PROPERLY WORKING FUEL SYSTEM

FUEL SYSTEMS

The fuel systeem is the most sophisticated, expensive and critical of all engines systems. Engine performance, economy and durability depend on proper performance of the fuel system. Keeping fuel clean and using high quality, high efficiency fuel filters will allow the fuel system components to perform properly until the engine reaches overhaul life.

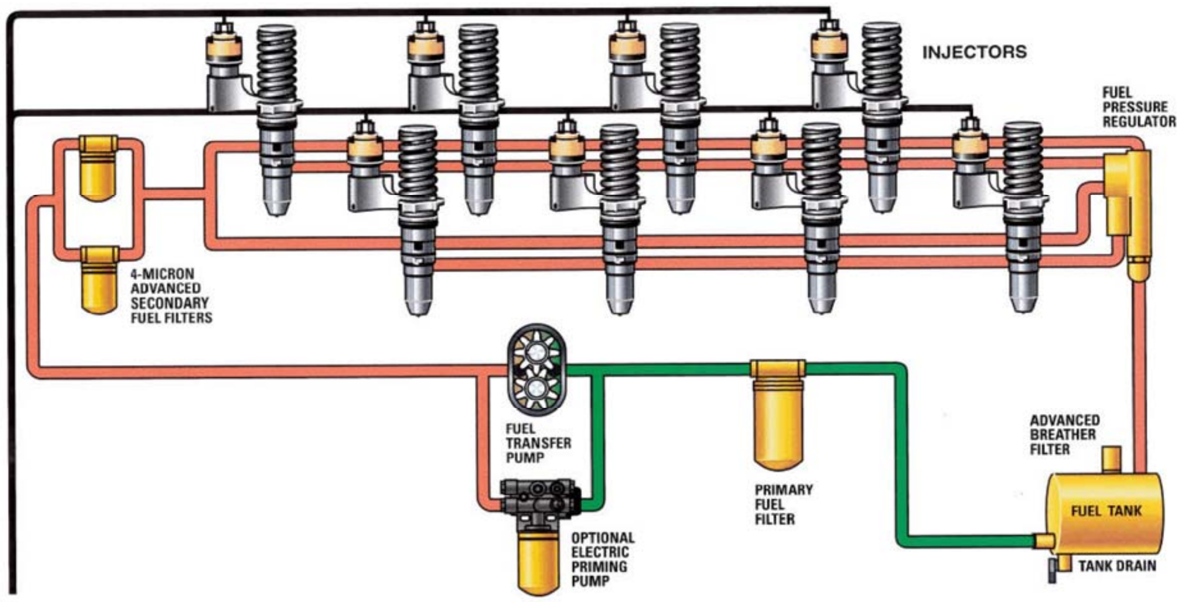
Fuel system problems are largely confined to accelerated abrasive ear or seizure of unit injectors. Injector seizure may also result in contingent damage to valve train components. The single large problem is:

- short unit injector life due to excessice abrasive particles in the fuel
    - Microscopic abrasive particles damage surfaces in the injector, causing internal leakage of hight pressure fuel and low engine power/
- abrasive particles are inherent in most fuels. Some fuels have very large amounts of abrasives.

In this whitepaper we would like to give you more information about how fuel systems work, what contamination does to a fuel system and what you can do to prevent this.

The basic fuel system
The basic fuel system, common to all Caterpillar diesel engines, includes an engine driven fuel transfer pump, a secondary fuel filter, unit fuel injectors and a fuel pressure regulator. Optional Caterpillar supplied fuel system components include flexible hoses, a manual fuel priming pump, and a duplex primary fuel strainer. A basic fuel system schematic is shown in this figure.

Fuel System Schematic



The engine driven transfer pump delivers fuel to the unit injectors via the secondary fuel filter. The pump is equipped with a pump-mounted safety valve and the fuel flow at rated rpm is listed in the technical data and varies with engine speed. The unit injector, either mechanically or hydraulically actuated, combines the functions of pumping, metering and injecting into a single unit. It is located near the center of the combustion chamber in each cylinder head, between the rocker arms. External manifolds supply fuel from the transfer pump to the injectors, eliminating the need for high pressure fuel lines. Fuel continuously circulates through the injectors, and the excess fuel that is not used for combustion cools the injectors and is returned to the fuel tank via the pressure regulating valve. This excess fuel also aids in the purging of air from the system. The fuel delivery pressure to the injectors is controlled by a pressure regulating valve. The pressure regulator must be adjusted at the installation site in order to provide the proper fuel pressure to the injectors.

