DESIGN AND PERFORMANCE EVALUATION OF A FUEL FILTER

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ABSTRACT

DESIGN AND PERFORMANCE EVALUATION OF A FUEL FILTER

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This thesis analyzes design criteria's, performance evaluation of fuel filter. Fundamental concepts, definition and systems has been discussed at literature survey parts. Fundamentals of filter design tests and calculations are discussed. In Addition Frequency and amplitude effect on fuel filter efficiency investigated with different particle sizes by preparing special test set up. Test results has been analyzed by using Regression, Anova and Analyze of Variance methods with Minitab software.

Key Words; Fuel filter, Filter efficiency, Filter design

ÖZ

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YAKIT FILTRESI DIZAYNI VE PERFORMANS DEĞERLENDIRMESI

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Tez Yöntecisi : Prof. Dr. Kahraman Albayrak
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Bu tezde yakıt filtresi dizayn kriterleri ve performans değerledirmesi analiz edilmiştir.Temel tanımlar , konseptler ve sistemler kaynak araştırmalarında incelenmiştir.Filitre dizayn kriterleri , dizayn testleri ve temel hesaplamalar anlatılmıştır. Vibrasyon ve amplitudenin (genliğin) filitre verimliği üzerine olan etkisi , hazırlanan özel test duzeneğinde yapılan deneyle incelenmiş.Test sonuçları Anova , Analyze of Variance methodları ile minitap yazılımı kullanılarak analiz edilmiştir.

Anahtar Kelime: Yakıt Filtresi, Filtre Verimliliği,Filtre Dizaynı

To My Wife

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LIST OF SYMBOLS AND ABBREVIATIONS

psi	Pound Squire Inch	pound / inch^2
ΔP	Pressure Difference	
IEB	Interrupted Exhaust Beat	
gph	Gallon per hour	
lph	Litre per hour	
µm	Mikro meter –micron	
mm	mili-meter	
OEM	Original Equipment Manufacturer	
FIS	Fuel Injection System	
HCPR	High Pressure Common Rail	
EUI	Electronic Unit Injector	
HEUI	Hydraulic Electronic Unit Injector	
ºC	Celsius	
ºF	Fahrenheit	
WIF	Water In Fuel Sensor	
cc	Cubic Centimeter	
PTC	Positive Temperature Coefficient	
DC	Direct Current	
lpm	Liter per minute	l/min
hp	Horse power	
rpm	revolution per minute	
DDM	Digital Diagnostics Monitoring	
l	liter	
P	Pressure	
ppm	Part per million	
3D	3 Dimension x,y,z	
PC	Personnel Computer	
R	large standardized residual	
DF	Degrees of Freedom	
Seq SS	Sequential sums of squares	

Adj SS	Adjusted sum of squares
Adj MS	Adjusted mean square
F	F = (MS regression) / (DF regression).
P value	The probability of making a Type 1 error, which is rejecting the null hypothesis when it is true.
Coef	Estimated coefficient for the predictor in the regression equation.
SE Coef	Standard error for the estimated coefficient
T	T-values are calculated as the ratio of the corresponding value under Coef and its standard error (SE Coef).

CHAPTER 1

INTRODUCTION

1.1. Filtration Technology

The two major branches of physical separations technology, filtration and sedimentation, work by quite different mechanisms. Filtration operates entirely on particle or droplet size (and, to some extent, shape), such that particles below a certain size will pass through the barrier, while larger particles are retained on or in the barrier for later removal. The separating size is a characteristic of the barrier, the filter medium. The wide range of filter designs is very largely a consequence of the need to pack as much filter medium area into a given equipment floor space (or volume) can be another design decider. The operation of a filter usually needs a pressure differential across the filter medium, and this can be effected by means of fluid pressure upstream of the medium (pressure filters) or suction downstream (vacuum filters).

Sedimentation, on the other hand, operates on the density of the particle or droplet, or, more correctly, on the density difference between the suspended particle and the suspended fluid. It is the force of gravity working on this density difference (or the much higher centrifugal force operating in a centrifuge) that causes separation by sedimentation- either of a solid from its suspension, or of a lighter solid from a heavier one. Particle size also has a part to play in sedimentation- a larger particle will settle faster than a smaller one, of the same density .Settlement area is the prime consideration in sedimentation, with throughput being directly proportional to available area, which is why the extra cost of a sedimenting centrifuge will often pay for itself because of much smaller space that it occupies.

Solid separating technologies have two prime purposes: the removal of unwanted solids from suspension in a fluid (which may itself be a wanted product or a waste that needs cleaning prior to discharge), and the recovery of a wanted solid product from its suspension (often following a prior crystallization or precipitation step.) Either kind of equipment, filter or sedimenter, may be used for either of these purposes, although it is true that most solid recovery is achieved in filters or sedimenting centrifuges.

The particle sizes covered by filtration range from large pebbles of the mineral sector's screens to the ultra-fine particles and large molecules of the membrane ultra-filtration systems. Most systems involving contaminant removal are concerned with fine particles- fine enough, for example, to have stayed suspended in atmospheric air for long periods of time.

The mean particle size, and the particle size distribution, will both have a major influence on the type of filter chosen to treat a suspension, a choice that would be made in order to produce the most filtration-efficient, energy-efficient and cost- effective solution. The apparent filtering range of a particular type of filter can be misleading in terms of both efficiency and cost- effectiveness. The finer the filter, the more readily it will become clogged by coarser particles, so that, where very fine filtration required, it becomes both more efficient and more cost-effective to filter in stages, using two or more filters in series with progressively decreasing cut-points. Thus, a full system might include an initial strainer, followed by a thick medium filter, and then an ultra-filter for the final stage (or even this whole pre-filtration system ahead of desalination by reverse osmosis)

The size of the separated particle is used to delineate the terms used for the various filtration processes. Thus 'macro filtration' is used for separating in the approximate range of 1 mm down to 5µm (with 'screening' used for particles above 1 mm, without upper limit). From 5µm down to about 0.1µm the process is termed 'micro-filtration', while below that the term 'ultra-filtration' applies. Ultra-filtration covers the finest distinct particles (such as colloids), but its lower limit is usually set in molecular weight terms, measured in Daltons.

Below ultra-filtration in size terms come nano-filtration and reverse osmosis, which look just like filtration processes and are often counted in with them-they have a liquid flow, and a semi-permeable membrane is placed as a barrier across this flow. However nano-filtration and reverse osmosis differ from ultra-filtration in operating principle: the liquid treated is now a solution with no (or extremely little, if properly pre-filtered) suspended matter. The membranes have no physical holes through them, but are capable of dissolving one or more small molecular species (such as water in the case of reverse osmosis desalination) into the membrane material itself .These species diffuse through the membrane, under the high trans-membrane pressure, and emerge in their pure state on the other side.

1.2. Introduction to Fuel Filtration

Fuel filters today have changed significantly in appearance from those in the past. However, their purpose remains the same: to protect the fuel system by removing contaminants (rust, dirt, and other foreign matter) from the fuel.

The most significant change today, is that the majority of engines being produced are fuel injected. The filters used on these engines are exposed to much higher pressures than those of the past. With modern engines now injecting fuel at pressures up to 30,000 psi, and injector tolerance being measured in microns, even a small amount of dirt or water corrosion can start problems. Water or particulates can cause microscopic surface damage that is then focused on by the high-pressure fuel flow, which causes wear that will eventually lead to reduced efficiency and complete breakdown. With this in mind, managing fuel delivery and system cleanliness through proper filtration becomes and absolute imperative for economical engine operation.

1.2.1 Petrol engines

Contaminants in engine fuel can clog or partially clog jets, and drilled or cored passages in the carburettor, upsetting their metering performance and causing loss of power, poor starting characteristics, or even damaged exhaust valves through over heating , produced by an excessive weak mixture. Quite small particles may lodge on the seat of the needle valve, causing the carburettor to flood. Abrasive particles may abrade the accelerator pump seal valves or valve seats. There is the further consideration that abrasive particles carried through the carburettor and into the combustion chambers may result in scoring of cylinder walls or loss of efficiency of piston rings.

Provided normal precautions are taken when filling the tank, few contaminants should be introduced at this stage. The possible exception is water, which is always likely to be present in small proportions in pumped petrol. The main cause of fuel contamination is corrosion or deterioration of the inner surfaces of the tank itself, or the redistribution of foreign matter already in the tank.

Coarser particles can be retained in the tank by a coarse mesh strainer fitted in the tank at the outlet point. Water will settle to the bottom of the tank and would not normally be drawn up if the outlet pipe positioned correctly, and even if it is drawn up, the coarse strainer is reasonably effective in arresting it. Most tanks have strainers and additional protection provided by an in-line disposable filter on the entry side of the fuel pump, together with a settling or sediment bowl on the pump inlet. Further protection is usually provided at the carburettor or fuel injection system entry point with other simple strainers.

If the fuel delivery is screened at the point of entry to the fuel pump, this dispenses with the need for a sediment bowl. In the recent past, in-line fillers mounted between the pump and the carburettor consisted of a nylon cloth, porous ceramic, sintered bronze or phenolic resin- impregnated paper element, while in tank filters were made of saran or saran polyester cloth. The size of the filter needs to be fairly generous, as relatively high flow rates may be involved with large capacity engines operating at maximum speed (when fuel delivery requirements are most critical)

To assist in assessing the condition of the filter, the body was often made in transparent plastic or glass. The contaminants to be looked for included both dirt and water. The paper element needed to be resistant to both petrol and water. Working pressure was very low, so little support was needed for the element. Typically, flow was arranged from the outside to the inside, with the element simply located in housing. This was normally connected to the fuel line at each end by short length of hose.

