Chapter 3

INDUCTION, EXHAUST, AND TURBOCHARGER SYSTEM PRINCIPLES

INTRODUCTION

The induction system must provide the engine with an adequate supply of clean air for good combustion (and for scavenging cylinders on two-stroke-cycle engines) for all operating speeds, loads, and operating conditions. Up to 1500 ft^3 of air per minute or more may be required, depending on engine size and load.

On a naturally aspirated four-stroke-cycle engine, the system includes the air cleaner, a precleaner (if used), the intake manifold, and the connecting tubing and pipes **(Figure 3–1).** On the two-stroke-cycle, the system also includes a blower for scavenging air and for combustion.

On a turbocharged engine, additional air is supplied by means of a turbocharger, which is exhaust gas–driven **(Figure 3–2).** On a supercharged engine a mechanically driven blower is used to supply additional air.

An air shutdown valve may be included to allow engine intake air to be shut off completely for emergency engine shutdown.

An intercooler or aftercooler may also be included in the induction system. Since cooler air is more dense, a greater amount of air is in fact supplied if the air is cooled. The intercooler is mounted to cool the intake air after it leaves the discharge side of the turbocharger and before it enters the engine (before it enters the blower on two-stroke-cycle diesels). The aftercooler is mounted in the two-stroke-cycle diesel engine block so that it will cool intake air before it enters the cylinder ports. Air-to-air aftercoolers are mounted in front of the radiator.

PERFORMANCE OBJECTIVES

After adequate study of this chapter and sufficient practical experience on appropriate training models and with proper tools, equipment, and shop manuals, you should be able to do the following:

1. Describe the function, design, and operation of dry- and oil bath–type air cleaners.
2. Describe the function, design, and operation of the exhaust-driven turbocharger.
3. Describe the function, design, and operation of the two-stroke-cycle engine blower.
4. Describe the function and operation of the exhaust system and its components.
5. List and describe the five types of harmful diesel engine exhaust emissions.

TERMS YOU NEED TO KNOW

Look for these terms as you study this chapter, and learn what they mean.

induction system	rotor timing
naturally aspirated engine	intercooler
turbocharged engine	aftercooler
air cleaner capacity	air-to-air aftercooler
precleaner	liquid-to-air aftercooler
dry-type air cleaner	exhaust system
air filter element	exhaust backpressure
restriction indicator	exhaust manifold
oil bath air cleaner	muffler

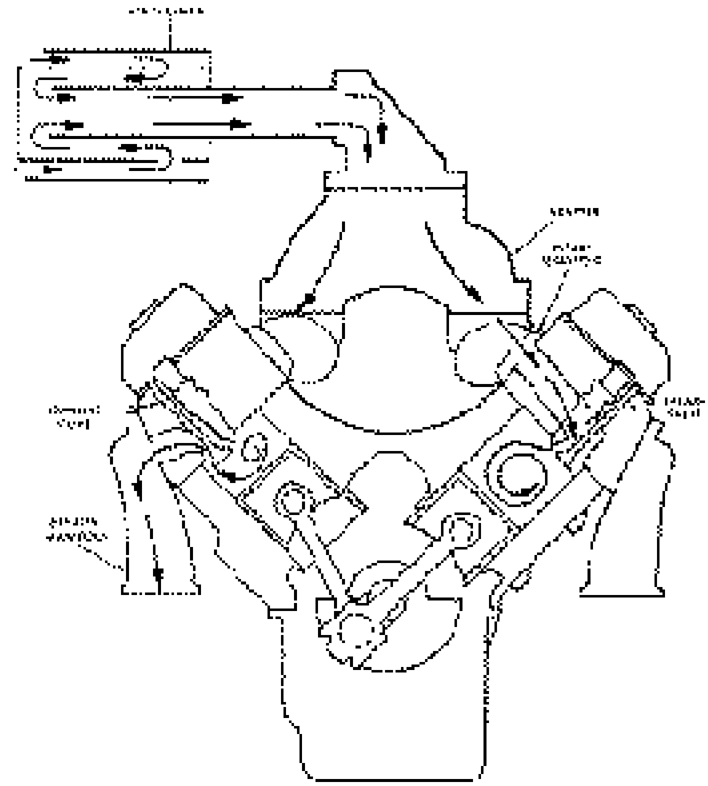


FIGURE 3–1. Naturally aspirated air intake system schematic. (Courtesy of Detroit Diesel Corporation.)

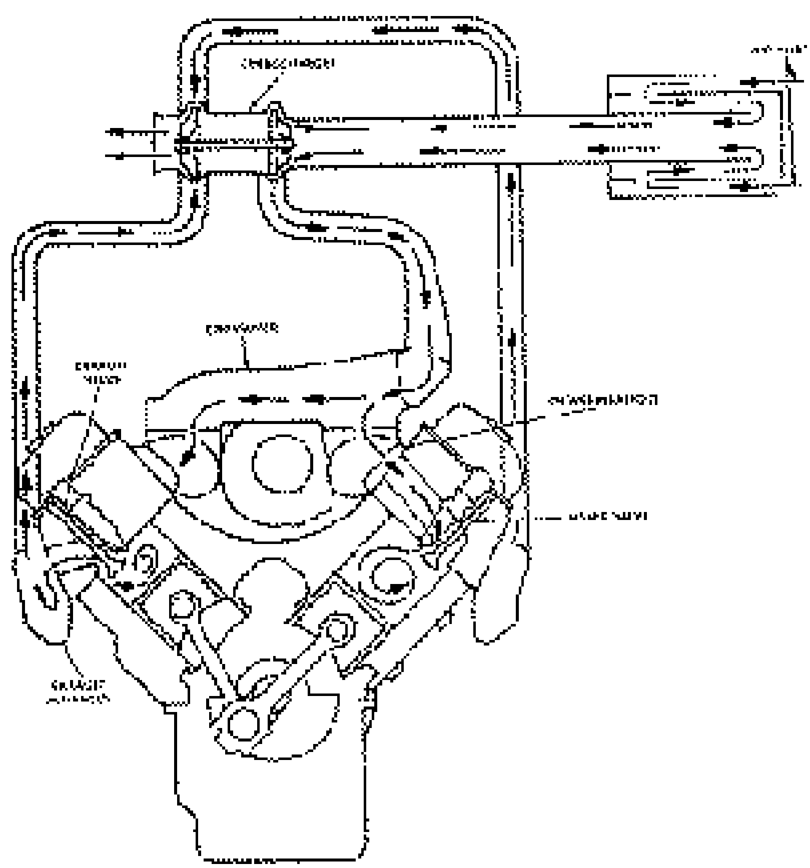


FIGURE 3–2. Turbocharged air intake system schematic. (Courtesy of Detroit Diesel Corporation.)

intake manifold
turbocharger
turbine wheel
compressor wheel
air shutdown valve
blower
blower rotor
exhaust emissions
NO_x
HC
CO
PM
SO_2
particulate trap

AIR CLEANER FUNCTION

The air cleaner is designed to remove moisture, dirt, dust, chaff, and the like from the air before it reaches the engine. It must do this over a reasonable time period before servicing is required. The air cleaner also silences intake air noise.

If dirt is allowed to enter the engine cylinders, the abrasive effects will result in rapid cylinder and piston ring wear. If the air cleaner is not serviced at appropriate intervals for the conditions in which it must operate, it will become restricted and prevent an adequate air supply for complete combustion from reaching the cylinders. Incomplete combustion results in carbon deposits on valves, rings, and pistons, which in turn cause engine wear and oil consumption problems.

Air cleaner types include (1) precleaners, (2) dry types of various designs, and (3) oil bath types. Air cleaner capacity (cubic feet per minute or liters per minute) may have to be up to twice as great on a turbocharged engine as compared with the same engine naturally aspirated.