The manual fuel priming pump is recommended if no electrical priming pump is available. The manual pump helps to bleed air from the fuel piping before initial engine operation and following engine maintenance such as filter element changes and injector replacement. Caterpillar also recommends the use of a duplex primary fuel filter prior to the engine driven fuel transfer pump. When used, the duplex primary fuel filter is installed, remotely from the engine, in the fuel transfer pump suction piping. Their are different types of fuel systems: MEUI, HEUI and Common Rail fuel systems.

HEUI Fuel System

The Hydraulically actuated Electronically controlled Unit Injectors (HEUI) use a hydraulic pump and engine oil to generate fuel injection pressure, and an ECM to control the pressure and amount of fuel injected into the cylinders. The operation of the HEUI fuel system is completely different from any other type of fuel system that is actuated mechanically. The HEUI fuel system is completely free of adjustment. Changes in performance are made by installing different software in the ECM.
Later in this whitepaper we will highlight this type of fuel system.

MEUI Fuel System

The Mechanically actuated Electronically controlled Unit Injectors (MEUI), formerly known as Electronic Unit Injectors (EUI), also use the engine camshaft and push rods to generate fuel injection pressure, but use an Electronic Control Module (ECM) to control the amount of fuel injected into the cylinders. A solenoid on each injector receives voltage signals from the ECM to become energized. The injectors will inject fuel only while the injector solenoid is energized.
The ECM controls the amount of fuel that is injected by varying the signals that are sent to the injectors. By controlling the timing and the duration of the voltage signal, the ECM can control injection timing and the amount of fuel that is injected.

Common Rail Fuel System

Unlike the MEUI fuel system, in a common rail fuel system injection pressure is created external to the unit injectors in a high-pressure fuel pump which is driven off the engine. The pump pressurizes a highpressure fuel manifold that runs along both sides of the engine feeding high pressure fuel to the injectors. The electronic fuel injectors at each cylinder control the delivery and timing of the fuel injection(s). Similar to some other systems, the common rail fuel system has capability of multiple injections for a given combustion event.
The main components of a common rail system include the high-pressure pump, the highpressure lines and rail system, and the injectors. The low-pressure fuel system utilizes similar components to the unit injector fuel system. The common rail fuel system does not continually circulate fuel through the entire system like the unit injector fuel system. Instead, small amounts of fuel are bypassed during the injection event. Due to the very high pressure in the fuel manifold, more heat is put into the fuel than on previous systems. Because of the additional heat added to the fuel, it is critical that the fuel inlet temperature is maintained within guidelines provided for the engine model. Recommended, and sometimes required, is the use of a fuel cooler to maintain the appropriate inlet fuel temperature. Otherwise, the overheated fuel will have very low viscosity and film strength which makes the fuel system components, especially the injectors, more susceptible to damage from fuel contaminants and wear, hence the importance of proper filtration practices on common rail engines.

FUEL INJECTION

The performance of diesel engines is heavily influenced by their injection system design. In fact, the most notable advances achieved in diesel engines resulted directly from superior fuel injection system designs. While the main purpose of the system is to deliver fuel to the cylinders of a diesel engine, it is how that fuel is delivered that makes the difference in engine performance, emissions, and noise characteristics. Unlike its spark-ignited engine counterpart, the diesel injection system delivers fuel under extremely high injection pressures. This aspect implies that the system component designs and materials should be selected to withstand higher stresses, while still performing for extended durations matching the engine’s durability targets. Greater manufacturing precision and tight tolerances are also required for the system efficient function. In addition to expensive materials and manufacturing costs, diesel injection systems are characterized by more intricate control requirements. All these features add up to a system whose cost may represent as much as 30% of the total cost of the engine.

COMBUSTION

In diesel engines, fuel is injected into the engine cylinder near the end of the compression stroke. During a phase known as ignition delay, the fuel spray atomizes into small droplets, vaporizes, and mixes with air. As the piston continues to move closer to top dead center, the mixture temperature reaches the fuel's ignition point, causing instantaneous ignition of some pre-mixed quantity of fuel and air. The balance of fuel that had not participated in premixed combustion is consumed in the rate-controlled combustion phase, also known as diffusion combustion

The interface between the fuel injection system and the combustion process is in the form of a fuel spray. In fact, it could be said that the complication and sophistication of the control of the fuel injection system is mainly for the purpose of delivering a proper spray into the cylinder. The component responsible for delivering the fuel spray is the injector nozzle. The spray is formed with the help of a differential pressure across its spray holes. The fuel is broken into droplets of different sizes and concentrations in the spray. The combustion process depends a great deal on the development of the spray from the start of injection, even before the spray is fully developed. The behavior of that spray is very important to the combustible mixture formation and start of ignition. In addition, the behavior of the spray after the end of injection and fuel cut-off is very critical for the emissions formation.

