Fuel Filtration

- Diesel
- Gasoline
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- Jet Fuel
# Fuel Filtration Index

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Chapter 1

HISTORY

Invention of Internal Combustion Engine

Fuel filtration was found to be necessary after both the spark ignition (gasoline) engine, invented by Dr. Nikolaus Otto in 1876, and the compression ignition (diesel) engine, invented by Rudolph Diesel in 1892 became practical sources of power for transportation.

Both types of internal combustion engines require the metering of fuel for speed, power, control, and pressure to deliver the fuel in a useable form to the combustion chambers of the engine cylinders. The metering systems and pressure source need to be kept free of dirt, water and abrasive particles for trouble free service.

Carburetor Filters

For about one hundred years, 1880 through about 1980, spark ignition (S.I.) engines relied on the simple carburetor which through the use of a venturi, creates a vacuum, drawing fuel through small orifice jets. Relatively coarse filtration was suitable to protect these jets. These filters, usually built into the carburetor were quite small in-line devices, measuring up to one inch in diameter and up to about two inches long. They lasted at least as long as the engine was under warranty and usually for the life of the engine.

Early diesel engine fuel systems were protected by felt or cloth type filters requiring replacement when choked with tars and gums. The first automotive filter was patented in 1923, followed by the first use of a paper media in the late 1930’s. For the last 50 to 60 years, diesel fuel filters have usually been made from specialty filter paper.
**Chapter 2**

**FUELS**

**Gasoline**

With the advent of gasoline/petrol fuel injection in the 1980’s, the fuel filter became more important. Spark Ignition (S.I.) fuel injection uses smaller orifices and the injectors have small clearances between their moving parts. The fuel is delivered from the injectors into the air intake manifold under pressure from a pump (normally at about 40 psi/270 kPa) located in the fuel tank. The injectors are electronically controlled to deliver the fuel in precisely measured amounts.

Filters for gasoline/petrol fuel injection require the retention of particles larger than 20 microns, and are larger than those for carburetors, generally ranging in diameter from 1.5 inches to 3.0 inches and lengths from 2 inches to 4 inches. They are usually mounted in the fuel line (similar to the one shown in Fig. 1).

Diesel Fuel

Filtration of diesel fuel has been a more critical requirement since the diesel became a prime source of power for mobile equipment in the early 1900’s. Since diesel fuel is subject to (and when dirty, the cause of) many more problems than gasoline/petrol, this manual will concentrate on diesel fuel, diesel fuel injection systems, diesel fuel filtration and separating water from diesel fuel.

Diesel engines have the unique capability to burn almost any type of oil that can be delivered to the point of combustion in the engine. Diesel fuel oil ranges from fuel as refined as kerosene and jet fuels, to fuel so thick it has to be heated to reduce the viscosity to be able to pump it to the point of injection.

The heavier, more viscous fuels are generally known as bunker fuels or Diesel #4, #5, and #6. Depending on their viscosities these fuels are used with very large and slow RPM engines such as in ships and power stations, etc., and are beyond the scope of this manual.

**Automotive Diesel Fuel Production**

Automotive diesel fuels are produced from petroleum stock known as paraffinic or naphthenic and come from different parts of the

**An ideal filter would:**
- Remove All Contaminants
- Have No Pressure Loss
- Never Need Cleaning
- Last Forever
- Take Up No Space
- Cost Nothing

*But, there is no such filter!*
world. The refining process produces diesel fuel to a specification designed for fuel injection from these various sources of crude oil. Even though the fuels produced are similar, there are some differences which result in different oxidation rates.

Differences in the crude stock require different treatments for the crude petroleum to meet Federal requirements as to the percentage content of sulfur and volatile aromatics. These treatments can reduce the lubricity and increase the oxidation rate of the fuel. Oxidation of diesel fuel results in the formation of soft particles of asphalt and other gums. These particles are not usually visible, but are in molecular form until they are adsorbed onto the filter media, or until they agglomerate and settle out in fuel tanks as “sludge.” When fuel tanks are nearly empty and are refilled, this sludge is stirred up and remains in suspension for a couple of days — slowly resettling to the bottom of the tank.

This asphaltic contamination of the fuel is a “nuisance” contaminant and will be covered in detail in the section on “Fuel Contamination” (starting on page 22).

Number 2 diesel fuel is known as a “dirty fuel” in contrast to gasoline, kerosene or jet fuels. Due to its higher viscosity and lower surface tension, it tends to hold contaminants in suspension much longer. The contaminants must be removed from diesel fuel before it reaches the pumping system of the engine if trouble-free operation and long engine life are to be obtained. These contaminants have many sources and some are more common than others. Some are naturally inherent in the fuel and are more of a nuisance rather than damaging. The nuisances, however, can shut the engine down until the problem cause is removed.

Diesel fuel is the major fuel for all mobile equipment in the U.S. except for the beloved passenger car, where gasoline is still king. The trucking industry is the largest user of diesel fuel in the transportation industry. The U.S. alone has four-million diesel powered trucks (Class 1 through Class 8) on the highways.
The paraffin contributes to the amount of BTU's (resulting in horsepower) that can be produced during combustion. It is also the paraffin, however, that when the fuel is below a given temperature, comes out of solution in crystals of various sizes and shapes which will choke or plug fuel filters.

Alternate Fuels and Their Filtration Requirements

Two Common Alternative Fuels (Gaseous & Alcohol Blended)

As of this publication date of 2000, there are two basic alternate fuels for transportation use, gaseous fuels and alcohol blended fuels.

The gaseous fuels are, compressed natural gas (CNG), liquid natural gas (LNG) and propane (LPG), which are all delivered to the point of combustion as a gas.

- **LNG and LPG are transported** from the storage tanks to the fuel control system in liquid form under pressure and are generally clean fuels.
- **CNG, however, requires a coalescing filter** to remove aerosols consisting of water and compressor lubrication oil.
- **CNG is stored on board vehicles** at a maximum pressure of 3,600 psi when the fuel tanks are full.
Because gaseous fuels do not contain substantial material that is adsorbed onto the filtration media nor significant amounts of hard particulates, the coalescing filters need only be large enough to retain the small amount of system debris and to meet an acceptable pressure drop for the volume of fuel being consumed (generally 30 to 80 cfm) in the combustion process. The housing, however, has to withstand the pressure of the fuel system which is very high. For safety purposes, most applications require CNG fuel filters and connections to have a four-to-one burst pressure – (14,400 psi). CNG is quite corrosive and filter housings should be made of stainless steel or anodized aluminum. LNG and LPG are stored at maximum pressures of 500 psi.

**Alcohol Based Fuels**

*(Ethanol & Methanol)*

Filtration for ethanol and methanol, if used as a supplement with diesel fuel, can use the same fuel filters best determined for the application as if it were straight diesel. Methanol is a highly corrosive fuel and fuel filter housings and headers should be made with stainless steel or anodized aluminum housings. Because of a number of handling and storage problems, methanol has lost favor as an alternate fuel.

Other types and blends are used in some areas in the U.S. and elsewhere where alcohols, such as ethanol, are blended with diesel fuel in amounts up to 20%.

The alcohol based fuels are blended with diesel fuel and gasoline for economic reasons.

**Biodiesel Fuel**

Biodiesel is becoming popular, but will generally be a local fuel dependant on supply. Because it is a “special fuel” and not transported and transferred from its source to point of use like diesel fuel, biodiesel fuel should be cleaner. Water is always a potential problem with higher viscosity fuels, and biodiesel fuel should be handled the same care as diesel fuel.

Rapeseed oil (a biodiesel fuel) is also becoming popular, especially in Europe. Typical Buna N rubber seals tend to swell excessively in rapeseed oil, but a special compound of Buna N or Viton solves the problem. Rapeseed oil has been found to cause early choking of fuel filters from a glycerin type substance that collects on the filter media fibers.

*Fig. 3 Aviation Mobile Fueler and Tank Filtration*
Aviation Fuels

Gasoline is used in light planes having Otto cycle engines. Kerosene and jet fuels known as JP4, through JP8, are used in jet engine and gas turbine engine applications. The greatest danger from contamination in aviation fuels is water, which must be removed before loading on board the aircraft.

One type of fuel filter is called a monitor and acts like a fuse, any water present is adsorbed and in the process shuts off fuel delivery.

Jet engine aircraft use vast quantities of fuel and the handling of the volume required for a given aircraft is such that flow rates during the transfer of the fuel are very high; 500 to over 1,000 gallons per minute. Filters used in aircraft fueling operations must have American Petroleum Institute (A.P.I.), or International Petroleum (I.P.) approvals. Racor has an extensive line of aviation fuel handling products.

The U.S. Military uses jet fuel in many areas due to its abundance for aircraft.

Racor
American Petroleum Institute (A. P. I.) Fuel Filter Coalescer
Chapter 3

FUEL APPLICATION PURPOSES

There are six major application purposes for diesel fuel filters (included in this list is gasoline for light duty marine use where water contamination is similar to diesel applications):

1. Trucks and Buses
   • Heavy duty engines with 6.0 liter and higher liter displacements

2. Marine
   • Pleasure Yachts and Workboats
   • Gasoline/Petrol Powered Outboard and Inboard Pleasure Craft

3. Domestic Transportation
   • Light Trucks and Passenger Cars

4. Off Highway
   • Agriculture and Industrial
   • Railway Locomotives

5. Stationary
   • Electric Power Generation
   • Irrigation Pumps, etc.

6. Heating & Storage
   • Oil Burners and Storage Tanks

Major Fuel Related Problems
There are several common but major fuel related problems encountered in all of these areas of use, they are: fuel oxidation, water and dirt. Other situations peculiar to some of these applications that have the potential to create problems include, air in the fuel, high system pressures, and high or low temperatures.

Marine Fuel Problems
The marine use of diesel power is divided between large pleasure craft and commercial workboats. Diesel powered vessels have many of the same fuel problems as those in mobile applications. Gasoline powered boats generally have only one fuel problem which is water. Filtration requirements for marine gasoline applications, however, pose another more critical consideration — safety.

All of these noted applications have the need for water-free fuel, and freedom from particulate contamination varying from 2 to 300 micron size range.