Current fuel injection systems use both in-tank and in-line fuel filter. These systems use a rotary electric fuel pump, mounted in the fuel tank, with the filters made of nylon cloth to cope with the increased heat generated by the pump. In-tank pumps operate continuously at their maximum flow capacity when the engine is switched on. Depth filter media can double the capacity of automotive fuel filter, trapping contaminants in the depth of the medium, rather than just on the surface like conventional cloth media.

1.2.2 Diesel engines

In the case of diesel engines, the need for effective fuel conditioning is essential to protect the highly sophisticated fuel pumps and injection equipment. Main filters, pre-filters (sedimenters), fuel heaters and hand primers are needed to keep fuel flowing under the harshest operating conditions. The most damaging contaminants to fuel injection system are abrasive particles in the 5 to 20μm range .The critical areas for wear in in-line pumps are delivery valves and pumping elements. The distributor rotor is equally crucial for rotary pumps. Water, as well as dirt, can be presented in diesel fuel and this can have the same disastrous effect on the fuel injection pump as dirt contamination. Waxing can also mean blocked fuel lines, clogged filter elements and a general deterioration of the engine caused by starting difficulties.

Before the selection of the most appropriate fuel conditioning equipment, the worst operating conditions that will be encountered must be identified, together with any special requirements. The key operating factors and areas of consideration for diesel fuel filtration are listed in Table 1.01

Main filters to protect the fuel injection equipment and usually contain paper elements with high burst pressure and the ability to withstand the large pressure drop that can exists across the filter when high performance feed pumps are used. In the selection of diesel fuel filters, it is important to verify that have been tested in accordance with the appropriate ISO test standard, which measures the effectiveness of fuel filters

Table 1.1 Diesel fuel filter operating factors

Operating Factors	**Considerations**
Fuel Flow	Engine full load / speed consumption plus fuel recirculated to tank
Fuel Contamination	Fuel quality / Storage / Handling Operating Environment Condensation / Atmospheric conditions Operator custom and practice
Lowest operating temperature	Lowest ambient temperature Vehicle / Plant overnight storage Chill factor on exposed equipments Fuel quality / waxing temperature
Highest Temperature	Highest ambient temperature Proximity of exhaust system Ventilation Vehicle / plant production
Vulnerability to damage	Mounting positions Likelihood of abuse / damage from stones…etc
Safety / Protection features (water warning / engine shut-down)	Operator conscientiousness Variability of fuel quality / Contaminants Operating temperature, Fuel handling Safety (engine shut-down)
Service periods	Cost of service Availability of vehicle / plant for service Operating periods, Quality of services
Application	Legal requirements / Construction and use regulations Safety

Sedimenters are pre-filters that separate water and other contaminants out of the fuel by sedimentation. Sedimenters should be mounted as close to the fuel tank as possible and before the feed pump.

Agglomerators are fitted on the pressure side of the feed pump. They are also used to separate water from the diesel fuel. The fine pores of the filter paper isolate and retain solid particles, while fine water droplets are forced through the pores and agglomerate into large droplets, which are then deposited by sedimentation into the bottom of the unit.

1.2.3 Heavy Fuels

Heavy Fuel oils are mainly used in land-based engines or marine engines, where there is space (and the ease of mounting) for large filter, necessary to deal with higher viscosity oil. A full-flow duplex filter, designed for use with heavy fuel oils is shown Figure 1.01 .A changeover valve either one element one element or the other to be in use, provision being made for priming the standby element while the in use element is carrying the full flow. With the valve in the mid position, fully opened ports allow both elements to operate in parallel.

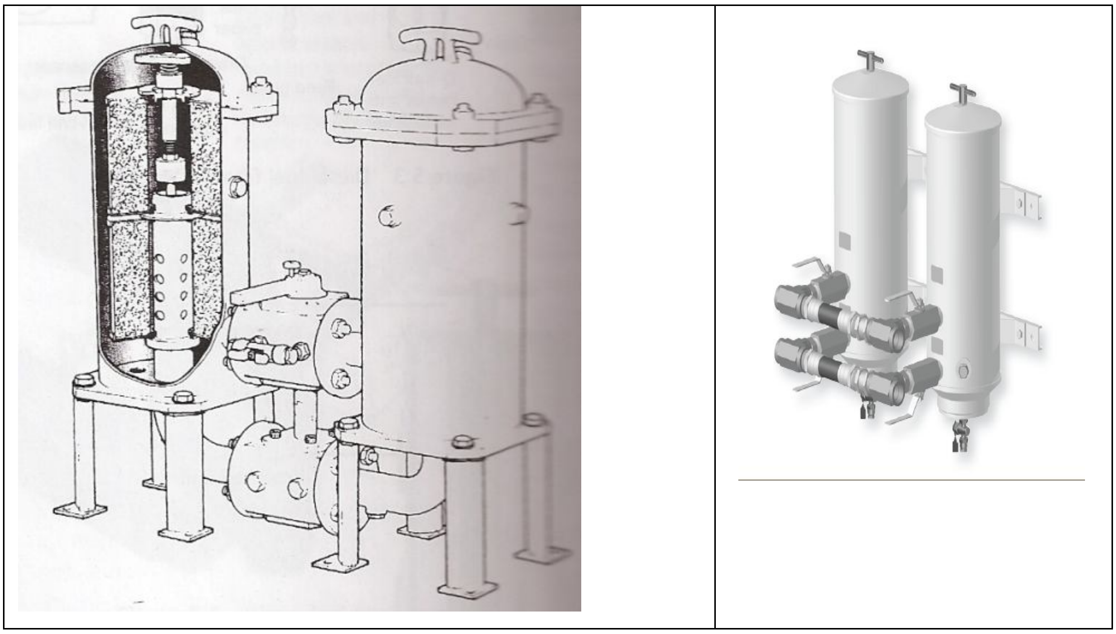
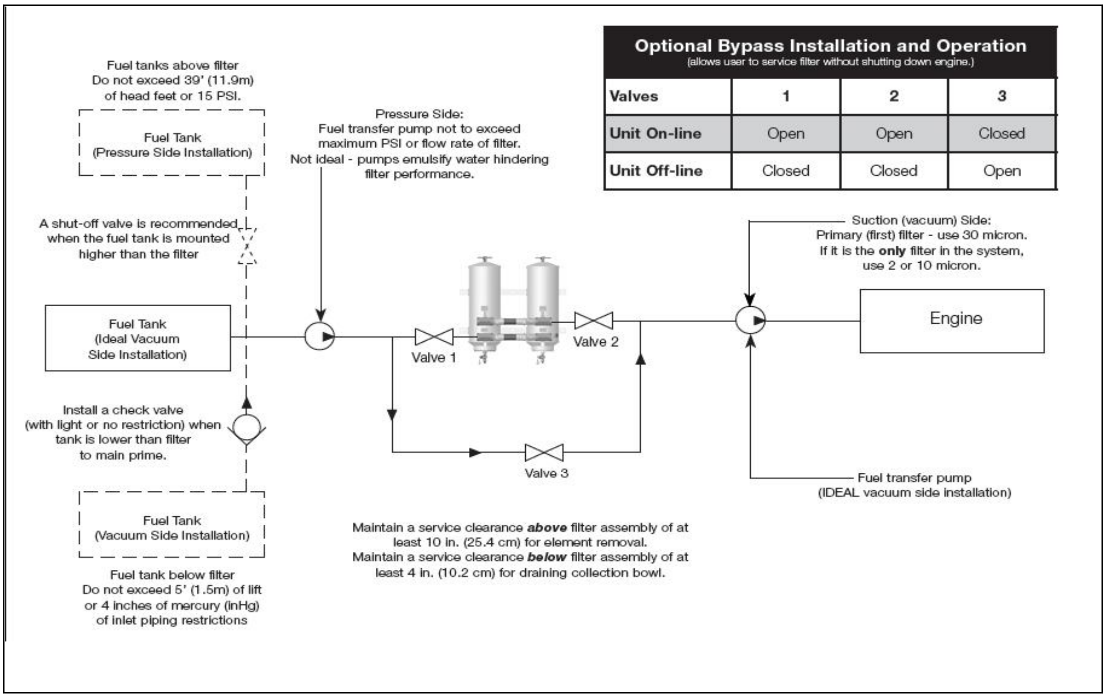


Figure 1.1 Duplex fuel oil filter with changeover valve


Optional Bypass Installation and Operation
(allows user to service filter without shutting down engine.)

Valves	1	2	3
Unit On-line	Open	Open	Closed
Unit Off-line	Closed	Closed	Open

Figure 1.2 Duplex fuel oil filter installation

Duplex filters are designed for use where an uninterrupted fuel flow is required, or where an immediate standby filter is essential. Fuel oil filters can generally incorporate air vents, drains and tapping for pressure differential instruments. Steam jackets, magnetic elements and interlocking safety devices may also be fitted. Fuel oil cartridges for this type of filter are fitted with media capable of operating up to 160°C, with 4µm nominal filtration efficiency, and can withstand a 10 bar pressure differential.

CHAPTER 2

REVIEW OF LITARETURE

2.1 Filtration Mechanisms

Filters acts like a porous screen, allowing those arriving particles- which are below a certain size- to pass through the openings that give the medium its porosity, together with the carrier fluid. Those particles that are too large to pass are retained on (or in) the medium, for subsequent removal in some other way.

