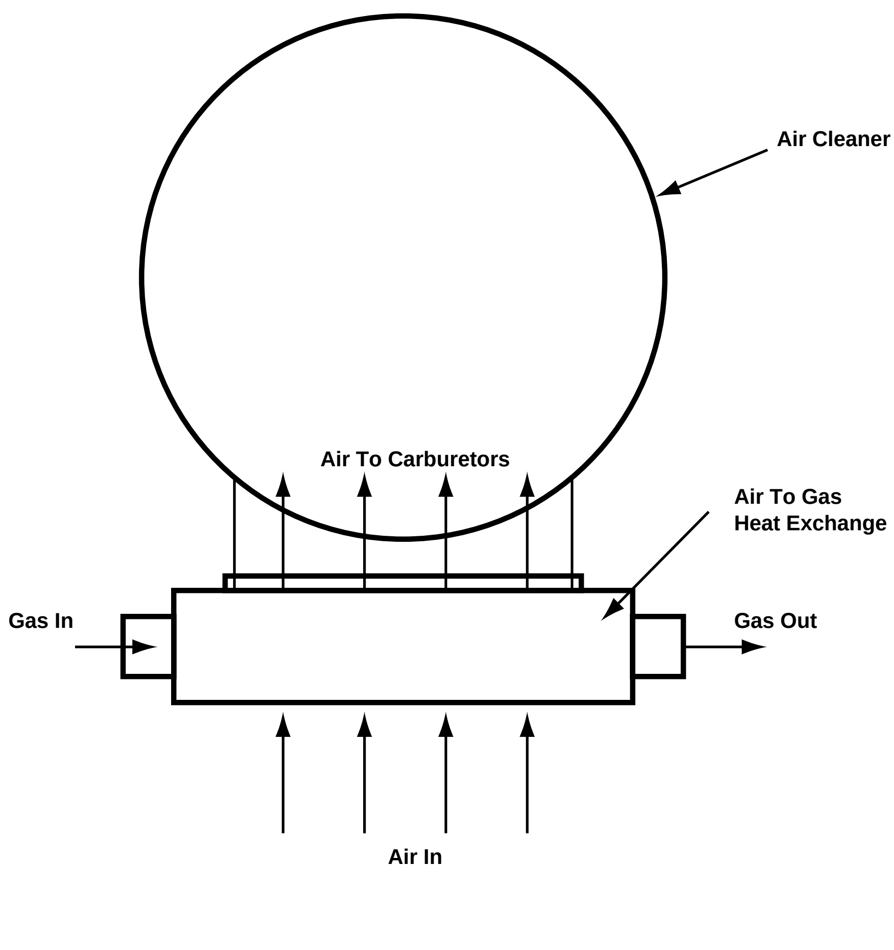


Figure 9.

CATERPILLAR®

G3600–G3300 Exhaust Systems

Exhaust Backpressure
Calculating Exhaust Backpressure
Piping
Flexible Connections
External Loading
Thermal Growth
Exhaust Connections
Cleanliness
Silencer Selection and Installation

Exhaust Systems

Exhaust systems collect exhaust gases from engine cylinders and discharge them as quickly and silently as possible. A primary aim of the exhaust system is to minimize backpressure since exhaust gas restrictions cause horsepower losses and exhaust temperature increases.

Exhaust Backpressure

The exhaust backpressure for Caterpillar G3300, G3400, & G3500 engines is limited to 6.7 kPa (27 in. H_2O) on turbocharged (TA) engines and 3 kPa (12 in. H_2O) on naturally aspirated (NA) engines. The G3600 turbocharged engine is limited to 3 kPa (12 in. H_2O). Excessive backpressure can cause excessive exhaust temperature and loss of horsepower.

On Caterpillar G3300, G3400 and G3500 Gas Engines there is only one exhaust outlet. Either there is a single turbocharger or the two exhaust systems are merged into one outlet.

Vee engine exhaust piping for the G3600 series should be designed with equal restrictions on each bank to prevent unequal bank-to-bank back pressure.

Measure exhaust system backpressure from a straight length of the exhaust pipe at least 3 to 5 pipe diameters away from the last size transition. The back pressure should be measured as close to the engine as is possible.

Calculating Exhaust Backpressure

These formulae allow the exhaust system designer to calculate a pipe diameter which, when fabricated into an exhaust system, will give exhaust backpressure less than the appropriate limit.

Calculate the pipe diameter according to the formula, then choose the next larger commercially available pipe size.

Backpressure limits of the exhaust system includes losses due to piping, muffler, and rain cap.

Calculate backpressure by:

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

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

P = Backpressure (kPa), (in. H_2O)
P_s = pressure drop of silencer and rain cap
psi = 0.0361 x in. water column
kPa = 6.3246 x mm water column
L = Total Equivalent Length of pipe (m) (ft)
Q = Exhaust gas flow (m^3/min), (cfm)
D = Inside diameter of pipe (mm), (in.)
S = Density of gas (kg/m^3), (lb/ft^3)

$$S\ (kg/m^3) = \frac{352.5}{\text{Stack Gas Temperature (°C)} + 273°\text{C}}$$

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

To obtain equivalent length of straight pipe for various elbows:

$L = \frac{33D}{X}$ Standard Elbow (Radius of elbow equals pipe diameter)

$L = \frac{20D}{X}$ Long Elbow (Radius > 1.5 Diameter)

$L = \frac{15D}{X}$ 45° Elbow

$L = \frac{66D}{X}$ Square Elbow

Where X = 1000 mm or 12 in.

As can be seen, if 90° bends are required, a radius of two times the pipe diameter helps to lower resistance.

As a general rule, the flow losses of the optional Caterpillar supplied exhaust adapters are 1 kPa (4 in. H_2O). This leaves approximately .75 kPa, (3 in. H_2O) loss available for installation piping and .75 kPa (3 in. H_2O), for a muffler/silencer.

The following table lists exhaust restriction for various Caterpillar supplied exhaust components on G3600 Engines based on full load power ratings.

Rectangle to Round Adapter
(Turbo Outlet).............0.623 kPa (2.5 in. H_2O)
Exducer 356 mm x 457 mm
diameter (14 in. x 18 in.)
Round Expander ....0.4 kPa (1.6 in. H_2O)
14 in. Diameter
Bellows..............................0.2 kPa (0.8 in. H_2O)
18 in. Diameter
Bellows.........................0.075 kPa (0.3 in. H_2O)

Piping

The physical characteristics of the engine room will determine the exhaust system layout. Exhaust piping should be designed to minimize the exhaust backpressure while keeping engine serviceability in mind. The exhaust piping should be securely supported with rubber dampers or spring installed in the bracing to isolate vibrations.

Piping must be designed with engine service in mind. In many cases, an overhead crane will be used to service the heavier engine components.

The following recommendations should be followed when designing an exhaust piping system:

- All piping should be installed with a 229 mm (9 in.) minimum clearance from combustible materials
- To prevent heat radiation, exhaust pipes should be shrouded with suitable, high temperature insulation.
- Install metal thimble guards for exhaust piping passing through wooden walls or roofs. The thimble guards should be 305 mm (12 in.) greater in diameter than the exhaust pipes, see Figure 10.
- Extend exhaust stacks upward and away from engine room to avoid heat, fumes and odors.
- Locate the exhaust pipes away from the air intake system. Engine air cleaners, turbochargers, and aftercoolers clogged with exhaust products can cause premature failures.
- Pipe outlets cut at 30° to 45° angles, rather than 90° angles, will reduce gas turbulence and noise.
- Rain caps forced open by exhaust pressure will keep water from entering the exhaust system.
- Gas engines burning natural gas creates one pound of water for each 10 ft^3 of natural gas burned. For this reason long runs of exhaust piping require traps to drain moisture. Traps installed at the lowest point of the line near the exhaust outlet prevent rain water from reaching the engine. Slope exhaust lines from engine to the trap so condensation will drain, see Figure 10.

Although economically tempting, *a common exhaust system for multiple installations is* ***not*** *acceptable.* Combined exhaust systems with boilers or other engines allow operating engines to force exhaust gases into engines not operating. Water vapor created during combustion will condense in cold engines and quickly causes engine damage. Duct valves separating engine exhausts is also discouraged. High temperatures warp valve seats causing leakage.

Exhaust draft fans have been applied successfully in combined exhaust ducts, but most operate only whenever exhaust is present. To prevent turbocharger windmilling (without lubrication), the fans should not be operable when the engine is shut down. The exhaust system of non-running engines must be closed and vented.

