



# **Electric Power Application and Installation Guide**

## **Exhaust Systems**

LEBX0058-01



WHERE THE WORLD TURNS FOR POWER



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# Exhaust Systems

Exhaust systems collect exhaust gases from engine cylinders and discharge them as quickly and silently as possible. A primary design consideration of the exhaust system is to minimize backpressure. Backpressure will indirectly rise the exhaust temperature which will reduce exhaust valve and turbocharger life. A well designed exhaust system will have minimum backpressure.

All internal combustion engines generate heat as a result of the full combustion. The temperatures in Caterpillar engines can reach 1927° C (3,500° F). 30% of this total heat is expelled through exhaust.

## System Elements

The main components of an exhaust system are the exhaust manifold, turbocharger, wastegate, piping and the muffler. The individual components and their function will be explained below.

### Exhaust Manifold

Engine exhaust manifolds collect exhaust gases from each cylinder and channels them into an exhaust outlet. The manifold encourages minimum backpressure and turbulence. Several types are available for varying installation requirements. The watercooled and watershield manifolds are mainly used in Gas and Marine applications.

#### Dry Manifolds

Dry manifolds are usually standard equipment as they are the most cost effective, but they are also the least effective type of manifold for heat shielding (see Figure 1, #1). During engine operation, dry manifold surface temperatures can range from 430° C to 480° C (800° F to 980° F).

#### Watercooled Manifolds

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

and Health Agency, MSHA, requires watercooled manifolds to maintain engine surface temperatures below 200° C (400° F).

Passages within watercooled manifolds allow engine jacket coolant to flow around the manifold removing heat otherwise carried by exhaust gases (see Figure 1, #2). Heat rejection to the jacket water will increase 20-40%, 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.

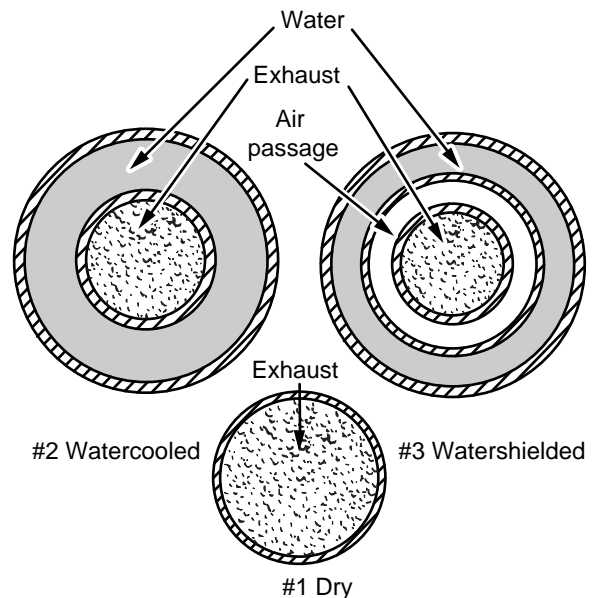


Figure 1. Three types of manifolds.

### Watershielded Manifolds

Watershielded and air cooled watershielded (ACWS) manifolds incorporate an auxiliary jacket or shield. Engine water circulates through the shield but does not come into direct contact with the inner manifold (see Figure 1 #3.) Watershielding allows air to circulate between the inner and outer casings, adding little to jacket water cooling load and not affecting engine performance. ACWS manifolds trap the air so, as with watercooled, jacket water and engine performance are affected.

## Turbochargers

Turbochargers are optional components used to get more power out of an engine by utilizing some of the remaining power in the exhaust. It is done by forcing more air into the cylinder which allows more fuel to be burned resulting in a higher horsepower output.

Hot exhaust gases exit the cylinder and enter the turbine side of the turbocharger (see Figure 2). The turbine blades and the compressor blades share a common shaft.

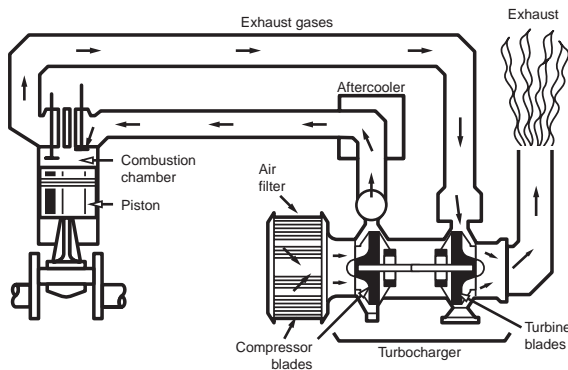


Figure 2. Schematic of a Turbocharger.

Gases drive the turbine blades which in turn drive the compressor blades on the air intake side. This high speed spinning compresses the intake air and at the same time increases its temperature.

## Wastegate

For most gas engines and some diesel engines a wastegated turbocharger is being used. When the engine is running at the lower end of the rpm's the turbocharger with wastegate is maximized for improved response and performance. As the rpm's increase the boost pressure opens the wastegate. This allows the turbocharger to "bleed" excess exhaust around the turbine wheel through the wastegate so the turbocharger does not overspeed and produce excessive boost. (Tampering with the boost line to the wastegate will raise heat rejection, increase turbo speed and peak cylinder pressure. This will negatively affect engine reliability, durability and overall performance.)