The differences in the filtration and water separating requirements for these applications have to do with:

- Fuel Filter Location
- Fuel System Pressures
- Fuel Consumption Rates
- Total Flow Rates
- Type of Fuel Injection Equipment

While each of these applications have similar requirements for fuel handling and filtration there are some important differences as well. Each of these situations are covered in detail in the sections on “Fuel Contamination,” “Water Separation” and “Diesel Fuel Systems.”
Chapter 4

FUEL SYSTEMS

The fuel systems employed in the first five purpose applications mentioned in the previous section use several basic systems to deliver the required amount of atomized fuel to the combustion chamber of the engine. They all require two pumping actions: a transfer pump to move the fuel from the fuel tank to the high pressure pumping mechanism, and the other to produce a very high pressure to force the fuel through very small orifices in the engine's fuel injection nozzles; (See Fig. 4). The atomized fine spray of fuel will then burn readily in the engine.

Higher injection pressures produce finer atomization resulting in more efficient burning of the fuel. Transfer pump pressures generally range from 5 to 120 psi depending on the requirements of the system. The high pressures created by the injection system generally range from 2,000 psi (older systems) to 25,000 psi (new common rail systems), and will become higher as technology develops to produce it. Both the transfer pump and injection pump require protection from abrasive dirt and water.

Transfer Pumps – Also Called Lift Pumps – Diaphragm Type

Transfer pumps on some smaller diesels are often of a diaphragm type. They are engine camshaft operated and, therefore, the output is speed dependent (Fig 5). They are, however, designed to produce a constant pressure of 5 to 7 psi, regardless of engine speed.

The areas requiring protection in diaphragm pumps are the inlet and outlet valves. If these become fouled by dirt, lint, etc., the pumping action is defeated. A cleanliness level of 150 to 300 micrometers is required to protect the valves.
Transfer Pumps – Piston Type

A piston pump is a positive displacement pump – each stroke of the piston causes a displacement of fuel. The areas requiring protection are the piston seal, its bore, and the inlet and outlet valves.

Some in-line fuel injection pumps have an integral manual piston type priming pump. These are basically the same as those that will be described under priming pumps except that they are mechanically driven by the engine. Filtration requirements usually call for preventing particles in the 150 to 300 micron size range from reaching the transfer pump. (Figure 6) shows a typical piston type pump as part of a fuel injection pump.

Rotary type fuel injection pumps have an integral transfer pump and are generally known as “vane” types, which are positive displacement pumps and have no valves.

Transfer Pumps – Gear Type

Many larger diesel engines employ gear-type pumps to transfer fuel. Gear pumps usually have only an inlet valve, which is primarily used to prevent the fuel in the pump and fuel lines from “leaking down” and allowing air to take its place. They are often used when the fuel injection system requires a very high (60-120 psi) charging pressure, or very high flow rates.

Filtration protection from particles in the 20 to 150 micron size range is required to prevent wear damage to the gears and from fouling the inlet valve.
One problem with gear pumps is that manual priming of the fuel system downstream of the gear pump cannot be done, unless a fuel line with a check valve is provided to allow priming fuel to bypass the pump as shown in (Fig. 7). Gear pump output volume is speed dependent. Figure 8 shows the gear arrangement to create a liquid transfer.

Electric fuel pumps have never been placed directly in diesel fuel tanks in the U.S.A., as is done in automobile gasoline fuel tanks. The vapor in gasoline fuel tanks is always so rich that it prevents oxygen from being present to cause an explosion if a spark occurs. In diesel fuel tanks, however, there can be a volatile mixture of oxygen and fuel vapor. This explosive atmosphere can result in an explosion from a spark or an electrical short circuit caused by a vehicle accident (some diesel vehicles in Europe, however, do have electric pumps in their fuel tanks).

Most electric pumps usually are designed with relief valves or pressure regulators to control pressures between 15 & 60 psi. In this pressure range, the volumetric output of typical electric fuel pumps is between 40 & 60 gph (160 & 240 lph). Some fuel filters have an integral regulator to control transfer pump pressure when required for the new common rail injection systems.

**Fuel Filter Priming Pumps**

**Manual Type**

The purpose of priming pumps is to permit the recharging of the fuel lines and filters after replacing a filter element or after fuel exhaustion ("running out of fuel").

These are often referred to as hand primers because the operator’s hand is involved in the pumping action. These are generally of two basic types, piston and diaphragm. They are discussed in this manual because some fuel filters have integral priming pumps.
There are several important things to consider when planning the use of a priming pump. To completely prime the fuel system with fuel and purge it of any air, it is necessary to pump the fuel through the “gallery” of in-line pumps, common rail and unit injector systems.

In some systems, there is a pressure relief valve at the end of the gallery to maintain a given pressure of about 35 psi. A priming pump must be able to overcome this relief valve pressure setting to move the fuel through the system. Other fuel injection systems have only an orifice to control this pressure during engine operation and there is no problem in pumping fuel through it.

If a gear type transfer pump exists between the priming pump and the secondary fuel filter, priming of the secondary filter requires a bypass valve and fuel line around the gear pump. The bypass valve is simply a check valve to prevent the transfer pump from bypassing fuel back to its inlet during engine operation (Fig 7). Racor’s Series 400 fuel filters include models with a bypass valve to allow sending fuel around a gear type transfer pump.

A major consideration is the pressure drop that is created by the valves and passage ways in the priming pump. If the plumbing circuit plans to have the priming pump in line with the fuel flow during engine operation, the porting and valves have to be large and free flowing with minimal spring force employed in the pump valve springs.

Some priming pumps have a mechanical lock-out feature that diverts the flow around the priming pump during engine operation. Racor’s series 200 and 400 filters have a unique arrangement using a patented bypass valve that automatically diverts the fuel around the priming pump during engine operation.

Another matter to consider is the need to protect the priming pump valves from dirt which can make them useless. Ideally, the priming pumps should be on the clean side of a filter or have screen protection, and/or have valves which by design will not catch dirt or debris.

### Priming Pumps

**Piston Type**

Piston type priming pumps have the advantage of creating higher pressure because the diameter of the piston is usually considerably smaller than a diaphragm pump. However, smaller pistons, often require a greater number of pumping strokes to displace or move an adequate volume of fuel. (See Fig. 9 and 9A.)

When these primers are part of the filter assembly, the volume of fuel per stroke is generally 10 to 20 cc. There are piston pumps designed for diesel fuel systems that can pump much larger volumes per stroke, but they are usually separate devices located elsewhere in the fuel system. Some require push and pull action for each stroke, others have a spring to return the piston.
Priming Pumps
Diaphragm Type

Diaphragm type priming pumps, on the other hand, use a smaller stroke, but are usually limited to pumping pressures under 15 psi. This is due to the increased resistance because of the larger area of the diaphragm (Fig. 10). They generally have displacement volumes of about 15 cc per stroke. All diaphragm pumps have a spring return.
**FUEL INJECTION SYSTEMS (FIS)**

**IN-LINE PUMPS**

The four basic injection systems are:

- In-line Pumps
- Unit Injectors, Mechanical, Electronic, Hydraulic and Unit Pump (UPLN)
- Distributor Pumps
- HPCR (High Pressure Common Rail)

The in-line type of pumps were the first to be commercially available and are still plentiful. In-line pumps contain pumping plungers, one for each cylinder, and an engine-driven cam shaft as seen in **Fig. 11**. Each plunger has a port that allows fuel under pressure from a transfer pump to enter each individual pumping chamber when the cam is down (**Fig. 12 A on next page**).

As the cam moves the plunger up, the inlet port to the pump chamber is closed off and the plunger pressurizes the fuel in the chamber and pushes it out through a fuel line leading to a nozzle (injector) in the engine cylinder.

The pressure generated by the cam pushing against the plunger is between 5,000 and 10,000 psi, depending on the particular system. The metered amounts of fuel under this pressure travel in a high pressure wave through a fuel line (pipe) to each cylinder. The pressure opens a spring-loaded valve in the nozzle (injector) (**See Fig. 13**) and the fuel is delivered into the combustion chamber in an atomized spray.
The throttle/governor controls the amount of fuel required by rotating the plungers via a rack and pinion. Each plunger has a helical groove so that the pumping stroke travels, more or less, before the helical groove coincides with a port or passageway that allows the excess, fuel to “spill” (See Fig. 12-D & E).

The pumping stroke is always constant. The rack, which rotates the pinion, is controlled by the throttle or governor position. The spill port passageway leads to the same inlet fuel line as the source from the transfer pump. This excess fuel that is spilled at the end of the metered delivery can cause another pressure wave to travel back through the inlet fuel line.

Problems Caused By Shock Waves

These waves while much lower in pressure, can create spikes of 100 to 300 psi at the rate of, one for each cylinder, times half the engine speed (for a four stroke engine). A six cylinder engine at 2000 rpm generates 6000 injections per minute.

All fuel injection systems that control the required amount of fuel by spilling the excess at the end of the fuel delivery create a shock wave that moves backward to the filter and which can cause problems with filtration (See Page 20).

Mechanical Unit Injectors

Unit injectors (Fig. 14) are individual high pressure pumps and nozzles all in one.
There is one for each cylinder and they are located in the engine cylinder head. These are classified as mechanical unit injectors because the pumping plunger is activated by an engine camshaft. The fuel delivery and metering is similar to that of the “in-line” injection pump. In a simple mechanical unit injector, the fuel metering control is via a rack and pinion arrangement. The throttle controls the rack position and the pinion rotates the plunger with its helical fuel control groove.

**EUI Electronic Unit Injector**

Newer types use an electrical solenoid valve, activated by electronic sensors, to control the fuel metering instead of rotating the plungers. When the required amount of fuel that has been called for by the throttle position has been delivered to the cylinder, the solenoid valve opens and spills the unwanted fuel that is being delivered to the cylinder into the inlet line from the transfer pump. This system is known as an EUI (electronic unit injector). The pressure to open the valve in the injector tip or “nozzle” for both of these type unit injectors is provided mechanically through a cam shaft in the cylinder head which is part of the engine **(Fig. 15).**

Another very high pressure version of a unit injector system is the unit pump, fuel line and nozzle, (UPLN) as shown on **(Fig. 19) on page 18.**
Each injector (nozzle) is pressurized by its own individual pump which is cam shaft actuated. These systems can create injection pressures up to 30,000 psi.

