CATERPILLAR®

Electric Power Application and Installation Guide

Air Intake System

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Air Intake System

A well designed air intake system provides cool, clean air while minimizing inlet air 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. There are also needs for special filtration and ducting due to fumes, dust, airborne mists, ambient temperature or even altitude. Any inlet restriction can cause an engine to be derated.

Efficient engine combustion is based on the proper mass flow ratio of fuel and air. The ratio is mass based and not volume based. It is always important to remember this fact when considering the impact of installations with elevated altitude and temperature.

Combustion Air Requirements

Depending on the engine model and rating, an engine requires approximately 0.07 m^3/min (1.84 cfm) of air per brake horsepower for combustion. Consult TMI (Technical Marketing Information) for exact data on a specific engine. A better way is to evaluate the required air mass flow, which can be as high as 32 kg (lbs) to 1 kg (lb) of fuel. Volumetric (V) and mass (M) intake air flow have the following general relationships;

$V\ (m^3/min) = 0.01486 \times M\ (kg/hr)$ @ 40°C, or
$V\ (cfm) = 0.2382 \times M\ (lb/hr)$ @ 105°F

Air Cleaners

Dirt is the major source of engine wear. Any moving engine part may be subjected to accelerated wear when dirt is contained in the inlet air. Since the air intake is one of the primary locations where dirt may enter an engine, frequent replacement of air cleaners, (and increased maintenance costs) may be needed.

Dirt may be introduced into the piping at initial assembly, enter the system during the filter change, be sucked into leaks in the piping system, or be carried by the intake air flow.

Engine wear tests have shown that dust particles under 1 micron (0.00004 in.) size have little effect on the engine. 99.5% of this dust will pass out through the engine exhaust. 1 micron to 10 micron (0.00004 to 0.0004 in.) size dust has a measurable effect on engine life. Put another way, inlet air dust particle sizes larger than bearing oil film thicknesses will seriously affect bearing and piston ring life.

Well designed air cleaners are the most efficient way of assuring that clean air enters the engine and harmful particles are not distributed through the engine systems.

Air Cleaner Efficiency

Air cleaner selection should be based upon the following air cleaner efficiency test:

A satisfactory air cleaner must meet the requirements of the SAE (Society of Automotive Engineers) Air Cleaner Test Code J726a, Section 8.1. The filter should have 99.5% minimum efficiency as calculated following test code with additions and exceptions as follows:

- Air flow corrected to m^3/min at 99.9 kPa pressure and 32.2°C (ft^3/min at 29.6 in. Hg pressure and 90°F).
- Use sonic dust feeder.
- Dust quantity determined by light-duty class.
- Filter to be dried and weighed in an oven at 93°C to 107°C (200°F to 225°F) before and after test.
- Use 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

99.5% filtration of the AC fine dust has been determined to be a practical combination of the kind of dirt likely encountered in service, and will result in an air cleaner efficiency expected to give optimum engine wear life.

Air Cleaner Design Requirements

Following the procedure will establish sufficient control on the filter media filtering ability of the tested air cleaner, but there are other design variables needing further control which include:

- Choose filters supplied by manufacturers that can best provide quality control.
- Design filters to be resistant to damage at initial assembly or during cleaning. If end seal and filter media are subject to damage, dust leakage into the engine can result.

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. Precleaners, however become an added maintenance item.

Caterpillar Air Cleaners

All Caterpillar engines come standard with engine mounted air cleaners.

Most standard Caterpillar air cleaners consist of high efficiency, dry paper elements, packaged in low restriction, weather resistant housings. They remove 99.5% of AC fine dust and are designed to minimize dust entrance during filter changes.

Heavy-Duty Air Cleaners

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

Two-Stage Air Cleaners

For conditions where dust concentrations are higher or where increased service life is desired, air cleaners are available with a precleaning stage. This precleaner imparts a swirl to the air, centrifuging out a major percentage of the dirt particles which may be collected in a reservoir or exhausted out on either a continuous or an intermittent basis.

Exhaust Ejector

In extremely dusty environments where dust and other particles cause air cleaners to plug up quickly an improved precleaner has been designed. It is an integral part of any exhaust aspirated air cleaner system and will extend the service life of the air cleaner elements.