## Piping

Physical characteristics of the equipment room determine exhaust system layouts. Arrangements with minimum backpressures are favored. Securely support pipes and rubber dampers or springs 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.

For both installation economy and operating efficiency, engine location should make the exhaust piping as short as possible with minimum bends and restrictions. Usually the exhaust pipe extends through an outside wall of the building and continues up the outside of the wall to the roof. There should be a sleeve in the wall opening to absorb vibration and an expansion joint in the pipe to compensate for lengthways thermal expansion or contraction (see Figure 3).

Install piping with 229 mm (9 in) minimum clearance from combustible materials.

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

Extend exhaust stacks to avoid heat, fumes and odors. Also, the exhaust pipes should not be in close proximity to the air intake system for the engine or the crankcase ventilation system. Engine air cleaners, turbochargers, and aftercoolers clogged with exhaust products can cause premature failures. Pipe outlets cut at 30° to 45° angles will reduce gas turbulence and noise. Rain caps forced open by exhaust pressure will keep water from entering.

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 carbon buildup in the muffler; a drain removes condensation.

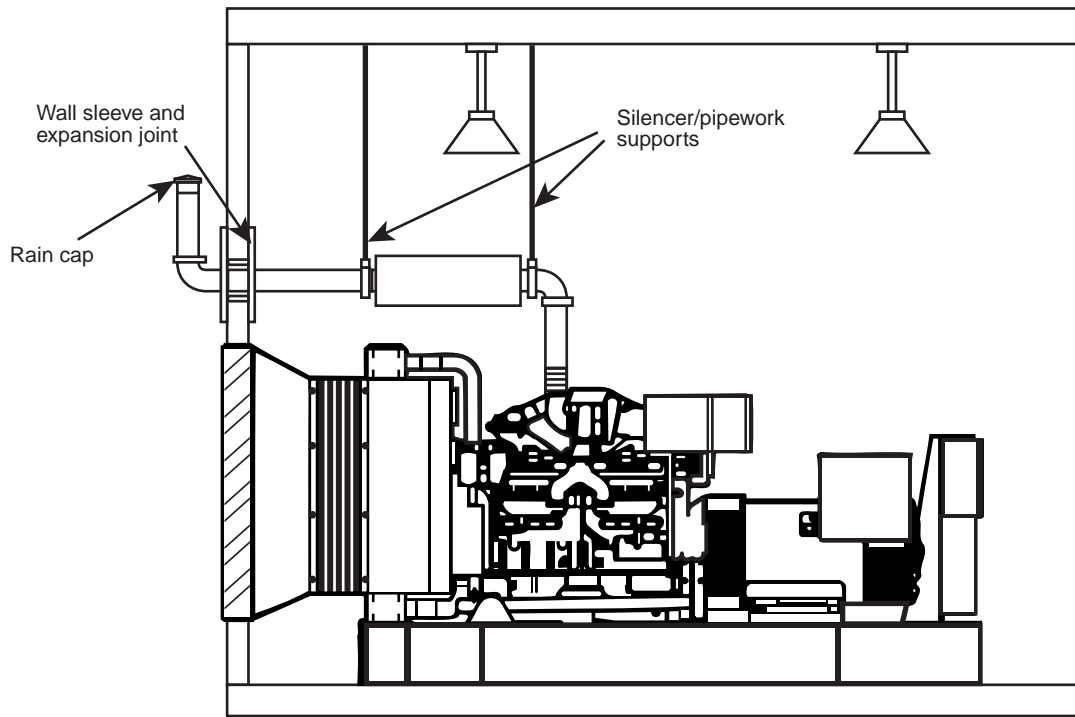


Figure 3. Exhaust arrangement.

### Muffler

The purpose of the muffler, or silencer as it also is called, is to reduce the noise of the exhaust before it is released to the atmosphere.

When leaving the combustion chamber the exhaust gas is under pressure. In the muffler, the gas can expand, thereby reducing the sound pressure waves which cause the noise.

The muffler or silencer is generally the single element making the largest contribution to exhaust backpressure. The factors that influence the selection of a silencer include: available space, cost, sound attenuation required, allowable backpressure, exhaust flow, and appearance.

Silencer design is a highly specialized art. The silencer manufacturer must be given responsibility for the details of construction.

Mufflers will be discussed further later in this booklet.

### Engine, Exhaust System Design

#### Slip Joint

Slip joints are designed to have controlled leakage when the system is cold. When the engine starts and the exhaust pipes warm up, the joints will expand and make a tight fit. The slip joints require good support on each side.

Exhaust fumes, slobber and water due to condensation can be expected from leaks.

When considering utilizing slip joints the movements of the pipe must be carefully considered. Slip joints are only flexible in one direction where the exhaust pipe requires flexibility in various directions.

Slip joints are normally not recommended by Caterpillar though they will be seen used on exhaust manifolds.