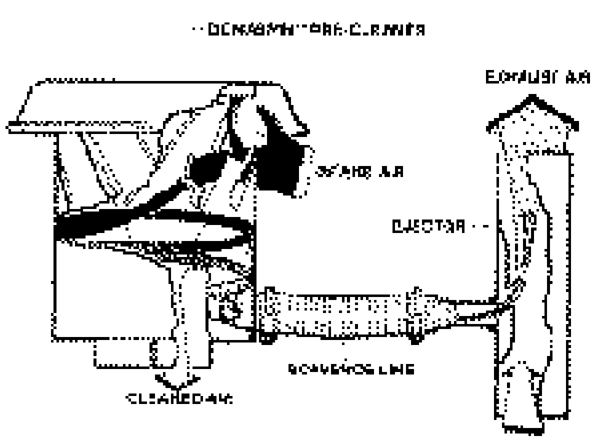


FIGURE 3–3. Precleaner with dirt ejector and scavenge line connected to exhaust system. (Courtesy of Donaldson Company Inc.)

PRECLEANERS

Precleaners are mounted on the intake tube of the air cleaner on some diesel engine–powered equipment. The simplest precleaner consists of a screened hood at the top of the air cleaner inlet. Other precleaners include a spirally vaned drum, which causes incoming air to spin and to force dirt, which is heavier, to the outside. There the dirt falls into a dust cup or passes through a scavenging line connected to the exhaust pipe, where it is ejected into the atmosphere by exhaust gases **(Figure 3–3).**

When dust in the transparent dust cup reaches the level indicated by a line on the cup, it is removed, emptied, and reinstalled.

DRY-TYPE AIR CLEANERS

Dry-type air cleaners may have one or more replaceable filter elements and may include primary and secondary or safety filtering elements. Most dry-type air cleaners also include a vaned type of precleaning device. The vanes may be part of the filter element or they may be part of the air cleaner housing **(Figures 3–4** and **3–5).**

As air enters the air cleaner, it passes over the vanes, which impart a swirling action to the air. The swirling action causes the heavier dust and dirt to be thrown outward centrifugally against the air cleaner housing, where it goes to the dust collector cup or bin. A one-way rubber discharge valve ejects dust and water from the dust cup into the atmosphere directly or through a scavenge line connected to the engine's exhaust. A one-way check valve in the exhaust scavenge line prevents engine exhaust gases from entering the air cleaner.

Air is further cleaned as it passes through the filter element or elements. Air cleaners that use primary and secondary filter elements have the advantage of protecting the engine in cases of primary filter element damage, since air passes through the primary element first and then through the secondary or safety element. Filtered air then passes through the air cleaner outlet and to the engine.

An air cleaner restriction indicator that reflects intake air vacuum may be mounted near the outlet side of the air cleaner **(Figure 3–6).** The restriction indicator may be of the self-contained type, which shows a red flag or card when restriction reaches filter replacement levels, or it may be of the vacuum-actuated light type. Another type is a gauge that continuously reads restriction in inches of water (H_2O)

FIGURE 3–4. Dry-type air cleaner components. (Courtesy of Detroit Diesel Corporation.)

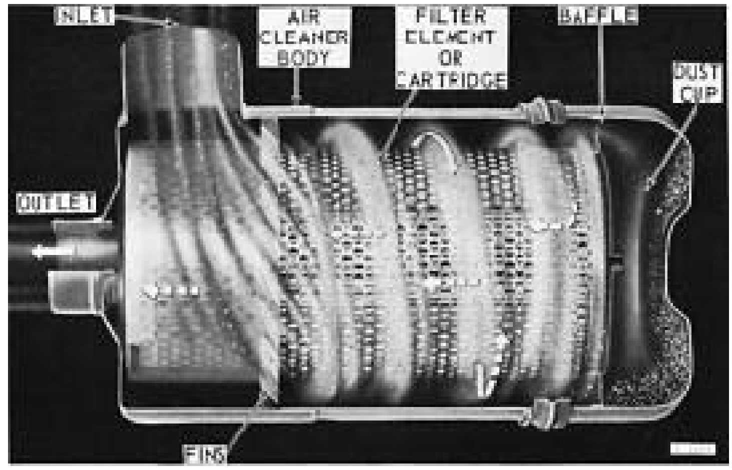


FIGURE 3–5. Air flow in a dry element air cleaner. Fins cause circular flow and centrifugal separation of dirt from air. (Courtesy of Deere and Company.)

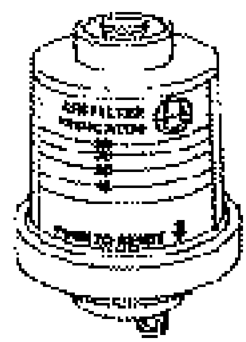


FIGURE 3–6. Air cleaner restriction indicator shows when filter must be replaced. (Courtesy of Caterpillar Inc.)

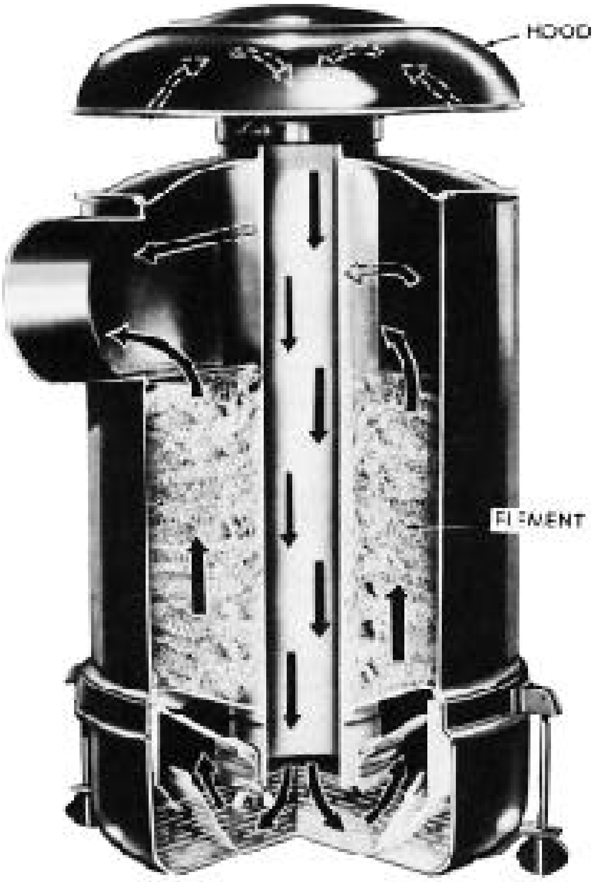
vacuum when the engine is in operation. The restriction indicator may be remote-mounted where it may be easily observed by the vehicle or engine operator.

OIL BATH AIR CLEANER

In the oil bath air cleaner, shown in **Figure 3–7,** air is drawn through the inlet and down through the center tube. At the bottom of the tube, the direction of air flow is reversed and oil is picked up from the oil reservoir cup. The oil-laden air is carried up into the separator screen, where the oil, which contains the dirt particles, is separated from the air by collecting on the separator screen.

A low-pressure area is created toward the center of the air cleaner as the air passes a cylindrical opening formed by the outer perimeter of the central tube and the inner diameter of the separator screen. This low pressure is caused by the difference in air current velocity across the opening.

The low-pressure area, plus the effect of gravity and the inverted cone shape of the separator screen, causes the oil and dirt mixture to drain to the center



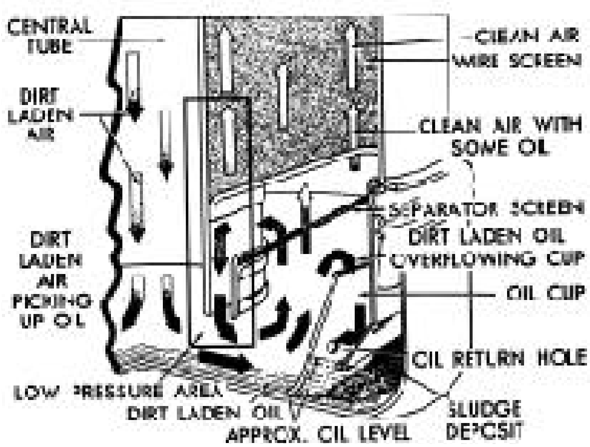


FIGURE 3–7. Oil bath air cleaner operation. (Courtesy of Detroit Diesel Corporation.)

of the cleaner cup. This oil is again picked up by the incoming air, causing a looping cycle of the oil; however, as the oil is carried toward another cycle, some of the oil overflows the edge of the cup, carrying the dirt with it. The dirt is deposited in the outer area surrounding the cup. Oil then flows back into the cup through a small hole located in the side of the cup. Above the separator screen, the cleaner is filled with a wire screen element, which removes any oil that passes through the separator screen. This oil also drains to the center and back into the pan. The clean air then leaves the cleaner through a tube at the side and enters the intake system.