**HEUI Hydraulic Electronic Unit Injector**

Another recent development is the HEUI (hydraulic electronic unit injector) system where the electronics are similar but the force to activate the plunger is hydraulic, as shown in *(Fig. 16)*. It is capable of delivering fuel into the combustion chamber at pressures greater than 20,000 psi. A new variation of this system uses a piezo crystal to take the place of the control solenoid.

**HPCR (High Pressure Common Rail Systems)**

The latest fuel injection system (FIS) is the common rail system in which the pumping pressure is supplied by a single high pressure pump *(Fig. 18)*. The metering & timing is controlled by the electronic unit injector (E.U.I.). These systems are capable of pressurizing the fuel to 25,000 psi and higher. This system is unique in that the fuel rail that supplies the fuel to the injectors is common to them all and has constant high pressure in it, waiting for each injector to open. This system while allowing such high pressure to be available, requires extremely clean fuel. If the injector valve and/or valve seat becomes damaged through wear, the pressurized fuel could leak or spill into the cylinder during the time between planned injections. This could result in catastrophic engine damage and at the least, unacceptable performance. HPCR systems also require a very efficient transfer pump.

If trouble is encountered under hot fuel conditions due to faulty transfer pump operation, an excellent solution would be to install an RFCM *(Racor Fuel Conditioning Module)*. The RFCM is a fuel filter/water separator that has a built-in electric fuel pump. *(See Fig. 17.)*
Distributor Type Injection Pumps

Distributor or Rotary Fuel Injection Pump

The third fuel injection system is the distributor or rotary fuel injection pump. (See Fig. 20 for typical styles.) This type of injection system is quite different than the first two. One of the major differences is that the required transfer pump is integral with the injection pump. The transfer pump portion consists of vanes which rotate in an eccentric cam ring, sliding back and forth as they follow its surface. Being a positive displacement pump it does not have inlet or outlet valves.

Inlet Metering and Spill Metering

There are two basic designs - inlet metering and spill metering. The inlet metering pumps have a rotor which has two or four opposing plungers in a radial arrangement. The plungers are charged with fuel by the transfer pump which forces them outwards, and then a master cam ring squeezes them together. The cam has a lobe for each cylinder of the engine. As the rotor carrying the plungers rotates, the plungers are forced in by opposing lobes of the cam ring to produce the high delivery pressure. As the master cam begins to force the plungers in, the rotor carrying the plungers has rotated to a position where a passageway from the plungers is lining up with a port that leads to an engine cylinder nozzle. After the fuel has been injected, the plungers are forced back out by a fresh charge of new fuel from the transfer pump. This recharging takes place while the rotor is revolving to the next cam position.
Differences of Inlet Metering Over Others

One of the main differences in the inlet metering distributor pump over most all of the others is that the fuel is metered before it is fed to the high pressure pumping plunger and there is no dumping of high pressure fuel at the end of the pumping stroke.

Spill Port Metering

The other type of distributor pump uses spill port metering that tends to produce the same spill back pressure spikes as other spill port metering systems. It has a single pumping plunger arranged axially with the drive shaft of the pump, and creates high pressure by lobes on a face cam (Fig. 21). The plunger is rotated by a drive shaft and pumping & distribution of the fuel is similar to the inlet metered rotary pump.
Clean Fuel Requirement

Because of the high pressures generated by all fuel injection systems, elastomeric seals are not possible and the internal sealing of the high pressure must be accomplished by the closely fitted components in the injection pump and nozzle. These clearances between the various moving parts of the high pressure pump and injector are about 40 to 60 millionths of an inch (1 to 1½ microns).

It is obvious then, that the need for abrasive particulate filtration is critical, however, there are different requirements for the three systems. As injection pressures become higher to provide lower emissions from combustion, filtration becomes more critical. The in-line pumps are the least sensitive to contamination, but still require efficient filtration down to the 10-15 micron particle size range.

Filtration Requirements

♦ Mechanical and E.U.I. unit injectors require filtration down to the 8 to 12 micron size range.
♦ The HEUI and distributor pump systems require filtration in the 4 to 7 micrometer size range.
♦ Common rail systems (HPCR) require the most critical filtration and for most applications require filtration to 2-4 micrometer particles.

The very high pressures in an HPCR system are constant in the injectors and if an injector valve or valve seat becomes damaged or the valve sticks open, excess fuel will feed continuously into the engine cylinder and a catastrophic engine failure may occur.

Filtration Requirements for Distributor Pumps

In distributor pumps, the rotor that distributes the fuel has a very high surface speed and abrasive particles can cause the rotor to seize in the closely fitted bore where the clearance is about one micron. In contrast, the reciprocating plungers of the in-line or unit injector systems are not rotating, but oscillate in a straight line and at a slower velocity.

Other differences are that:

♦ The distributor pump contains not only the high pressure pumping elements, and the metering valves, but also a governor and automatic timing of injection.
• The advance/retard timing mechanism is operated hydraulically through the action of pistons, check valves, and pressure regulating valves.

• The total pump is lubricated by diesel fuel.

Cause of Damage
If water and debris enter the fuel injection pump with the fuel they tend to find their way into the areas where corrosion and wear cause significant damage; particles can also jam the somewhat delicate controls rendering the sophisticated pump inoperable.

The Effects of Engine Vibration on Fuel Filter Efficiency
As mentioned earlier, the spilling of the excess pressurized fuel causes reverse pressure waves in the fuel inlet line. These pressure waves can reduce the effect of the fuel filter to retain the captured particles, especially those smaller than 12 microns. The same release of dirt particles can result from engine vibration with filters mounted directly to the engine. The difference between filters in resisting this effect is tremendous. High quality filter medium has excellent resistance to these pressure waves compared to common filtration medium as expressed in Figs. 22 & 23.

High frequency vibrations or high velocity fluid shock waves can disrupt the filtration mechanics of the filter medium. Particles are dislodged from their attachment to the fibers of the filter medium (filter paper) and they then pass unhindered into the fuel injection system.
Effects of vibration can be successfully negated by using high quality media containing glass fibers.

Figure 22 shows the effect on filter efficiency by engine vibration on a number of different filters that were tested to SAE and ISO test methods (laboratory) in contrast with the same filters with the efficiency measured while on engines. These filters in this comparison test contained filter media made using only cellulose fibers.

Figure 23 shows the same tests made on three different filters of which the media contained microglass fibers. The effect on filtration is seen in the much lower transmission of particles in the 6-12 micron size range.

In applications where the diesel engine must operate in extremely dusty conditions (earth moving and agriculture), the secondary fuel filter should be mounted on the vehicle frame or chassis. Frame mounted installation will allow the use of 10 micron media instead of 2 micron which will provide a much longer service life.
Chapter 5

FUEL CONTAMINATION

Particulates

Diesel fuel contaminants include abrasive dust, water droplets, rust and organic materials such as lint and field dust. Particles of grass and leaves, etc., are an added contamination factor in agriculture and earth moving environments. Common dust is composed of 98% by weight of silica or quartz which is very abrasive. Abrasive particles can cause damage as indicated in the previous sections on transfer pumps and fuel injection systems.

The most damaging particles for most injection systems, excluding high pressure ones (10-20 bar) are in the 5 to 15 micron particle size, even though the critical clearances are between one and three microns. The reason for this is that while the edges of the metering ports and grooves appear sharp, they are actually slightly bellmouthed. Particles of quartz that are 10 or 20 microns in size can get trapped in these areas and as the operating pressure drives them into the clearance spaces they break down and are ground smaller (one 10 micron cube shaped particle contains the equivalent of 1000 one micron particles) (See Fig. 24). If the sharp edges of the plungers or metering ports become worn, the fuel delivery characteristics will change.

Without any filtration taking place, it is possible that some particles that measure in thousandths of an inch (.006 or 150 microns and above) could actually block an orifice in an injector tip. The holes through which the fuel is injected into the combustion chamber are very small and range between .006 and .009 inches in diameter (150 to 225 microns). Injector tips are currently under development that will result in holes of .004 (100 microns).
The most common damage from abrasive particles, however, is the scoring of the plungers of “in-line pumps and unit injectors and the rotors of distributor pumps.” The wearing of the blades (vanes), the internal cam rings (transfer pump and high pressure cam), control mechanisms and metering edges (See Fig. 26) of distributor pumps are other areas that are sensitive to wear and often the first place that wear damage will occur. The injector plungers or needle valves, valve seats, and tip orifices of the injectors (See Fig. 25) are yet another very sensitive area that need protection. Wear in either of these areas will lead to an inoperable condition, beginning with loss of performance.

Fuel Tank Breathers

All equipment used in off-road applications should have their fuel tanks equipped with breather filters. Air is drawn into the tanks as the fuel is used, as the fuel sloshes back and forth and as tanks cool at the end of the day.
Most off-road pieces of equipment operate in dust-laden air which allows abrasive dust to enter the tanks during this breathing process.

**Water Problems**

Water poses many of the same problems for fuel systems as it does for hydraulic and lubricating oil systems. A major distinction of fuel systems though, is that dissolved water is seldom a problem. But free water-in-fuel can cause problems not found in automotive lube oil systems.

**Condensation**

Water gets into diesel fuel from many sources and is the second most damaging contaminant encountered. Water that is a result of condensation occurs constantly, it is by itself pure, but is quickly contaminated by rust and microbes.

Water condensation can be reduced by filling storage and vehicle fuel tanks to the top as soon as possible after fuel usage. Most sources of larger quantities of water in fuel is the result of poor fuel handling and comes from rain or ground water, etc. (See Fig. 27). Fill caps are often left off the many different storage facilities that fuel passes through in route to an engine’s fuel supply tank. Washing operations are also a source of high concentrations of water in fuel tanks, either from cleaning of tankers, washing vehicles or pressure washing of engines, etc. Some storage practices call for putting water in fuel storage tanks for safety purposes so that if a leak occurs, the fluid escaping first is from the “water bottom.” In any case, water eventually finds its way into diesel engine fuel tanks.