#### Bellows

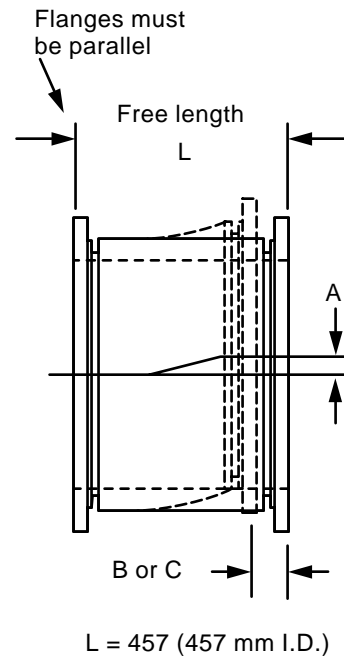
Bellows work as flexible connections. Where the flexible connections are built out of several pieces of metal, the bellows are either solid or welded together.

Pre-stretch the exhaust bellows during installation to allow for thermal growth.

Four (4) 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 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 Table 1.

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



Installation Limits 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 Limits 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

Table 1. Installation limits for bellows and flexible connections.

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

Table 2. Spring rates.

## Heat Shielding

Heat shielding is not used much in EPG applications. If a heat shielding is necessary, guards will be used.

### Blankets

Blankets are made of an insulating layer of fiberglass with a thermal outer layer. Most blankets will be held in place with a stainless steel wire which will be laced over the blankets (like on boots). Blankets will isolate both heat and noise.

Caterpillar does not recommend use of blankets on the turbo.

### Hard Wrap

Hard wrap is often used on the engine itself, for example in the vee.

The hard wrap consists of three layers: A thermal sheet, a blanket of fiberglass and sheet of bendable metal. It is installed with the thermal sheet facing the hot surface but not touching as the air then will work as an insulator. Holes for bolts can be drilled in the metal sheet and it is then very easy to mount or dismount.

### Guards and Shields

Guards and shields are manufactured from a sheet of perforated iron. They are installed with an air gap between the shield and the hot surface. With proper airflow around the engine the heat transfer from iron to air will lower the temperature of the shield considerably.

## Piping

### Flexible Connections

The exhaust pipe must be isolated from the engine with flexible connections. They are designed to 0% leakage and they are flexible in all directions. Flexible connections are

normally made out of several pieces which are being fitted together. 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. No more than 28 kg (60 lb) of exhaust piping weight should be supported by 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.

A typical piping layout with flexible connections can be seen on Figure 4.

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.

The flexible connections should be pre-stretched during installation just as it is done on bellows. Please refer to the section on Bellows for instructions.

Softness or flexibility is very important to prevent excessive vibratory stresses. The flexible connector must have high fatigue life to enable it to survive for indefinite periods. Softness prevents transmission of vibration beyond the connection. Resistance to fatigue keeps it from breaking under vibratory or recycling stresses.

