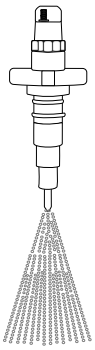
10 Mechanical Injectors, Injection Nozzles

Many types and designs of fuel injectors have been developed over the last 100 years as diesel systems have evolved – ranging from simple mechanical injectors with spring, needle and nozzle, to fully electronic injectors capable of injecting fuel five times during each injection phase (5 times in 0001-0.002 seconds!)

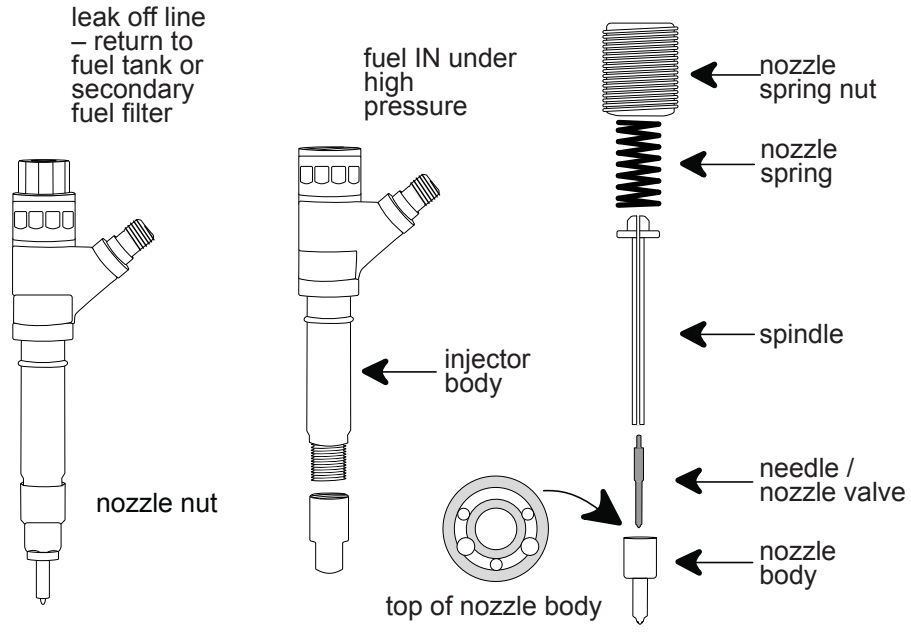


The functions of a fuel injector is to:

- inject fuel into the combustion chamber, pre-combustion or swirl chamber
- atomize the diesel into a fine spray, which increases the surface area of fuel to burn faster and cleaner
- promote optimal fuel/air mixing across the entire width of the combustion chamber to promote more complete combustion
- ensure the widest possible distribution across the combustion chamber
- enable precise injection timing and fuel delivery by opening and closing rapidly to avoid mistiming and fuel dribble
- regulate minimum injection pressure through spring tension (injector only opens when fuel pressure is above spring tension)

The precise moment of fuel injection and the quantity of fuel injected are not controlled by the injector. They are controlled either by a pulse wave travelling through the fuel line from the injection pump (inline or distributor), or by control signals from an ECU (engine control unit). Unit injectors may use a combination of mechanical fuel pressure generation and electronic control signals depending on the type and generation.