Combining the individual vee engine exhaust outlets together on G3600 engines by using a fabrication can create problems. The fabrication may result in unequal thermal

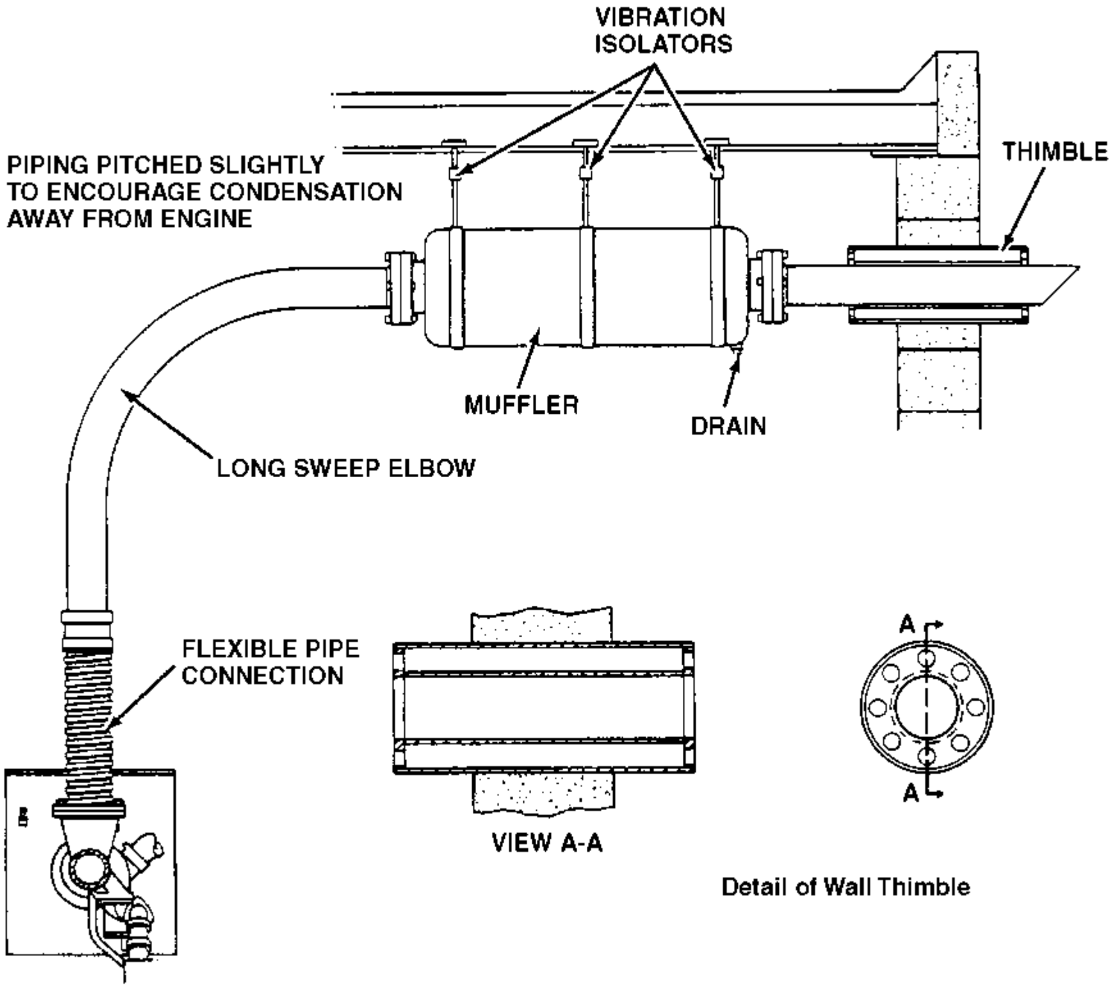


Figure 10.

growth and backpressure from one bank to the other. This unequal growth can put unwanted loading onto the turbocharger mounting or the flex bellows. The unequal backpressure can adversely affect the operation and performance of the engine. These problems can be minimized by providing a flexible connection on each leg, and by keeping each leg equal in length.

Flexible Connections

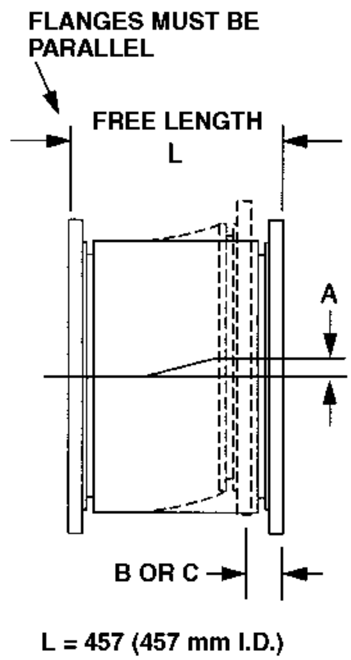
The exhaust pipe must be isolated from the engine with flexible connections. Install the flexible connections close to the engine exhaust outlet. A flexible exhaust connection has three primary functions:

- To isolate the weight of the exhaust piping from the engine.
- To relieve exhaust components of excessive vibrational fatigue stresses.
- Allow relative shifting of exhaust components. This has numerous causes. It may result from expansion and contraction due to temperature changes, by creep processes that take place throughout the life of any structure, or torque reactions when the generator set mounts on spring type isolators.

Pre-stretch the exhaust bellows during installation to allow for thermal growth. *Four small straps can be tack-welded between the two end flanges to hold the engine exhaust bellows in a rigid position during exhaust piping installation.* This will prevent the bellows from being installed in a flexed condition. Attach a warning tag to the bellows noting

Installation Limitions of Flexible Metal Hose-Type Exhaust Fittings						
Hose Diameter	A Maximum Offset Between Flanges		B Maximum Compression From Free Length		C Maximum Extension From Free Length	
	mm	in.	mm	in.	mm	in.
4 & 5 in.	25.4	1.0	6.25	.25	6.25	2.5
6 in.	38.1	1.5	6.25	.25	6.25	2.5

Installation Limitions of Bellows-Type Flexible Exhaust Fittings						
Hose Diameter	A Maximum Offset Between Flanges		B Maximum Compression From Free Length		C Maximum Extension From Free Length	
	mm	in.	mm	in.	mm	in.
8 & 12 in.	19.05	0.75	38.1	1.50	25.40	1.00
14 in.	19.05	0.75	76.2	3.00	25.40	1.00
18 in.	22.86	0.90	76.2	3.00	44.45	1.75



Spring Rate for Bellows-Type Flexible Fittings		
	Spring Rate	
Diameter	kN/m	lb/in.
8 in.	29.7	170
12 in.	33.9	194
14 in.	68.5	391
18 in.	19.3	110

Figure 11.

that the weld straps *must* be removed prior to starting the engine.

The installation limitations of the Caterpillar supplied flexible exhaust bellows are shown on Figure 11.

For maximum durability, allow the bellows to operate as close as possible to its free state.

External Loading

Careful consideration must be given to the load external piping may induce on the turbocharger.

Figures 12 and 13 show how to calculate the forces and moments on the G3500, G3400 and G3300 Engines. G3300 and G3400 engines should be limited to 111 N (25 lb) of vertical force and the G3500 is limited to 178 N (40 lb). The maximum allowable moment is 120 N•m (89.5 ft-lb) for G3300, G3400, and G3500 series engines

For G3600 series engines the Caterpillar supplied bellows and adapter account for the maximum allowable vertical load on the turbocharger and other external piping must be self-supporting.

When horizontal piping connects to the turbocharger exhaust, the design must

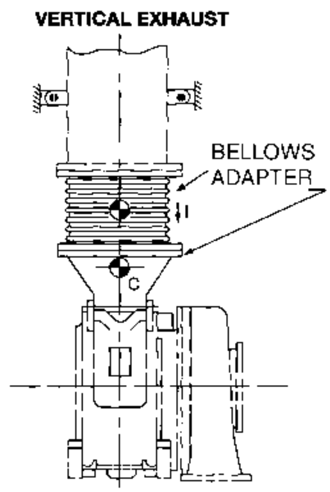


Figure 12.

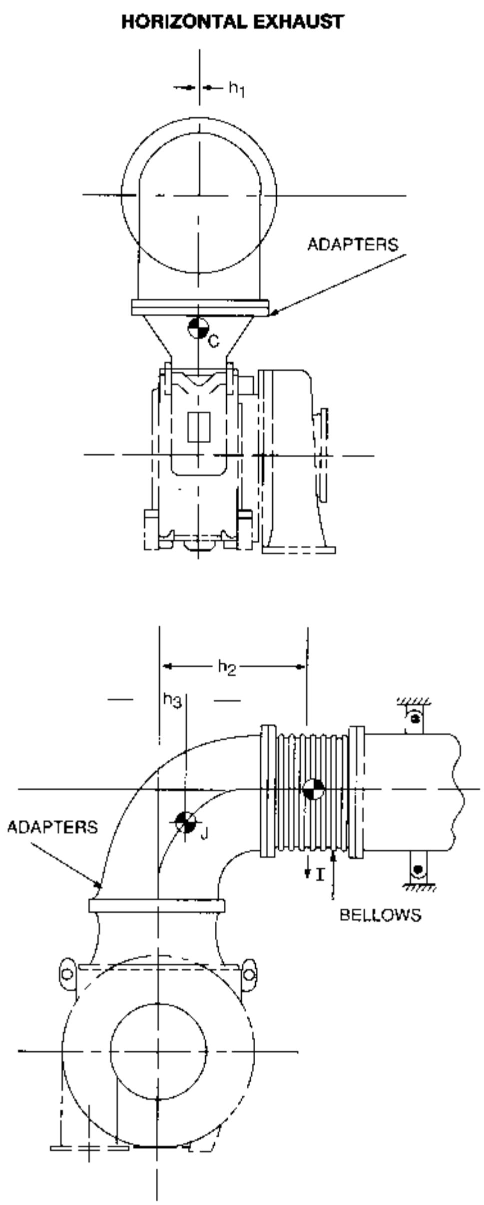


Figure 13.

account for thermal growth. See *Thermal Growth* Section.