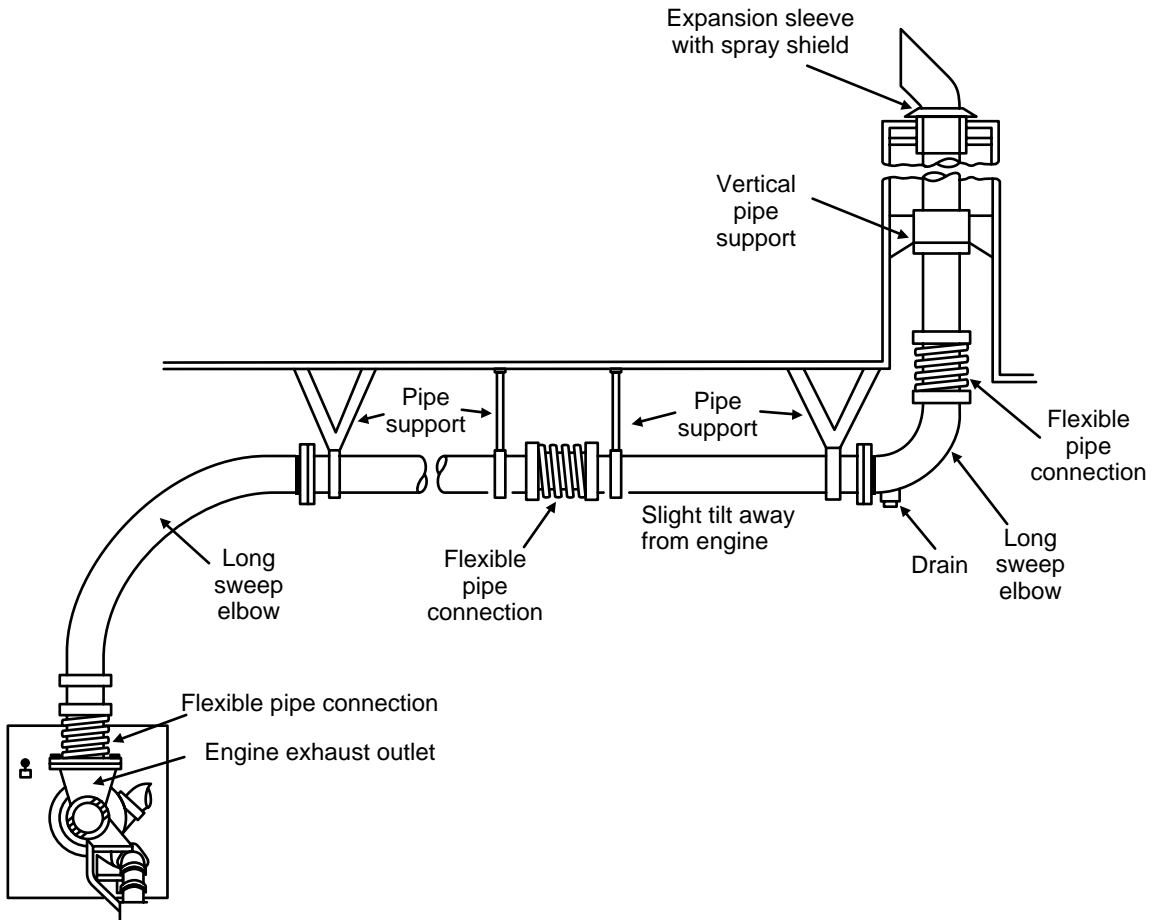


Figure 4. Typical exhaust piping with flexible connections.

**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.

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

## Turbocharger Loading

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

Figure 5 shows where to take the various distances from when calculating the forces and moments on the turbocharger.

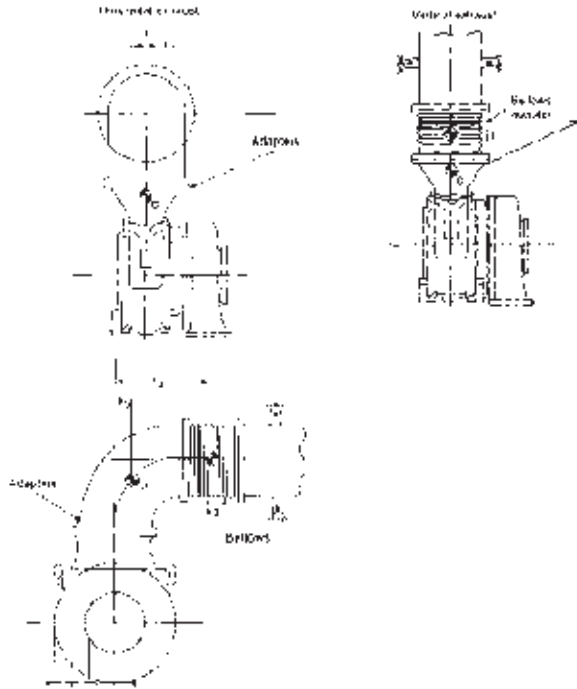


Figure 5. Vertical and horizontal exhaust.

The vertical force for the 3300 and 3400 engine family should be limited to 111 N (or 11 kg) (25 lb) and 178 N (or 18 kg) (40 lb) for the 3500 engine family.

The maximum allowable moment is 120 N•m (89.5 ft•lb) to all the engines.

For 3600 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 account for thermal growth. The maximum allowable moment for the 3600 is equal to what is applied by the Caterpillar supplied elbow and bellows.

Example:

Assume a Gas 3516 with single exhaust outlet.

### Vertical Exhaust

W = Adapter Weight

I = 1/2 Bellows Weight

g = gravity = 9.82 m/s (32.2 ft)

*With Caterpillar Hardware:*

W = 2.9 kg (6.4 lb)

I = 0.6 kg (1.4 lb)

*Forces:*

$F_w = W \times g = 2.9 \times 9.82 = 28 \text{ N (6.4 lb)}$

$F_I = I \times g = 0.6 \times 9.82 = 6 \text{ N (1.4 lb)}$

*Sum of Vertical Forces:*

$F_v = F_w + F_I = 28 + 6 = 34 \text{ N (7.8 lb)}$

*Sum of Moments*

$M = h_1 \times F_w + h_2 \times F_I = 0 \times 28 + 0 \times 6 = 0 \text{ N}\cdot\text{m (ft}\cdot\text{lb)}$

Since  $F_v < 111 \text{ N (25 lb)}$  and  $M < 120 \text{ N}\cdot\text{m (89.5 ft}\cdot\text{lb)}$  the exhaust system meets the load and moment requirements.

### Horizontal Exhaust

W = Adapter Weight

J = Elbow Adapter Weight

I = 1/2 Bellows Weight

*With Caterpillar Hardware:*

W = 2.9 kg (6.4 lb)

I = 0.6 kg (1.4 lb)

J = 4.8 kg (10.7 lb)

$h_1 = 0$

$h_2 = 100 \text{ mm (3.9 in)}$

$h_3 = 580 \text{ mm (22.8 in)}$

*Forces:*

$F_w = 28 \text{ N (6.4 lb)}$

$F_I = 6 \text{ N (1.4 lb)}$

$F_J = J \times g = 4.8 \times 9.82 = 47 \text{ N (10.7 lb)}$

*Sum of Vertical Forces*

$F_v = F_w + F_I + F_J = 28 + 6 + 47 = 81 \text{ N (18.5 lb)}$

*Sum of Moments*

$M = h_1 \times F_w + h_2 \times F_I + h_3 \times F_J = 0 \times 28 + .100 \times 6 + .580 \times 47 = 27.9 \text{ N}\cdot\text{m (20.8 ft}\cdot\text{lb)}$

Since  $F_v < 111 \text{ N (25 lb)}$  and  $M < 120 \text{ N}\cdot\text{m (89.5 ft}\cdot\text{lb)}$  the exhaust system meets the load and moment requirements.