Using a louvered body design, the precleaner has a very high separator efficiency. It will separate and remove over 90% of the dirt and chaff from the incoming air stream.

The air comes into the precleaner where the dirt and chaff is removed from the air (see Figure 1). With a slight vacuum, the dirt is sucked directly through the muffler into the exhaust flow and does no harm to the engine.

The remaining dust in the air is then removed by the air cleaner before it enters the turbo.

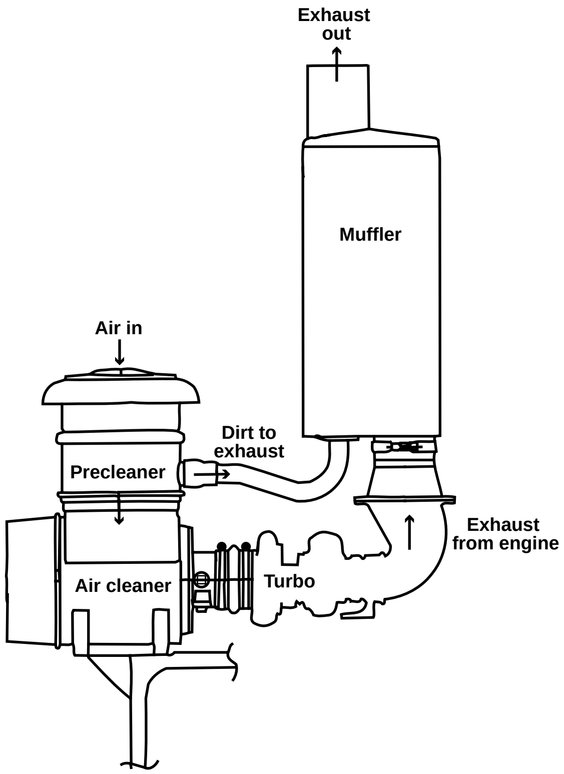


Figure 1. Exhaust aspirated air cleaning system.

With this system, consideration must be made regarding the location of exit of the exhaust and the surroundings, as there may be particles in the engine exhaust.

Oil-Bath Air Cleaners

Oil-bath air cleaners, while sometimes required to meet customer specifications, are not recommended by Caterpillar. At best their efficiency is 95% as compared to 99.5% for dry-type filters. Their relative ease of service and insensitivity to water are advantages easily outweighed by disadvantages, such as:

- Lower efficiency
- Low ambient temperatures, low oil level, high restriction @ low air flow (such as at low idle), and installed tilt angle may lessen efficiency further.
- Oil carry-over, which is the oil becoming airborne in the air intake system whether resulting from overfilling or increased air flow, can seriously affect turbocharger and engine life, and may actually become an engine fuel.

Service Indicator

Vacuum sensing devices designed to indicate the need for air cleaner servicing are commercially available and when added to the air intake system, serve a vital function. There are two types of sensing devices, both recommended for use.

The first type incorporates a trip lock device which indicates that the air cleaner condition is either satisfactory or when in need of service, it typically will have a red display. This type of mechanism uses a spring loaded diaphragm to measure the pressure differential between the clean and dirty side of the air cleaner. The trip or latching type is preferred.

The second type is a direct reading differential gauge. One end is connected to the inlet duct. The second recommended connection point would be on the straight length of pipe immediately upstream of the turbocharger.

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.

Design Considerations

Routing

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.

In addition to locating the inlet so that the coolest possible air from outside the engine compartment is used, and engine exhaust gas is not drawn in, it is best to locate the air piping away from the vicinity of the exhaust piping when possible to do so. Air temperature to the air inlet should be no more than 11°C (20°F) above ambient air temperature.

Section Before Turbocharger

When possible, the piping to the turbocharger inlet should be designed to ensure that air is flowing in a straight, uniform direction into the turbocharger compressor. A straight section of at least two or three times pipe diameter is recommended because air striking the compressor wheel at an angle can create pulsations which can cause premature compressor wheel failure.

Pressure Limit

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

Diameter

Piping diameter should be equal to or larger than the air cleaner inlet/outlet and the engine air inlet. A rough guide for pipe size selection would be to keep maximum air velocity in the piping to 10 m/s (2,000 fpm). Higher velocities will cause high noise levels and excessive flow restrictions.