The maximum allowable moment for the G3600 is equal to what is applied by the Caterpillar supplied elbow and bellows.

Maximum Loads for Turbocharger Exhaust

Assume G3516 with single exhaust outlet.

Vertical Exhaust
C = Adapter Weight
I = 1/2 Bellows Weight
With Caterpillar Hardware:
C = 28 N (6.4 lb)
I = 6 N (1.4 lb)
Sum of Vertical Forces
$F_v = C + I = 28 + 6 = 34$ N (7.8 lb)
Sum of Moments
$M = h_1 \times C + h_2 \times I = 0 \times 28 + 0 \times 6 =$
0 N•m (ft–lb)
Since $F_v < 111$ N (25 lb) and $M < 120$ N•m (89.5 ft–lb) the exhaust system meets the load and moment requirements.

Horizontal Exhaust
C = Adapter Weight
J = Elbow Adapter
I = 1/2 Bellows Weight
With Caterpillar Hardware:
C = 28 N (6.4 lb)
I = 6 N (1.4 lb)
J = 47 N (10.7 lb)
$h_1 = 0$
$h_2 = 100$ mm (3.9 in.)
$h_3 = 580$ mm (22.8 in.)
Sum of Vertical Forces
$F_v = C + I + J = 28 + 6 + 47 + 81$ N (18.5 lb)
Sum of Moments
$M = h_1 \times C + h_2 \times I + h_3 \times J = 0 \times 28 + .100 \times 6 + .580 \times 47 = 27.9$ N•m (20.8 ft–lb)
Since $F_v < 111$ N (25 lb) and $M < 120$ N•m (89.5 ft-lb) the exhaust system meets the load and moment requirements.

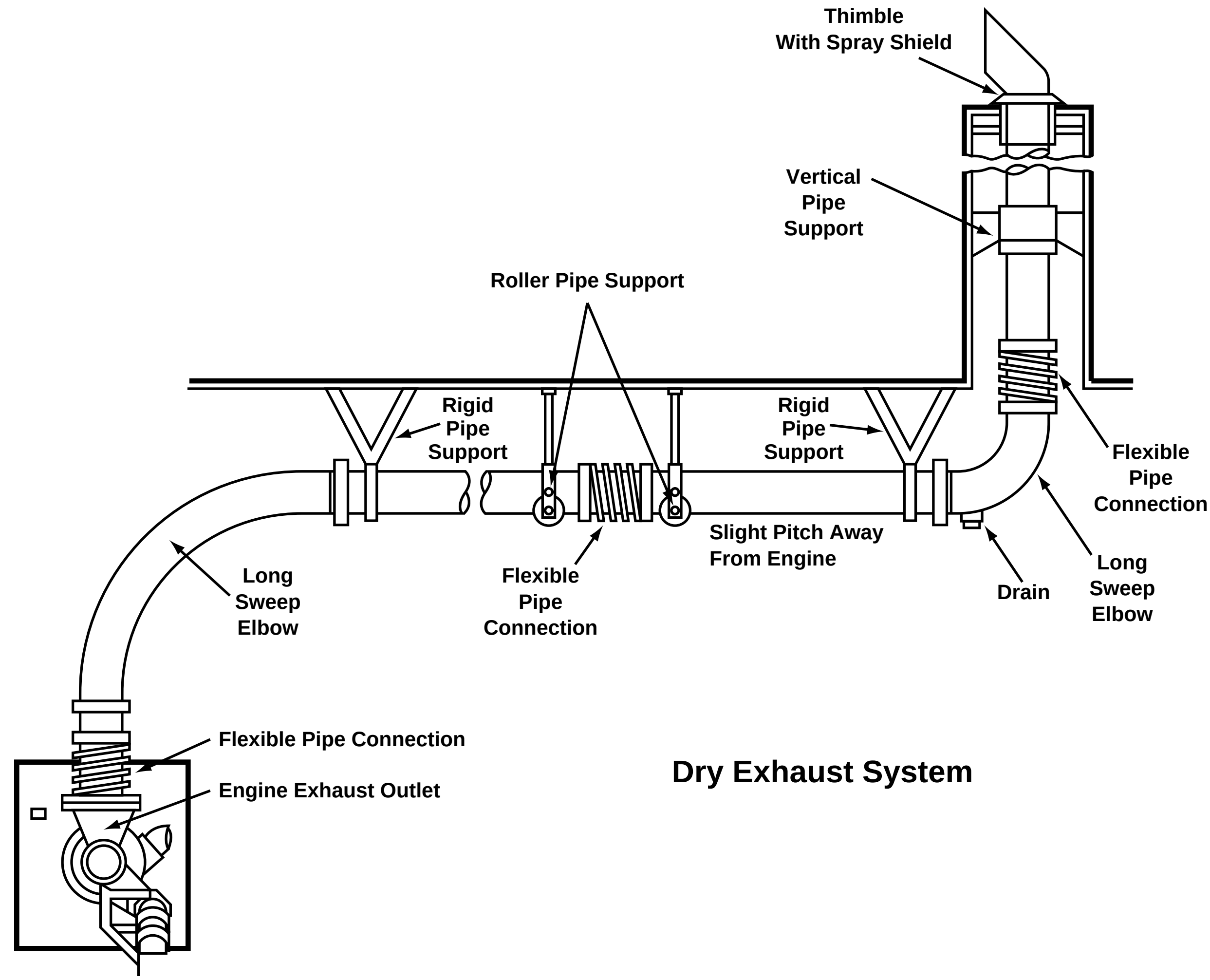


Figure 14.

Thermal Growth

Thermal growth of exhaust piping, away from the engine, must be planned to avoid excessive load on supporting structures. Steel exhaust pipe expands 1.13 mm/m (0.0076 in./ft) for each 100°C (100°F) rise of exhaust temperature. This amounts to 16.5 mm (0.65 in.) expansion for each 3.05 m (10 ft.) of pipe from 35° to 510°C (100° to 950°F).

Add expansion joints to long pipe runs. Each section is fixed at one end and allowed to expand at the other. Supports are located to allow expansion away from engine, avoid strains or distortions to connected equipment, and to allow equipment removal without additional support. A restraint member is often used to keep the ends of a long pipe run fixed in place, forcing all thermal growth towards the expansion joints. See Figure 14.

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.

Piping connected to generator sets requires isolation, particularly when the sets are mounted on spring isolators. These pipes 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 build up of resonant pipe vibrations, support long piping runs at unequal distances. See Figure 15.

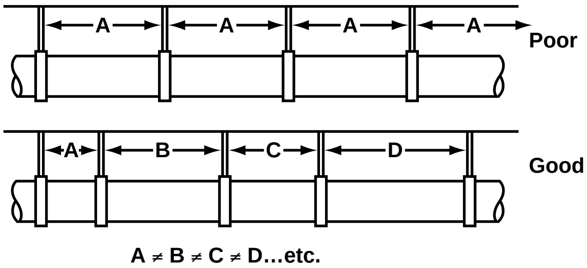


Figure 15.

Exhaust Connections

G3300, G3400 and G3500 engines use a fixed, round exhaust outlet. The outlet diameter is given as follows:

Exhaust Outlet Diameter in. (mm)		
	NA	TA
G3500	6 (152.4)	8 (203.0)
G3400	6 (152.4)	8 (203.2)
G3300	4 (101.6)	5 (127.0)

The turbocharger exhaust outlet on G3600 Engines is rectangular with an area equivalent to a 311 mm (12.24 in.) diameter pipe. An optional cast adapter mounts to the turbocharger to provide a circular connection point. For alternative outlet orientation, for alternative exhaust outlet orientation, a 90° exhaust elbow from the turbocharger is also available which be rotated in 30° increments. See Figure 16.

Cleanliness

Install an identifiable blanking plate to prevent debris from falling into the turbocharger during installation. The Caterpillar shipping cover can be used for this purpose. Install it directly on top of the turbine housing. Attach a warning tag to the plate indicating it must be removed prior to starting the engine.

Silencer Selection and Installation

The following are some general guidelines to aid in proper selection of the silencer.

Use silencer supplier data, correct for outlet temperature and velocity. Determine silencer size and type that satisfies noise reduction criteria with .5 to .75 kPa (2 to 3 in. H_2O), maximum pressure drop.

After calculating pressure loss, it may be necessary to check a second silencer, or a different pipe size, before an optimum combination is achieved.