2.1.1 Mechanisms for particle entrapment in a bed of fibres:

The first major point to note is that any particle, in the absence of electrical charges on fibre or particle, one brought close enough to fibre, will be attracted to fibre, until contact is made, and then the particle will stay put. The attractive forces are quite weak (known as Van Der Waal's forces), but are sufficiently strong to hold the particle on the fibre surface once it is there, independent of the way in which the particle arrived. They should be very close to the fibre for this process to occur, but once it has been trapped, then the trapped particle acts like an extension of the fibre, and can then, in its turn, trap other particles.

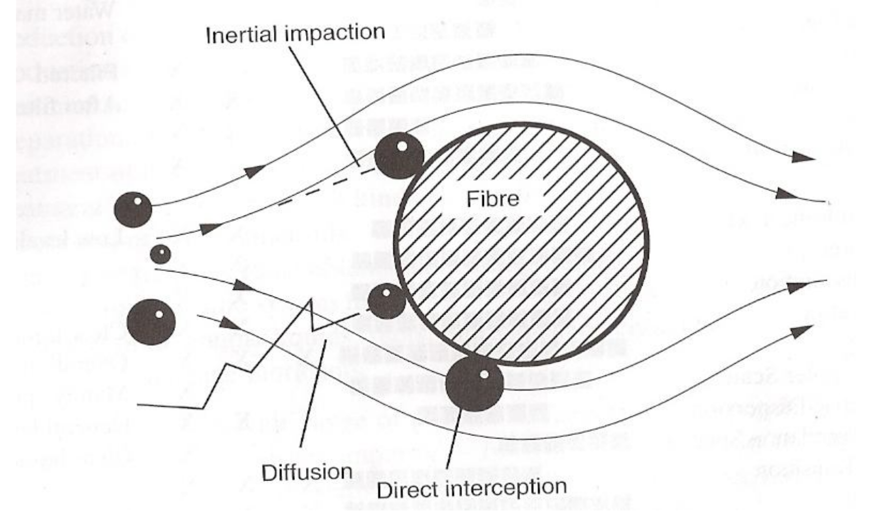


Figure 2.1 Particle Collection mechanisms

It follows that, if the fluid flow is such that the particle is brought into contact with the fibre, it will be caught and held by the fibre-it has been filtered. Another point to remember is that the flow inside the medium is close to, if not actually, laminar, so that the fluid flows in smooth streamlines around obstacle in its path, as shown Figure 2.1. Unless otherwise disturbed, the particles follow these streamlines through the bed of fibres. If the particle is small, it will be contained within a packet of streamlines, and will be swept past the fibre and onwards without being caught.

As the streamlines bend round the obstacle, they carry particles with them, and if a particle in so doing is taken to a distance of less than half of its diameter from the fibre surface, as has happened to the lowermost particle in Figure 2.1, then it will come into contact with the fibre and so get trapped. This mechanism is known as Direct Interception, and, by definition, it must happen on the flanks of fibre, not directly in front of it.

In turning their path to pass by the fibre the streamlines take the suspended particles with them. However, a larger particle (or a particle moving fast) will carry too much inertia to make the turn. It will then cross the streamlines and collide with the fibre, and be trapped. This mechanism is termed Internal Impaction, which has happened to the topmost trapped particle Figure 2.1.

Another group of particles do not stick to the streamlines but meander about, in and across them. This is Diffusion behavior, affects mainly small particles, and is largely caused by the Brownian motion of the carrier fluid. The particle thus pops out of the streamline pattern near to the fibre surface, and once again trapped, as is the case for the smallest of the trapped particle as shown Figure 2.1

These are three main mechanisms for particle entrapment in a bed of fibres, but there are others. For Example, the small particle on the left of Figure 2.1 is going to find it difficult knowing which way to go around the fibre. It will probably be carried straight towards the front face, but before it reaches it, will became involved in the fluid eddy pattern that must exists just in front of the fibre. It is then likely to exit from this pattern either into the by passing streamlines, or by getting trapped on the front surface of the fibre.

2.1.2 Surface vs. depth filtration:

It has been stated that a filter medium is a porous barrier placed across the flow of a suspension to hold back some or all of the suspended material. If this barrier were to be very thin compared with the diameter of the smallest particle to be filtered (and perforated with even sized holes), then all the filtration would take place on the upstream surface of the medium. Any particle smaller than the pore diameter would be swept through the pores and any particles larger than that (assuming the particles to be rigid) would remain on the upstream surface. Some of the larger particles, however, would be of a size to settle into the individual pores and block them. The medium surface would gradually fill with pores in this way, until the fluid flow reduced to below an acceptable level.

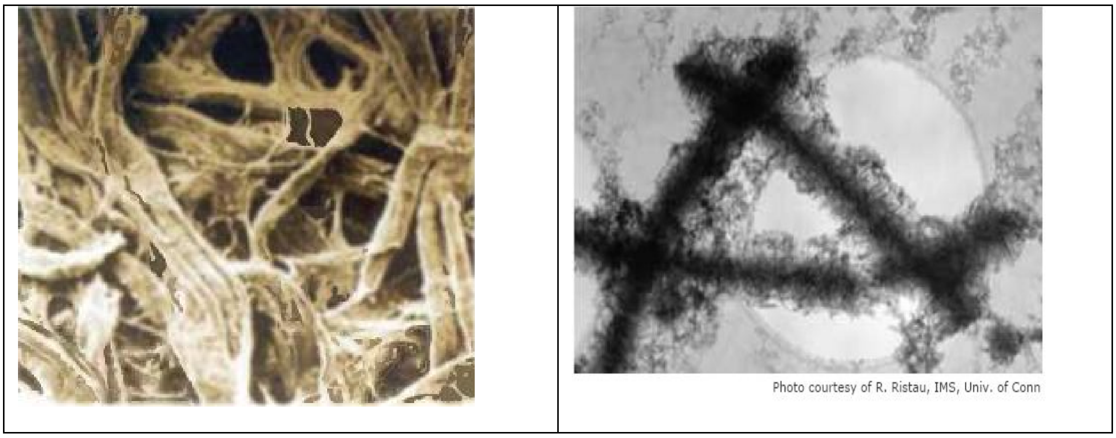


Photo courtesy of R. Ristau, IMS, Univ. of Conn

Figure. 2.2 Surface of a filter paper seen through a microscope

The filtration mechanism is termed surface straining, because it works entirely on the relation between the particle size and the pore size in the screen. Unless the particles are easily deformable, then surface straining will separate solids in the feed suspension absolutely on the size of the pores in the filter medium. This mechanism is that working in screening through a perforated plate..

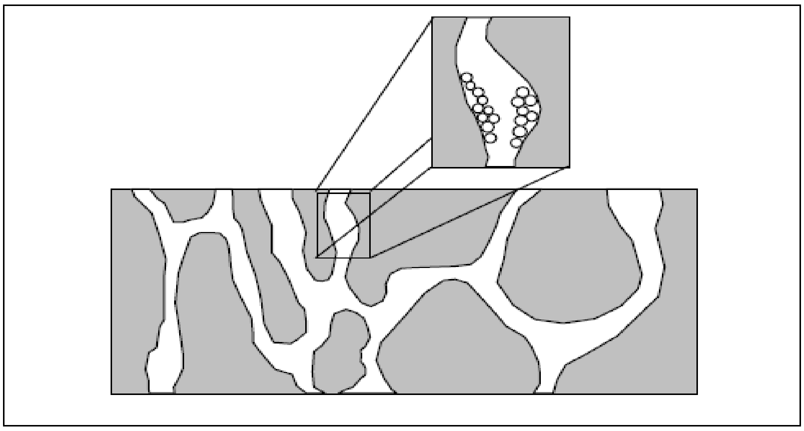


Figure 2.3 Gradual Pore Blockages

Most real media are, of course, not infinitely thin, but have a finite thickness in the direction of fluid flow, while most pores through such material vary in diameter along the fluid path. A second mechanism, termed depth straining, then applies when a particle moves through a pore until it meets a point where the pore is too small, and the particle held entirely because of its size. The pore then blocked, and remains so until the filter medium becomes too clogged in this way for it to have any further use. At this point it must be discharged, or, preferably, blown free of the trapped solids, by a reverse flow of fluid

In the same way that particles can be trapped in a bed of fibres by the adsorption processes described earlier, so can fine particles moving through a tortuous path imposed by an irregular pore be trapped on the pore surface by the mechanisms of direct or inertial interception or diffusion? This process is known as depth filtration, and shown in Figure 2.4. Pore blockage also occurs with this mechanism, as particles became trapped to one other, although no pores become absolutely blocked, because the fluid can still flow through the spaces between the particles.

In practice, the effects of depth straining and depth filtration are effectively the same- the medium clogs because of particles trapped in the pores- and difficult to tell apart, so both mechanisms are usually grouped together under the title of depth filtration.