The problems water creates are listed as follows:

1. Promotes corrosion of ferrous metals and die cast aluminum components in the fuel injection system. (See Fig. 26.)

![Fig. 27 Stored Fuel Can Be Contaminated By Many Sources](image)
2. Causes cavitation leading to nozzle tip failure.
3. Reduces lubricity, causing nozzle and pump plunger scoring.
4. Breeds microbial growth at the water/fuel interface which plugs filters.
5. Solid water (in large droplets or slugs) does not burn — causing poor engine performance.
6. When emulsified water freezes, the finely dispersed ice crystals will plug the filters or jam sensitive control mechanisms in the fuel injection system.
7. Shortens the useful life of filters by swelling the filter media.

Water Indicating Tests

There are two easy tests to find out if there is water in a fuel storage tank. A water-indicating paste can be smeared on the end of the stick used to check the fuel level in the tank. If water has collected at the bottom of the tank, the paste changes color due to water contact.

In the second test, a fuel sample collected in a clear glass jar can be examined for water and particle contamination. By holding the sample up to light, it will be cloudy if the water is emulsified. It may also reveal small microbe masses. When allowed to stand for a few hours, non-emulsified water in the fuel will settle to the bottom of the jar where it can be easily seen.

If water could be easily drained from fuel tanks, it might not pose so many problems, but automotive fuel tanks rarely have drain valves for safety reasons. Fuel systems for the transportation industry also do not allow the use of water absorption filters, (as in hydraulic applications), which would shut the engine down. It is better to have a damaged system than to shut down an on-highway engine at a critical time.
Emulsification

In the process of transferring fuel with water in it, there will be some degree of emulsification when pumping from the storage supply to a vehicle’s fuel tanks. Emulsification, however, is greater after the fuel and water go through the engine’s “transfer” pump. The shearing action of pumping churns or emulsifies the mixture and the large water droplets are dispersed as much smaller ones. High speed electric pumps tend to create a very high shearing action. These small droplets are in a random distribution of sizes from visible to submicron size. The return fuel carries these small droplets back to the fuel tank where they are fed back into the system to be sheared again.

Because the ratio of surface area to mass is greater as the water particles become smaller the gravitational effect is offset by increased buoyancy. This characteristic increases the tendency for emulsified water to remain suspended.

Water Settles to Bottom of Tank

Water will, however, generally settle to the bottom of a fuel storage tank, the larger droplets first, followed in time by the smaller ones -- some are so small, however, that they never settle out and can only be removed by filtration. Once water has collected in the fuel tank, microbes can soon begin to grow at the fuel/water interface (See Fig. 28).

Microbes in Fuel

The most common organism found at this interface is algae. Algae cells are always present in non-sterile water, and often find their way into fuel tanks during fueling operations. When conditions are right, some types of algae can double their population every 20 minutes. A layer up to 1/4 inch thick often can be found at the water/fuel interface.

When fuel contaminated with microbes and water enter the fuel tank, the microbes are soon pumped to every part of the fuel system. They can cling to most metal surfaces, trapping their acidic wastes and water against the metal. Corrosion increases at these sites, slime and sludge begin to appear throughout the fuel system.
The fuel may begin to smell like rotten eggs, which results from the formation of sulfur dioxide. If enough algae from a contaminated water/fuel interface enters a vehicle or boat fuel tank, it could cause rapid plugging of the fuel filter.

**Rusty Water (Iron Hydroxide)**

Fuel received from poorly maintained storage facilities (old tanks and barrels), found on farm and industrial sites or other off-road refueling facilities, often contains rusty water under the scientific name of iron hydroxide. When rusty water finds its way into fuel injection pumps, especially distributor types, severe corrosion will usually quickly result, affecting the critical control components, etc., and usually requiring fuel injection pump replacement *(See Fig. 29).*

**Fuel Tank Strainers**

All gasoline engine passenger car fuel tanks have a strainer *(Figs. 30 & 31)* as part of the fuel pickup unit also called the fuel tank module or sender. Most light duty diesel engine vehicles also have such strainers. The media typically used for light duty diesel fuel tank strainers are woven nylon or polyester meshes with ratings from 100 to 4,000 microns.

Even with these open weaves, "in-tank" filters, are subject to plugging from algae. These strainers are, however, part of the original vehicle equipment and so are outside the scope of this publication. Generally, heavy duty trucks, construction equipment and farm machinery do not come equipped with strainers in the fuel tanks. Adding a primary fuel filter to these fuel systems is critical to the protection of the complete fuel system.
Biocides

To prevent damage from algae, fuel storage tanks should be treated with a quality biocide. If the vehicle operator does not have control of the storage or supply facility then the vehicle fuel tank should be treated with biocide.

Racor provides a field tested biocide that has had proven success (Fig. 31). The best insurance to protect fuel injection systems from damage by water is to remove the water from an engine’s fuel supply system by installing water separators that are described in Chapter 14.
Chapter 6

NUISANCE CONTAMINANTS
(Air and Asphaltenes)

Nuisance contaminants are so called because they do not cause damage to the fuel injection equipment, but if not properly handled or understood will create various and severe engine performance problems.

Air

Air is a form of contamination, although not usually classified as such. When air is drawn into a diesel fuel system, deterioration of engine performance will follow and be somewhat proportional to the amount of air that reaches the fuel injection system. When enough air is present the injection pumping system will not be able to create enough pressure to open the injector nozzle valves and the engine will not run. Electronically controlled fuel injection systems may also sense slugs of air as "no fuel" and shut the engine down. The most common problems associated with air ingress are a rough running engine, loss of power or inability of the engine to start.

Air can leak in where fuel will not leak out. This simply results from the difference in viscosity of the two fluids. Damaged seals, fuel lines, porous castings, mismatched or cracked fittings, or housings are all sources of air ingestion. Air leaks on vacuum side systems are difficult to find because generally the source cannot be seen. The fuel filter and/or water separator itself can be inspected for the source of vacuum leaks by draining the unit of fuel, removing the assembly from its installation; plugging all openings and pressurizing it with air at about 5 to 10 psi and submerging the unit under clear fuel oil or water. The whole unit must be visible to be able to pinpoint the source of the leak.

Fig. 32
An Air Bleed Vent Can Be On Either The Dirty Side Or The Clean Side Of The Filter

Problems from air drawn into the filter can be averted by using a constant bleed orifice.

Diesel fuel filters clog from asphaltens, not dirt!
If a piece of clear fuel hose is substituted for the standard exit port fuel line of the filter as a “diagnostic tool,” care must be taken to avoid a possible false impression. Some air is naturally inherent in diesel fuel, but is normally invisible. At even the smallest vacuum conditions, however, this air may coalesce into visible bubbles as the fuel passes through filtration medium.

This air passing out of the filter with the fuel may be recognized as a tiny stream of very fine bubbles. If there is a steady stream of bubbles that appear to be larger than about one mm$^3$ (the size of the period in this text), they probably are from a leak point and should be further determined by a pressurized submersion test.

**On pressure side** installations, problems resulting from air that comes into the filter from conditions upstream of it, can be averted by using a constant bleed orifice. Located in the top of the filter head or housing, an air bleed vent can be connected to the fuel system return line *(Fig. 33)*. As any air enters the filter it will rise and collect in the highest point in the filter where it can be vented out and sent back to the fuel tank along with the small amount of fuel that will always be exiting this vent. The bleed vent can be located on either the clean or dirty side of the medium, *(Fig. 32)* but must be small enough to prevent loss of fuel supply to the injection system. An orifice up to about .040 (or 1.0 mm) is more than sufficient. If the air bleed vent is located on the clean side of the filter for a distributor type fuel injection pump, there must be a check valve installed in the line leading to the return so that if the filter begins to plug in service, the negative pressure between the clean side of the filter and the inlet to the pump, will not draw in air or dirty fuel from the fuel tank *(See Fig. 28)*.
Contamination and Filter Life

Unlike many other kinds of filters, diesel fuel filters do not generally plug from dirt but from another nuisance contaminant which is naturally present in diesel fuel. It has been called many names such as gum, varnish, resin, etc., but is really an asphaltic substance called asphaltene (or tar). On filters that have choked or plugged in service, a layer of dark brown or black material will generally be found coating the filter medium. This material precipitates out of the fuel and is adsorbed onto the filter medium fibers. It is generally molecular in size, and is in solution in the fuel. Asphaltene is the result of oxidation and while oxidation of all diesel fuel is enhanced by age and heat, some fuel stock is more prone to it than others.

All number 2 diesel fuel contains some asphaltene but the amount will vary with fuel from different sources. Most of the sludge that has settled on the bottom of storage tanks is asphaltene and when disturbed by refueling, the fuel can choke even a new filter very quickly. Number 1 diesel fuel or kerosene has much less of this asphaltene.

Even though most diesel fuel systems recirculate two to 15 times the amount of fuel that the engine uses, a diesel fuel filtration system must be considered a “single pass” system because all of the fuel eventually passes through the filter to the engine and is consumed.

*Diesel fuel filters generally do not choke from abrasive dust, which is what they are designed to stop.*

SAE Test Method For Capacity

The SAE J905 test method calls for measuring a filter’s capacity by determining how much dust the filter will capture before reaching a terminating pressure drop. Some fuel filters are rated as having a capacity of 100 to 300 or more grams of test dust. Average diesel fuel, however, only contains about five grams of dust per 1,000 gallons, and only under the worst conditions (earth moving or agriculture, etc. (Fig. 34) may contain 40 grams of dust per 1000 gallons. (Marine applications contain less than two grams of dust per 1,000 gallons.)

On the other hand, an SAE publication #720777 describes the true factors involved in diesel fuel filter life and a method to compare filters. The shortcomings of current SAE test methods and the effect of asphaltic choking are also described in this publication. While it is true that the primary cause for filter life termination is plugging with asphaltene, choking will occur more rapidly when significant amounts of dust are present in the fuel.
It has been clearly demonstrated in repeated tests, that the asphaltene is deposited on the fibers of the filter in its first pass through a filter (see Fig. 35). And, as mentioned, for this reason filter life is dependent on the amount of fuel consumed by the engine and not how many recirculated passes it makes. The asphaltene in the fuel coats the fibers that compose the filter medium until the space between them is closed.