## Pipe Supports

### Slope

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 3).

### Hanger Spacing

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 6).

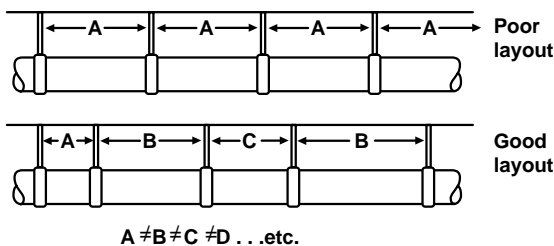


Figure 6. Layout of piping support.

### Exhaust Thimbles

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

### Insulation

#### Hot Surfaces

No exposed parts of the exhaust system should be near wood or other inflammable material. Exhaust piping inside the building (and the silencer if mounted inside) should be covered with suitable insulation materials to protect personnel and to reduce room temperature. A sufficient layer of suitable insulating material surrounding the piping

and silencer and retained by a stainless steel or aluminum sheath may substantially reduce heat radiation to the room from the exhaust system.

An additional benefit of the insulation is that it provides sound attenuation to reduce noise in the room. Exhaust piping passing through wooden walls or roofs require metal thimble guards 305 mm (12 in) larger than the pipe diameter (see Figure 7).

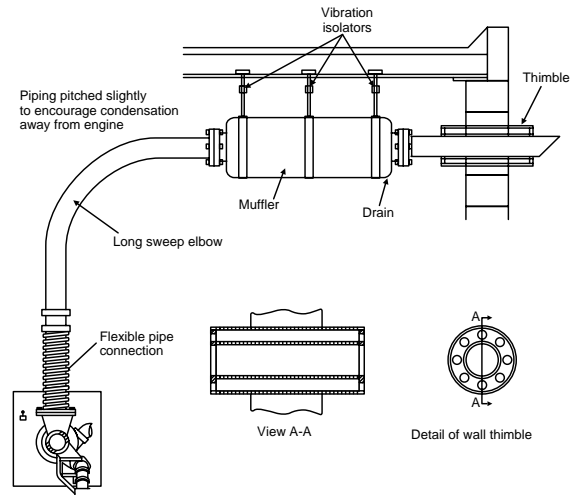


Figure 7. Exhaust layout with thimble.

### Radiated Heat

The exhaust stack will remain cooler and cleaner if the engine exhaust is contained within the exhaust piping throughout its run through the stack. The discharged ventilation air will tend to cool the exhaust stack upstream of the point where it is mixed with the exhaust gases.

For further discussion of radiated heat and engine room requirements, please consult the booklets “Cooling Systems” and “Ventilation systems” guides.

### Mufflers

Mufflers were introduced earlier in this booklet. The following discussion goes into more depth.

Excessive noise is objectionable in most locations. Since a large part of the generator set noise is produced in the engine’s pulsating exhaust, this noise can be reduced to an

acceptable level by using a muffler (or silencer). The required degree of silencing depends on the location and may be regulated by law. For example, the noise of an engine is objectionable in a hospital area but generally is not as objectionable in an isolated pumping station.

### **Muffler Rating**

Mufflers are rated according to their degree of silencing and commonly referred to by such terms as “residential” or “critical” and “supercritical”.

- Level 1 Silencer System “Residential” — Suitable for industrial areas where background noise level is relatively high or for remote areas where partly muffled noise is permissible.
- Level 2 Silencer System “Critical” — Reduces exhaust noise to an acceptable level in localities where moderately effective silencing is required — such as semi-residential areas where a moderate background noise is always present.
- Level 3 Silencer System “Supercritical” — Provides maximum silencing for residential, hospital, school, hotel, store, apartment building and other areas where background noise level is low and generator set noise must be kept to a minimum.

### **Size Considerations**

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.

Use silencer supplier data, correct for outlet temperature and velocity. Determine silencer size and type that satisfies noise reduction criteria with 0.5 to 0.75 kPa (2 to 3 in. H<sub>2</sub>O), 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.

### **Noise**

Exhaust noise attenuation is best performed with a quality muffler. However, the attenuation characteristics of a muffler are not the same for all frequencies. The effect of a given muffler could be quite different if the engine runs at two different speeds. The manufacturer must be contacted for any specific muffling characteristics.

The muffler may be located close to the engine, with exhaust piping leading from the silencer to the outside: or it may be located outdoors on the wall or roof. Locating the muffler close to the engine affords best overall noise attenuation because of minimum piping to the muffler. Servicing and draining of the muffler is likely to be more convenient with the muffler indoors.

### **Backpressure**

At least 5 diameters of straight pipe upstream, and 2.5 diameters downstream are required to minimize turbulence and backpressure.

### **Insulation**

Mufflers or exhaust piping within reach of personnel should be protected by guards or insulation. Indoors, it is preferable to insulate the muffler and piping because the insulation not only protects personnel, but it reduces heat radiation to the room and further reduces exhaust system noise. Mufflers mounted horizontally should be set at a slight angle away from the engine outlet with a drain fitting at the lowest point to allow the disposal of any accumulated moisture.

However, mounting the muffler outside has the advantage that the muffler need not be insulated (though it should be surrounded by a protective screen). The job of insulating piping within the room is simpler when the muffler is outside, and the insulation then can aid noise attenuation.