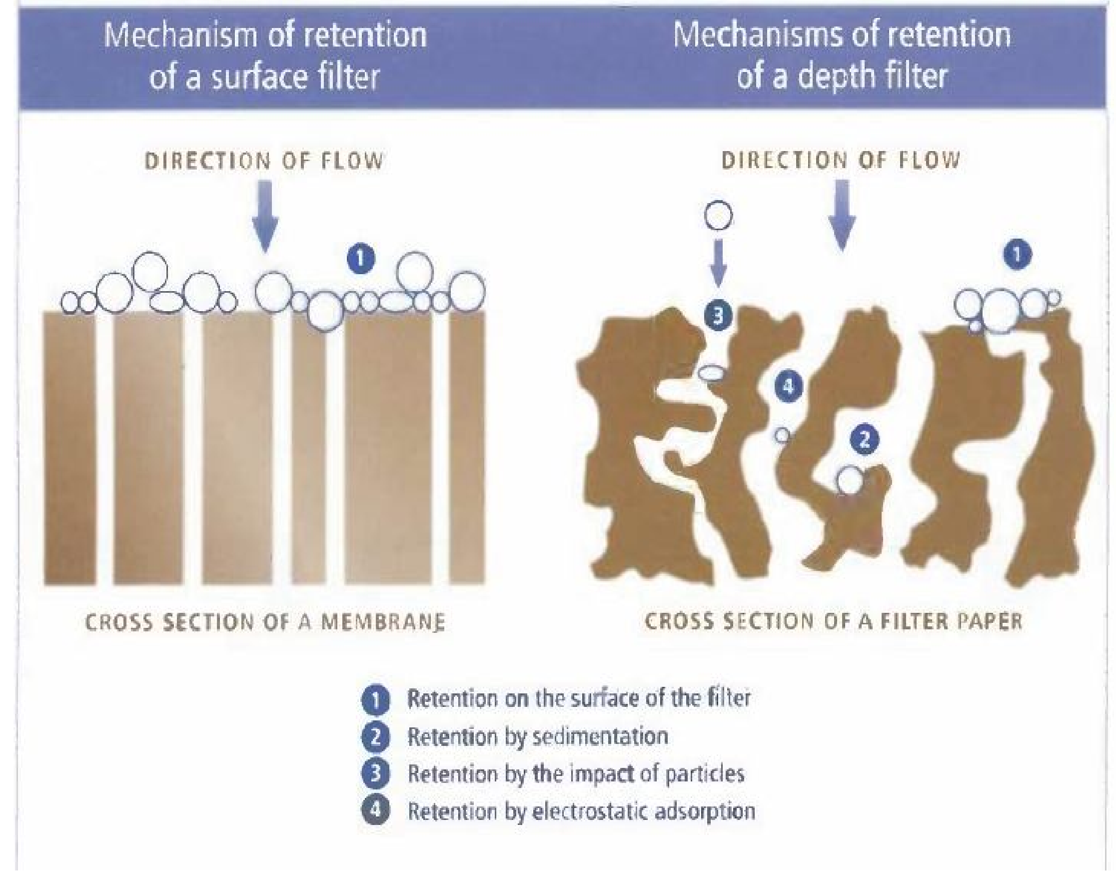


Figure 2.4 Mechanism of depth filtration and surface filtration

Where solid concentrations are higher, as is the case with a large number of process separations, a different mechanism is called into play, which is the development of surface straining. Now, because of the high concentration of solids in the suspension, the particles jostle with one another at the entrance to each pore and, after a very short period when some small particles escape through the pore, the particles bridge together across the opening to the pore. These particle bridges then act as the filter medium to allow layer of particles to form upstream of them and the fluid to flow through these layers to be filtered. The build-up of particles on the filter medium produces a cake of separated solids, and the mechanism is termed cake filtration, with actual separation by depth filtration within the thickness of the cake and surface straining on its upstream face. This mechanism is illustrated in Figure 2.5

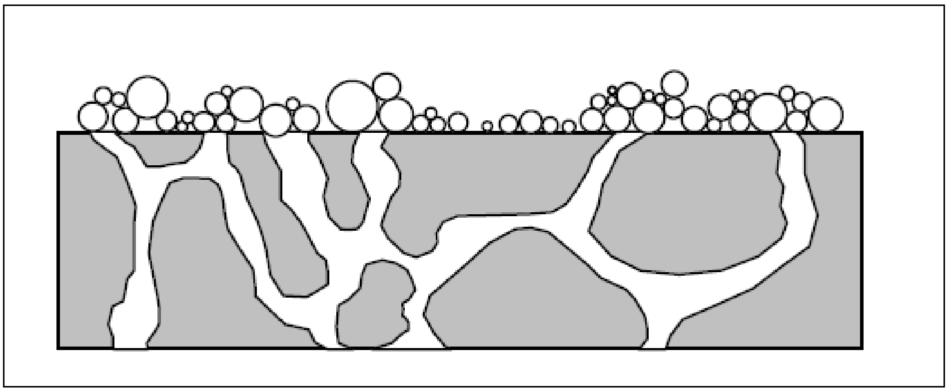


Figure 2.5 Cake filtration

- Caking - material retained on the surface, producing a layer - pores remain 'unblocked'

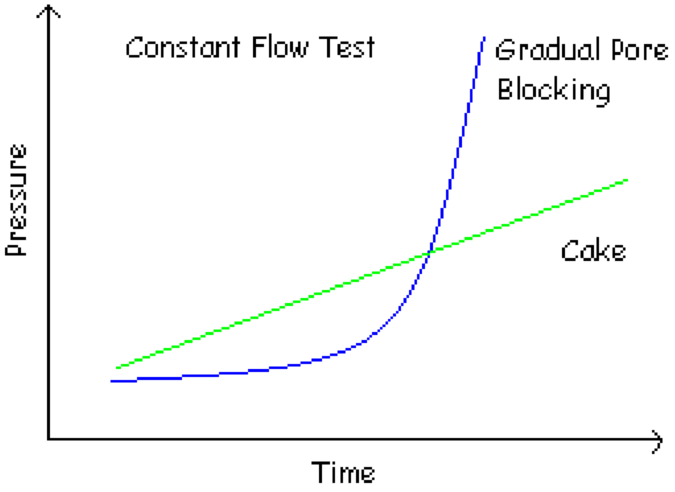


Figure .2.6 Gradual Pore Blocking and Caking effect on filter blockage

- As fouling increases within the filter structure the resistance to flow increases
    - slow, then rapid increase in upstream pressure
    - eventual decrease in flow rate (at max ΔP)

Filter Permeability

The permeability is the reciprocal of the resistance to flow offered by the filter-thus, high permeability represents a low resistance and vice versa. Permeability is usually expressed in terms in terms of a permeability coefficient, which is directly proportional to the product of flow rate, fluid viscosity and filter medium thickness, and inversely proportional to the product of filter area and fluid density, which gives the permeability coefficient the dimension of a length.

Such a derivation is cumbersome, and permeability behavior is better expressed by a series of curves relating pressure drop across the filter medium with flow rate of the fluid through it. A separate series of pressure drop curves can be set up with respect to:

- Filter Size (i.e. filtration area)
- Fluid Temperature , and
- Filtration time (i.e. degree of contamination of the medium)

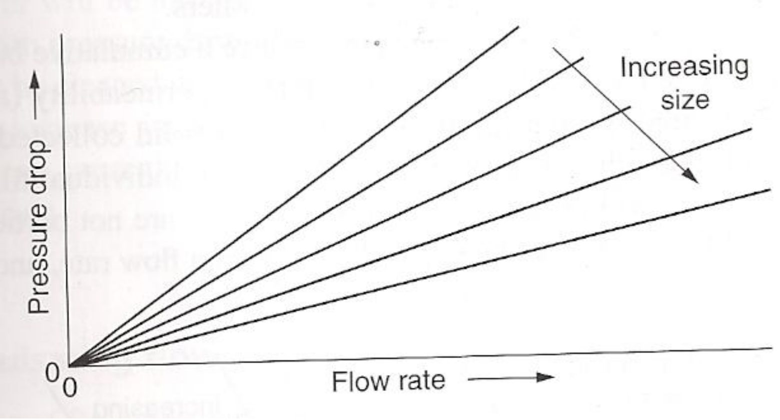


Figure 2. 7 Filter Size Curves

A typical set of curves for the relationship with size is given Figure 2.7 . For a given flow rate, an increase in filter area will reduce the pressure drop the filter, because the amount of fluid flowing per unit of filtration area is decreased (pressure drop is inversely proportional to filter area).This leads to a standard method for sizing of a filter, a combination of the process flow rate required and acceptance pressure drop leading to the optimum area (although it should be noted that the pressure drop will increase with filtration time as the medium becomes clogged)

If the medium thickness is increased at the same time as its area, then a different set of curves will be produced, because the medium also imposes a restriction on the flow of fluid. Each individual filter element will, therefore, have its own specific pressure drop-flow curve, depending upon its area, thickness and permeability.

The operating temperature of the fluid will affect the pressure drop across the filter because the fluid viscosity will change. A less viscous fluid will experienced less resistance to flow through the medium, and so a lower pressure drop will be needed to drive it. As a result, pressure drop is inversely proportional to temperature, with a decrease in temperature causing a rise in pressure drop, as shown Figure 2.8 a series of pressure drop vs. flow rate curves at differing temperatures will thus establish the characteristics of a single filter over its working temperature range. (It should be noted that the temperature effect is much more pronounced for liquids than for gases.)