HEUI FUEL SYSTEM

Advanced technology yields higher performance

The HEUI (Hydraulically Actuated Electronically Controlled Unit Injector) Fuel System represents one of the most significant innovations in diesel engine technology in decades. HEUI surpasses many of the limitations of mechanical and conventional electronic injectors, and sets new standards for fuel efficiency, reliability and emission control. Available as standard equipment on an ever-widening range of Caterpillar engines and machines, the highly sophisticated HEUI system uses hydraulic energy instead of mechanical energy to operate fuel injectors. Working in tandem with the engine's ECM (Electronic Control Module), the HEUI system provides extremely precise control of fuel metering and timing, resulting in unmatched engine performance and economy.

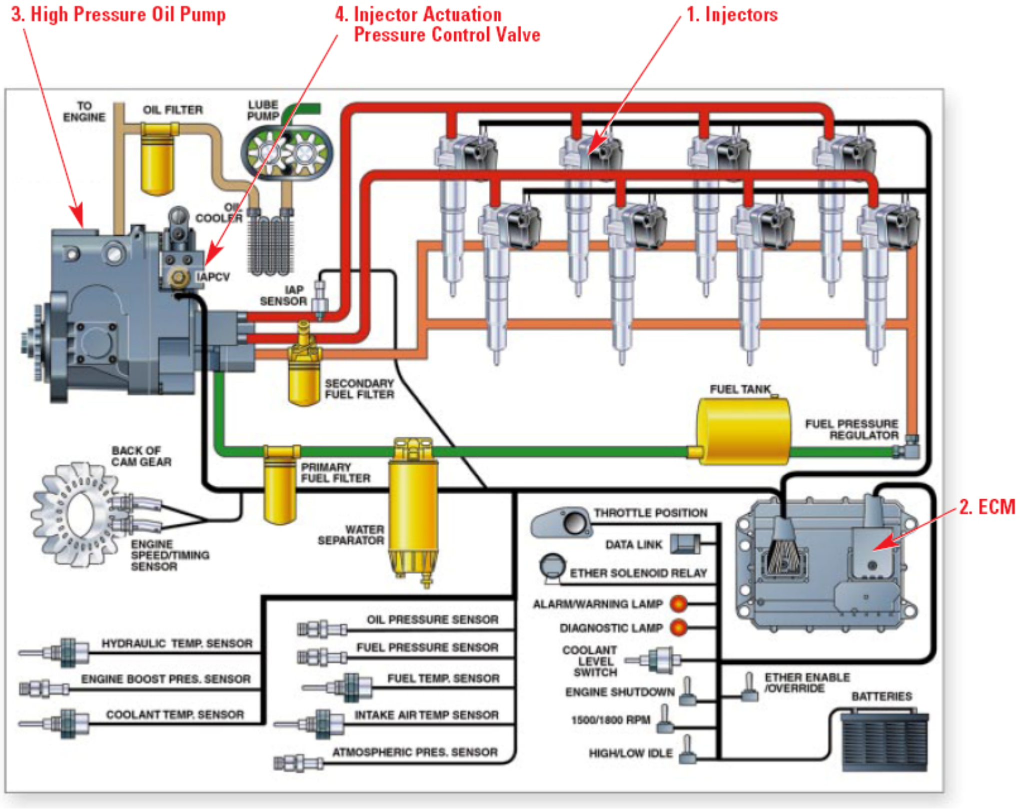
Meeting the demand for lower emissions, better fuel economy and higher performance.

HEUI injector technology is changing the way equipment owners, technicians and operators think about diesel engine performance. HEUI performance surpasses mechanical unit injectors and conventional electronic unit injectors, bringing new value to your investment in engines and machines.

Precise injection pressure at any engine speed

In the traditional common rail fuel system, the entire fuel line is under high pressure. With the HEUI system, fuel remains at low pressure until it is injected into the cylinder. Fuel pressure is created hydraulically in response to a signal from the Electronic Control Module (ECM). HEUI controls injection pressure electronically. This unique capability means the regulation of injection pressure is completely independent of crankshaft speed. Peak injection pressure can be achieved under acceleration and lug conditions, providing better fuel economy, better response and reduced smoke.

A close look at the HEUI System



The HEUI fuel system consists of four basic components:
Four basic components work together to bring precision, reliability and simplified maintenance to the HEUI fuel system.