INTAKE MANIFOLD

The intake manifold is of cast-iron or cast-aluminum alloy construction. It is designed to direct air from the air cleaner or turbocharger to each cylinder intake port on four-stroke-cycle engines. On the two-stroke-cycle engine, it directs air from the air cleaner or turbocharger to the blower inlet opening.

The intake manifold is equipped with an emergency air shutdown valve on some engines. Closing the air shutdown valve prevents air from reaching the cylinders, thereby stopping combustion in the cylinders, which stops the engine.

Inside diameters of manifold air passages must be of sufficient diameter to provide adequate air for combustion for all engine operating speeds and loads **(Figures 3–8** and **3–9).**

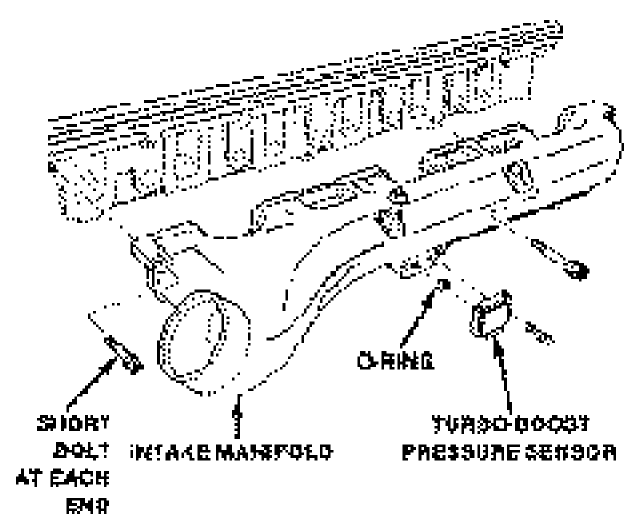


FIGURE 3–8. One-piece intake manifold. (Courtesy of Detroit Diesel Corporation.)

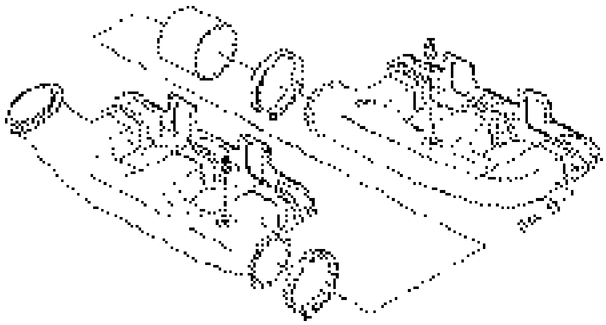


FIGURE 3–9. Two-piece air intake manifold for in-line engine. (Courtesy of Mack Trucks Inc.)

INTAKE-AIR HEATER

Some diesel engines are equipped with an electric intake-air heater located in the intake manifold. The basic components of the system include the electric heating element, heater relay, coolant temperature sensor, intake manifold air temperature sensor, electronic control module, and dash-mounted indicator lamp. When engine conditions are within the range in which heating the intake air will aid starting (based on sensor input to the ECM), the electronic control module turns the heater on. The system is able to deliver heat for 30 seconds prior to starting, during cranking, and after the engine has started. After starting, heating is continuous for several minutes, after which it cycles on and off for as long as required. The system aids in starting and reduces the amount of white exhaust smoke otherwise present after starting a cold engine.

TURBOCHARGER AND BLOWER FUNCTION

Turbochargers and superchargers are designed to increase the amount of air delivered to each of the engine's cylinders. In general, superchargers are mechanically driven from the engine crankshaft, while turbochargers are driven by waste exhaust gases from the engine's exhaust system. Turbochargers are the most common. Two-stroke-cycle engines use a mechanically driven blower as well as a turbocharger. The blower is required to provide startup air and scavenging air on the two-stroke diesel.

TURBOCHARGER OPERATION

The turbocharger compresses intake air to a density up to four times that of atmospheric pressure. This greater amount of dense air allows more fuel to be burned, thereby doubling the engine's power output. The turbocharger also reduces exhaust emissions and exhaust noise. It compensates for the less dense air encountered in higher altitude operation **(Figure 3–10).**

A naturally aspirated engine has a limited supply of air for combustion. The air has only atmospheric pressure pushing it into the cylinders. A turbocharger provides pressurized air, which allows for more air to be packed into a cylinder for each firing. This provides more power and much better combustion efficiency. Thus, more power is realized from a given engine size, fuel economies improve, and emissions are reduced.

A centrifugal compressor pulls air through a rotating wheel at its center, accelerating the air to a high velocity, which flows radially outward through a shell-shaped housing. The air velocity is slowed after leaving the wheel, which converts velocity energy into pressure. This type of compressor is a high-speed device. Current turbochargers run at 80,000 to 130,000 rpm. A normal engine may run at only 2500 to 4000 rpm. Gear- or belt-driven compressors require engine power to drive them. Of the fuel energy available for an engine, about 40% is wasted in the exhaust. A turbocharger uses some of this waste energy to drive its compressor.

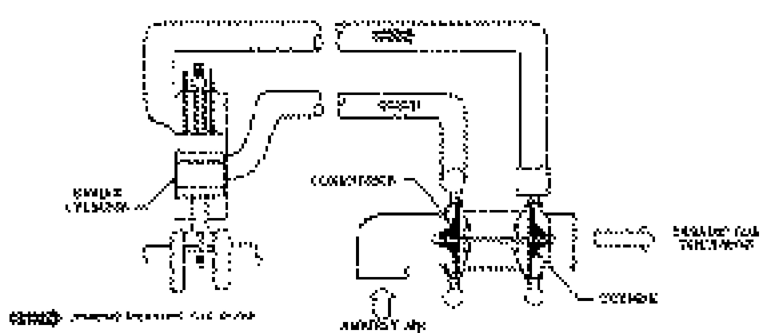


FIGURE 3–10. Schematic diagram of basic turbocharger operation. (Courtesy of Detroit Diesel Corporation.)

The centrifugal compressor wheel is attached to a shaft, which has a turbine wheel on the other end. This arrangement can be likened to a water wheel mounted in a flowing river, with the force of the water turning the wheel, which in turn powers machinery. Like the river, flowing exhaust gases drive the compressor wheel. The turbine wheel is enclosed by a shell-shaped housing much like the compressor section, but the flow is the reverse, or rapidly inward. Exhaust gases enter tangentially and flow toward the rotating wheel at the center. After flowing through the wheel, the gases exit at the center and continue through the exhaust pipe to the atmosphere. The turbine works best at high speeds, which makes it a good match to the compressor section. The common shaft runs in sleeve bearings between the wheels.

These bearings are free-floating, having an oil film on both the inside and outside diameters. The action of the oil flow and the shaft rotation causes the bearings to rotate at approximately one-third of the shaft speed. Each turbocharger has a *journal* bearing system and a *thrust* bearing system. There are system variations for different sizes of turbochargers. The compressor cover is attached to one end of the bearing housing, and the turbine housing is attached to the other end. The bearings are lubricated by engine oil. Only the wheels, shaft, and bearings rotate. The turbocharger unit can nearly double an engine's horsepower, can fit in a 1-ft^3 space, and weighs approximately 45 lb for a medium-size unit. Turbochargers will flow up to 1750 ft^3 of air per minute at pressure ratios up to four times atmospheric **(Figures 3–11** to **3–14)**.

An engine may be equipped with one or two turbochargers. In the dual turbocharger arrangement

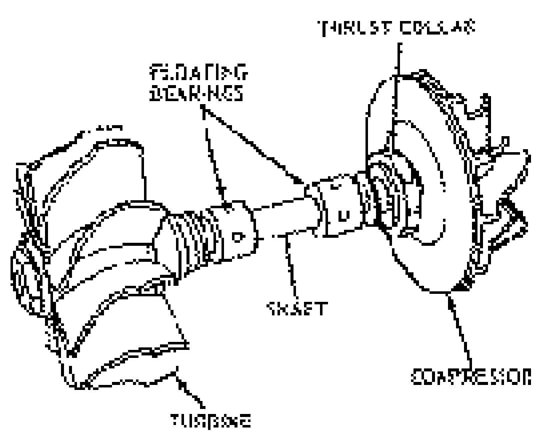


FIGURE 3–11. Rotating parts of a turbocharger. (Courtesy of Deere and Company.)