Small tanks or large, the life of the filter is determined only by the amount of fuel consumed, and the flow rate (velocity). A high flow rate will create a more rapid pressure drop as the filter begins to choke from the asphaltene.

The surface area of small diameter fibers is greater in proportion to their diameter than large diameter fibers. Since many more small fibers can be contained in the same space than large fibers, they provide a greater total surface to be coated, which extends the time before the spaces are closed. This same principle of using small fibers to extend filter life is also true for increasing the filtration efficiency of the media. Racor’s AquaBloc® filter media is composed of various fine fibers.

Fig. 35
Asphaltene Collection on Filter Papers
Flowed In Series
Chapter 7

PARTICULATE FILTRATION

A proper understanding of the mechanism of filtration, especially as it relates to diesel fuel is necessary to appreciate these protective fuel filtration systems.

Purpose of Filter Media

Filter media is intended to stop harmful particles while letting fuel pass readily. The media must not create any more of a pressure drop than necessary in stopping the particles. Some time in the distant past, someone discovered that paper composed of fibers that were not pressed into a tight sheet could do this. The surprising thing is that most of the open spaces between the fibers are much larger than the particles that are being trapped. Research has shown that the filter paper does not necessarily only act as a screen or sieve. The particles moving through the fibers in the sheet of paper can be trapped in the small spaces created by the fibers close proximity to each other or/and impact the fibers and stick to them (Fig. 36). And while the particles touch the fibers by various means and/or forces, it is the theory of “Vanderwall’s Force” that holds them there; and different fibers of different material may have different holding powers. Put in layman’s language, the force to remove the particles is greater than that which caused them to stick there in the first place. But, sudden shocks such as high frequency vibration or fluid pressure shock waves can cause them to break free and pass through the filter.

Medium Sizes & Fiber Types

The more fibers there are in the cross section of filter paper, the more chance there is of every particle striking a fiber. The smaller the diameters of the fibers, the more there can be in a sheet of filter media.

A typical ordinary filter paper is about .020 inches (0.5 mm) thick and is composed of cotton and wood fibers. These coarse cellulose filter fibers are 30 to 50 microns (wood) in diameter. The finest natural cellulose fibers, however, are about 9 microns in diameter and come from Esparto grass. A paper made from these fibers could contain 16 times as many fibers in the same space as paper made from 40 micron diameter wood fibers. Micro glass fibers are the smallest that are generally available for filter paper and normally range from .5 to 4 microns in diameter and are generally mixed with cellulose fibers to create a high quality filter paper. A combination of microglass and other small diameter cellulose fibers make up Racor’s Aquabloc® media.

Fig. 36
Media Doesn’t Necessarily Act As A Screen
When To Replace A Filter & Micron Sizes

Chapter 7

It is obvious then that a filter medium made with a great percentage of fine fibers will have a higher efficiency in capturing particles.

**When to Replace A Fuel Filter**

Because the fibers of the filter paper for diesel fuel filtration become coated with asphaltene, the flow area eventually becomes occluded and the pressure differential across the media increases until the filter element must be replaced. If the media is of poor quality and contains a lot of non-uniform spacing between the fibers, the total flow area shifts to the larger spaces that have not been choked. With fewer fibers available for particles to attach themselves to, the efficiency goes down, because all the fuel must now pass through these larger openings carrying dirt/particles. High quality filtration media with a uniform distribution of the fibers will be able to maintain uniform efficiency during the life of the filter.

<table>
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<th>Inches</th>
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<td>.0003</td>
</tr>
<tr>
<td>Bacteria</td>
<td>2</td>
<td>.0001</td>
</tr>
</tbody>
</table>

**Relative Size of Particles**

Micrometer Scale

Particle sizes are generally measured on the micrometer scale. One micrometer (or “micron”) is one-millionth of one meter, or 39 millionths of an inch. The limit of human visibility is approximately 40 micrometers. The most damage-causing particles are smaller than 40 micrometers and cannot be seen by the unaided eye.
Chapter 8

PRIMARY FUEL FILTRATION

Purpose

Primary fuel filters play a very important role in the diesel fuel system. Their primary purpose is to protect the transfer pump and remove water contamination. Another purpose is to protect the secondary filter from much of the asphaltene carried by the fuel (Fig. 37).

The finer the level of filtration that the secondary filter is designed for, the more quickly it will choke from the asphaltene in the fuel. A properly specified primary filter will share the choking effect of asphaltene, thus allowing the secondary to be replaced less frequently.

If the secondary filter has a rating of two (2) microns, the primary filter should have a rating of (10) microns. If the secondary filter is rated at 10 microns, the primary should be 30. It is recommended that filters which combine water separation with the task of primary filtration be used instead of a simple primary filter.

It is desirable to choose a primary filter that will provide the lowest pressure drop or negative pressure at the outlet of the filter at rated flow when the filter element is new. No more than two inches of mercury (2”/hg) negative pressure should ever be allowed when a new primary filter is first installed.

Recently (1998), many engine and fuel injection system companies have begun to recommend that the fuel injection system be protected by a water separator. In fact, suppliers of common rail fuel injection systems demand that high efficiency water removal be part of the primary fuel system. The best value in meeting this demand is to install a primary filter that is designed to separate water on the suction side of the fuel system. Water separators are discussed in detail in Chapters 9 and 10.
Pressure Side Vs. Vacuum Side Fuel Filter

There is a growing trend by some engine and vehicle manufacturers to have a single fuel filter/water separator located before (upstream of) the transfer pump. The purpose is to reduce filtration and installation costs, etc.

If a single unit is specified for the suction side of the fuel system, the filter must be able to protect not only the transfer pump but the complete fuel injection system. The filter has to be much larger than when installing it on the pressure side of the transfer pump to prevent cavitation from restriction in the filter when the fuel is hot. The filter must be an effective water separator and have some means of fuel heating to handle cold fuel supplied from the fuel tank. A priming pump should also be included with the fuel filter.

In Europe, vacuum side filters are referred to as depression systems. They have been very common because of the popularity of distributor type fuel injection pumps which have the transfer pump built in.

Pressure drop through a fuel filter or water separator is a function of flow rate vs. the restriction of the flow path through the unit. The pressure drop on vacuum side installations is very critical due to the vaporization or boiling point of fuel.

Vapor or Fuel Starvation

Diesel fuel begins to vaporize at a negative pressure as low as 10 inches of mercury if the fuel is hot. Vapor in the fuel is related to the term “fuel starvation” and the lack of solid fuel will result in poor engine performance or actual engine shut down.

With the advent of the high pressure common rail fuel systems, the fuel recirculated to the tank can cause fuel tank temperatures to climb to over 200°F under some conditions. Racor’s 400 & 600 Series spin-on filters (Fig. 36) for primary or secondary use, have large ports with very low pressure drop for fuel flow rates up to 120 GPH.

The Turbine Series filters manufactured by Racor have very low pressure drops, and elements are installed from the top. (Fig. 47A & B & 48B). Racor’s designs of canister/cartridge filters are such that if fuel is added to fill the canister during element replacement, it is kept on the dirty side of the element so that there is no danger of dirt getting into the fuel injection system.

Racor has always had environmentally friendly cartridge filters available. These tend to be very user-friendly as well. Besides the Turbine Series and Model 110, TC and BC Models are also cartridge/canister type.

Racor provides a very unique and comprehensive product for primary or secondary filtration. The RFCM (Racor Fuel Conditioning Module) contains an electric fuel pump located in the center of the filter element (Fig. 17 on page 17). Filtration takes place on the inlet (vacuum) side of the electric fuel pump. Clean fuel is then delivered under pressure to the rest of the fuel system. This product eliminates many installation problems and fuel line connections.
Filtration Efficiency

Fuel filters are supplied for various applications and, therefore, there is a need for different levels of filtration efficiency in the removal or retention of particulates. The hydraulic industry uses a rating method that uses the term "Beta Ratio" to describe a filtration efficiency level. The diesel fuel filtration industry generally uses simple efficiency as the method of rating a fuel filter. Since there is no such thing as a fuel filter that provides absolute filtration of the particle sizes that are cause for concern, the industry uses terms like 96% @ 5 microns. This term means, that when tested to SAE or ISO test methods the filter will retain 96% of all 5 micron size and larger particles.

Racor makes filters with various filtration efficiencies, but its standards for non-OEM (Original Equipment Manufacturer) are 2, 10, and 30 micron filter elements. The actual efficiency ratings for these are 98%, 95%, 90%, respectively. Racor also makes extensive use of a 7 and 20 micron filter medium which are used to meet certain engine manufacturer's requirements for a final filter and a primary filter.

Racor's two micron filter medium should only be used in final or secondary filters where the fuel is first filtered by a primary filter. The primary filter for a two micron final filter should use a 10 micron medium. The exception in using two micron filter in a primary filter is to obtain high-efficiency water separation, and is usually used in marine applications where the fuel supply may be cleaner but also many contain water more often. If the installation can allow the use of a filter large enough, then a two micron filter can serve in a system at the only filter in that system.

The new high pressure common rail fuel injection systems require high efficiency in removal of small particles. The requirement is 95% for three micron particles. Racor fuel filters have a medium designed for these applications. Replacement elements should state, "For Use With Common Rail Fuel Injection Systems."

Dirt levels in fuel also direct the level of efficiency required. Since the filter removes a percentage of dirt particles, it follows that when a much greater amount of dirt is present in the fuel, a greater number of particles will pass through the filter. Diesel engines used in earth moving or agriculture should use fuel filters that have higher efficiency than those for over-the-road or marine use.

