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General Service Information
ENGINE INSTALLATION & SERVICE HANDBOOK
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Exhaust System Formulas

Water Cooled Exhaust

There are two basic types of exhaust systems used. The two systems are "wet" (water cooled) and dry exhaust systems. The main consideration is to design the system to remove the exhaust gases from the engine room and limit the backpressure to a minimum.

The limits for a given engines' exhaust backpressure can be located in the TMI system. In general terms the backpressure limit is 27 inches of water for all Caterpillar turbocharged/turbocharged aftercooled engines. 34 inches of water is the limit for naturally aspirated engines. The 3600 series of engines have a limit of 10 inches of water. Some special rating, such as the 435 Hp 3208 E rating have a limit of 40 inches of water. You need to determine the limit of your engine, rating and then size the exhaust system to be below the limit. Remember that the closer you get to the limit the more affect the exhaust backpressure will have on the performance of the engine.

Many "wet" exhaust systems utilize an exhaust riser to help prevent sea water from entering the engine through the exhaust system when the engine is not operating or when the boat is "backed down" quickly. As a general rule of thumb the riser should be at least 22 inches above the level of the sea water to the lowest portion of the riser.

The minimum water flow requirements to a wet exhaust system can be calculated by using the following formula.

$$Flow = \frac{Vd \times Ne}{66000}$$

$$Flow = \frac{Vd \times Ne}{285.785} = Metric$$

Flow = Gallons per minute (L/min)

Vd = Engine displacement [cubic inches (liters)]

Ne = Rated speed (rpm)

66,000 = constant for gallons

285.785 = constant for liters

A water lift muffler is also common in some of the smaller pleasure craft. If a water lift muffler is to be used the following are some points to pay close attention to.

1. Size the muffler outlet for a minimum exhaust velocity (gas only) of 5000 ft/min at rated engine power and speed. The following formula will give the maximum pipe diameter, "De" that can be used to insure the 5000 ft/min velocity.

$$De = 0.19 \sqrt{Qe} \qquad De = 28.67 \sqrt{Qe} = \text{Metric}$$

De = The maximum water lift exhaust outlet pipe diameter [inches (mm)]

Qe = Exhaust flow rate from the muffler [cfm (m^3/min)]

2. The tank itself should be of sufficient size. A rule of thumb would be at least 8 cubic inches per rated horsepower.
3. The inlet pipe to the tank should be truncated near the top of the tank.
4. The outlet pipe should extend to near the bottom of the tank (about 1 inch from the bottom) and should be angle cut (mitered) to increase exit gas velocity at lower loads and flow rates.
5. A siphon break should be installed between the exhaust elbow and the high point of the outlet pipe from the muffler.

Dry Exhaust

The dry exhaust system has some typical points that need to be considered as well.

1. A flexible connection at the engine exhaust outlet. No more than 60 pounds of exhaust piping weight should be supported on the flexible connection.
2. Flexible connection(s) are installed on the horizontal portion and on the vertical stack of the exhaust system.
3. Horizontal portions of the exhaust system are sloped away from the engine.
4. A spray shield/rain trap is used on the exhaust outlet.

The exhaust gas flow rate for a given engine and rating can be obtained from the TMI system. It can be closely estimated by using the following formula.

$$Qe = \frac{(Te + 460) \times Hp}{2'4} \qquad Qe = \frac{(Te + 273) \times kW}{3126.52} = \text{Metric}$$

Qe = Exhaust gas flow rate [cfm (m^3/min)]

Te = Exhaust gas temperature [°F (°C)]

Hp = Engine rated horsepower (kW)

After you have determined the exhaust gas flow rate the exhaust system backpressure can be calculated using the following formula.

$$dP = \frac{Lte \times Se \times Qe}{187 \times d^5} \qquad P = \frac{\frac{Lte \times S \times Qe^2}{\times\ 3600000}}{d^5} = Metric$$

P = Exhaust system backpressure [inches of water] or kPa

Lte = Total length of piping for diameter "d" [ft (m)]

d = Duct diameter [inches (mm)]

Lte is the sum of all the straight lengths of pipe for a given diameter "d", plus, the sum of equivalent lengths, "Le", of elbows and bends of diameter "d". Straight flexible joints should be counted as their actual length if their inner diameter is not less than "d".

Le = equivalent length of elbows in feet of straight pipe

Standard elbow - Le (ft) = 2.75 × d (inches)

Long elbow - Le (ft) = 1.67 × d (inches)

45° elbow - Le (ft) = 1.25 × d (inches)

NOTE: "Le" results are in feet but "d" must be in inches

Le = equivalent length of elbows in meters of straight pipe

Standard elbow - Le = 0.033 × d = (metric)

Long elbow - Le = 0.020 × d = (metric)

45° elbow - Le = 0.015 × d = (metric)

NOTE: "Le" results are in meters but "d" must be in mm

Qe = Exhaust gas flow [cfm (m^3/min)]

Se = Specific weight (density) of exhaust gas [lbs/cu. ft. (kg/m^3)]

The specific weight of the exhaust gas is calculated using the following formula.

$$Se = \frac{39.6}{(Te + 460)\ °F} \qquad Se = \frac{352}{(Te + 273)\ °C} = Metric$$

Se = Specific weight [lbs/cu. ft./kg/m^3)]

Te = Exhaust gas temperature [°F (°C)]

d = pipe diameter [inches (mm)]

The values of Lte, Se, Qe, and d must be entered in the units specified above if the formula is to yield valid results for backpressure.

To get the total exhaust pressure you must add to the answer from the above formula the pressure drop of the muffler. The pressure drop for Caterpillar mufflers is available in the TMI system.

Exhaust gas velocity should also be checked. If the velocity is too high, excessive noise or whistle may occur and inner pipe and wall surfaces may erode at an unacceptable rate. As a rule of thumb, the velocity is best kept to 18,000 ft/min or less. The velocity can be calculated using the following formula:

$$Vc = \frac{183 \times Qe}{d^2} \qquad Ve = \frac{1{,}270{,}691.83 \times Qe}{d^2} = \text{Metric}$$

Ve = Exhaust gas velocity [ft/min (m/min)]

Qe = Exhaust gas flow rate [cfm (m^3/min)]

d = Pipe diameter [inches (mm)]

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