See *Fuel Wave*, page xx

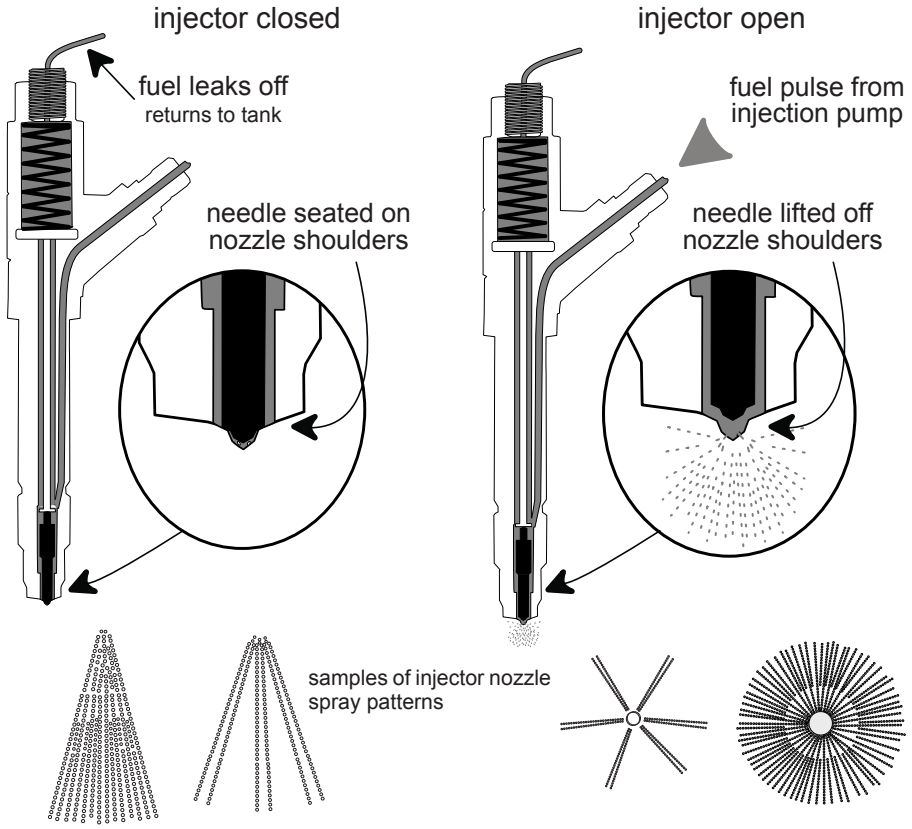


How a Mechanical Injector Works

Fuel from the injection pump floods the injector via the high pressure line; spring pressure holds the needle down against the shoulders of the nozzle to prevent fuel injection. When the reciprocating plunger in the injection pump generates enough pressure to open the delivery valve, a pulse of high pressure fuel flows almost instantly through the fuel line to the injector to overcomes the spring pressure. The increased fuel pressure lifts the needle off its seat, opening the nozzle and injecting fuel as a fine mist into the engine – into the pre-combustion, swirl or combustion chamber – where it instantly ignites.

How much fuel is injected (and therefore engine rpm) depends on how long the needle remains off its seat and the nozzle stays open. This is controlled by the position of the governor or control lever (throttle) which controls the fuel spill port opening. As soon as the fuel spill port in the injection pump opens, fuel pressure falls, allowing spring pressure in the injector to push down the needle; close the nozzle valve and end fuel injection.

Some fuel is allowed to leak from the nozzle up past the spring and out of the injector to flow back to the fuel tank, or the secondary filter. This lubricates the injector's moving parts and helps to cool the injector. For a fuel system to work correctly, all air must be removed from the injectors (and lines and injection pump) because air can be compressed which would prevent injection, as well as degrading lubrication.

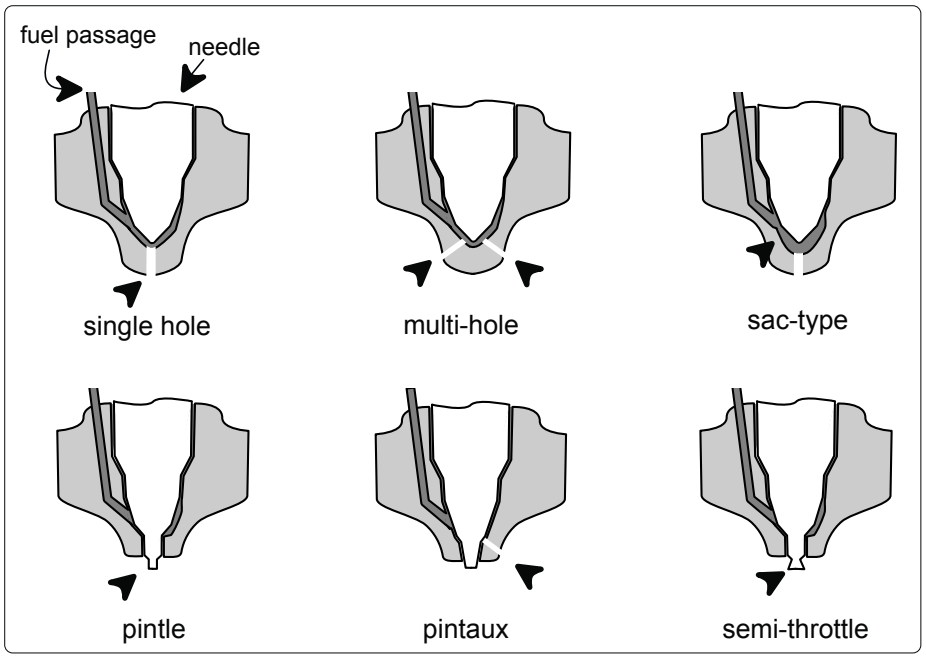


Types of Injector Nozzles

Five types of injector nozzles are commonly used :