The planning must also take into consideration whether the filter is to be installed on the engine or the chassis and whether on the vacuum or pressure side of the system. Filter installations on the engine make the filter subject to high frequency vibrations which reduces the efficiency level, (as do spill port metering injection pumps). See page 20 "Effects of Engine Vibration."
Chapter 9

WATER REMOVAL

Operating Principles of Water Separators

This section covers the application of fuel filter/water separators typically used in protecting fuel system equipment for diesel engines. Some filter/separators discussed in this chapter can be used for either gasoline or diesel fuel systems. Others are intended for a specific type of fuel system. Fuel water separators primarily use three mechanisms for separating free water droplets from fuel. Some devices depend almost entirely on one mechanism for separation, while others may make use of all three which are settling, coalescing and barrier.

Gravity Sedimentation Separation

Diffuser or Primary Separator

Some water separators used on mobile equipment and marine vessels use a diffuser or primary separator to capture large water droplets. A diffuser reduces the velocity of the fuel stream, which allows the water droplets to settle and collect in a reservoir or bowl due to their higher density. This type of separator is effective only for suction side installations and for very low flow rates.

The process may be enhanced by imparting a rotary motion to the fuel stream within the reservoir thus supplementing normal gravitational forces with centrifugal force. In Racor's Turbine Series, fuel enters the center of a hollow conical element that has small flow passages shaped like turbine blades. These passages change the velocity and direction of the flow, slowing and imparting a swirling motion to the fluid.

This centrifugal action moves the larger water droplets and solid particles out of the flow stream allowing them to settle to the bottom of the bowl. And, when incorporated with a filter, a very high level of efficiency is obtained.

Some diffuser types use a cone shaped baffle that causes the fuel to flow outwards and downwards slowing the velocity of the water droplets in the fuel stream so they can fall out of the fuel stream (Fig. 39). These enhancements, however, are limited in effectiveness only with suction side filter applications where large droplets normally are found. Better efficiencies are possible with very large housings, but this is usually not practical.
Gravity Separators

Gravity type separators, however, have the advantage of being relatively insensitive to fuel additives and contaminants and remain relatively stable in efficiency unless the droplet size is altered dramatically. They generally require no servicing and usually function for the life of the system or equipment.

Coalescer Separation

Coalescing water to remove it is the action of causing small droplets to join together to form larger ones so gravity can cause the water droplets to fall out of the fuel stream.

Barrier type coalescers function through use of a hydrophobic (non-wettable) barrier to stop even very small water droplets. The hydrophobic action causes them to stop on the upstream side on the media surface and coalesce together into large droplets. In this case all the water droplets separated from the fuel stream drain off of the media on the upstream (inlet) side and collect in the filter’s reservoir (Fig. 41).

Barrier coalescers are relatively sensitive to low fuel temperatures (below 60° F) and also surfactant contaminants. Efficiency can be reduced dramatically at temperatures below 60°F (15°C), or after lengthy exposure to the normal asphaltenes found in fuel. Even short term exposure to any additive will reduce water separating efficiency. Quoted efficiency by most filter manufacturers are the result expected when new, and with fuel having no additives. In all cases they are highly dependent on the flow rate — a water separator should never be used in an application that has a higher total flow rate than the unit is rated for.

Suction Side Water Separators

Barrier type coalescers are usually quite efficient at separating the water droplets that are found on the suction side of the fuel system. Initial efficiencies of 99% are typical in suction side applications for these devices. If not so stated, barrier coalescers may be identified by examining the flow path through them because water separated from the fuel is designed to collect on the inlet or dirty side of the filter.
Generally barrier type separators contain only one stage of media.

Although filter medias with cellulose fiber and hydrophobic coatings are most commonly used in barrier coalescers, devices fabricated from hydrophobic textiles such as nylon and polyester also provide excellent water separation of large droplets on suction side applications. These materials can be readily formed into screens, bags or baffles.

Racor makes a water separator having a sock-shaped knit nylon fabric which resists plugging from solid contaminants and cold weather paraffin wax crystals. The knit structure allows the openings in the fabric to expand and pass the paraffin as the paraffin crystals begin to plug the fabric. In normal use (temperatures above freezing) the fabric provides a hydrophobic lattice that repels water droplets, and has a particulate filtration efficiency of 100 microns (Fig. 40).

**Pressure Side Water Separators**

Water separators used on the pressure side of fuel system transfer pumps, or filters used with high rpm fueling station transfer pumps, cannot rely on gravity alone to separate the small (five to ten microns) water droplets formed by these high shear pumps.

These droplets may take weeks to settle by gravity even in totally stationary fuel. Instead, pressure side water separators must rely on properly designed filter medium to coalesce these fine emulsions into large visible droplets that can separate rapidly by gravity.

**Barrier Type Coalescers** with a particle filtration rating at or below 10 microns also perform quite well in removing water droplets found on the pressure side of a fuel system. Racor’s 2 & 10 micron fuel filters do an excellent job in separating water on most pressure side applications. Efficiencies of 80% to 99% are not uncommon for such barrier coalescing media.
Media more open than 10 microns, however, has more difficulty separating emulsified water/fuel on pressure side systems and should not be used in these applications.

**Depth Type Coalescers**
(For Demanding Pressure Side Applications)

Depth type coalescers, are usually far more complex and function by an opposite mechanism. They often contain four or more stages of separation including a primary filter stage, a depth type coalescing medium, a release layer, and a final barrier medium. In this device the fibers in the media except the final barrier, are hydrophilic (wettable) and the water is allowed to penetrate the media, wet the fibers, and coalesce together in the depth of the medium. The water droplets are then released on the downstream side of the depth type medium for collection in a reservoir.

The final hydrophobic barrier stage acts as “the insurance policy” preventing any small droplets from being carried into the fuel flow stream. And while multi stage coalescers may be desirable for more demanding water separating situations because they are more efficient, they are also more costly, and due to their higher cost are not very common in automotive applications. Multi-stage coalescers are used extensively in the filtration of aviation fuels.

Depth coalescers are very effective under the following conditions:

- High Fuel flow rates.
- When fuel temperatures are lower than 60°F.
- When water in fuel contamination is high. (ISO test methods usually require depth type coalescers to satisfy the requirements for protecting common rail fuel injection systems.)
- If the fuel is highly contaminated with surfactants such as additives or asphaltenes.
- Where there are size limitations to the filter.
- In aviation jet fuel filtration.

Water coalescence with depth type media is improved because the situations and/or contaminants that cause water coalescence to fail are removed in the first layers of fiber. The thicker the sheet of filter medium and/or additional layers, the cleaner the exit layer stays, retaining its coalescing properties.

**Fig. 42**
This multi-stage coalescer has a water drain passage between the primary and secondary barriers.
The water that has been coalesced into larger droplets is free to drop into the collection chamber.

When the coalescing area is followed by a hydrophobic barrier sheet which also remains clean, even the small droplets are stopped and the highest efficiency of water removal is attained (Fig. 37).

One must consider the application carefully prior to choosing a coalescer for fuel/water separation. If equipment being protected is expensive, and contamination levels are high, there will be a definite cost benefit by using the more expensive depth type coalescer. Some applications, (jet fuel) require a coalescer fuel filter water separator and are strictly regulated by industry organizations such as the American Petroleum Institute (API), and the International Petroleum Institute (IP) and is discussed in detail in Chapter 15 on page 57.

Recent Developments

Recent developments in super absorbent fiber technology have made absorption a practical mechanism for separating either large water droplets or fine emulsions from fuel streams. Super absorbent fibers have a very high affinity for water droplets even when saturated with fuel. They very quickly absorb water and then swell to many times their original size forming a gelatinous matrix. These super absorbent fibers are usually combined with other fibers in a sheet of medium to prevent the water absorbing material from migrating.

Limitations of Super Absorbent Devices

The limiting characteristic of super absorbent devices is that, as the media absorbs water, resistance to fuel flow increases rapidly. A super absorbent element, if not maintained may rapidly close off entirely to fuel flow. This water adsorbing medium is intended to be the second stage, either separately or in series and inside a primary water separating element. It then acts as an “insurance policy” to stop water that may pass the primary element.

Racor produces a filter containing a second stage water absorbing material that is designed to protect sensitive fuel injection systems in stationary or industrial diesel applications and is not suitable for on-highway applications. It is never safe to shut an engine down on a moving vehicle for any other reason than that driver has allowed the engine to run out of fuel.

Consider the cost versus the performance balance.

Absorption
Chapter 10
WATER SEPARATION PRODUCTS

The two most common filtration products that Racor makes are the 600 and 400 series. Both of these filters can be used as a primary or secondary filter/water separator. The 600 series is popular for systems that do not require a priming pump. The filter head is available with as many as seven ports; four inlet and three outlet as shown in Fig. 43. The 400 series has two inlet and outlet ports as shown in Fig. 44. They both are available for total flow rates of 45, 60, 90 and 120 gph.

Decisions as to what type of water separator should be used are dependent on the following factors:

1. Pressure Side or Vacuum Side
2. Total Flow Rate
3. Extent of Known Water Problem
4. Water Removal Efficiency Required
5. Allowable Size & Installation Location Available
6. Fuel Temperature Conditions
7. Cost
8. Service/Maintenance Requirements
9. Regulations

As discussed earlier, all heavy duty diesel engines have separate transfer pumps as part of the fuel system and these pumps need protection which is provided by either a screen/strainer or primary type filter. A significant economic advantage may be had by combining a water separator with the primary filter or strainer to protect the transfer pump. This puts the water separator on the vacuum side of the transfer pump where the water can be removed before it becomes emulsified. If a strainer or primary filter already exists, a water separator still needs to be added, but can be installed before or after the existing primary filter/strainer. As discussed previously, removing water before it is emulsified is much easier than after it has passed through a pump.

Almost all Racor fuel filter/water separators (FF/WS) have rugged clear water collection bowls made from engineered plastic which allow the operator to see water that has been separated from the fuel.

It is somewhat critical that the fuel filter/water separator be placed where it may be easily seen and serviced. If the clear collection bowl can not be seen and kept clean, the operator may not notice water is present. And if the drain valve cannot be easily reached and operated, the operator may not attempt to drain the collected water.
Racor water collection bowls are capable of being frozen solid with water in it, and also able to withstand any of the chemicals or alcohols that may be added to diesel fuel.