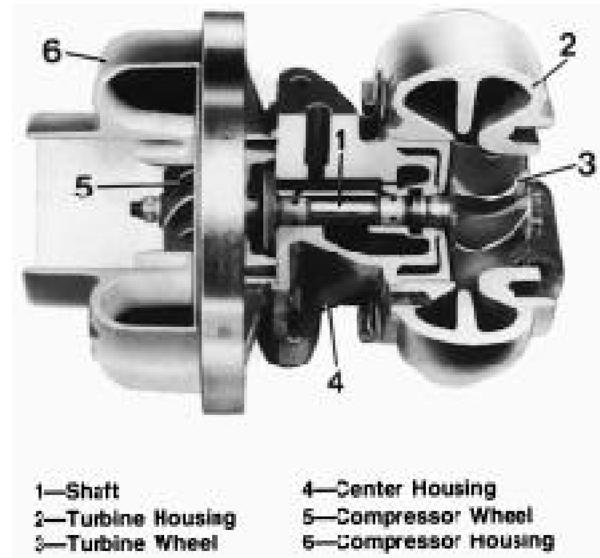


FIGURE 3–12. Turbocharger cross section. (Courtesy of Deere and Company.)

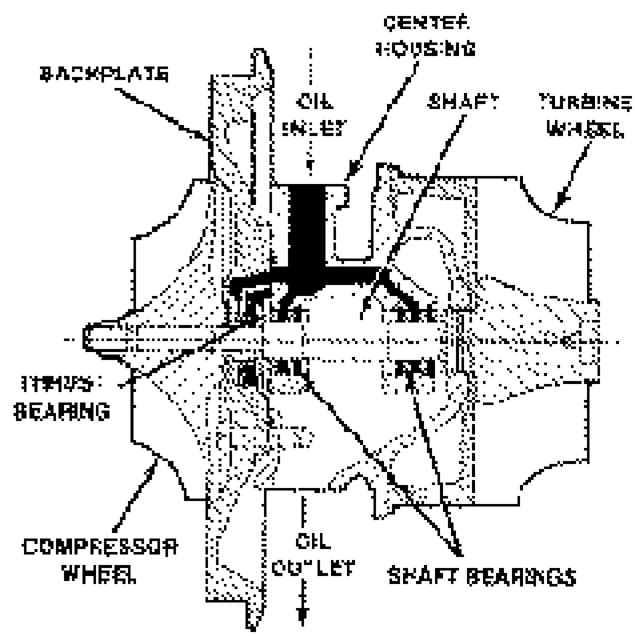


FIGURE 3–13. Turbocharger lubricating oil flow. (Courtesy of Detroit Diesel Corporation.)

each unit provides boosted air to half of the engine's cylinders. When connected in series, boosted air from the primary turbocharger is fed to the secondary turbocharger, where it is boosted to even higher pressure before going to the aftercooler and engine.

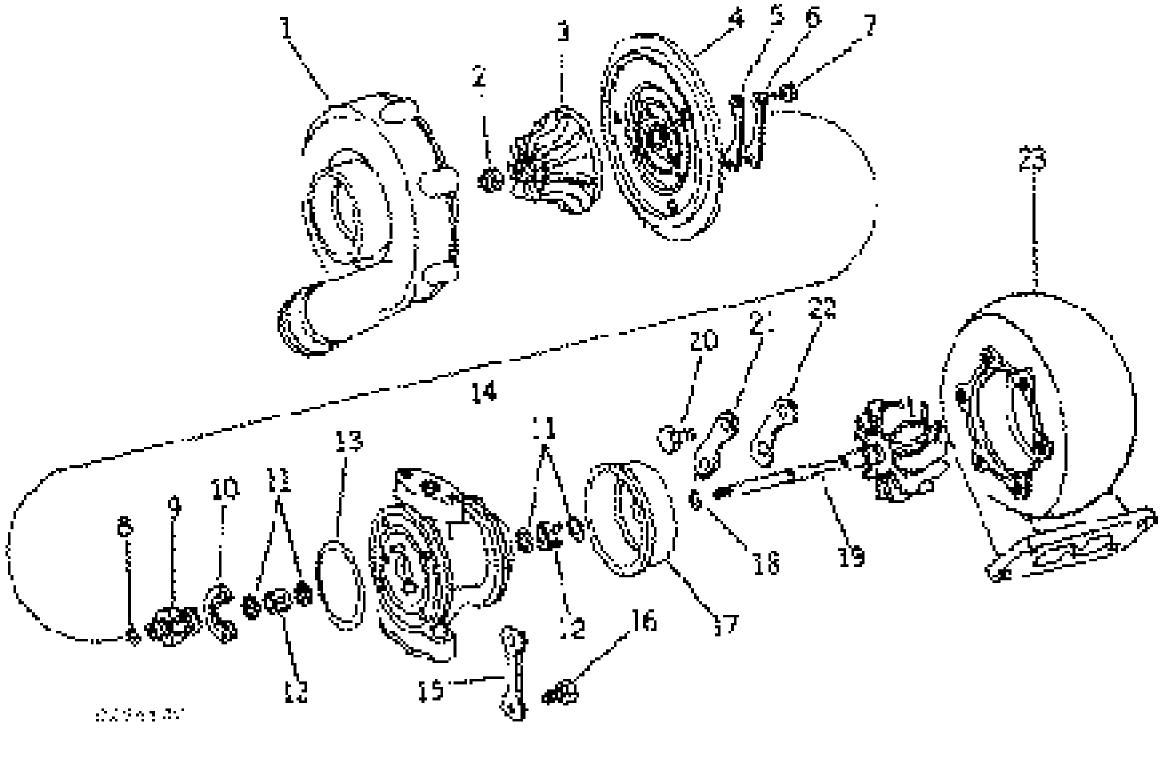


FIGURE 3–14. Turbocharger components. (Courtesy of Deere and Company.)

WASTEGATE OPERATION

Some turbochargers are equipped with a wastegate. This device allows some of the exhaust gases to bypass the turbine rotor at higher engine speeds **(Figure 3–15).** With this arrangement the turbocharger can be designed to be more effective at lower engine speeds.

The wastegate consists of a valve, actuator, and connecting linkage. The actuator consists of a diaphragm and spring enclosed in a canister housing. The valve is located in an exhaust bypass line. Under low boost conditions the spring pushes against the diaphragm moving the linkage to close the wastegate valve. Turbo boost pressure is directed against the other side of the diaphragm. As boost pressure increases with increased engine speed, the diaphragm moves against spring pressure to open the valve and allow a portion of the exhaust gases to bypass the turbine wheel through a connecting line. As boost pressure drops, spring pressure moves the diaphragm and linkage to close the valve. The wastegate is preset at the factory and no adjustment can be made.