Pipe Ends and Hose Connections

Beaded pipe ends at hose joints are recommended. Sealing surfaces should be round, smooth, and free of burrs or sharp edges that could cut the hose. The tubing should have sufficient strength to withstand the hose clamping forces. Avoid the use of plastic tubing since it can lose much of its strength when subjected to temperatures of 149°C (300°F) or above. Either “T” bolt-type or SAE-type F hose clamps providing 360° seal should be used. They should be top quality clamps. Double clamps are recommended on connections downstream of the air cleaner.

Flexible 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 and should incorporate the same clamping guidelines as “Pipe Ends and Hose Connections”.

Duct Support

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.

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

Turbocharger Loading

When remote-mounted air cleaners are used, turbocharger loading from the weight of the air inlet components becomes a concern. The turbochargers are not typically designed to support any additional weight beyond standard factory attachments. Make the flexible connection directly to the turbocharger air inlet, as in Figure 2. All duct work to that point must be supported.

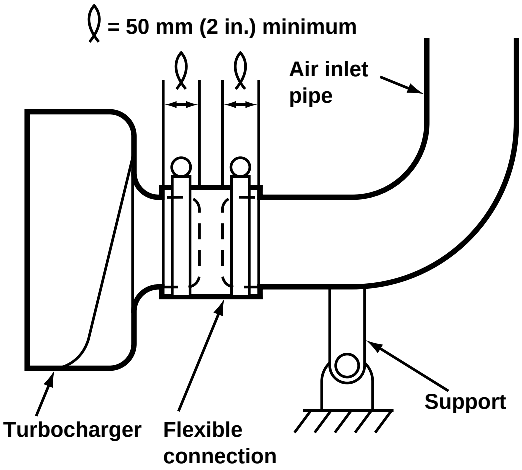


Figure 2. Flexible connection to turbocharger.

Joining Two Turbochargers

When duct work feeding two turbochargers is combined to form a single duct, a steadying zone of the length $L_S > 5 \times D$ must be provided after the dividing joint, see Figure 3.

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 prior to start-up. The ducting material must be designed and constructed such that prolonged operation will not result in materials 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 and will minimize pre-heating of intake air.