- single-hole – fuel enters the combustion chamber through a 0.2 mm (0.00787 inch) diameter hole in a narrow 15°-wide spray. Though simple, this design does not promote good atomization, nor wide fuel/air mixing.
- multi-hole – the nozzle may have 4 - 12 holes in the tip, which increases fuel atomization and fuel/air mixing. Multi-hole nozzles are commonly used in common rail systems where the high injection pressure and multiple holes creates a finer fuel spray prmoting a more complete burning and lower emissions.
- sac-type – a small fuel cavity (or *sac*) surrounds the bottom of the needle in the nozzle, allowing better fuel injection under a wider range of engine operating conditions.
- pintle – the end of the needle extends out of the end of the nozzle through one hole. Pintle nozzles are more commonly used on fully mechanical diesel engines with pre-combustion or swirl chambers (indirect injection) and provide adequate atomization at lower injection pressures. Pintle nozzle are self-cleaning and usually free of fuel *dribble* (*after-drip*), in which fuel leaks after the end of injection.
- pintaux – similar to the pintle nozzle, the pintaux has an extra hole in the body of the nozzle that allows a small amount of fuel to be injected before the main injection event (similar to pilot injection in common rail systems).
- semi-throttle – similar to a pintle nozzle, except that the end of the nozzle is tapered and the nozzle is longer. This injects less fuel at the beginning of injection; fuel supply increases as the needle lifts. Used in smaller, high speed engines.

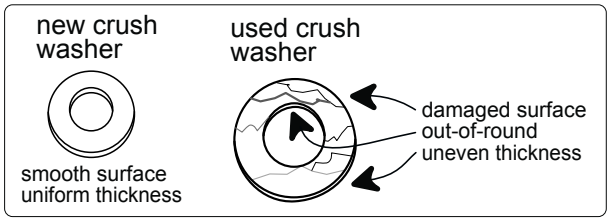
See *Pre-Combustion Chambers,* page xx



Injector Installation Best Practices

Care must be taken when removing or installing injectors

- read and follow instructions in the engine's service manual
- cleanliness is very important:
  - wipe area around injectors before removing or installing them
  - cover each injector hole to prevent dirt etc. falling inside
  - thoroughly clean the injector
  - clean soot out of the injector well
  - check the old crush washer has been removed from injector well
- keep needle and nozzle holder as a pair; do not mix between injectors
- use new crush washers – reusing a washer risks leaks
- install a new injector oil seal (if fitted)
- grease o-rings before installation (if fitted)
- loosen, or tighten, retaining nuts evenly to the specified torque



Leak Off Line, Return Line

Diesel engines draw more fuel from the fuel tank than they burn (some engines may return up to 50% of the fuel to the fuel tank). This helps to ensure:

1. the injection pump always has enough fuel even with any sudden increase in demand for fuel
2. heat is removed from the injectors by returning the warmed fuel to the fuel tank, which acts as a heat sink
3. air bubbles are removed from the fuel circuit

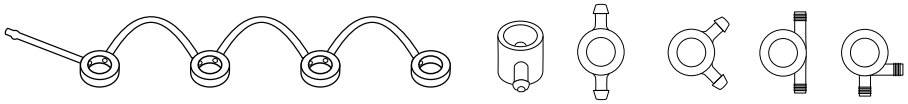
Functions of the Leak Off/Return Line

The function of the return line/leak off line is to remove the warmed excess fuel from the injectors, along with any air bubbles in the system. Depending on the design of the engine, the return line may return fuel from the injectors to:

- fuel tank (should be the same tank that the diesel was supplied from)
- secondary fuel filter (on-engine filter). This may have a hose barb to fit a hose to return diesel to a tank, (though the hose may not be installed)
- injection pump, sometimes with a small overflow hose back to the secondary fuel filter

See *Return Line/Leak Off Line,* page XX

return line connections between injectors



leak off pipe, made of steel, connects the injectors in a daisy-chain to a fuel hose