1. HEUI Injector Uses hydraulic energy (as opposed to mechanical energy from the engine camshaft) from pressurized engine lube oil for injection. The pressure of the incoming oil (800 to 3300 psi) controls the rate of injection, while the amount of fuel injected is determined by the ECM.

2. Electronic Control Module (ECM)

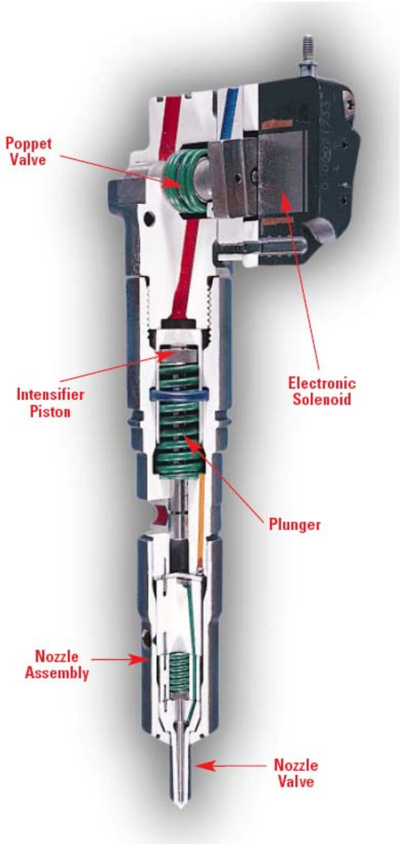
This sophisticated on-board computer precisely manages fuel injection and other engine systems. The HEUI injector solenoid is energized by an electronic signal generated in the ECM. Using input from multiple
sensors, the ECM's dual microprocessors use proprietary software and customersupplied performance parameters to produce maximum engine performance under any conditions.

3. High Pressure Oil Pump (Hydraulic Pump)

The variable displacement axial pump features a built-in reservoir to immediately supply oil at cold starts.

4. Injector Actuation Pressure Control Valve (JAPCV)

This electronically operated valve controls oil pump output and injection pressure



HEUI brings new value to your engine and equipment investment.
Engines equipped with HEUI injectors have outstanding response and improved high altitude operation. The ability to inject fuel at any crank angle results in up to 2.7 percent better fuel economy compared to scroll mechanical injectors. Optimum fuel economy also means reduced gaseous emissions and less white smoke during cold engine starts.
The control of fuel delivered during ignition delay and main injection, known as rate shaping, is made possible by the HEUI's ability to operate independent of engine speed. Rate shaping modifies engine heat release characteristics, which also helps reduce emission and noise levels. Rate shaping optimizes engine performance by varying the idle and light load rate characteristics independent of rated and high load conditions.

Since the HEUI injector's performance does not depend on engine speed, it can maintain high injection pressures through a wide operating range. Electronic control of these pressures helps improve emissions and low-speed engine response.
A split injection feature leads to a more controlled fuel burn and lower noise levels. Additional benefits include reduced shock loads as well as less wear and tear on drive train components.

CONTAMINATION

Stop Contamination before it stops you
Contaminants can be as abrasive as the materials used to machine parts in the manufacturing process, so it's important to remove as many contaminants as possible before the fuel reaches critical components. Fuel system contaminants are known to cause premature injector wear, reduce component life, reduce performance and cause sudden injector seizure. Abrasive contaminants of only 5-10 microns and larger can damage injectors by breaking down the fluid film between moving parts and eventually scratching injector plungers and barrels, causing metal-to-metal contact and injector seizure. As little as one spoonful of dirt in a tank of unfiltered fuel can ruin a fuel injector in less than eight hours.

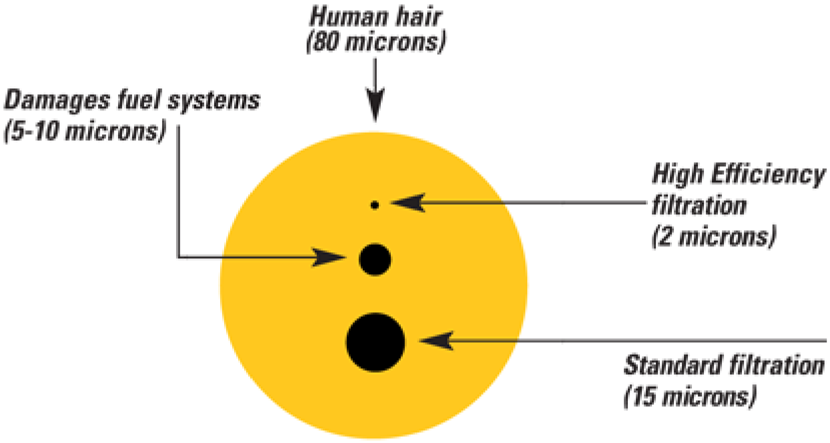
Contamination control is increasingly important for maximizing importance and service life in fuel systems. Some Cat fuel systems exceed pressures of 30.000 psi in order to deliver more horsepower, better fuel economy and fewer emissions. This necessitates tolerances smaller than five microns between parts. These tolerances and injection pressures make fuel systmes more vulnerable to wear and abrasion.