### **Installation**

Mufflers normally are available in two configurations — (a) end inlet, end outlet, or (b) side inlet, end outlet. Having the choice of these two configurations provides flexibility of installation, such as horizontal or vertical, above engine, on outside wall, etc. The side inlet type permits 90° change of direction

without using an elbow. Both muffler configurations should contain drain fittings in locations that assure draining the muffler in whatever attitude it is installed.

Since mufflers are large and heavy, consider their dimensions and weight when planning the exhaust system. The muffler must be adequately supported so its weight is not applied to the engine's exhaust manifold or turbocharger. The muffler must fit into the space available without requiring extra bends in the exhaust piping, which would cause high exhaust backpressure. A side-inlet muffler may be installed horizontally above the engine without requiring a great amount of headroom.

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

## Exhaust Discharge

The exhaust can be directed into a special stack that also serves as the outlet for radiator discharge air and may be sound-insulated. The radiator discharge air enters below the exhaust gas inlet so that the rising radiator air mixes with the exhaust gas (see Figure 8 and 9). The muffler may be located within the stack or in the room with its tail pipe extending through the stack and then outward. Air guide vanes should be installed in the stack to turn radiator discharge air flow upward and to reduce radiator fan air flow restriction, or the sound insulation lining may have a curved contour to direct air flow upward. For a generator set enclosed in a penthouse on the roof or in a separate outdoor enclosure or trailer, the exhaust and radiator discharges can flow together above the enclosure without a stack. Sometimes for this purpose the radiator is mounted horizontally and the fan is driven by an electric motor to discharge air vertically.

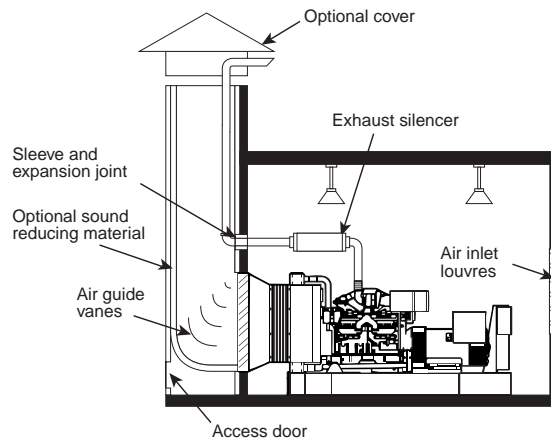


Figure 8: Horizontally mounted exhaust silencer with exhaust pipe and radiator air utilizing common stack.

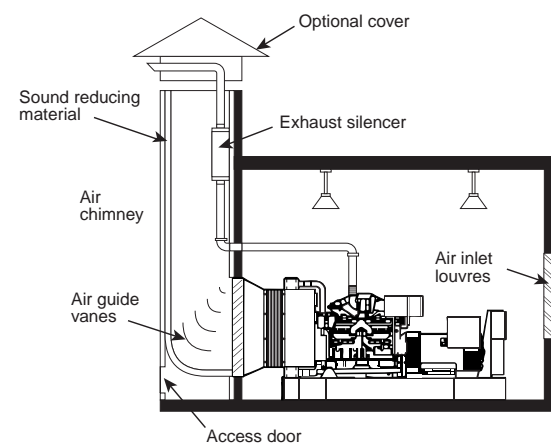


Figure 9: Radiator air discharging into sound-insulated stack containing exhaust silencer.

## Rain Caps

It is the responsibility of the engine installer to provide appropriate drain connections, rain caps or other means to protect the engine from rainwater or sea spray entering the engine through the dry exhaust piping. 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 and silencer to the trap so condensation will drain.

Traps may be built by inserting a vertical pipe, with a drain petcock, down from a tee section in the line.

Slope the last few feet of the exhaust pipe discharge to prevent rain water or spray from entering the pipe. Alternatively, fit some form of rain cap to a vertical exhaust pipe section.

Saw cuts in the exhaust pipe to allow rain/spray to drain harmlessly. Deform the edges of all slots. Use a punch on engine side slot edges. Bend inward. Cut through no more than 60° of the pipe circumference.

## System Design Considerations

The major difference in the exhaust system between gas and diesel engines is that the gas engines run with a higher exhaust temperature. This is because it runs with a constant air-fuel ratio at any load. The diesel engine runs with an excess amount of air at any load. Only the amount of fuel burned increases with the load. This additional air also cools the charge in diesel engines.

### Common Exhaust

A common exhaust system for multiple engine installation is rarely acceptable even though it would be an economical benefit. Combined exhaust systems with boilers or other engines allow operating engines to force exhaust gases into engines not operating.

Every gallon of fuel burned provides about one gallon of water in the exhaust. This water vapor condenses in cold engines and quickly causes engine damage. Soot clogs turbochargers, aftercoolers or air cleaner elements. Duct valves separating engine exhausts is also discouraged. High temperature warp valve seats or soot deposits cause leakage.

Separate exhaust systems assure expected engine performance and life.

### Exhaust Fans

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 on non-running engines must be closed and vented.