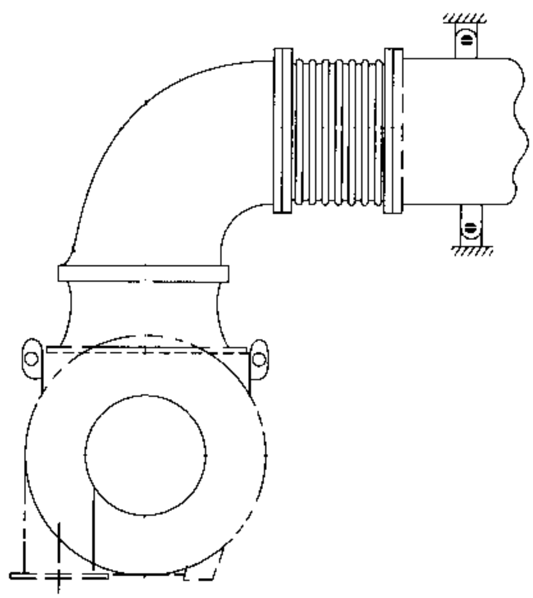


Figure 16.

Installation: *Provide a minimum of 5 diameters of straight piping upstream from the silencer inlet, and 2.5 diameters downstream from the silencer outlet to minimize turbulence and backpressure.*

When practical, orient the silencer vertically and use side inlets to eliminate extra inlet and discharge elbows. If not practical, insure the radius of all elbows is two times the pipe diameter.

A heat resistant material is required if lagging is used on the silencer to reduce radiated heat.

On G3600 Vee engines, consider using a dual inlet silencer instead of a “Y”, “T”, or 180° abrupt enlargement.

Exhaust thimbles separate the exhaust pipe from walls or ceiling to provide mechanical and thermal isolation. Single sleeve thimbles must have diameters at least 12 in. (305 mm) larger than the exhaust pipe. Double thimbles (inner and outer sleeve) should have outside diameters at least 6 in. (152 mm) larger than the exhaust pipe.

CATERPILLAR®

G3600-G3300
Engine Room Ventilation

Required Air Flow
Generator Radiated Heat
Temperature Rise
Engine Mounted Radiators

Engine Room Ventilation

Three to six percent of fuel consumed by a gas engines is lost to the environment in the form of heat radiated to the surrounding air. Consult TMI for specific data. Additionally, heat lost from generator inefficiencies and exhaust piping can easily equal engine radiated heat. The use of insulated exhaust pipes, silencer, and jacket water pipes will reduce the amount of heat radiated by auxiliary sources.

Required Air Flow

The required volumetric flow of engine room air required for ventilation can be estimated by the following formulas, assuming 38°C (100°F) ambient temperature:

$$V\ (\text{cfm}) = \frac{H + \text{Engine Combustion Air}}{0.070 \times 0.24 \times \Delta T}$$

$$V\ (\text{m}^3/\text{min}) = \frac{H + \text{Engine Combustion Air}}{1.099 \times 0.017 \times \Delta T}$$

V = Ventilating air m^3/min (cfm)
H = Heat radiation (Btu/min) (kW) from Engine and Auxiliary Equipment
Δ T = Permissible temperature rise in engine room °C (°F)
Density of air at 100°F = 1.099 kg/m^3 (0.070 lb/cu ft)
Specific heat of air, Cp = 0.017 kW/°C (0.24 Btu/°F)

Note: If duct work is used to bring in air for the engine's combustion air, the last term in the equation can be dropped.

Generator Radiated Heat

The heat radiated by the generator can be calculated by the following formulas:

$$\text{HRG (kW)} = P \times [(1/\text{Eff}) - 1]$$

$$\text{HRG (Btu/min)} = P \times [(1/\text{Eff}) - 1] \times 56.9$$

Where:

HRG = Heat Radiated by the Generator (Btu/min) (kW)
P = Generator Output at Maximum Engine Rating (ekW)
Eff = Generator Efficiency %/100% (Example: Eff = 94%/100% = 0.94)

Temperature Rise

The temperature rise in the engine room resulting from these heat sources can adversely affect maintenance personnel, switchgear, and generator set performance.

A 7 to 10°C (15 to 20°F) temperature rise is a reasonable target for engine rooms. In cold climates, discomfort may be caused by the flow of cold air. Restrict flow only if engine combustion air is available.

Engine Mounted Radiators

Installations utilizing engine-mounted radiators using engine room air for cooling (Figure 17), generally provide more air flow than is necessary for adequate ventilation. The high air flow combined with low ambient temperatures, below 21°C (70°F), can cause water to condense inside exposed engine components, like valve covers. This can result in oil and maintenance problems. Therefore, the system in Figure 17 is not recommended.

There are two methods that can be used to overcome this problem.

- Remote mounted and engine-mounted radiators are available that do not require engine room air for cooling (Figure 18). One advantage of such a system is that the air used to cool the radiator is not pre-heated by the engine, thus increasing the ambient capability (or reducing the size) of the unit. The disadvantage is that motor-driven fans must be installed to provide ventilation for the engine which increase the overall cost of the system.
- Thermostatically controlled louvers can be installed to recirculate some of the radiator exhaust in order to maintain a warm air flow across the engine (Figure 19). This

also maintains a comfortable working environment for maintenance personnel. Caution must be exercised so that the recirculated air is reintroduced upstream of the engine and is well mixed by the time it reaches the radiator.

For any arrangement where a radiator fan is used to ventilate an engine room, the vacuum created in the engine room must not exceed 0.12 kPa (0.5 in. H_2O). Any restriction above this limit could reduce air flow through the radiator and overheat the engine.

Correct routing of ventilation air is vital. Without it, airflow will not adequately maintain comfortable engine room temperatures. Locate room air intakes to provide maximum cooling air to the generator set, yet avoid hot, stagnant air in other areas.

Openings for intake air should be low, and positioned to admit the coolest, cleanest air possible. The air should flow past the generator end of the unit first. Due to the location of exhaust silencers, air cleaners, fumes disposal tubes, etc, this may not always be possible. Position outlets high on the opposite wall or roof. If automatic dampers are required to admit cooling and combustion air, the control logic should open the dampers immediately on engine start-up.

Examples of good ventilation systems are shown in Figures 20 and 21. Both systems bring the air in low across the engine and remove the heated air from above the engine(s).

The system shown in Figure 22 is an example of very poor ventilation. This system provides little air flow across the engine and does not circulate air throughout the engine room.

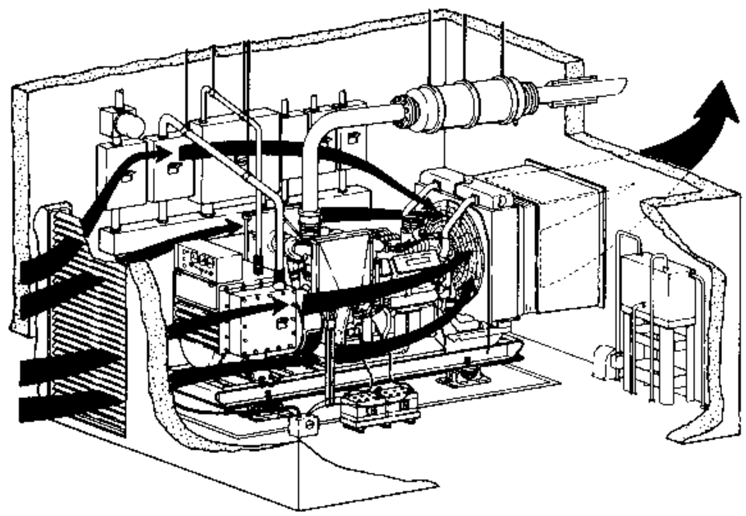
When installing multiple engine units within the same building, air flow between the individual generator sets must be planned. Figure 23 A and B show examples of both correct and incorrect air flow between multiple units.

Intake and exhaust ventilators may have movable or fixed louvers for weather protection. If movable louvers are used, they must be actuated by pneumatic, electric, or hydraulic motors. Never depend on air pressure developed by a fan to move the vanes.