- Injector Nozzles – Contaminants move quickly in high-pressure systems, causing damage, eroding ofirices and resulting in incomplete atomization of fuel and overfueling. This harms performance and fuel economy. Contaminants also result in hard starts and increased emissions. Larger contaminants can actually clog orifices.

- Injector Plungers and Barrels – Abrasive particles cause wear between an injector's plunger and barrel. Contaminants scuff metal surfaces, causing metal-to-metal contact and eventuel injector seizure.

- Control valves – Contaminants damage valves that control fuel pressures, eroding mating parts of the valves. This excessive wear causes leaks and eventuel loss of engine power.

Size of contamination
A particle five microns across can damage fuel systems. A micron is onmillionth of a meter. To give you an idea of how small that is, an average human hair is 80 microns in diameter. Tolerances in Caterpillar fuel injectors are 1/20th the diameter of a human hair. It's easy to understand how even small contaminations can damage today's fuel systems.



Sources of contamination

- In the fuel – contaminants can enter during storage or transportation of fuel. A reliable supplier, filtered dispensing and periodic sampling and testing assures consistent quality.
- During operaton – Airborne particles can be drawn into your fuel tank through the vent tube. A fuel tank vent can ingest dust when it is not properly sealed.
- External – Contamination can enter during maintenance and service, even when chaning filters.

Measuring Contamination
Contamination is measured by counting particles and reported by comparing those results to an International Standards Organization (ISO) code. This ISO standards refers to the number of particles in three different size categories contained in a one-milliliter sample. The first number refers to the number of particles that are greater than 4 microns, the second number refers to particles that are greater than 6 microns, and the third number refers to particles that are greater than 14 microns.

An ISO leverl of 18/15/13 would mean that a one-milliliter sample of fuel contains ISO Code 18 or between 1300-2500 particles greater than 4 microns, ISO code 15 or between 160-320 particles greater than 6 microns, and ISO code 13 or between 40-80 particles greater than 14 microns. If the contamination level is allowed to rise one ISO code, the amount of particles for that size will double.

Filtering contamination
The precision components in today's fuel systems require specially designed fuel filters. The critical component is a super-fine filtration media that removes more than 98 percent of particles 2 microns and larger. Quality filters feature:

- Maximum engine performance and fuel economy
- Reduced exposure to abrasives
- Reduced wear on injectors and pumps
- Fewer fuel system adjustments
- Easier starting
- Longer filter life

KEEP IT CLEAN, AND KEEP RUNNING AT PEAK EFFICIENCY

During storage and transfer of fuel

- Periodically drain and flush all fuel storage containers to remove any sediments.
- Maintain a regular schedule for draining machine fuel tanks: weekly for severely dusty conditions, every three months for normal conditions.

- Keep all fuel equipment clean.
- Maintain all hoses, gaskets and seals in your fuel storage and transfer equipment.
- Use line filters on all fuel transfer equipment.
- Never transfer fuel into open containers.
- Only purchase fuel from a reliable source, and demand periodic testing to ensure quality.
- Repair any fuel line leaks immediately.
- Keep fuel tank breathers open and functioning properly. Use an appropriate breather.
- Never operate a machine without the fuel cap.
- If a fuel cap does not seal properly, replace it immediately.

When changing filters

- Follow the recommended filter change schedule.
- Keep filters packed in their original box until they are installed.
- Never pre-fill a new filter — doing so allows some fuel to bypass the filter altogether.
- Maximize filtration protection by using fuel filters of good quality.

When performing engine service

- Clean debris from the engine compartment before removing filters and other fuel system components.
- On earthmoving equipment use a high pressure wash to blast built-up grime off the engine before "opening" the engine for repairs.
- Tightly cap or plug all openings during repairs, even if they are only needed for a few minutes.
- Clean reusable parts with solvents, using proper cleaning and drying methods.
- Keep new parts in their original package until needed.
- Never place components directly on the ground.
- Don't reuse seals, replace them.
- Perform routine inspection of fuel line connections from the tank to the fuel pump.

In case you have any questions concering fuel systems, contamination or fuel filters, please do not hesitate to contact Pon Power, phone: +31 (0)78-6 420 420.