AIR SHUTDOWN VALVE

An air shutdown valve on two-stroke-cycle engines allows the air supply to be closed off to stop the engine when abnormal operating conditions require an emergency shutdown. It is located between the air cleaner and the blower. The major components are the housing, valve, and control linkage. When the valve is open, the air supply is not restricted. When the valve is closed, the air supply to the engine is completely shut off, thereby stopping the engine **(Figure 3–15).**

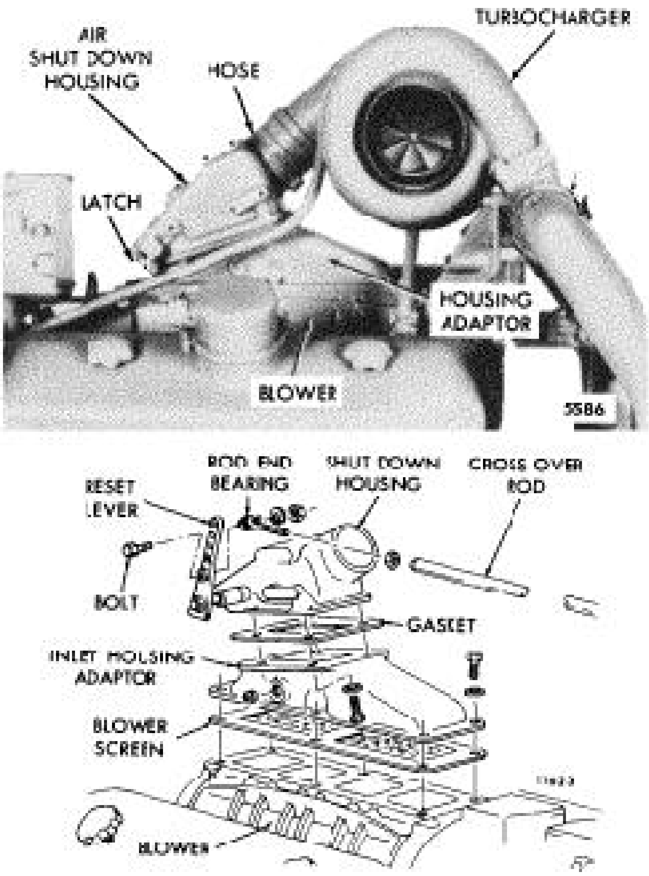


FIGURE 3–15. (Courtesy of Caterpillar, Inc.)

BLOWER DESIGN AND OPERATION (TWO-STROKE-CYCLE ENGINE)

The blower supplies the fresh air needed for combustion and scavenging. Its operation is similar to that of a gear-type oil pump. Two hollow two-lobe or three-lobe rotors revolve with very close clearances in a housing bolted to the cylinder block. To provide continuous and uniform displacement of air, the rotor lobes are helical-(spiral) shaped.

Two timing gears, located on the drive end of the rotor shafts, space the rotor lobes with a close tolerance; therefore, because the lobes of the upper and lower rotors do not touch at any time, no lubrication is required.

Oil seals located in the blower end plates prevent air leakage and also keep the oil used for lubricating the timing gears and rotor shaft bearings from entering the rotor compartment.

FIGURE 3–16. Blower mounting on two-stroke V engine. (Courtesy of Detroit Diesel Corporation.)

Each rotor is supported in the end plates of the blower housing by a roller bearing at the front end and a two-row preloaded radial and thrust ball bearing at the gear end **(Figures 3–16** and **3–17).**

The blower rotor is driven by the blower drive shaft, which is coupled to the rotor timing gear by means of a flexible drive hub.

The ratio between the blower speed and the engine speed, and the number of teeth in the blower drive gears and reduction gears, is dependent on engine type and size and whether it is naturally aspirated or turbocharged.

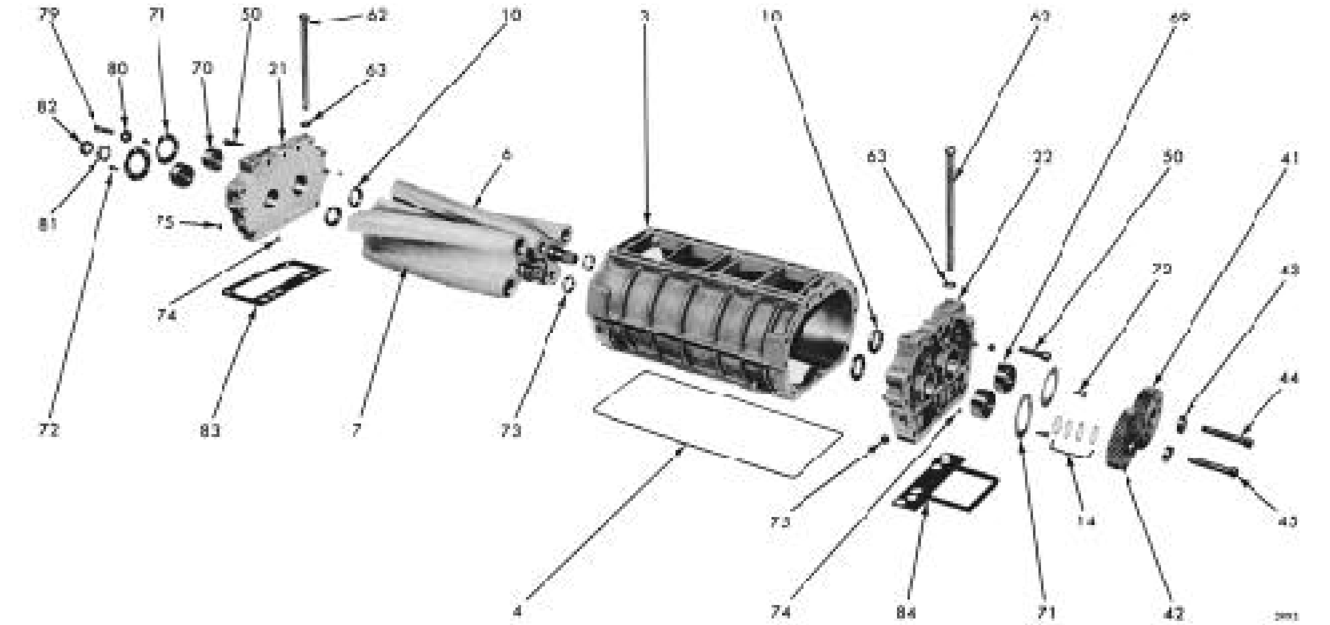
The blower rotors are timed by the two rotor gears at the rear end of the rotor shafts. This timing must be correct; otherwise, the required clearance between the rotor lobes will not be maintained.

Normal gear wear causes a decrease in the rotor-to-rotor clearance between the edges of the rotor lobes. Clearance between the opposite sides of the rotor lobes is increased correspondingly.

Worn blower components can result in blower noise and increased friction. Rotor-to-rotor contact abrasion can cause abrasives to be ingested into the engine, which in turn will cause piston, piston ring, and cylinder liner damage. Normal preventive maintenance and inspection procedures should prevent this kind of damage from occurring, since deterioration would be detected in time.

INTERCOOLERS AND AFTERCOOLERS

The intake air temperature increases considerably as a result of turbocharging. Compressing the air



3.	Housing—Blower	22.	Plate—Rear End	62.	Bolt—Blower-to-Block	74.	Strainer—End Plate Oil Passage
4.	Gasket	41.	Gear—Rotor Drive L.H. Helix	63.	Washer—Special	75.	Plug—Pipe
6.	Rotor Assy.—R.H. Helix	42.	Gear—Rotor Driven R.H. Helix	69.	Bearing—Rotor Rear (Roller)	79.	Belt
7.	Rotor Assy.—L.H. Helix	43.	Pilot—Rotor Gear	70.	Bearing—Rotor Front (Ball)	80.	Washer
10.	Oil Seal—Rotor Shaft	44.	Bolt—Drive Gear	71.	Retainer—Bearing	81.	Lock Washer
14.	Shims	45.	Bolt—Driven Gear	72.	Bolt—Bearing Retainer	82.	Nut
21.	Plate—Front End	50.	Bolt—Socket Head	73.	Sleeve—Oil Seal	83.	Gasket
						84.	Gasket

FIGURE 3–17. Typical blower components for two-stroke-cycle engine. (Courtesy of Detroit Diesel Corporation.)

causes friction between the air molecules. Because friction creates heat, the air temperature rises. Boosted air temperature may reach 300°F (148.8°C) or higher. Higher air temperature means that the air is less dense, so less air is delivered to the engine.

The intercooler (or aftercooler) is designed to cool turbocharger boost air before it enters the engine. Both terms refer to the same unit, which is located between the turbocharger and engine at the output side of the turbocharger. Cooling is accomplished by using either ambient air or engine coolant as the cooling medium.