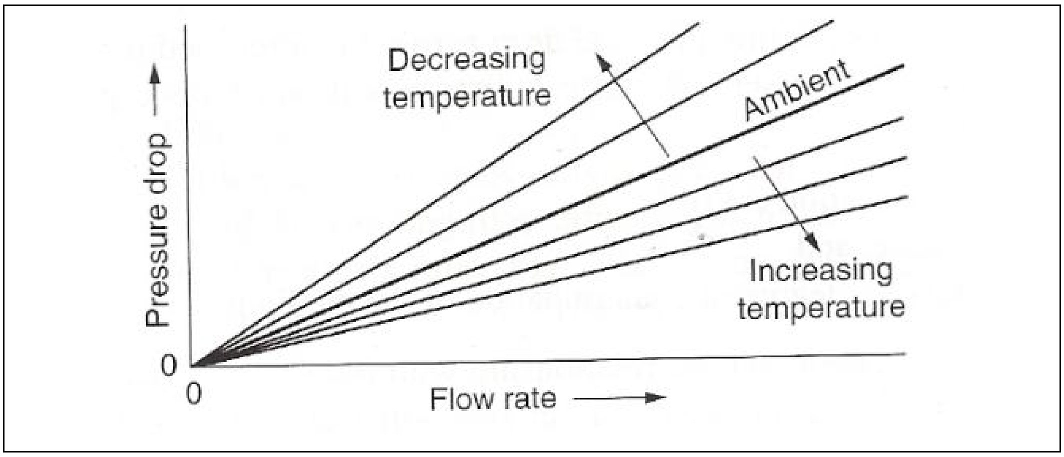


Figure 2.8 Effect of temperature change, Pressure drop and flow rate

An impact on fluid velocity is not the only potential effect of temperature change. At low temperatures, water contained in fuel may freeze, causing blockage or at least partial blockage of the filter, and an abnormal rise in pressure drop. A similar effect occurs with waxes dissolved in an fuel. These are changes that must be guarded against in an aircraft flying high, or a ship sailing into polar waters.

The effect of prolonged filtration time is to produce a cumulative built-up of collected solids on or in the filter medium, thus reducing permeability (and increasing flow resistance) in direct proportion to the amount of solid collected, as shown in Figure 2.9, which is another set of curves specific to an individual filter.

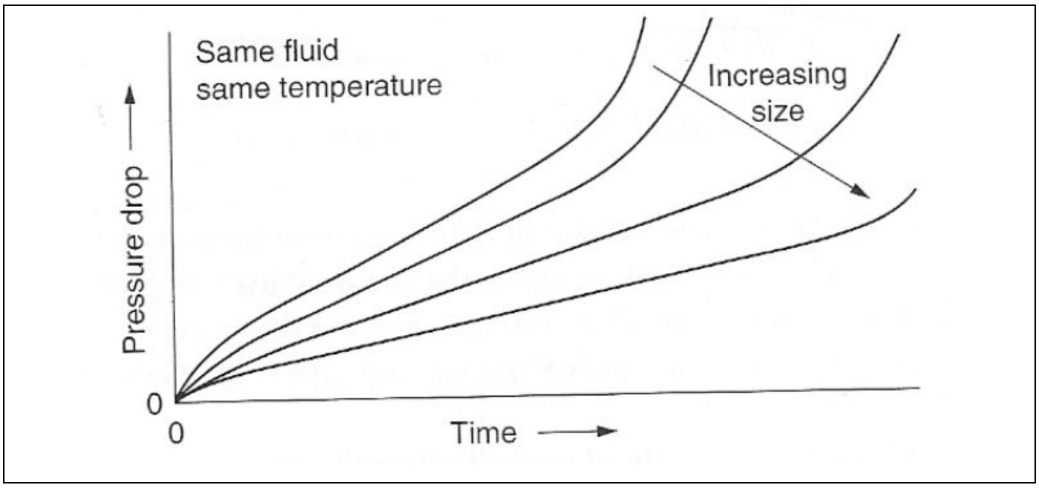


Figure 2. 9 Effect of solid loading

Characteristics expressed in the manner of Figure 2.9 are not particularly useful, because a practical filter will have been sized for a design flow rate, and this is then a working figure. It is more informative to plot the pressure drop across the filter as it changes with filtration time, to yield a single curve, as shown in Figure 2.10. The fact that this increase is caused by a build-up of contaminants is only a cause, and not an effect, although the load of contaminants retained by a filter during its working cycle can be significant as it may dictate choice both of the type and of the size of the filter element.

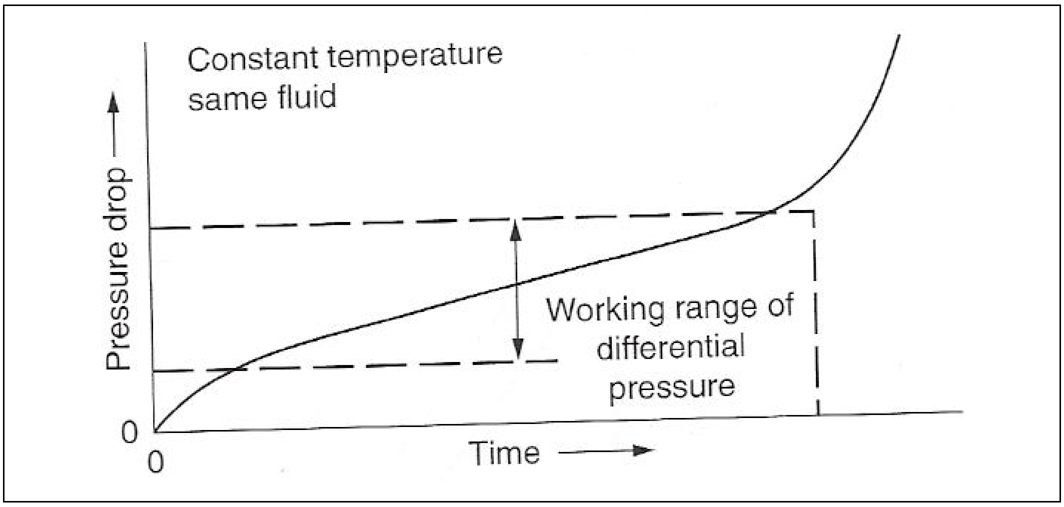


Figure 2.10 Pressure drop/time curve

The shape of the curve in Figure 2.10 is very typical: a fairly sharp initial rise, falling away to prolonged linear growth section, which then curves up into a much steeper rise. The point at which this steeper rise begins is the time beyond which the filter will be too clogged for effective use- the efficiency will continue to increase with pressure drop, but the cost of operation too high, and the element must be cleaned or changed.

The sharp increase in pressure drop can be used to indicate the need for the change, or it can cause the switch between an operating filter and its standby unit in duplex housing.

2.2 Fuel contamination and fuel filter plugging

Fuel contamination is a fact of life. 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 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 bell mouthed. 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. 2.11). If the sharp edges of the plungers or metering ports become worn, the fuel delivery characteristics will change

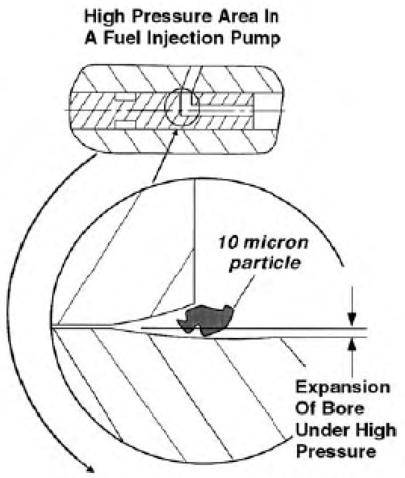


Figure 2.11 A 10 Micrometer Particle Can Be Trapped At Critical Metering Port Edges

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. 2.13) 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.2.12) 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.

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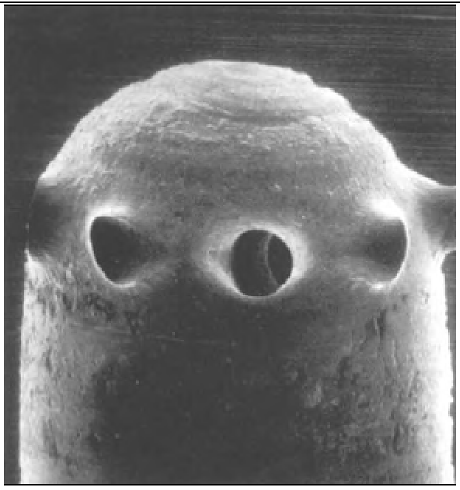
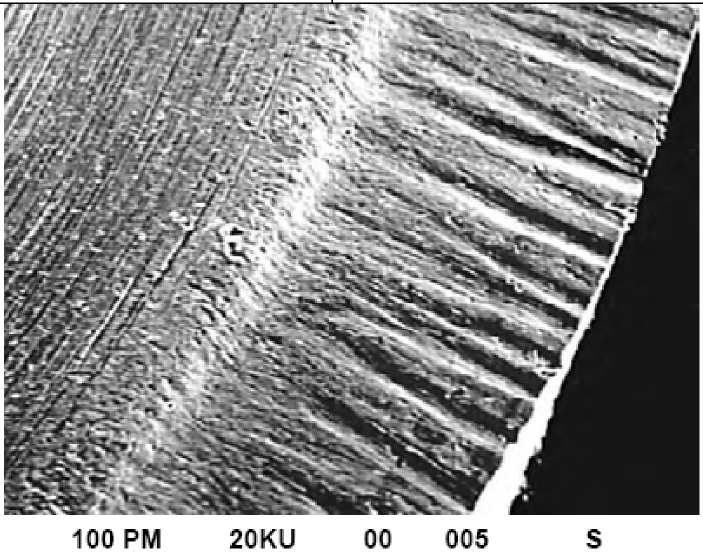
<tr><td></td><td></td></tr>
<tr><td>Figure 2.12 Abrasive Damaged Fuel Nozzle Rotor 100 x Magnification of Cut-A-Way Section Inside Nozzle Tip The Hole Edges Should Be Sharp</td><td>Figure 2.13 Rust and Corrosion On Distributor Pump & Hydraulic Head</td></tr>
<tr><td colspan="2"> </td></tr>
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Figure 2.14 Control Valve Seat Wear By Particle Erosion 100 x Magnification

Fuel filters capture unwanted contaminants from the fuel. Left unchecked, these contaminants may cause serious and expensive damage to many system components including pumps, lines, and injectors. Fuel contaminants have many sources. Most sources are external to the fuel system itself, that is, most contaminants come with the fuel that is delivered to the fuel tank. As it comes from the refinery, diesel fuel is clean. Contaminants in diesel fuel are generally introduced in fuel storage systems through mixing, transferring, and storage. Fuel filters naturally build resistance to the flow of fuel as they go about their job of removing unwanted contaminants from the fuel system. Fuel systems, unlike lube systems, do not have the opportunity for bypass flow and consequently, as flow through the fuel filter decreases, decreased performance of the fuel system and the engine will result. Fuel filters will become restricted or plugged over their life .This is an expected result. A thorough investigation of the filter and the fuel source should be conducted anytime a fuel filter is suspected of delivering less than its expected life.