plastic or metal "hats" are connected by fuel hose between the injectors

Rotary Distributor Injection Pumps

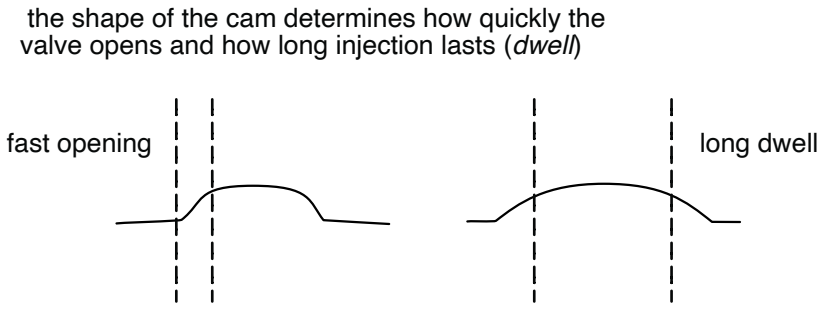
Two types of rotary distributor injection pumps were developed in the early 20th century for smaller, lower hp engines, such as in trucks and cars. Instead of requiring a plunger and barrel for each cylinder on the engine, both designs of rotary distributor pump use only one plunger and barrel to supply fuel at the correct time to each of the engine cylinders. Rotary distributor fuel pumps are simpler, more compact and less expensive to manufacture than inline fuel pumps and led to the global adoption of diesel trucks, cars, tractors and other equipment machinery, including in boats.

The first distributor-type injection pump was developed in 1947 by Vernon D. Roosa in America at the Stanadyne Corporation. This pump, the Roosa Master, is a *radial piston pump*. Pistons pressurize a measured amount of fuel which is supplied, in turn, by a rotor to each of the engine's injectors.

The *axial piston pump* was developed by the Bosch Corporation in West Germany in 1989. This uses a single reciprocating and rotating plunger within a barrel to pressurize fuel and to supply, in turn, each of the engine's injectors. A control collar linked to the governor and throttle controls fuel quantity.

Key Differences between Distributor Injection Pumps and Inline Jerk Pumps

- distributor injection pumps incorporate two fuel pumps – a low pressure transfer/lift pump to supply fuel to the high pressure pump ,which pressurizes the fuel to injection pressure
- inline injection pumps use one plunger and barrel for each engine cylinder (4 pairs in a 4 cylinder engine); distributor pumps use one rotor (or plunger) and barrel to supply fuel for all cylinders
- distributor pumps attain higher fuel pressures, ranging from 320 - 2000 bar (460 - 29,000 psi) compared to inline pump pressures of 200 - 360 bar (3 - 5,000 psi). Higher pressure creates better atomization of fuel in the cylinders
- distributor pumps are lubricated by the diesel fuel flowing through them; older models of inline pump were lubricated by their own reservoir of oil with a separate dipstick from the engine. Their governor was also lubricated by a separate oil reservoir and dipstick
- distributor pumps are cooled by directing some of the fuel in the pump to flow back to the fuel tank, via the return line. Inline pumps are cooled by the flow of fuel through them and the return of fuel from the injectors to the fuel tank (or secondary fuel filter)v
- inline pumps have at least one bleed screw in order to bleed air from the pump; distributor pumps are designed so that any air bubbles rise to the top of the pump and leak-off with the fuel returning to the tank



How a *Radial* Rotary Distributor Pump Works

A low pressure vane pump draws in fuel from the secondary fuel filter and supplies fuel to the high pressure side of the injection pump. Some fuel is allowed to leak off from the pump to improve pump cooling and to remove air bubbles. Fuel pressure inside the pump housing is controlled by a spring valve.

A rotor connected to the drive shaft turns inside a close-fitting barrel. When the ports align, fuel flows into a cavity through the rotor to the pressure chamber located between two pistons. The amount of fuel entering the rotor is controlled by the governor and throttle (engine control lever) rotating a plunger with a helix cut that allows more or less fuel to enter the rotor.

When the fuel port closes (fuel ports move out of alignment) cams push together the two plungers which pressurizes the fuel. At the same time, a channel cut in the rotor comes into alignment with one of the delivery ports; fuel pressure overcomes spring pressure, opening the delivery valve and sending a fuel pulse through the fuel line (pipe) to the injector.

Fuel delivery ends when the cam rotates off the plungers, allowing springs to push the plungers apart. This instantly drops fuel pressure and the delivery spring closes the delivery valve, (spring pressure now being stronger than fuel pressure).

The rotor has a delivery channel for each injector,

The engine is stopped when the governor/engine control lever is rotated to the no fuel position. This is done either by an electric solenoid or a manual cable.

The radial pump has an automatic timing advance device that rotates the cam ring (which drives the pistons pressurizing fuel) as rpm increases so that fuel is pressurized and injectors open slightly earlier in the combustion event – allowing more time for larger volumes of fuel to be injected and to burn in each engine cylinder. The device works by allowing fuel pressure to push against a plunger and spring. As rpm increases and fuel pressure rises, the plunger overcomes the spring resistance, and the cam ring moves to make fuel injection earlier (advance timing).

See *Vane Pump*, page 149
See *What is Effective Stroke*, page XX