The primary reason for cooling an engine room is to protect various components from excessive temperatures. Items that require cooling are:

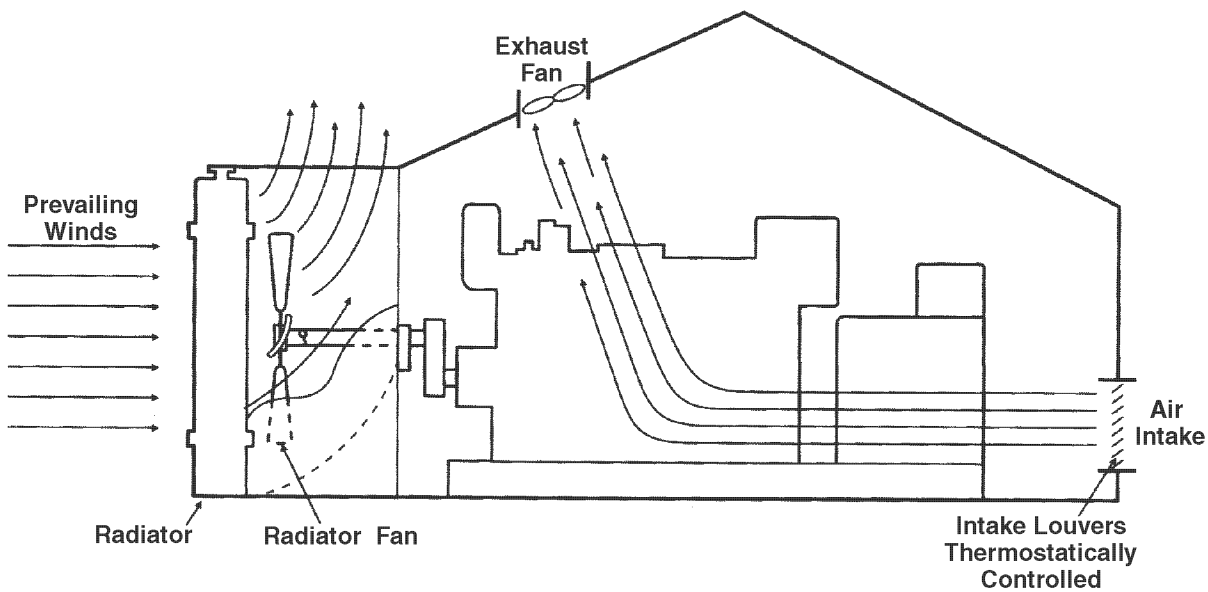
- Electrical components such as magnetos, interface box and timing control.
- Cool air to the air cleaner inlet.
- Cool air to cool the torsional damper.
- Habitable temperatures for the engine operator or service personnel.
- Cooling air for the generator or other driven equipment.

In larger multiple engine sites the normal 7° to 10°C (15° or 20°F) temperature rise guidelines for engine rooms require unobtainable or uncomfortable air velocities. For larger sites, a ventilation system that gives priority to the five items listed above and provides a bottom to top air flow similar to that shown in Figures 20 and 21 can be designed for temperature rise of 17°C (30°F).



Engine Driven Fan Arrangement
Not Recommended for Continuous Duty Applications

Figure 17.



Preferred Engine Driven Fan Arrangement
For Continuous Duty Applications

Figure 18.

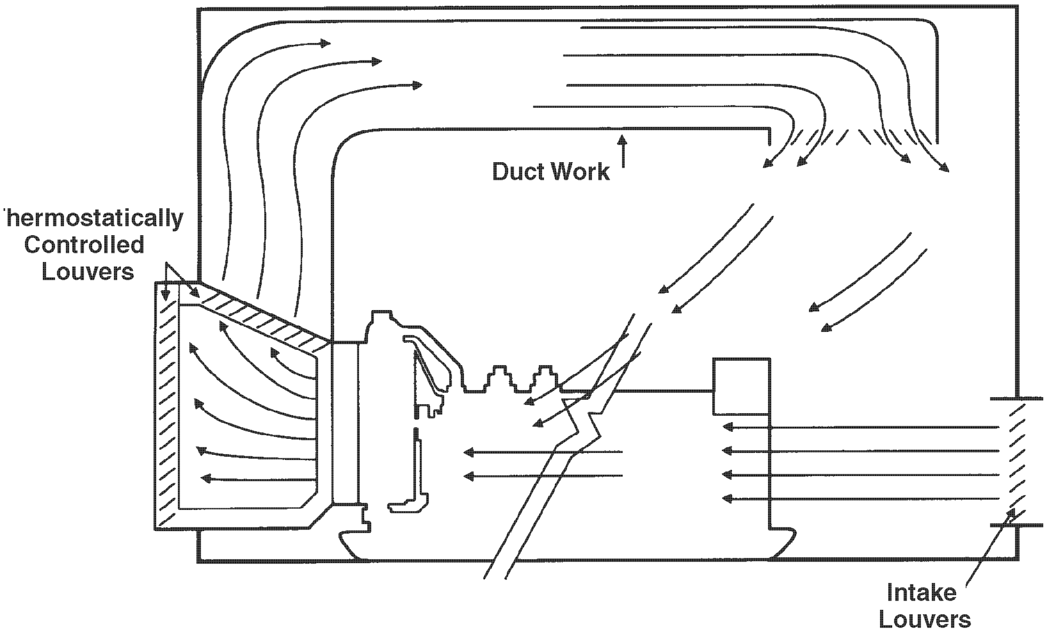


Figure 19.

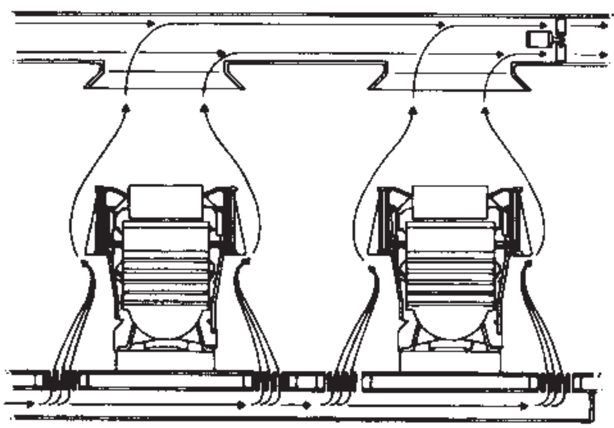


Figure 20.

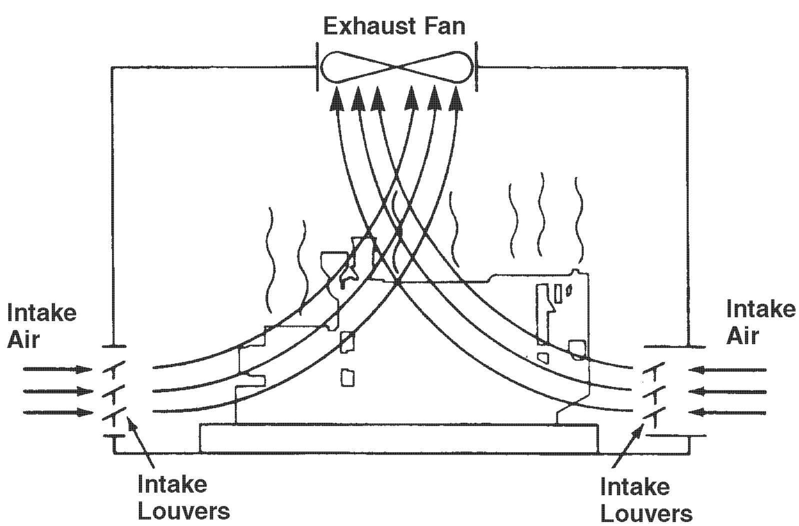


Figure 21.

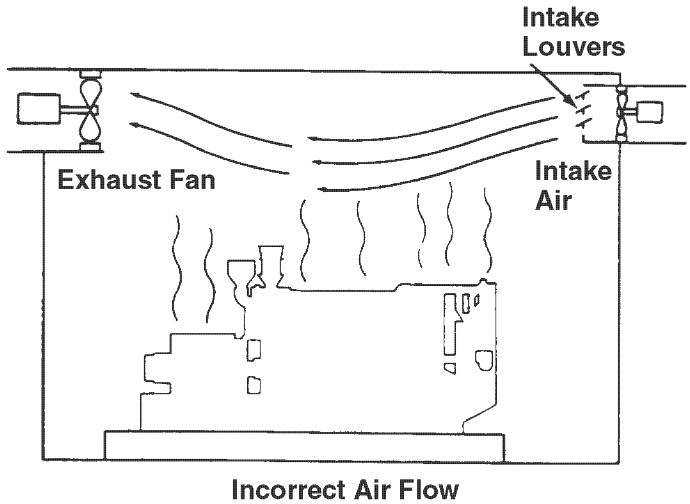


Figure 22.

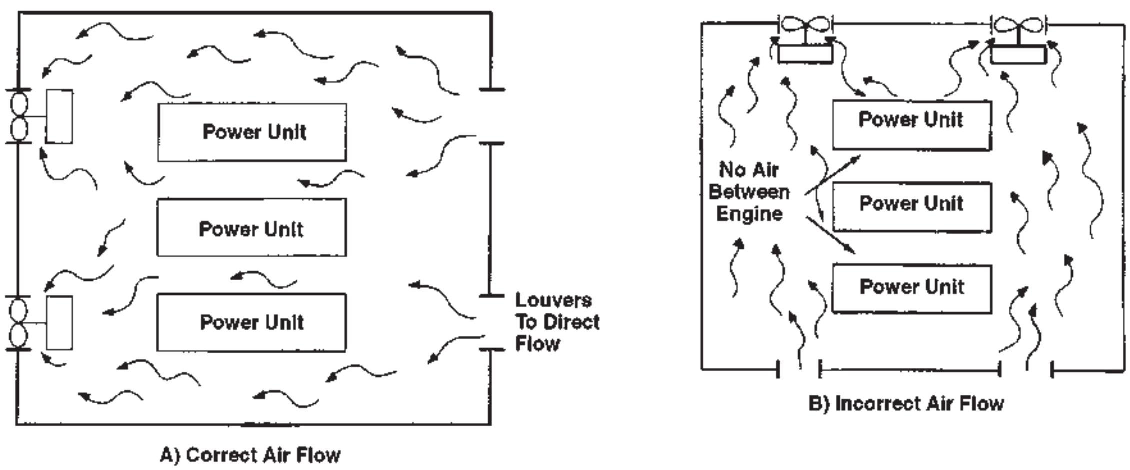


Figure 23.