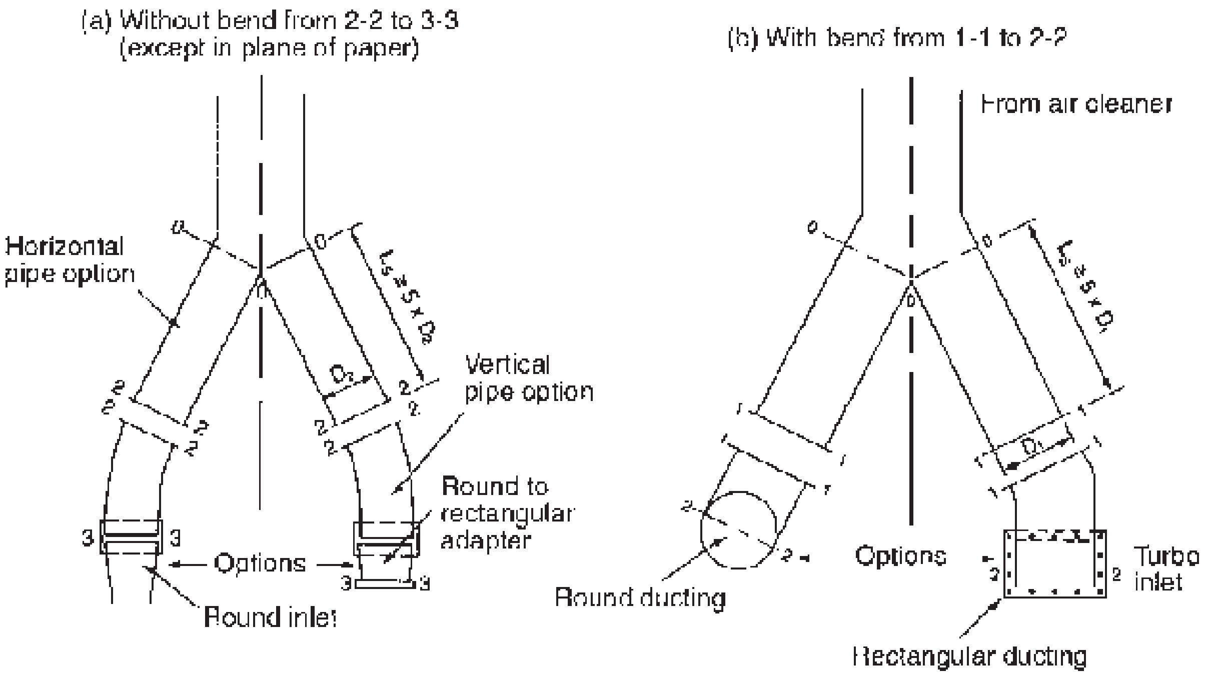


Figure 3. Pipe design when joining turbochargers.

Air Intake Restriction

Excessive vacuum on the inlet side of the turbocharger (or the air inlet on naturally aspirated engines) can result in reduced engine performance. Therefore, the air intake system's total restriction (including dirty filters, duct work, vents, etc.) is limited depending on engine model, rating and air configuration.

The gas engine total air intake restriction should not exceed 3.7 kPa (15 in. H_2O) with dirty air cleaner elements for all engine models except the G3516B. The G3516B engine can operate up to 2.5 kPa (10 in. H_2O) without derate. (See engine technical data for engine performance with an air inlet restriction above 2.5 kPa [10 in. H_2O]). The air intake restriction for all gas engine models should not exceed 1.3 kPa (5 in. H_2O) with clean elements. The air intake restriction for diesel engines can be found in TMI.

In order to maximize air filter life, it is important to keep total duct head loss (restriction) below 0.5 kPa (2 in. H_2O) for maximum filter life. Every additional restriction caused by the air inlet system subtracts from air filter life. The filter life is dependent on the absolute pressure differential between the turbocharger compressor inlet and atmosphere.

Calculate Duct Head Losses by the Following Formulas:

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

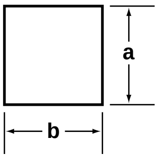
$$P\ (\text{psi}) = \frac{L \times S \times Q^2}{5184 \times D^5}$$

P = Restriction (kPa), (psi)
kPa = 0.0098 × mm H_2O
psi = 0.0361 × in. H_2O
L = Total equivalent length of pipe (m), (ft)
S = Density of air (kg/m^3), (lb/ft^3)
Q = Inlet air flow (m^3/min), (cfm)
D = Inside diameter of pipe (mm), (in.)

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

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

If duct is rectangular



Then

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

To obtain equivalent length of straight pipe for various elbows:

$L = \frac{33D}{X}$ Standard Elbow (Radius = 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.

Example:
An example of the air intake restriction's duct head loss:

A 3412 packaged genset has an inlet flow of 36.7 m^3/min (1292 cfm) (TMI) with pipe configuration consisting of 3 m (10 ft) of straight length pipe along with 2 standard elbows and a long elbow. The pipe has a diameter of 152.4 mm (6 in) and the temperature of the air is 55°C (131°F). What is the duct head loss from this air intake configuration?

Total equivalent length:

$$L = 3 + 2 \times \left(\frac{33 \times 152.4}{1000}\right) + \frac{20 \times 152.4}{1000} = 16.1 \text{ m}$$

$$L = 10 + 2 \times \left(\frac{33 \times 6}{12}\right) + \frac{20 \times 6}{12} = 53 \text{ ft.}$$

Density of air:

$$S = \frac{352.5}{55 + 273} = 1.075 \text{ kg/m}^3$$

$$S = \frac{39.6}{131 + 460} = 0.067 \text{ lb/ft}^3$$

Duct head losses:

$$P = \frac{16.1 \times 1.075 \times 36.7^2 \times 3598805.2}{152.4^5} = 1.02 \text{ kPa}$$

$$P = \frac{1.02}{0.0098} = 104 \text{ mm } H_2O$$

$$P = \frac{53 \times 0.067 \times 1292^2}{5184 \times 6^5} = 0.147 \text{ psi}$$

$$P = \frac{0.147}{0.0361} = 4.07 \text{ in. } H_2O$$

Cold Conditions

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 increases the pressure differential across the air cleaner. Eventually, a stage is reached where the pressure differential remains constant even though ice buildup may continue. Power loss and increased fuel consumption can result during these periods. Severe engine damage or air filter structural failures can occur if this condition is not corrected.