## Exhaust Recirculation

Exhaust stacks must be designed so engine exhaust is discharged high enough, and in a direction to keep it clear of the air turbulence created by wind swirling around the building. Engine air cleaners, turbochargers and aftercoolers clogged with exhaust products will cause engine failures.

### 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.

### Slobber

Extended engine operation at no load or lightly loaded conditions (less than 15% load) may result in exhaust manifold slobber. Exhaust manifold slobber is the black oily fluid that can leak from exhaust system joints. The presence of exhaust manifold slobber does not necessarily indicate an engine problem. Engines are designed to operate at loaded conditions.

At no load or lightly loaded conditions, the sealing capability function of some integral engine components may be adversely affected. Exhaust manifold slobber is not usually harmful to the engine; the results can be unsightly and objectionable in some cases.

Exhaust manifold slobber consists of fuel and/or oil mixed with soot from the inside of the exhaust manifold. Common sources of oil slobber are worn valve guides, worn piston rings and worn turbocharger seals. Fuel slobber usually occurs with combustion problems.

A normally operating engine should be expected to run for at least one hour at light loads with significant slobber. Some engines may run for as long as three, four or more hours before slobbering. However all engines will eventually slobber if run at light loads. External signs of slobber will be evident unless the exhaust system is completely sealed.

If extended idle or slight load periods of engine operation are mandatory, the objectionable effect of the engine slobber can be avoided by loading the engine to at least 30% load for approximately ten minutes every four hours. This will remove any fluids that have accumulated in the exhaust manifold. To minimize exhaust manifold slobber, it is important that the engine is correctly sized for each application.

## Backpressure

Excessive exhaust restrictions can cause performance losses, particularly in fuel consumption and exhaust temperature. Pressure drop across the exhaust system should not exceed 6.7 kPa (27 in. H<sub>2</sub>O) of water for most Caterpillar turbocharged (TA engines). The G3516B engine is limited to 5.0 kPa (20 in. H<sub>2</sub>O) without derate. (See engine technical data for engine performance effects when exhaust backpressure exceeds this limit.) 3600 Naturally Aspirated (NA) Gas Engines performances will be adversely affected above 3 kPa (12 in. H<sub>2</sub>O). Exceeding this limit on 3600 engines will increase fuel consumption approximately 0.8% per each 2.5 kPa (10 in. H<sub>2</sub>O) of backpressure above the limit. Engines burning heavy fuel have an absolute backpressure limitation of 2.5 kPa (10 in. H<sub>2</sub>O) to avoid excessive exhaust valve temperatures and loss of horsepower.

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. The backpressure should be measured as close to the engine as possible.

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 backpressure.

## Equivalent Length of Straight Pipe

To obtain equivalent length of straight pipe for various elbows:

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

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

$$L = \frac{15D}{X} \text{ 45° Elbow}$$

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

Where X = 1000 mm or 12 inches

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<sub>2</sub>O). This leaves approximately 0.75 kPa (3 in. H<sub>2</sub>O) loss available for installation piping and 0.75 kPa (3 in. H<sub>2</sub>O), for a muffler/silencer.

Restrictions imposed by mufflers relate to exhaust flow velocities. Figure 10 is applicable for mufflers.

$$V = \frac{Q}{A}$$

V = Velocity of exhaust gas (ft/min)

Q = Exhaust gas flow (cfm)

A = Area of muffler (Table 3)

(ft/min × 0.3048 = m/min)

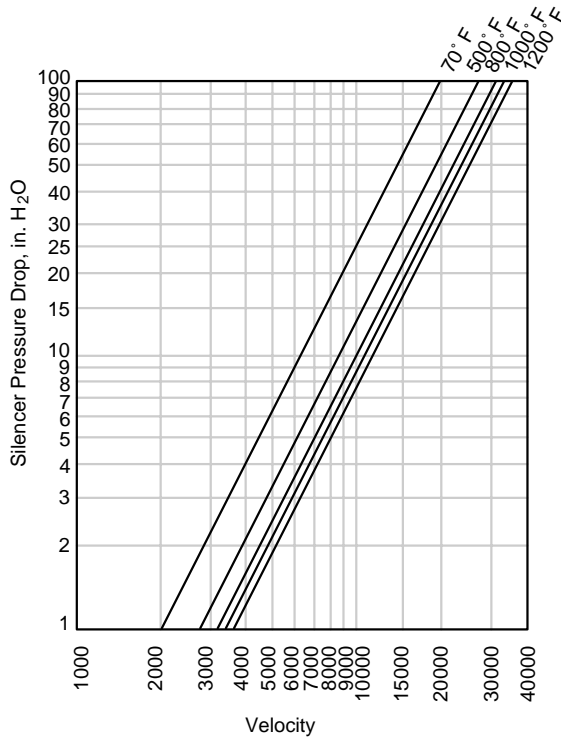


Figure 10: Restriction related to flow velocity.  
(kPa = 0.24908 × in. H<sub>2</sub>O,  
psi = 0.0361 × in. H<sub>2</sub>O).

Area (ft <sup>2</sup> )	Size (in.)
0.00546	1
0.0123	1-1/2
0.0218	2
0.0341	1-1/2
0.0491	3
0.0668	3-1/2
0.0872	4
0.136	5
0.196	6
0.349	8
0.545	10
0.785	12
1.07	14
1.39	16
1.77	18
2.18	20
2.64	22
3.14	24
3.68	26
4.28	28
4.91	30

Table 3. Area vs size of muffler.