Some common contaminants found in today's fuels might include:

2.2.1 Water

Water is the greatest concern because it is the most common form of contaminant. Water may be introduced into the fuel supply during fueling when warm; moisture laden air condenses on the cold metal walls of fuel storage tanks or from poor housekeeping practices. The effects of water in diesel fuel can be serious. Water can cause a tip to blow off an injector, or reduce the lubricity of the fuel which can cause seizure of close tolerance assemblies such as plungers. Once in the system, water can be removed by using in-line water separating filters or devices. Long term prevention of problems associated with water in fuel is best accomplished by obtaining fuel from reputable suppliers capable of providing high quality fuel. Further, fuel tanks should be kept well filled to prevent condensation, and fuel should be drawn from the top of a storage tank if possible, as water is heavier than diesel fuel and tends to settle to the bottom of storage tanks. Tanks can also be kept free of water with continuous off-line or "kidney-loop" filtration/separation.

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. 2.13.)
2. Causes cavitations 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.

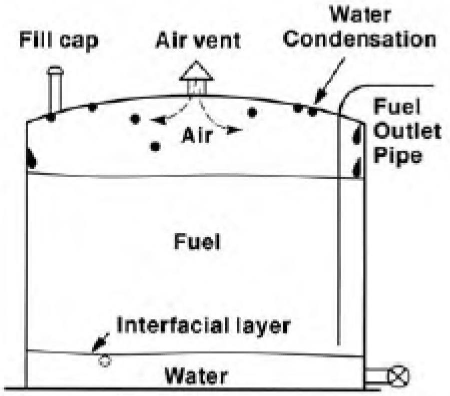


Figure .2.15 Stored Fuel Can Be Contaminated By Many Sources

2.2.2 Fungus and Bacteria

These micro-organisms live in water and feed on the hydrocarbons found in fuel. Called Humbugs for short, these active and multiplying colonies will spread throughout a fuel system and quickly plug a fuel filter. The fuel filter will have a slime coating over the surface of the media, dramatically reducing the service life of the filter. Bacteria may be any color, but is usually black, green or brown. Draining the system will reduce microbial activity, but will not eliminate it. The only way to eliminate microbial growth once it has started is to clean and treat the system with a biocide.

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.

2.2.3 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. 2.16).

Figure.2.16 . Fuel Metering and Governing Components of A Distributor Type Injection Pump Destroyed By Rusty Water Contamination

2.2.4 Air

Fact #1: There is air entrained in diesel fuel.

Fact #2: A very slight pressure drop can cause air to form visible bubbles.

Fact #3: Air can cause problems.

Fact #4: Air entrained in diesel fuel is not the same as diesel fuel vapor.
Fact #5: Air, once freed from fuel, will not go back into solution. Fuel vapor, however, can go back into solution (solid fuel).

Air is a form of contamination, although not usually classified as such
The Problem; When fuel is in storage and quiescent, air is not visible. Depending on how much air is present in molecular form, more or less will separate from fuel as it moves through any torturous path, such as a fuel filter, and collects in any high point in its path.

If this collection point is above the outlet of the filter, the air will collect until the bubble is large enough to reach down to the outlet. The air will begin to extend beyond the outlet orifice due to its surface tension until forces are great enough to break part of the air bubble free. It then passes into the outlet line as a significant size bubble. In the past, the average size engine never noticed air bubbles passing through its injection system because the absence of solid fuel was of such a short duration, the kinetic forces kept the engine running while missing a few power strokes until solid fuel reentered the injection system. In the vocabulary of diesel fuel injection engineering there is a term called IEB (Interrupted Exhaust Beat). One cause of IEB is air bubbles passing into the fuel injection system; other causes are not relevant here.

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

For small engines, the problem will often result in an engine shutdown, because the amount of fuel for each injection is so small that the air bubble lasts during too many injections and the engine will stall before solid fuel re-enters the system. With the advent of electronic controls, the problem can become even greater. In some of those systems, the air bubble may be sensed as “fuel exhaustion” and the engine goes into shutdown mode.

Many smaller engines, however, use rotary distributor type fuel injection pumps and these, due to their design, can often handle the incoming air bubble. The air escapes into the governor cavity before being metered to the high pressure pumping plungers.

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 ingression. 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.

The Solution; The simplest and best solution is to use a filter head that has the outlet line exiting directly from the top, with no place for air bubbles to collect. In this solution, air is not stopped from coming out of fuel, but as each minute bubble forms, or coalesces on the downstream side of the filter media and passes to the top side of the element, it will pass out of the filter as a very tiny bubble. These bubbles seen in clear tubing may appear in a minuscule stream as champagne type gas bubbles.

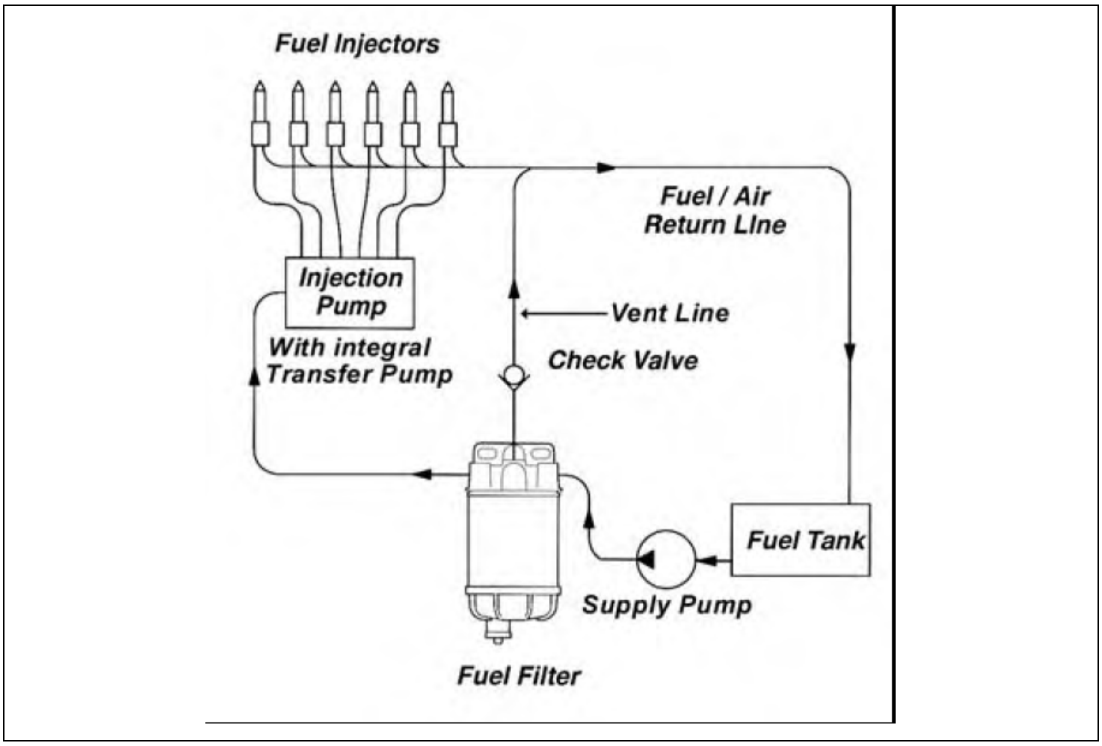


Figure.2.17 An Air Bleed Vent Can Be On Either The Dirty Side Or The Clean Side of The Filter

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.2.18). 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. 2.17) but must be small enough to prevent loss of fuel supply to the injection system. An orifice up to about .040mm (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

Figure 2.18 This Filter Has a Continuous Air Bleed Vent

2.2. 5 Wax/ Paraffin

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. US Nationwide surveys shows that in some years some fuels had a cloud point as warm as 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 -7°C and ranged from -28°C to -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.

2.2.6 Asphaltines

These are components of asphalt that are generally insoluble and are generally present to some extent in all diesel fuel. These black, tarry asphaltines are hard and brittle, and are made up of long molecules. Fuel with a high percentage of asphaltines will drastically shorten the life of a fuel filter.

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

2.3 Fuel filtration systems on automotive

The fuel system aims is 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. 2.19). The atomized fine spray of fuel will then burn readily in the engine

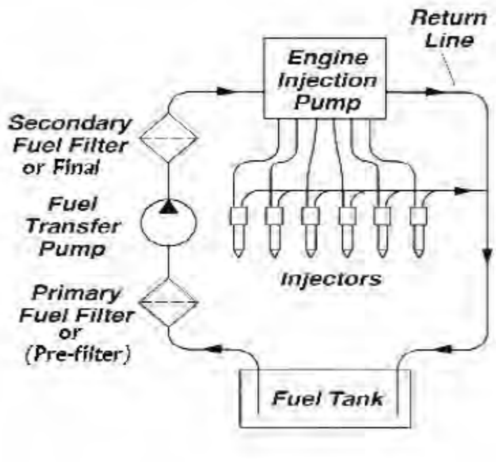


Figure 2.19 Typical Diesel Fuel Delivery System with High Transfer Pumps

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

2.3.1 Transfer Pumps

2.3.1.1 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 2.20). They are, however, designed to produce a constant pressure of 5 to 7 psi, regardless of engine speed.