In the air-to-air aftercooler arrangement, a radiator-like device is mounted in front of the radiator. Turbocharged air is routed through the tubes of the cooler and back to the engine. Ambient air flowing over the aftercooler fins and tubes cools the turbocharged air as it flows through the cooler **(Figures 3–18** and **3–19).**

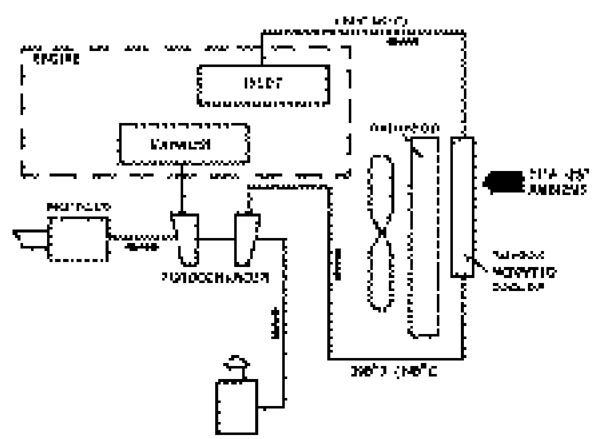


FIGURE 3–18. Air-to-air aftercooler schematic diagram. (Courtesy of Caterpillar Inc.)

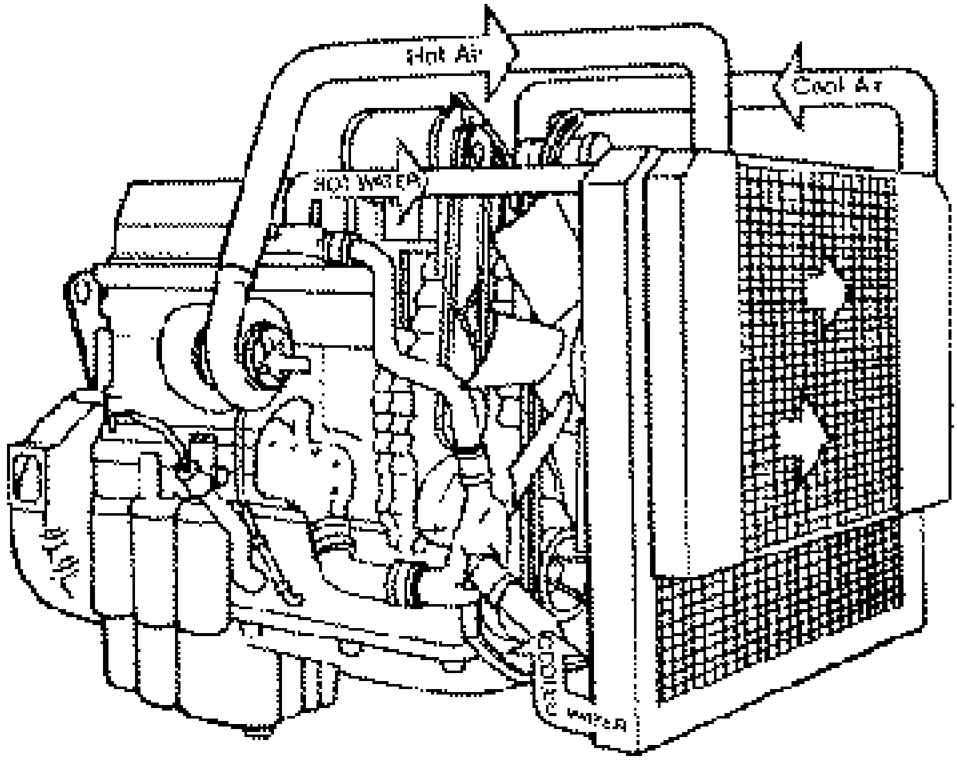


FIGURE 3–19. Layout of air-to-air aftercooler (ATAAC) showing airflow from turbocharger to cooler to engine intake. (Courtesy of Detroit Diesel Corporation.)

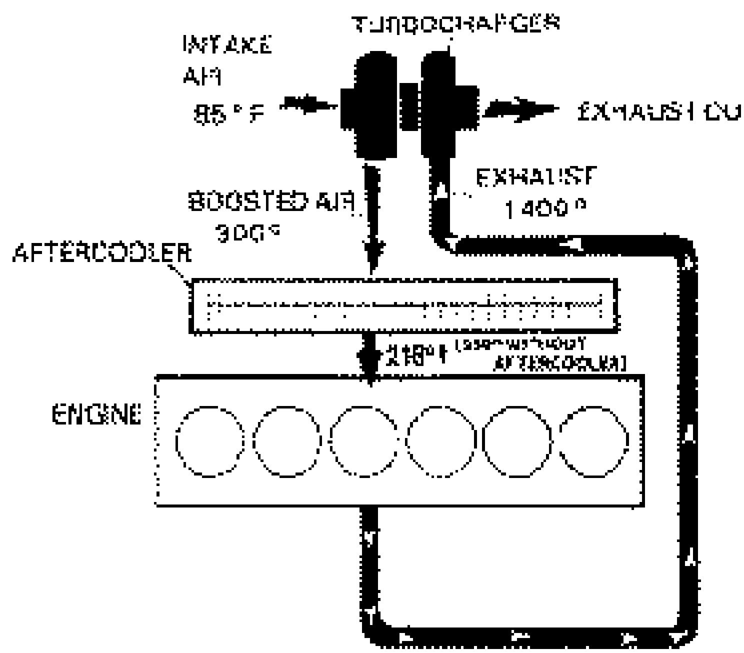


FIGURE 3–20. Typical temperatures of intake air, boosted air and aftercooled air. Note temperature of air without aftercooler. (Courtesy of Cummins Engine Company Inc.)

Alternatively, engine coolant passes through a series of tubes (aftercooler unit) and back to the engine cooling system. Turbocharged air flows across the tubes (usually in the direction opposite liquid flow) and then back to the engine air intake **(Figure 3–20).**

EXHAUST SYSTEM FUNCTION AND COMPONENTS

The exhaust system is designed to collect the exhaust gases from the engine cylinders, direct them to the muffler, where exhaust noise is reduced, and discharge them into the atmosphere **(Figures 3–21** to **3–24).** In addition, exhaust gases may be used to drive a turbocharger for improved air induction for combustion. The exhaust may also be used to eject dirt and dust from the air cleaner or precleaner into the atmosphere. Exhaust gas–driven turbine cargo unloaders for certain materials are used on some trucks. On some light- to medium-duty trucks an operator-controlled valve in the exhaust system is used for braking purposes.

Exhaust system components include the exhaust manifolds, exhaust pipe, muffler, muffler extension, and the connecting gasket and clamps. Exhaust pipes may include rigid steel tubing and flexible tubing. A hinged exhaust pipe cap is used on many vertical installations to prevent rain from entering the system. The cap closes automatically when the engine is shut off. A heat shield is used on many applications to prevent injury and component damage.

Exhaust system components must be of sufficient capacity to effectively remove exhaust gases produced by the engine at all operating speeds and loads.

Any restriction in the exhaust system through external damage or internal deterioration will affect the engine's performance.

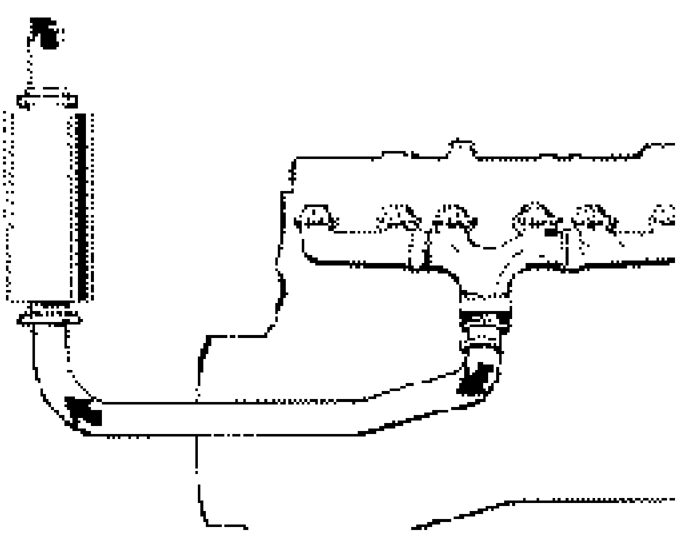


FIGURE 3–21. Typical exhaust system showing exhaust manifold, exhaust pipe, muffler, and extension. (Courtesy of Cummins Engine Company Inc.)