CATERPILLAR®

G3600–G3300 Crankcase Ventilation

Crankcase Emissions
Crankcase Ventilation ("Ingestive")
  Low Pressure Ingestive System
  High Pressure Ingestive System
  Water In Engine Oil
  Introduction Fresh Air Into Crankcase
  Crankcase Pressure
Crankcase Ventilation (Non-Ingestive)
Crankcase Emission's Affect on Oil Life
Crankcase Emission Amount
Measuring Engine Blow-by and Diluting Crankcase Emissions

Crankcase Ventilation

Crankcase Emissions

Crankcase emissions or “Fugitive Emissions” result from piston ring blow-by. The volume of blow-by varies due to cylinder pressure, piston ring pressure and component wear. Crankcase emissions contain essentially exhaust gases, wear particles and oil/air/gas/fuel emissions. The proportions of these elements vary due to fuel type, engine type, engine speed, load and maintenance history. Blow-by is made up of Hydrocarbons (HC), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxides (NO_x) and traces of sulfates ahd aldehydes. Crankcase, Hydrocarbon emissions are normally 3% of the total exhaust emissions tested at the mid-life of the engines. However, due to piston ring tolerances, the crankcase Hydrocarbon emissions can become as much as 20% of the total Hydrocarbon emissions. The amount of NO_x present in the blow-by decreases depending on the air/fuel ratio of the engine. The more lean the intake, the less NO_x that should be present. The sulfates and aldehydes will change depending on the fuel. An engine running on landfill or digester gas will have more sulfides present in the blow-by than an engine running on natural gas.

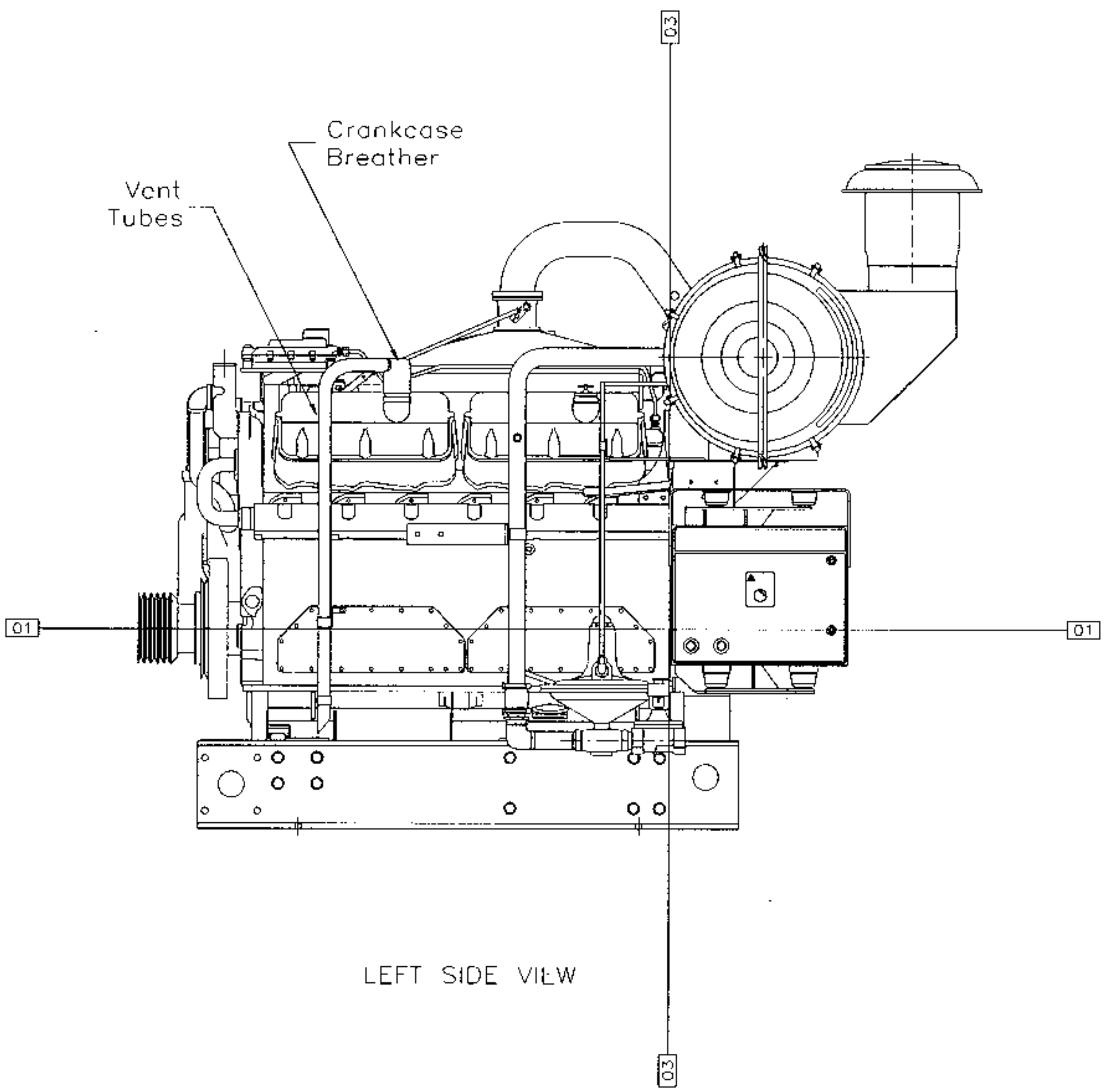


Figure 24.

As blow-by forms it builds pressure inside the crankcase; hence, it is important that the pressure is relieved. To prevent pressure buildup within the crankcase, vent tubes are provided to allow gas to escape (see Figure 24). Removing the blow-by from the crankcase is not very difficult, but the question of what to do with the blow-by once it leaves the crankcase is challenging. Basically, there are two techniques used in dealing with blow-by: “Ingestive” and “Non-Ingestive.” “Ingestive” involves placing the blow-by back into the combustion process and “Non-Ingestive” is using some method of venting the blow-by to the atmosphere.

The following paragraphs outline the benefits and drawbacks of each type of system. Currently, Caterpillar does not have an “Ingestive” system in production for Gas Engines.

Crankcase Ventilation (“Ingestive”)

As emission laws become more stringent, it is inevitable that crankcase emissions (or blow-by) will be included in total system emission values. Certain parts of Europe and California are already counting blow-by in the emission numbers. In the future, ventilating crankcase emissions to the atmosphere will be discouraged or prohibited.

To eliminate the worry of crankcase emissions, the blow-by can be returned to the combustion process. This method is commonly known as Positive Crankcase Ventilation (PCV) in the automobile industry. On naturally aspirated engines, like most cars, the blow-by can easily be returned to the combustion process without much added cost or engine component concern. The addition of a turbo-charger makes PCV a much more challenging task.

There are two ways of re-introducing the blow-by fumes back into the combustion process on a turbo charged engine. The blow-by can be put in the system at low pressure (before the turbocharger) or at high pressure (after the turbo charger).

Low Pressure Ingestive System

A low pressure, ingestive system involves piping the crankcase emissions into the low pressure side of the turbo charger (see Figure 25). The blow-by is drawn from the crankcase through the vent tubes, into the oil condensing device (or blow-by filter) and “sucked” back through the air cleaner by the turbo charger.

There are a number of hazards that can occur when using an “Ingestive” PCV systems on a turbo charged engine. Most tests have shown that no matter how effective the blow-by filter, over time, enough oil will be adsorbed to coat the aftercooler. This oil will act as an insulator, reducing the cooling capabilities of the aftercooler. A cleanable aftercooler should be used and cleaned regularly when using an “ingestive” PCV system.

The following is a list of considerations that should be followed while designing a low pressure, ingestive, PCV system:

- The blow-by MUST be sent through a filtering system prior to entering the turbo charger.
- A pressure relief valve must be put in place between the turbocharger and filtering system to ensure the draw on the crankcase does not exceed 26 mm H_2O (1.0 in. H_2O).
- Blow-by filters should be replaced or cleaned every oil change.
- Caterpillar’s recommendation is that the oil NOT be returned to the crankcase.