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 around 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.

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 contains enough volume 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 have a hard time maintaining air inlet temperature. Low pressure gas engines must maintain a steady air inlet temperature to maintain the proper air/fuel ratio, which will impact engine performance.

The preferred method is to use duct work to supply a temperature regulated air supply to the engine, see Figure 4. 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.

Considerations for Low Pressure Gas Engines

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 (V∆T) between the gas and the air going to the carburetor from changing beyond the limits given in Table 1.

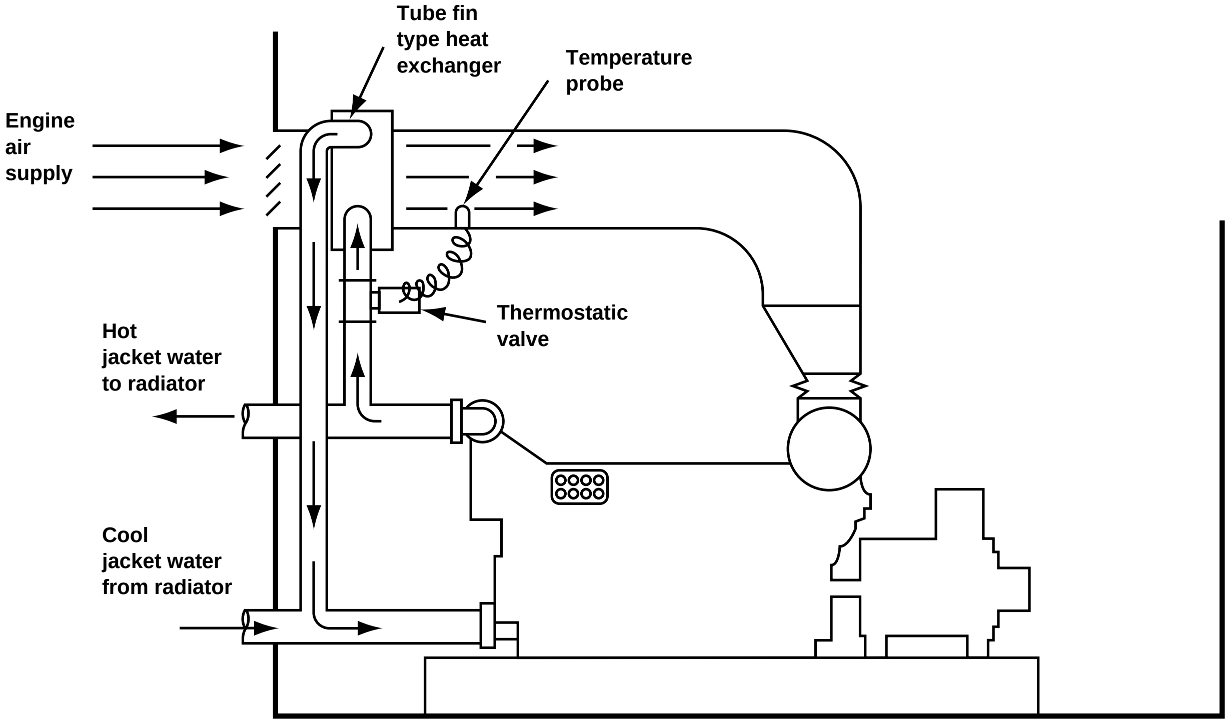


Figure 4. Ducting with temperature regulator.

Variation of $V\Delta T$	2.0 g NO_x/ hp-hr	1.5 g NO_x/ hp-hr	1.0 g NO_x/ hp-hr
Maximum Value of $V\Delta T$	± 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
$V\Delta T$ = | ΔT Condition 1 - ΔT Condition 2 |
(brackets indicate absolute value of the difference)

Table 1. Emission level

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/bhp-hr 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),

$$\Delta T1 = \text{Air} - \text{Gas}$$
$$\Delta T1 = 10°\text{C} - 21°\text{C} = -11°\text{C}$$
$$(\Delta T1 = 50°\text{F} - 70°\text{F} = -20°\text{F})$$

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

$$\Delta T2 = 32°\text{C} - 21°\text{C} = 11°\text{C}$$
$$(\Delta T2 = 90°\text{F} - 70°\text{F} = 20°\text{F})$$

Due to the absolute value the $V\Delta T$ would then become:

$$V\Delta T = |-11°\text{C} - 11°\text{C}| = 22°\text{C}$$
$$(V\Delta T = |-20°\text{F} - 20°\text{F}| = 40°\text{F})$$

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 5 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%.