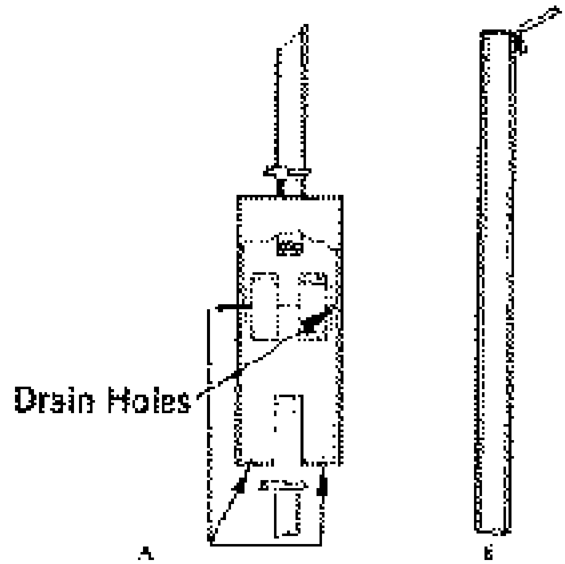


FIGURE 3–22. Drain holes in muffler exhaust system prevent moisture from entering the engine (A). Hinged rain cap (B) prevents moisture from entering exhaust system. Cap opens automatically when engine starts and closes when engine is shut off. (Courtesy of Cummins Engine Company Inc.)

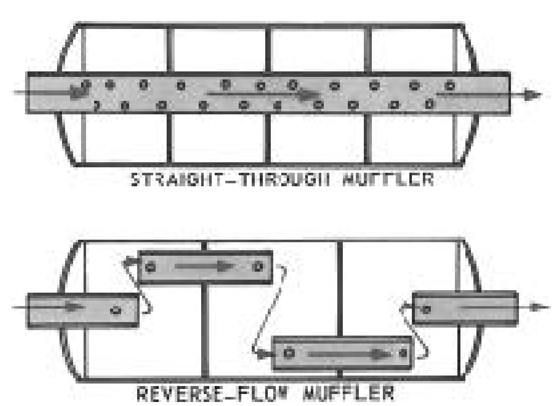


FIGURE 3–23. Muffler types. (Courtesy of Deere and Company.)

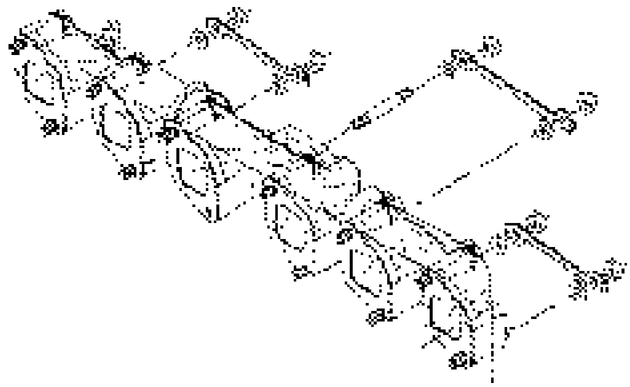


FIGURE 3–24. Exhaust manifold and related parts. (Courtesy of Mack Trucks Inc.)

WATER-COOLED EXHAUST MANIFOLD

In marine or industrial applications where the engine is contained in an enclosed engine compartment, a water-cooled exhaust manifold may be used to reduce the high heat radiation from the engine. A water jacket (part of the integral casting) surrounds the exhaust manifold. A water inlet fitting is provided near the exhaust pipe end of the manifold, and an outlet fitting at the other end. Coolant circulation is directed from the engine water jacket to the inlet fitting. Coolant leaving the outlet fitting is directed to the thermostat housing area. From there it circulates through an expansion tank and heat exchanger or the keel-cooled system. A drain plug is provided at the bottom of the manifold to allow water drainage when required **(Figure 3–26).**

EXHAUST EMISSIONS

Increasing concern over the effects of harmful exhaust emissions has resulted in increasingly stringent legislation designed to control and reduce their volume. The following emissions are of concern **(Figure 3–26).**

1. *Oxides of nitrogen* (NO_x): form by a reaction between nitrogen and oxygen at higher temperatures in the combustion chamber. NO_x reacts with hydrocarbons in the atmosphere in the presence of sunlight to form ozone and photochemical smog.
2. *Hydrocarbons* (HC): include over 100 different hydrocarbon compounds resulting from incomplete combustion. They are especially evident during cold ambient temperatures as white exhaust smoke.

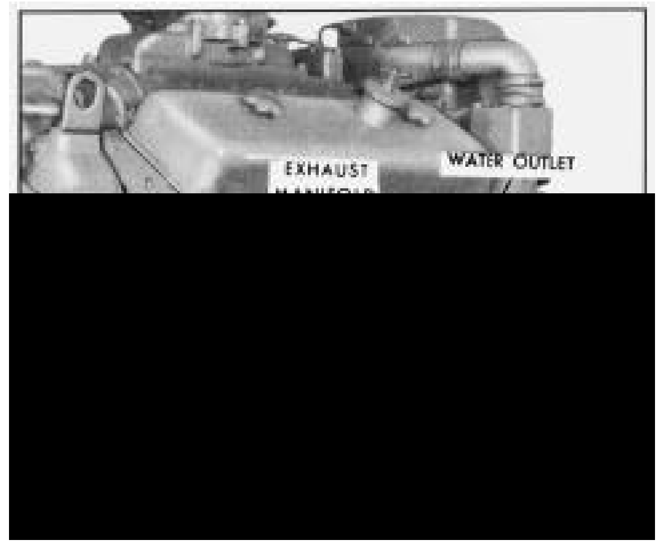


FIGURE 3–25. Water-cooled exhaust manifold on a Detroit Diesel engine. (Courtesy of Detroit Diesel Corporation.)

3. *Carbon monoxide* (CO): results from incomplete combustion. It is not a serious problem with diesel engines due to their lean combustion process.
4. *Particulate matter* (PM): consists mostly of partially burned particles of fuel and engine oil and appears as soot. Shows up as black exhaust smoke and is formed when there is too little intake air or combustion temperature is too low. A particulate trap is used on some engine exhaust systems to prevent dispersal of particulate matter into the atmosphere.
5. *Sulfur dioxide* (SO_2): caused by oxidation of sulfur contained in the fuel. Contributes to acid rain.

Factors Affecting Exhaust Emissions

The rated high-idle speed of an engine is an important factor affecting exhaust emissions. Engines designed to run at higher speeds have less time for combustion to take place than do lower speed engines. Consequently, injection must begin earlier for the combustion process, cylinder pressure, piston position, and crank angle to be at the most

U.S. EPA HEAVY-DUTY ENGINE EMISSION STANDARDS (G/BHP-HR MEASURED DURING THE EPA TRANSIENT TEST)

Model Year	*NO_x*	*HC*	*CO*	*PM*
1991	5.0	1.3	15.5	0.25
1993 (Urban Bus)	5.0	1.3	15.5	0.10
1994	5.0	1.3	15.5	0.10
1994 (Urban Bus)	5.0	1.3	15.5	0.05[a]
1998	4.0	1.3	15.5	0.10
1998 (Urban Bus)	4.0	1.3	15.5	0.05[a]

[a]EPA can set at 0.07

FIGURE 3–26. U.S. emission standards for 1991–1998. (Courtesy of Detroit Diesel Corporation.)

advantageous state and position to provide as much push on the piston as possible and still not produce excessive emissions. The duration and rate of fuel injection are precisely controlled to aid in achieving the best results in engine performance, economy, and low emissions. This process involves injector design and injection pressures. Injector design determines the spray pattern and the degree of fuel atomization achieved. Injection pressures generally have become higher in order to improve further the atomization of fuel as well as to provide a thorough mixing of fuel particles and air.

EXHAUST GAS TREATMENT

Various devices have been designed to treat exhaust gases to meet increasingly stringent emission regulations and to avoid igniting combustible materials in the area where equipment is being operated.

A spark arrestor or trap is added to the outlet pipe of the muffler to avoid the exhaust of glowing particles into the atmosphere where they can fall onto combustible materials in the working area. Internal vanes cause the gases to spiral upward in a swirling motion. Centrifugal force throws the glowing particles outward against the wall of the unit, from which they fall into a trap and cool. Servicing the unit involves periodically emptying the particle trap. This device is commonly used in the forest industry and in mining to prevent accidental fires.