**Water In Fuel Sensors (WIF)**

**Water Sensors**

Water sensors can alert the operator or maintenance personnel that water has been collected and these should be specified as part of the filtration system. Several types are available for Racor FF/WS.

**Electronic Water Sensors**

A very effective water detection sensor uses the collected water to carry a small electrical current from a probe to a ground or to another probe. The probes are connected to either an integral solid state electronic amplifying circuit or a remote one (*Fig. 45*). They are trouble free, but remember, they will not sense water if it is frozen; ice is an insulator. But then frozen water will not drain anyway! The probe should be accessible for cleaning when filter elements are replaced.

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*Fig. 44*  
*Four Port Head With A Hand Priming Pump*

*Fig. 45*  
*This Bowl – Used On Racor’s Model 900FG & 1000 Can Hold Over a Liter of Water*

*Fig. 46  
*Float Type WIF  
A Magnet Activates A Switch When Floated Up To It*
If contaminants are allowed to coat the sensor probe they may insulate the probe and not allow it to sense water. Probes should be made from stainless steel to prevent damage from any electrolysis activity.

**Float Switches** to indicate the presence of collected water are used in some large collection chambers and for some mobile applications. These generally incorporate magnetically actuated reed switches and need no electronic amplifier to process the signal (Fig. 46). Due to their size requirements, they are not easily packaged and are only offered for some OEM applications.

**Location of Water Sensors**

The water sensing probes should be located in the collection bowl high enough from the bottom so that they do not repeatedly call for draining after collecting only a small amount of water. The recommended minimum water holding capacity before activating the WIF sensor is 50 cc. But, they should not be at the very top of the collection area, because the operator needs time to find a suitable place and opportunity to drain the water before it begins to be carried out of the collection chamber into the fuel system.

**Draining Water Removed From Fuel**

**Priming Pump**

Some water/separators can take advantage of manual priming pumps to pump out the water and at the same time replace it with fuel drawn from the supply tank. Emptying the water by pumping it out eliminates the problems that can occur when the water is otherwise displaced by air via a vent valve.
To drain water with a simple drain valve, the filter must be able to be vented to allow air to enter or the water will not drain. Most Racor fuel filter/water separators have drain valves that are “self venting” and are designed to allow air to enter as water begins to drain.

Some fuel filter/water separators are of a canister type with a cartridge filter (*See Fig. 47A & B*), and other cartridge types are “Top Loading” (*See Figs. 48A & B*). All of these are readily filled with fresh fuel after draining by simply removing the cover or bowl.

Water drained from the fuel filter should be collected in a container and disposed of responsibly. An automatic draining system must be connected to a water collection bag or bottle to prevent any fuel from spilling on the road, etc., as shown in *Fig. 49A*.

**Automatic Draining**

A simple automatic water drain system can be added to any pressurized water separator. A WIF sensor when activated by water can open a solenoid valve. Racor has a model that is available (*Fig. 49*).
Chapter 11
Filter Testing

Short Circuits and Leak Paths

The greatest and most common problem causing poor secondary or final filtration is short circuits or leak paths within the filter itself. These can result from damaged or torn filter medium or the improper sealing of the filter medium to the end caps of the filter element. Leak paths are also created by missing or damaged rubber seals intended to seal the inlet or dirty fuel from the clean filtered outlet fuel.

Racor’s quality control system is ISO 9001 / QS 9000 certified (rating demanded for suppliers to the U.S. Auto Industry). This certification is required by all engine, vehicle and equipment makers worldwide.

Test For Short Circuit / Leak Path

Racor uses an industrial “Bubble Test” method in its manufacturing quality control process *(Figs. 50A & B)*. There is also a simple field test method to determine if there is a short circuit or leak path internal of the filter. The test is based on the phenomenon that it takes much more pressure to pass air through filter media that has been wet with fuel, than the pressure to pass fuel. Filter integrity is determined by the amount of air pressure required to force air through the filter paper when wetted with fuel, or by visual observation of “bubble formation.”

A simple field test method is done by filling the fuel filter assembly or cartridge element with clean diesel fuel.

- Connect an air tube to the inlet port of the assembly or to the I.D. of the element.
- Using air pressure supplied by a person blowing into the air tube, the air will quickly push the fuel through the paper.
- When all of the fuel is through, resistance will be felt and increased air pressure by mouth will force the air through the fuel wet medium.
- If the filter assembly has integrity the air will exit the outlet port or the visible paper of a cartridge/element as foam.
- If there is an internal leak path, there will be no foam but only large bubbles or just air with no bubbles at all.
- Shop air pressure can be substituted for lung pressure, but must be regulated down to one psi maximum.

Industry Test Methods

The Diesel Fuel Filtration Industry has a guiding engineering society in every country that manufactures diesel engines or diesel fuel filters. In the United States, this is known as the SAE (Society of Automotive Engineers); in Europe, it is the ISO (International Standards Organization). Each society publishes test method procedures for:

- Filtration Efficiency
- Filter Capacity or Life
- Media Migration
- Water Separation
The most recognized and utilized test methods are: SAE J905, SAE J1488, SAE 1839 (in North America), and ISO 4020 (in Europe and Asia). All of these test methods require complex and sophisticated test equipment and, therefore, are outside the scope of this publication.

Most filter manufacturers follow these test methods, but several use test methods of their own design.

The current SAE and ISO published test methods do not take the effects of engine vibration into consideration. They also measure capacity in grams of test dust collected instead of gallons of diesel fuel to determine filter life.

**50A**

*Foam Indicates Filter Has No Bypass and is a Good Filter.*

**50B**

*No Foam Indicates Bypass of the Media and Is Not A Good Filter.*
Chapter 12
HIGH TEMPERATURE PROBLEMS

Older in-line and distributor type fuel injection systems allow a high percentage of the fuel pumped to the engine to recirculate back to the fuel tank to carry heat away from the injectors and remove any air trapped in the system.

In some newer, very high pressure fuel injection systems, the energy required to reach high injection pressure increases the temperature of the fuel by as much as 60°F. The excess fuel that returns from the engine carries this heat back to the fuel tank. Without some additional means of cooling, the hot fuel will cause fuel tank temperatures to rise to levels higher than the maximum fuel inlet temperature limits in the injection system or plastic fuel tanks. In these instances, fuel heat exchangers are required and the cooling medium is generally “air to fuel.”

Vapor or Fuel Starvation

Diesel fuel begins to vaporize or cavitate, at a negative pressure as low as 10 inches of mercury if the fuel is hot. With the advent of the high pressure common rail fuel systems the fuel recirculated to the tank can cause fuel tank temperatures to climb to over 200°F (92°C). Vapor in the fuel is related to the term “fuel starvation” and the lack of solid fuel will result in poor engine performance or actual engine shut down.

When installing primary fuel filter/water separators, it is best if they can be mounted away from sources of high heat such as near or above exhaust manifolds.

There is a heat limitation on plastic filter water collection bowls and a combination of high fuel temperature, engine compartment air temperature, or radiant heat from exhaust systems for these applications must be taken into consideration when installing fuel filter/water separators. The maximum engine compartment temperature for clear plastic bowls is 250°F (120°C) for suction side applications. On pressure side applications the maximum ambient temperature is 200°F (92°C) and the maximum pressure allowable is 30 psi. The maximum fuel temperature is 140°F.
Paraffin
A Cold Temperature Problem

Cloud Point and Pour Point
Two major characteristics of diesel fuel — cloud point and pour point are critical factors in cold weather operation of fuel systems.

The cloud point is the temperature at which paraffin, which is naturally present in diesel fuel, begins to crystallize and the fuel suddenly begins to appear cloudy. The cloud point will vary greatly. Nationwide surveys show that in some years some fuels had a cloud point as warm as 40°F (5°C). When the fuel temperature reaches the cloud point, these wax crystals will begin to coat the filter paper of the element.

As the temperature drops lower, more paraffin crystallizes and may quickly stop the flow of fuel through the filter. The average cloud point temperature in US Diesel fuels in 1998 was 0°F (-7°C) and ranged from -18°F (-28°C) to +20°F (-7°C).

The pour point is the temperature at which the paraffin in the fuel has crystallized to the point where the fuel gels and becomes resistant to flow. Pour points also vary but they usually occur at about 10°F (-12°C) to 20°F (6°C) below the cloud point of a given fuel.

Cold Flow Improvers
Cold flow improvement additives will lower the pour point of diesel fuel, but do not change the cloud point (Fig. 51). A quality cold weather additive can help prevent filter plugging by altering the paraffin crystals to needle-like forms.
More of the needle-shaped crystals can pass through the filter medium, slowing the plugging process. *(Below freezing temperatures can cause any emulsified water in the fuel to form an icy slush, compounding problems which can cause the ice crystal problem mentioned earlier.)*

**Fuel Heaters**

Heating #2 diesel fuel during cold weather is the simplest solution to cold weather operation problems. There are a number of types of products and methods for heating the fuel, but the simplest is to integrate a fuel heating system directly into the fuel filter/water separator.

There are three common sources of heat energy that are available for fuel heating: electricity, engine coolant, and the heat in the recirculating return fuel.

**Electric Fuel Heaters**

**Types of Electric Fuel Heaters**

There generally are two basic types of electric fuel heaters, these are “PTC” and resistance.

**PTC Most Widely Used**

The most widely used heaters in original equipment are known as PTC type. While they tend to be self-regulating, thermostats are generally used with them. PTCs are usually disc shaped heating elements that are attached to a heat sink plate which transfers the generated heat to the surrounding fuel *(Figs. 52 & 53).*

Because of their ability to self regulate they can not heat fuel efficiently unless the fuel is constantly moving over them to take the heat away. For practical reasons, PTC heaters can be specified up to 300.

**Resistance Elements**

The other main type of electric heating is the use of resistance elements, like “Calrods” used in kitchen ranges. These produce constant heat whether the fuel is moving or not.

![PTC Heaters Attached to Heat Sink Plates](image)
Racor makes a complete line of products in which Calrod type heaters are located in the clear plastic water collection bowls, or internal of the filter housing  (Fig. 54).

For heaters that use an electric resistance element operating at over 250 watts, two thermostats should be used to share the load and a relay should be used to prevent damage to ignition key switches.