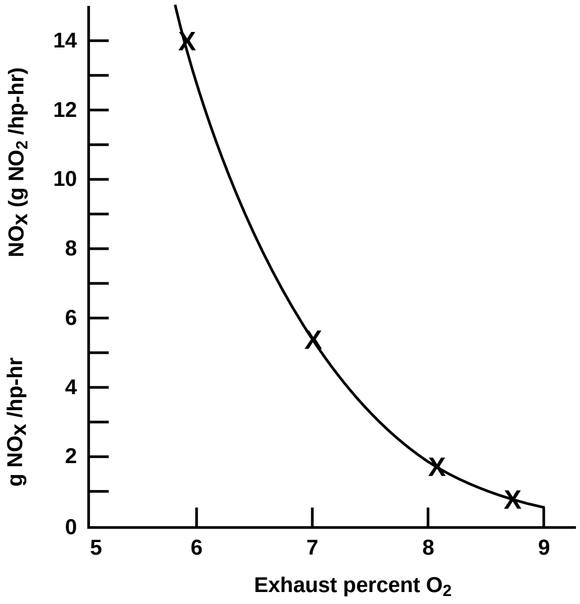


Figure 5. NO_X emission vs exhaust percent O_2 for 3500 low emission engines

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 $V\Delta T$:

- 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.

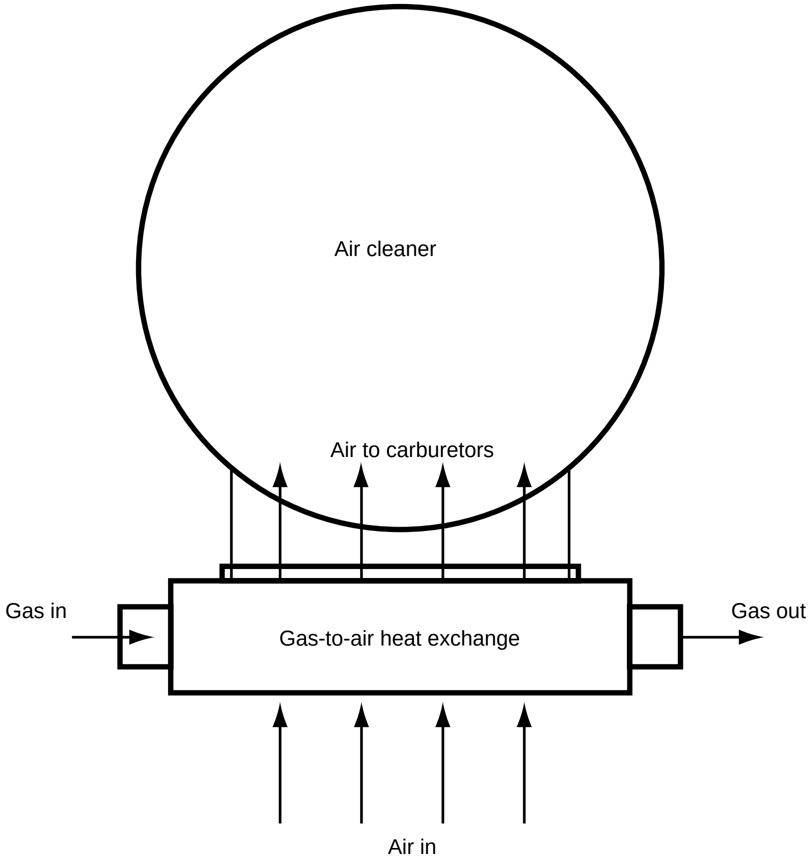


Figure 6. Gas-to-Air Heat Exchanger

Gas-to-Air 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 6. 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.

Notes

Notes

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