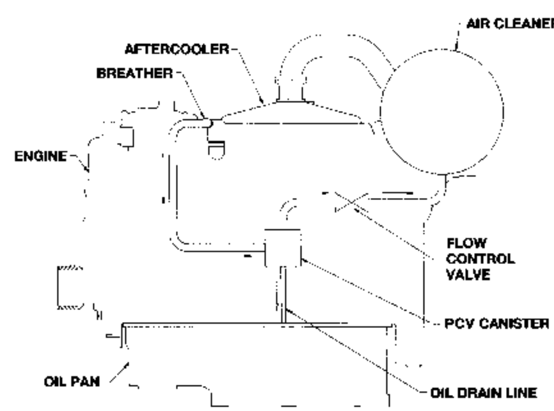


Figure 25.

High Pressure Ingestive System

A high pressure PCV system involves removing the blow-by from the crankcase and pumping it directly into the intake plenum (see Figure 26). This type of system removes the risk of coating the aftercooler and turbo, but the crankcase fumes should still be filtered to reduce the amount of oil going into the intake stream.

The limiting factor of this type of system is cost. An extra pump would be expensive and difficult to mount. Therefore, this type of system has been bypassed for the less effective, but more economical low pressure system.

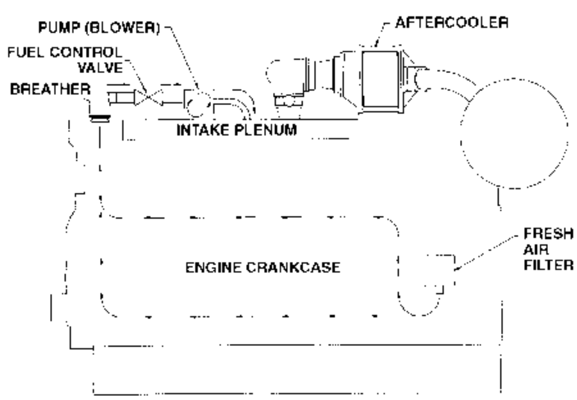


Figure 26.

Water in Engine Oil

Crankcase emissions are essentially concentrated exhaust fumes; therefore, they contain a considerable amount of water vapor. When oil is separated from the blow-by and filtered back into the oil sump, there is the risk of water condensing. Natural Gas Engines have a considerable amount of water in their exhaust, which has resulted in many PCV suppliers recommending that the excess oil be drained into a separate container.

When water is introduced to the engine oil, it forms an emulsion that clogs oil filters. As the amount of water increases, the ability for the additives to disperse the water in the oil decreases. The heat of the oil usually burns off water particles, but condensed blow-by contains so much water that the water can actually cool the oil and form sludge. Cooler oil temperatures may cause water and oil to combine to form dangerous acids that can corrode metals, thus reducing the lubricating qualities of the oil.

Introducing Fresh Air into Crankcase

Removing blow-by out of the crankcase may not be enough to ensure an emission free crankcase environment. It may be necessary to add fresh air directly into the crankcase in order to distill the air inside the crankcase. The quantity of this air should be about two times the volumetric flow rate of the blow-by.

One risk of adding fresh air might be the cold ambient air cooling off the crankcase, resulting in water condensing from the existing crankcase fumes. Therefore, it may be necessary to heat the air before introducing it to the crankcase.

Crankcase Pressure

The conventional wisdom of internal combustion engines is that the engine should operate at a slight positive pressure in order to keep any “engine surrounding” contaminants out of the engine. The effect of a PCV system tends to create a slight vacuum on the crankcase [0.25 kPa (1 in. H_2O) MAXIMUM]. The negative crankcase pressure is accepted in order to have fugitive emissions removed from the crankcase.

Under no circumstances should crankcase pressures vary more than 25.4 mm H_2O (1.0 in. H_2O) from ambient barometric pressure for G3300, G3400, & G3500 engines. The shutdown or maximum valve for G3600 engines is 4.0 in. H_2O. Restrictions higher than the limit on passive systems will worsen any oil leaks. A powered system should draw no more than a 25.4 mm H_2O (1.0 in. H_2O) vacuum, or dirt and dust could be drawn into the engine past the main seals. Measurement should be made at the engine dipstick location with the engine at operating temperature, speed, and load.

Crankcase Ventilation (Non-Ingestive)

Most areas do not include crankcase emissions as part of the total emissions for an engine. In order to save cost and potential engine hazards, it may benefit the customer to vent the blow-by to the atmosphere. The following discussion explains how venting an engine's blow-by should be performed.

When ventilating the crankcase, it is important not to vent crankcase fumes directly into the engine room without filtration. Fumes may clog air filters and increase air inlet temperature, possibly causing engine damage. Problems in electrical equipment can be caused by exposure to the fumes. The fumes can also be a health hazard if discharged in a poorly ventilated room. Therefore, crankcase emission should be ventilated to the atmosphere, by means of a venting system.

When there are multiple engines at a site, a separate vent line is required for each engine to prevent fumes and moisture produced by a running engine from entering an idle engine. The addition of moisture into an engine can cause corrosion and buildup of harmful deposits.

Crankcase vent pipes must be large enough to minimize back pressure. Normal blow-by on a new engine will be approximately .02 m^3/hr bkW (.5 ft^3/hr bhp). Adequately size the pipes to accommodate a worn engine, with a blow-by rate of .04 m^3/hr bkW (1 ft^3/hr bhp). Size the vent pipe with a maximum of 13 mm H_2O (0.5 in. H_2O)pressure drop at full load.

These formulas allow the crankcase ventilation designer to calculate a pipe diameter which will give a back pressure less than 13 mm H_2O (0.5 in. H_2O).

Calculate back pressure 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 = Back pressure (kPa), (in. H_2O)

psi = 0.0361 x in. water column

kpa = 6.3246 x mm water column

L = Total Equivalent Length of pipe (m) (ft)

Q = Exhaust gas flow (m^3/min), (cfm)

D = Inside diameter of pipe (mm), (in.)

S = Density of gas (kg/m^3), (lb/ft^3)

S (kg/m^3) = 1.08

S (lb/ft^3) = 0.067

To obtain equivalent length of straight pipe for various elbows:

$L = \frac{33D}{X}$ Standard Elbow (radius of elbow = pipe diameter)

$L = \frac{20D}{X}$ Long Elbow (Radius > 1.5 Diameter)

$L = \frac{15D}{X}$ 45° Elbow

$L = \frac{66D}{X}$ Square Elbow

Where X = 1000 mm or 12 in.

Calculate the pipe diameter according to the formula, then choose the next larger commercially available pipe size.

As can be seen, if 90° bends are required, a radius of two times the pipe diameter helps lower resistance.

Loops or low spots in a crankcase vent pipe must be avoided to prevent condensation from building up in the pipe and restricting the normal fumes discharge. Where horizontal runs are required, install the pipe with a gradual, 41.7 mm/m (1/2 in/ft), slope from the engine, see Figure 27. The weight of the vent pipes will require separate off-engine supports as part of the installation design. Any horizontal or vertical run of pipe that cannot be disassembled for cleaning should have clean-out ports installed.

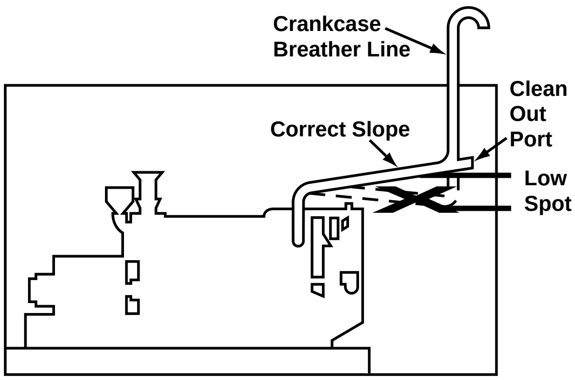


Figure 27.

Crankcase fumes must not discharge into the air ventilation ducts or exhaust pipes. They will become coated with oily deposits creating a fire hazard.

Vent the crankcase pipe directly into the atmosphere and direct it to keep rain or spray from entering the engine. Give consideration to equipment located near the discharge area as well as to the building itself. If not handled properly, very small amount of oil carry-over can accumulate and become unsightly and even harmful to auxiliary equipment.

A drip collector installed near the engine will minimize the amount of oil discharge through the vent pipe. It is necessary to provide some type of trap that will prevent crankcase gases from venting into the engine room, see Figure 28. If a trap as in Figure 28b is used, the designer must be sure the drip collector can be removed or drained for disposal. Another alternative is to install a valve on the end of the drip pipe and periodically drain it.

Figure 29 illustrates a powered fumes disposal system for a multiple engine installation. There are two main advantages to a powered system: the fumes will become diluted with air for better dispersal into the atmosphere, and it can improve oil life by removing the nitric oxides from the crankcase before they can cause nitration of the oil.

Since a vacuum will be drawn with a powered system, the addition of a small air filter somewhere on the engine crankcase is required. This will filter the air entering the crankcase and prevent dirt from being introduced into the oil. A valve connected in the line to each engine controls the flow of crankcase fumes out of the engine.