A catalytic converter is added to the exhaust system to reduce carbon monoxide and hydrocarbon emissions. The converter is a muffler-shaped device containing a porous ceramic element coated with a catalyst such as platinum or palladium. All the exhaust gases pass through this element, which converts them to carbon dioxide and water **(Figures 3–27** and **3–28).** Because of engine design improvements, most of the newer fuel injection systems do not require exhaust treatment devices to meet emissions standards.

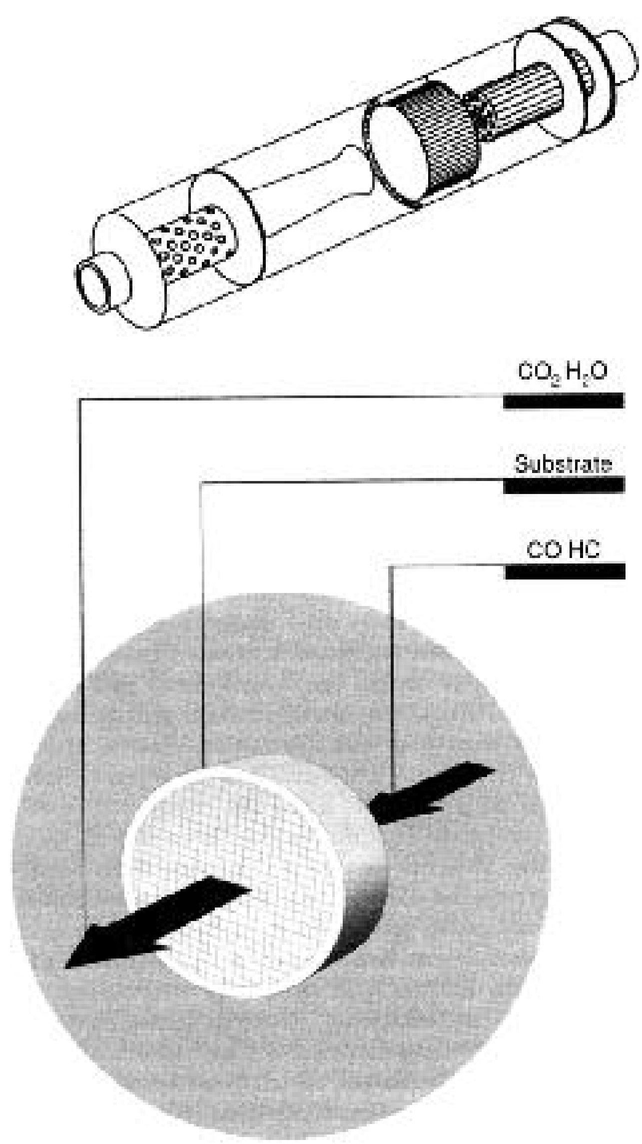


FIGURE 3–27. Basic diesel engine catalytic converter design and operation.

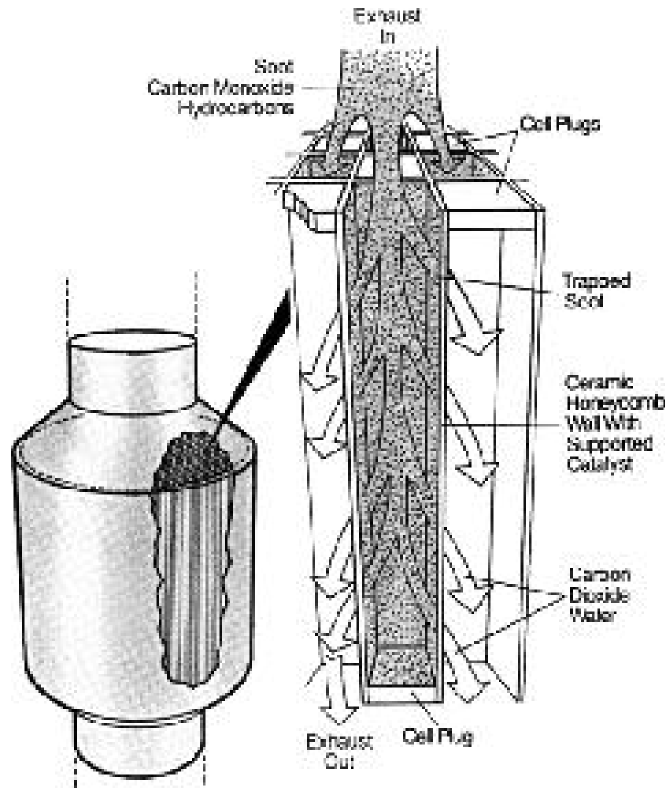


FIGURE 3–28. Exhaust flow through ceramic honeycomb cell plugs oxidized particulates to prevent them from being expelled into the atmosphere.

Electronically Controlled Fuel Injection

The electronic control of fuel injection systems has resulted in greatly reduced exhaust emissions. Very precise control of injection timing and fuel metering is achieved in response to a variety of sensors that closely monitor engine operation. Changes in the temperature of engine coolant, lubricating oil, fuel, and intake air are factors in determining the best injection timing and fuel metering. The altitude at which the engine operates and the turbocharger boost pressure also affect fuel metering and injection timing.

REVIEW QUESTIONS

1. The induction system must provide the engine with an adequate supply of ________ .

2. Up to ________ ft^3 of air per minute or more may be required from the induction system.

3. What does the term *naturally aspirated* mean?

4. Turbochargers are ________ ________ driven.

5. An intercooler or aftercooler may be included in the ________ ________ .

6. What is the function of the air cleaner?

7. Oil bath air cleaners are not often used. (T) (F)

8. The intake manifold is of a ________ ________ or ________ ________ construction.

9. Superchargers are usually ________ driven.

10. Two-stroke-cycle engines use a mechanically driven blower as well as a ________ .

11. Current turbochargers run at 80,000 to 130,000 rpm. (T) (F)

12. An engine may be equipped with ________ or ________ turbochargers.

13. What is the function of the blower on a two-stroke-cycle engine?

14. Explain the function of the (a) intercooler; (b) aftercooler.

15. Carbon monoxide emissions are a result of ________ ________ .

TEST QUESTIONS

1. A supercharged or turbocharged engine will have
- **a.** volumetric efficiency problems
- **b.** no change in volumetric efficiency
- **c.** increased volumetric efficiency
- **d.** decreased volumetric efficiency

2. Technician A says a turbocharger is driven by exhaust gas. Technician B says a supercharger is driven by exhaust gas. Who is correct?
- **a.** Technician A
- **b.** Technician B
- **c.** Both are right.
- **d.** Both are wrong.

3. The speed and power of a diesel engine are controlled by varying the amount of
- **a.** air only
- **b.** fuel and air
- **c.** fuel only
- **d.** atmospheric pressure

4. Boost pressure in a turbocharger is controlled by
- **a.** air density
- **b.** altitude compensation
- **c.** turbine speed
- **d.** engine vacuum

5. Diesel engines require an air filter with a capacity
- **a.** the same as that of a gasoline engine
- **b.** smaller than that of a gasoline engine
- **c.** larger than that of a gasoline engine
- **d.** three times as large as that of a gasoline engine

6. Technician A says some diesel engines have a muffler in the air cleaner inlet to reduce noise. Technician B says diesel engines do not use enough air to produce noise in the air inlet. Who is correct?
- **a.** Technician A
- **b.** Technician B
- **c.** Both are right.
- **d.** Both are wrong.

7. Many turbocharged engines cool the intake air to
- **a.** reduce manifold expansion
- **b.** prevent engine overheating
- **c.** increase volumetric efficiency
- **d.** reduce horsepower at high rpm

8. Exhaust manifolds are made of
- **a.** aluminum or steel
- **b.** steel or cast iron
- **c.** cast iron or aluminum
- **d.** aluminum or platinum

9. A substance or condition that does *not* produce smog is
- **a.** oxides of nitrogen
- **b.** unburned hydrocarbons
- **c.** sunshine and still air
- **d.** complete fuel combustion