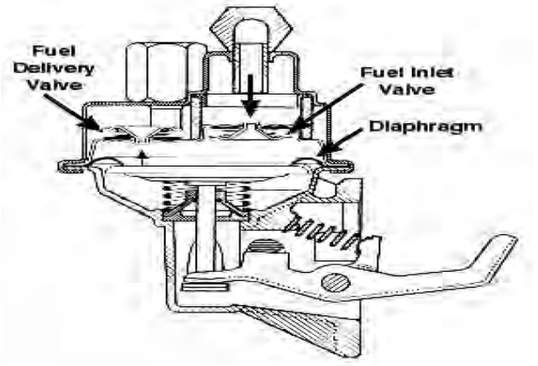


Figure 2.20 A Diaphragm Type Transfer Pump

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.

2.3.1.2 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 2.21) 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

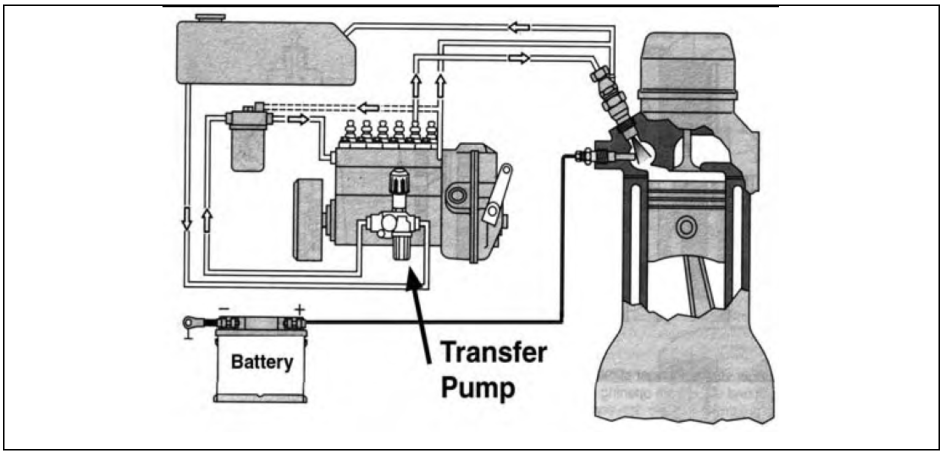


Figure 2.21 This Piston Transfer Pump Is Mounted On the Side of the Injection Pump

2.3.1.3 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.

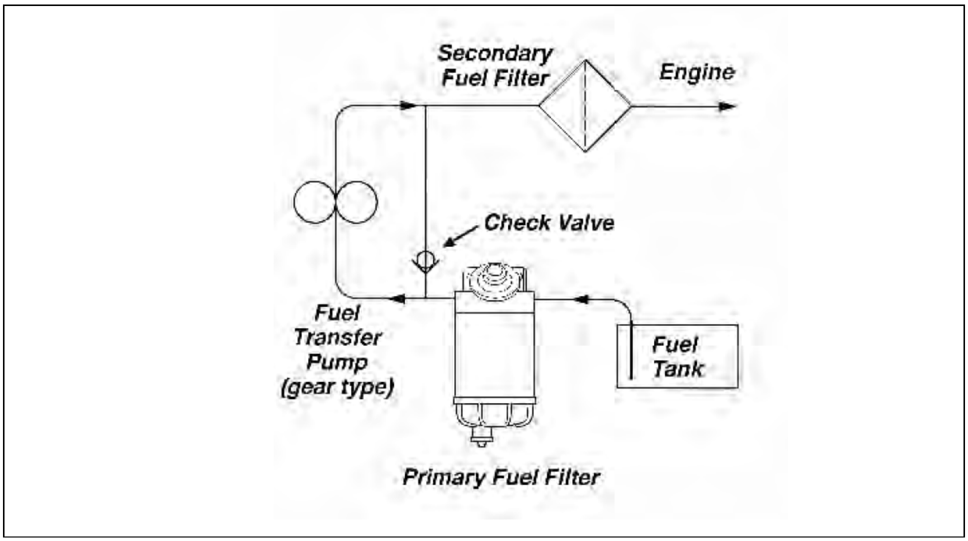


Figure 2.22 A Bypass Around A Gear Pump Is Needed to Prime the Secondary Fuel Filter

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. 2.22). Gear pump output volume is speed dependent. Figure 2.23 shows the gear arrangement to create a liquid transfer.

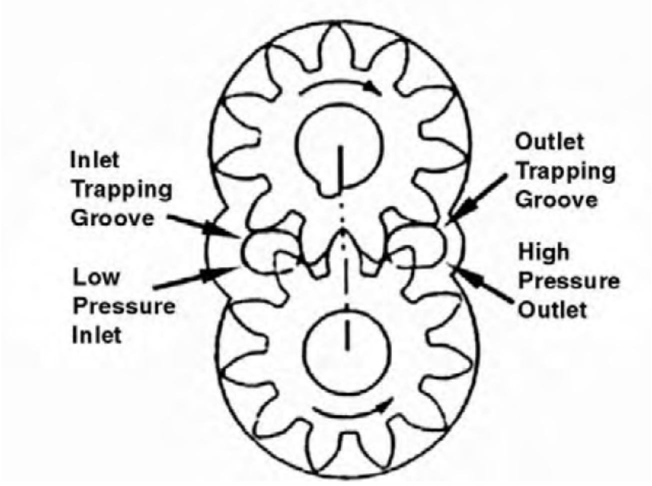


Figure 2.23 In a gear type pump, fuel is pushed around by the gear teeth and is pressurized by he teeth coming together

2.3.1.4 Electric Fuel Pumps

Electric fuel pumps have been mostly used in light & medium trucks, cars and boats, but are beginning to be used for large diesels. They are popular because of their ability to supply fuel to the injection pump immediately after keying to the starting mode even if the fuel has drained from the fuel lines back into the fuel tank. The high speed pumping mechanism is usually by rotation of a turbine (centrifugal pump), gears, vanes or rollers in a cam ring.

Electric fuel pumps have never been placed directly in diesel fuel tanks 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.

2.3.2 Fuel injection systems (FIS)

The four basic injection systems are:

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

2.3.2.1 In-line Pumps

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. 2.24). 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. 2.25).

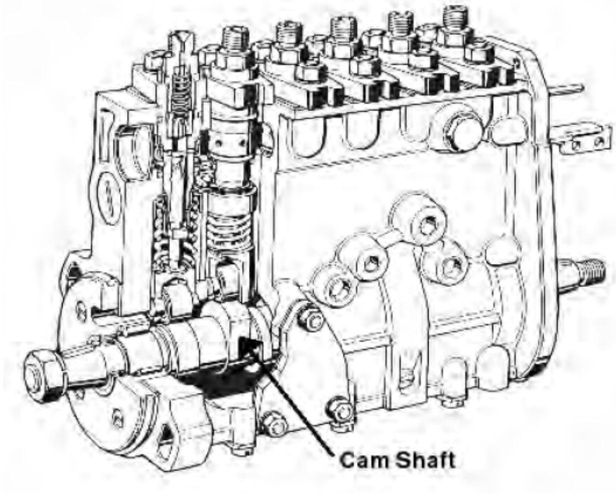
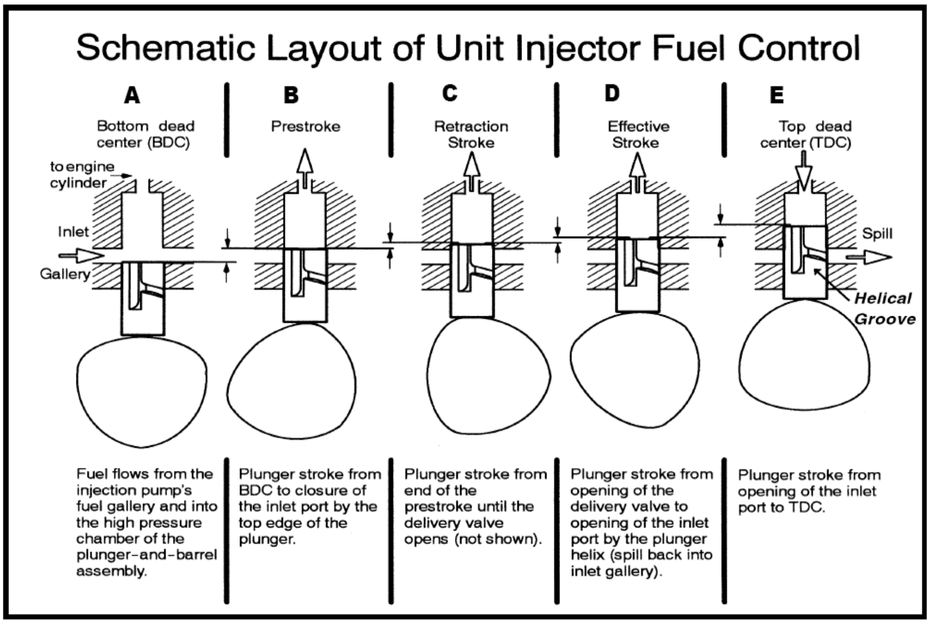


Figure 2.24 Inline Injection Pump Each Cam Lobe Drives A Piston As Shown In This In-Line Type Injection pump

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.