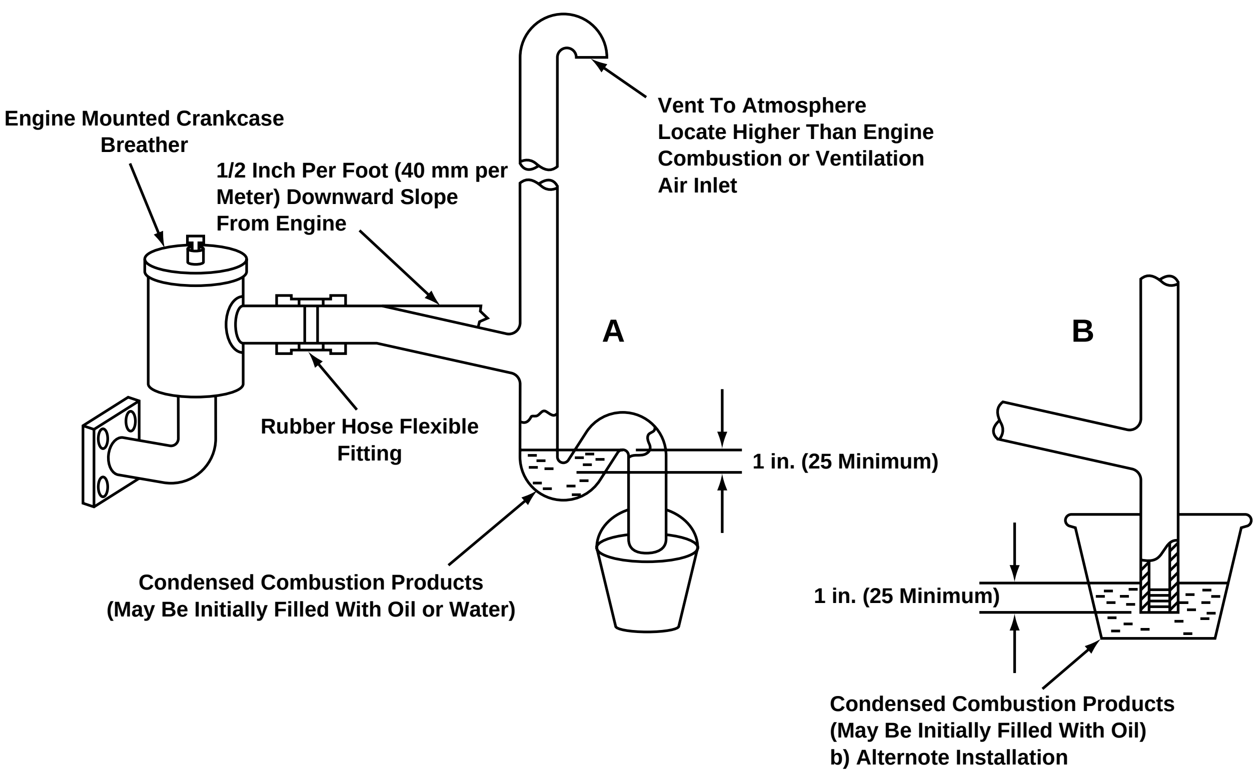


Figure 28.

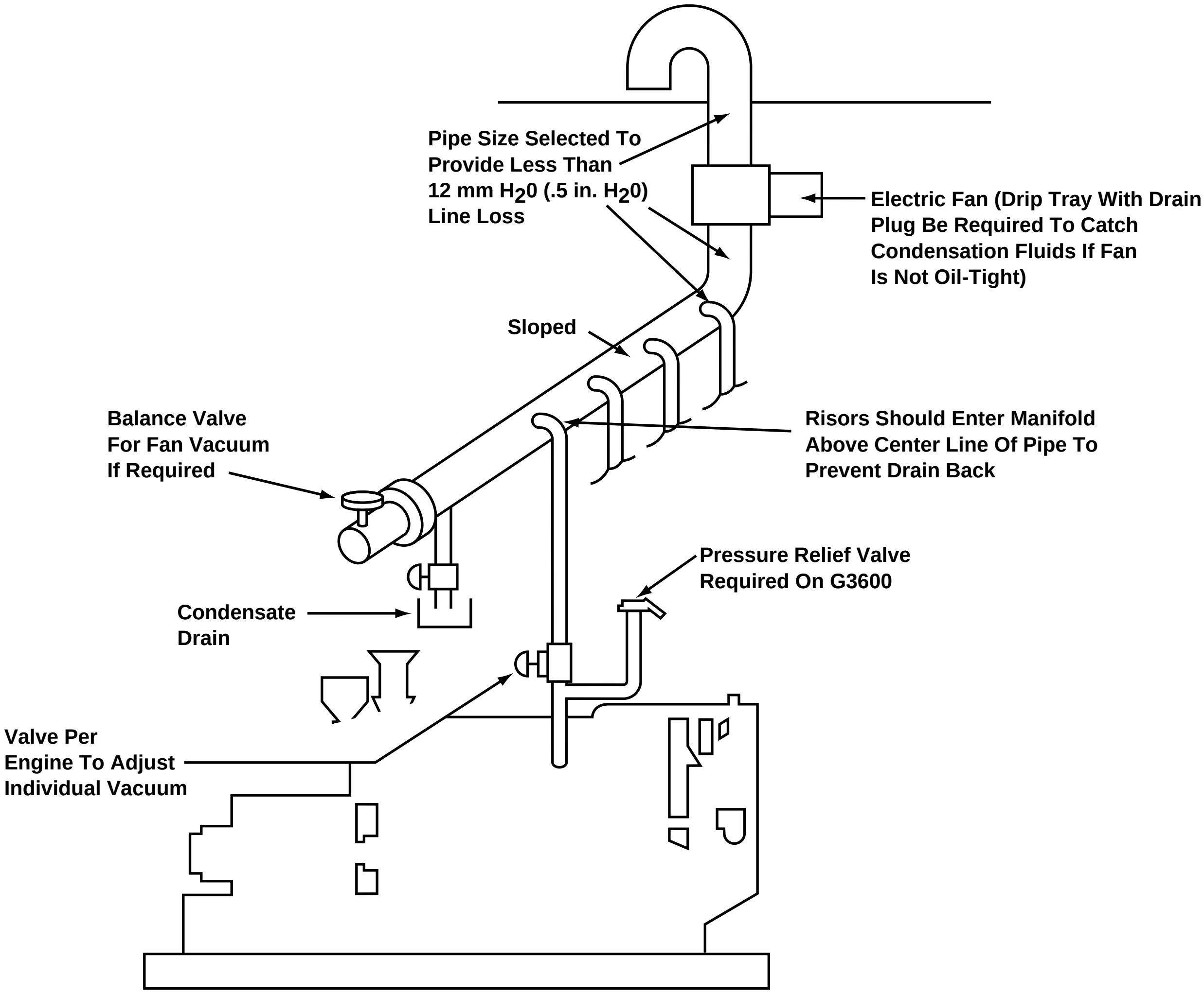


Figure 29.

Crankcase Emission's Affect on Oil Life

One of the goals of a PCV system is to increase the oil life of the engine. The removal of crankcase fumes can reduce the amount of oil degradation. It has been shown that a non-ingestive PCV system can double the oil life of an engine. However, the affects of PCV on oil life will vary with engine size, load, engine hours and ambient conditions.

Crankcase Emission Amount

Normal blow-by on a new engine will be approximately .02 m^3/hr bkW (.5 ft^3/hr bhp). Adequately size the pipes to accommodate a worn engine, .04 m^3/hr bkW (1 ft^3/hr bhp). Size the vent pipe with a maximum of 13 mm H_2O (0.5 in. H_2O) pressure drop at full load.

Measuring Engine Blow-by and Diluting Crankcase Emissions

The following is a step-by step procedure on how to dilute the crankcase with fresh air. This will measure the blow-by of an engine. This information is needed when designing a crankcase ventilation system.

To set up the system, a Blow-by/Air Flow Indicator (part number 8T2700) is required.

1. Measure the amount of combustion blow-by for a given engine. This is done by closing the crankcase ventilation valve, blocking the crankcase air filter, and attaching the Blow-by Indicator to the oil fill spout. The reading on the indicator is the engine's blow-by. All measurements are to be taken with the engine running at rated speed, load, and temperature.

2. Unplug the crankcase air filter and connect the Blow-by Indicator to it. Slowly open the crankcase ventilation valve until the indicator reads the same as in step 1.

This procedure will allow an equal amount of air to be drawn into the crankcase as is being blown past the piston rings. This will sufficiently dilute the fumes and increase oil life.

This procedure should be done for each engine. Make a final check of the crankcase pressure to insure the vacuum on the engine is less than 25.4 mm H_2O (1 in. H_2O).

Sometimes it is difficult to precisely size the blower for a powered system. If the only blower available is too large, it may draw too much vacuum on the crankcase ventilation valves and make adjustments difficult. To overcome this problem, a balance valve can be connected on the vacuum side of the blower to allow air to be drawn in the system and reduce the vacuum pressure on the adjusting valves.

An optional relief valve may be used to limit crankcase pressure to .14 kPa (.5 in. H_2O). This is used to avoid problems if the crankcase ventilation fan is not engaged.

Materials and specifications are
subject to change without notice.

Printed in U.S.A.