## Calculating Backpressure

Backpressure is calculated by:

$$P \text{ (kPa)} = \frac{L \times S \times Q^2 \times 3598805.2}{D^5} + P_s$$

$$P \text{ (psi)} = \frac{L \times S \times Q^2}{5184 \times D^5} + P_s$$

P = Backpressure (kPa), (psi)

L = Length of pipe (m), (ft)

Q = Exhaust gas flow (m<sup>3</sup>/min), (cfm)

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

P<sub>s</sub> = Pressure drop of silencer/raincap (kPa),  
(in. H<sub>2</sub>O)

kPa = 0.0098 × mm water column

psi = 0.0361 × inches water column

S = specific weight of gas (kg/m<sup>3</sup>), (lb/ft<sup>3</sup>)

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

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

The following can be some useful conversion factors:

psi = 0.0361 × in. of water column

psi = 0.00142 × mm of water column

psi = 0.491 × in. of mercury column

kPa = 6.3246 × mm of water column

kPa = 4.0 in. of water column

kPa = 0.30 × in. of mercury column

kPa = 0.145 psi

### Example:

Standby power genset 35 lb Di.TA.JW with Dry Manifold and 60H<sub>2</sub>, rated 1750 EKW with fan @ 1800 rpm.

The stack has 5 m (16.4 ft) of straight length pipe together with two standard elbows. The pipe has a diameter of 254 mm (10 in.).

### Solution:

Data from TMI:

Engine power: 1307.2 Bkw (1753 Bhp)  
@ 70% load

Exhaust temperature: 479° C (895° F)

Exhaust gas flow: 307.7 m<sup>3</sup>/min (10865 cfm)

From Figure 9, P<sub>s</sub> = 3.36 kPa (0.487 psi or 13.5 in. H<sub>2</sub>O)

Equivalent Length:

$$L = 2 \times \frac{33 \times 254}{1000} = 16.76 \text{ m}$$

$$L = 2 \times \frac{33 \times 10}{12} = 55 \text{ ft}$$

Specific Weight of Gas:

$$S = \frac{352.5}{479 + 273} = 0.468 \text{ kg/m}^3$$

$$S = \frac{39.6}{895 + 460} = 0.029 \text{ lb/ft}^3$$

Backpressure:

$$P = \frac{(5 + 16.76) \times 0.468 \times 307.7^2 \times 3598805.2}{254^5} + 3.36 = 6.64 \text{ kPa}$$

$$P = \frac{(16.4 + 55) \times 0.029 \times 10865^2}{5184 \times 10^5} + 0.487 = 0.96 \text{ psi}$$

The backpressure of 6.64 kPa (26.7 in. H<sub>2</sub>O) is within the limit for Caterpillar engines.

### Measuring Backpressure

Measure exhaust backpressure by a water manometer at the fitting provided in the engines exhaust discharge location. Use a system similar to that shown in Figure 11.

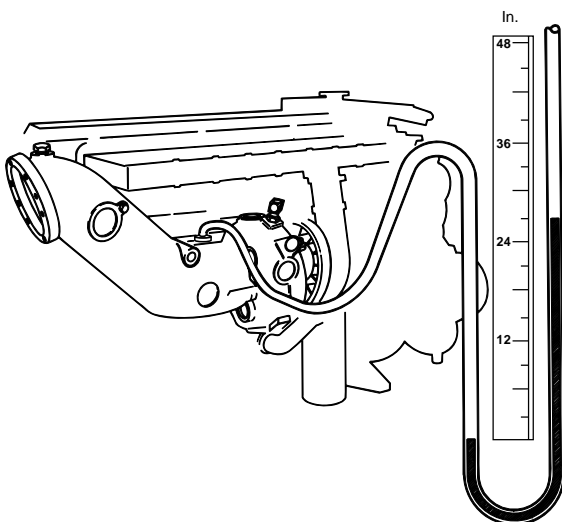


Figure 11. Measuring backpressure with a water manometer.

Exhaust backpressure is measured as the engine is operating under rated conditions. Either a water manometer or a gauge measuring inches of water can be used. If not equipped, install a pressure tap on a straight length of exhaust pipe. This tap should be located as close as possible to the turbocharger or exhaust manifold on a naturally aspirated engine, but at least 305 mm (12 in) downstream of a bend. If an uninterrupted straight length of at least 457 mm (18 in) is not available (305 mm [12 in]) preceding and 152 mm (6 in) following the tap, care should be taken to locate the probe as close as possible to the neutral axis of the exhaust gas flow. For example, a measurement taken on the outside of a 90° bend at the pipe surface will be higher than a similar measurement taken on the inside of the pipe bend. The pressure tap can be made by using a 1/8 NPT “half coupling” welded or brazed to the desired location on the exhaust pipe. After the coupling is attached, drill a 3.05 mm (0.12 in.) diameter hole through the exhaust pipe wall. If possible, remove burrs on the inside of the pipe so that the gas flow is not disturbed. The gauge or gauge hose can then be attached to the “half coupling.”

# Notes



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LEBX0058-01 (12-01)  
Replaces LEBX0058

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