More than 200 watts is rarely needed even when normal total fuel flows are very high. If paraffin wax begins to plug the fuel filter/water separator, the flow through the filter begins to slow until the flow rate is low enough for the fuel heater to be effective, and the FF/WS can still pass sufficient fuel to allow the engine to run. This is not so, however, for a system that may have a pressure regulator on the dirty side of the filter. Since the high flow rate that some fuel systems are designed to have is for “cooling” purposes, a high flow rate is not required when the fuel is cold enough to cause waxing.

Another helpful bit of guidance is that when fuel is cold enough to reach the cloud point, the system can have a negative pressure greater than 20 inches hg (135 kPa) without cavitation.

Blanket or wrap-around supplemental heaters are available that can be fastened to the outside of filter housings. for severe weather conditions. These, however, are only energized when the vehicle is parked. They operate on 110 VAC along with engine “block heaters” and allow easy start up on cold mornings. These heaters do not need to draw very much current, using only 30 to 60 watts of power.
Racor provides other fuel heater devices, such as the “Thermoline,” a fuel supply hose with an internal PTC type heating strip that runs the length of the hose (Fig. 55). Another model is a stand-alone heavy duty heater, the Thermocoil, providing 300 or 500 watts of electric heating (Fig. 56).

Formula For Raising Fuel Temperature
The formula for raising the temperature of fuel is the same as for water - except that the specific heat of fuel is half that of water. The simple formula for heating water is: one BTU per hour will raise the temperature of one pound of water 1°F. Example water (1 gallon of water = 8 lbs. approx.) flowing at 10 gph = (8 x 10) = 80 BTU per degree of heat rise. To raise water 10°F at that flow rate would require 800 BTUs per hour. For fuel the number would be 400 BTU’s per hour. There are 0.293 watts per 1 BTU hour so a heat source of 117 watts would be required.

Coolant Heaters

Engine Coolant Source of Heat Energy
Engine coolant is another source of heat energy that, through the use of a heat exchanger, can transfer engine heat to the fuel. Racor produces two series of fuel filter/water separators using integral heat exchangers; a large heavy duty unit with an internal thermostat which prevents overheating the fuel in warm weather, Model 6400; and a medium duty unit that must have the heat exchanger plumbed in series with the vehicle cab heater for temperature control (Racor’s Series 300 product line).

Other Coolant Energized Fuel Heaters
Other coolant energized fuel heaters are available as stand-alone units, which can be installed easily by simply splicing them into the coolant and fuel lines.

Racor’s “Nomad” model (See Fig. 57) has an integral thermostat. Coolant heaters are very efficient and can produce more than enough heat.

Return Fuel Heaters

Prevent Cold Weather Wax Plugging
Still another way to prevent cold weather wax plugging of the fuel filter or water separator is to allow the “return fuel” to ender the inlet side of the filter. Since the return fuel is always much warmer than the fuel going into the injection system, it can be routed in such a way that a portion or all of it is directed to the inlet side of the filtration unit.
Thermally controlled valves divert all the return fuel to the fuel tank when the temperature of the fuel coming into the filter is warm.

The products mentioned above can also be used with this source of heat as a supplement to electric fuel heaters. The return fuel also makes up a major portion of the inlet fuel, reducing the amount of cold fuel supplied from the tank. Racor’s Model RFCM has an integral thermal control valve (Fig. 17 on Page 17).
Chapter 14
Gasoline Fuel Filtration
Marine Applications

One particular gasoline/petrol application that requires special attention to filtration is marine. The boating industry uses both inboard and outboard gasoline/petrol engines as power sources. Because of the common contamination of onboard fuel with water, marine filtration systems must make water removal a prime consideration.

Biggest Fuel System Problem
Normally, gasoline fuel systems require only an in-line 10-20 micron filter which is intended to last the life of the engine. When gasoline engines are used in marine applications, however, a fuel filter/water separator is required to remove water before it reaches the fuel transfer pump and injection system.

Corrosion A Problem
The main problems created by water in the fuel system are corrosion and microbial growth. Racor has several models of fuel filter/water separators that are designed for marine use.

Placement of Filter to Prevent Leaks
Because of the danger of leaks resulting from corrosion, improper handling or improper installation, fuel filters in marine gasoline applications must never be installed on the pressure side of the fuel system.

Furthermore, for the sake of safety, marine gasoline filters should always be installed at a point higher than the highest part of the fuel system. Fuel filter elements should be replaced annually no matter how few operating hours have been used, to avoid damage and leaks from corrosion.

Many boat applications require that any fuel filter/water separator being used carry a U.L. (Underwriters Laboratory) certification. When installing a marine fuel filter, always follow marine regulations and codes.

Pleasure Boats Require Special Fuel Filtration
Chapter 15
Maintenance and Transfer of Fuel In Storage

Large Power Plant Fuel

Mobile equipment fuel tanks range in size from 20 to about 200 or more gallons, depending on engine and vehicle size. Fuel storage tank size for stationary consumption, however, can be anywhere from 200 to 200,000 gallons or more depending upon purpose and consumption rate.

Fuel for heating purposes has a broader range of specifications and values and may not be of the same quality as #2 diesel fuel. The fuel is often injected by high pressure into heating chambers of furnaces or into coal to begin a combustion process.

Storage Problems

Contaminated problems in fuel found in on-board fuel systems also create problems in storage facilities. Fuel problems can be caused by water, dirt, asphaltenes and cold weather if the storage is outside and above ground. Underground storage tanks cannot be equipped with bottom drain valves to drain off water.

Preventing Microbial Growth

To prevent microbial growth, the water that finds its way into fuel storage tanks should be removed as soon as possible. The most efficient way is to provide water separators for the fuel filtration system, and recirculate the fuel through them.

Filter Element Life

When filtering large quantities of fuel, filter element life is determined by total fuel flow after a fresh load of fuel has been delivered to the storage facility. After a new delivery of fuel and all of the fuel has been recirculated at least once, the life of the filter elements will be determined more by the rate of the fuel consumed.
Tanks Up to 5,000 Gallons

Racor offers several options for these large tanks. This includes manifolded filter systems such as the Racor 812 or the RVFS filter/separator family. Dependent upon the mobile, marine or high flow fuel dispensing operation, Racor has the correct filter system to provide clean and dry fuel. These units filter up to 75 gallons per minute.

Storage Tanks Up To 100,000 Gallons, Racor produces a fuel filtration/water separator series for higher flow rates or larger storage facilities. These models include the RVFS series or the duplex RVFS filter/separators. These filter combinations can filter diesel fuel up to 150 gallons per minute and up to 300 gpm with aviation fuels, kerosene and gasoline.

Storage Facilities Larger Than 100,000 Gallons, it is recommended that fuel be continuously recirculated through a water removing filtration system. One complete turnover of the fuel should be made every 168 hours. For these large terminal facilities, Racor offers a full line of prefilters and filter/separators. These filter vessels can accommodate flows up to 5,000 gallons per minute.

Applications for Racor series filter vessels include removing liquid and solid contaminants from jet fuel, gasoline, aviation gas, kerosene, diesel fuel and other hydrocarbon liquids. RVFS vessels can be used as coalescers, pre-filters or separators by changing internal components, flow direction or by selecting optional filter cartridges.
NOTES
NOTES
## Fuel Filtration Index

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Filtration Group Technical Sales & Services Locations

Filtration and Separation Division
100 Ames Pond Drive
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Fax: (978) 858-0199
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500 Glaspie Street
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Phone: (248) 628-6400
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Phone: (800) 451-7299
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Fax: (918) 652-8882
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Phone: (317) 275-8300
Fax: (317) 275-8410
State Road 66
Tell City, IN 47791
Phone: (812) 547-2371
Fax: (812) 547-2380

Filter Division Europe
Churwell Vale
Saw Cross Business Park
Dewsbury, England WF12 7RD
Phone: (44) 1924 487000
Fax: (44) 1924 487060
Fin-31700
Ujula As, Finland
Phone: (358) 3 54 100
Fax: (358) 3 54 10100
Teollisuus 2
89400 Haapsalmi
Finland
Phone: (358) 8 6532500
Fax: (358) 8 6532520
Oude Kerkstraat 4
P.O. Box 258
4870 AG Etten-Leur
The Netherlands
Phone: (31) 76 509 53 04
Fax: (31) 76 509 53 12

Filtration Group Headquarters
6035 Parkland Blvd.
Cleveland, OH 44124-4141
Phone: (216) 896-3000
Fax: (216) 896-4021
http://www.parker.com/filtration

Parker Hannifin Ind. e Com.
Linha, Filtration Division
05276-977 - Sao Paulo
SP, Brazil
Phone: +55 (11) 3917 1407
Fax: +55 (11) 3917 7898

Parker Hannifin Korea Limited
902 Daehan Bld.
646-23 Yeoksam-dong
Kangnam-ku, Seoul,
Korea 135-080
Phone: 82 2 561 0414
Fax: 82 2 556 8187

Parker Hannifin Corporation
Racor Division
P.O. Box 3208
Modesto, CA 95353 USA
800/344-3286
209/521-7860
Fax 209/529-3278
http://www.parker.com/racor
E-mail: racor@parker.com

Parker Worldwide Sales Offices
Contact Parker's worldwide service and distribution network by calling:

Argentina +54 (3227) 44 4129
Australia +61 (2) 634 7777
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Brazil +55 (11) 3917 1407
Canada 1-800-272-7537
Central & South America/Caribbean +1-305-470-8800
China +86 (21) 6445 9339
Czech Republic +42 42 634 1701
Denmark +45 (43) 541133
Finland +358 3 54 100
France +33 02 54 74 03 04
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India +91 (22) 577 1671
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Mexico +1-800-272-7537
Netherlands +31 (541) 58500
New Zealand +64 (9) 573 1523
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Poland +48 (22) 8634944
Singapore +65 261 5233
South Africa +27 (11) 3927 280
Spain +34 (1) 6757300
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Thailand +662 693330
United Arab Emirates +971 (2) 788587
United Kingdom +44 1442 238100
United States of America +1-800-272-7537
Venezuela +58 (2) 238 5422