Schematic Layout of Unit Injector Fuel Control

Fuel flows from the injection pump's fuel gallery and into the high pressure chamber of the plunger-and-barrel assembly.

Plunger stroke from BDC to closure of the inlet port by the top edge of the plunger.

Plunger stroke from end of the prestroke until the delivery valve opens (not shown).

Plunger stroke from opening of the delivery valve to opening of the inlet port by the plunger helix (spill back into inlet gallery).

Plunger stroke from opening of the inlet port to TDC.

Figure 2.25 In-line Pump Plunger Stroke Phases

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. 2.26) 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”

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.

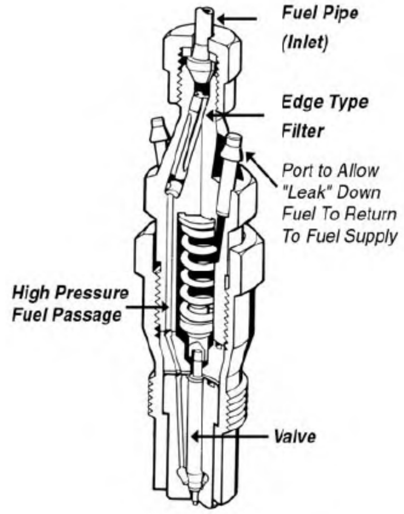


Figure 2.26 Injector Nozzle Spring Loaded Valve

2.3.2.2. Unit Injectors

2.3.2.2.1 Mechanical Unit Injectors

Unit injectors (Fig.2.27) 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 "inline" 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.

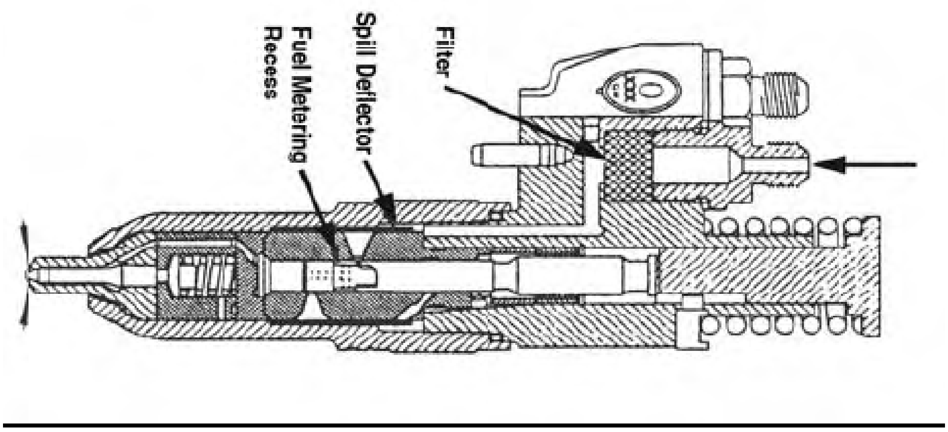


Figure 2.27 A Mechanical Unit Injector

2.3.1.2.2 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. 2.28).

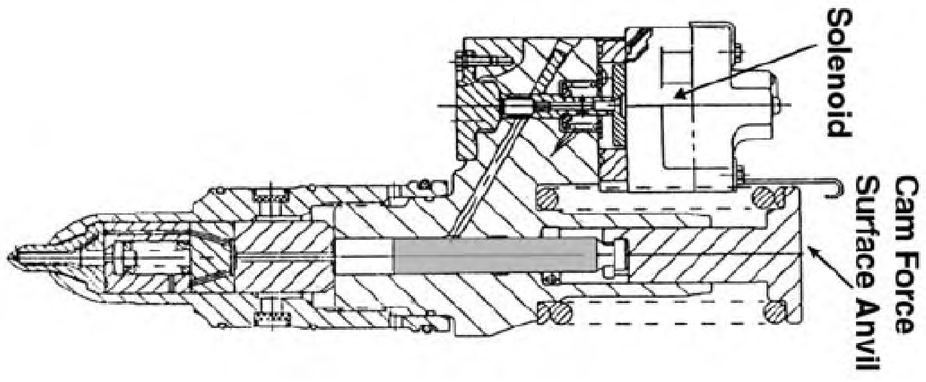


Figure 2.28 A Solenoid Operated Unit Injector

Another very high pressure version of a unit injector system is the unit pump, fuel line and nozzle, 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.

2.3.1.2.3 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.2.29). 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.

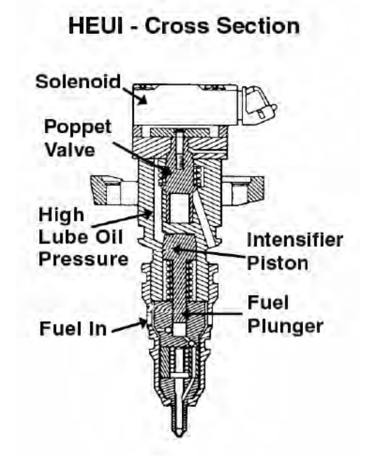


Figure 2.29 A Hydraulic Electronic Unit Injector

2.3.2.3 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. 2.30), the metering & timing is controlled by the electronic unit injector. 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.

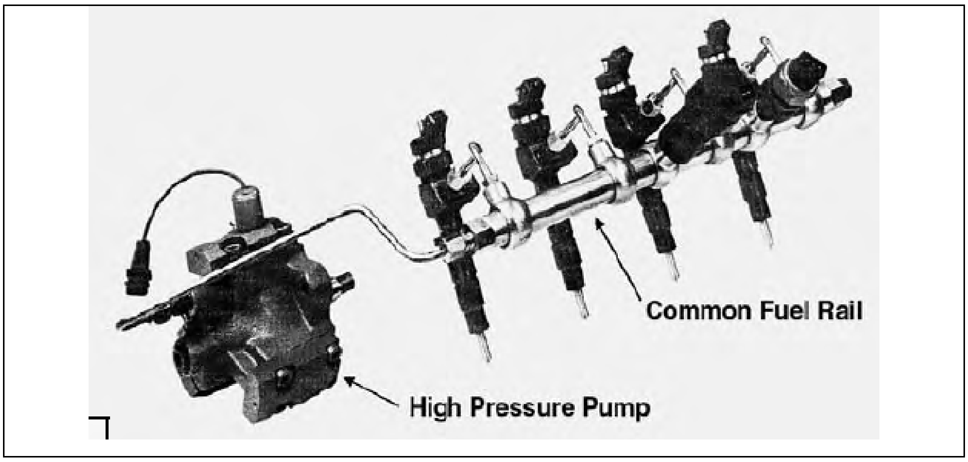


Figure 2.30 Common Rail System

2.3.2.4 Distributor Type Injection Pumps

The third fuel injection system is the distributor or rotary fuel injection pump. (See Fig. 2.31) 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.

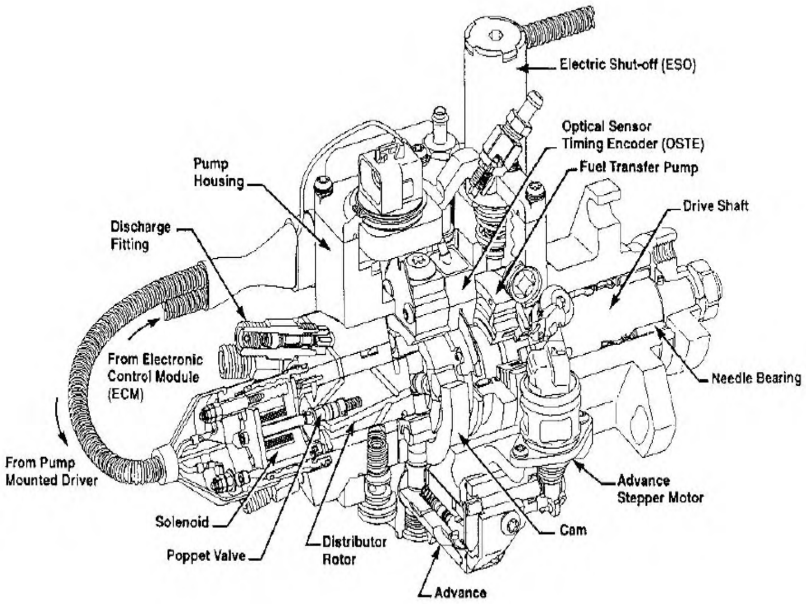


Figure 2.31 A Distributor Type Injection Pump

2.3.3 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.

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.

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.

2.3.4 High Temperature Problems

Older in-line and distributor type fuel injections systems allow a high percentage of the fuel pumped to the engine to re-circulate 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 16ºC. 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”. 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 120°C for suction side applications. On pressure side applications the maximum ambient temperature is 92°C and the maximum pressure allowable is 30 psi. The maximum fuel temperature is 60°C

2.3 5 Vapor or Fuel Starvation

Diesel fuel begins to vaporize or cavitate, at a negative pressure as low as 0.33 bar if the fuel is hot. With the advent of the high pressure common rail fuel systems the fuel re-circulated to the tank can cause fuel tank temperatures to climb to over 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

2.3.6 Fuel Delivery Systems

2.3.6.1 Primary (Pre-) Fuel/Water Separator For Vacuum Applications And Final Fuel For Pressure Applications

Fuel is drawn out of the fuel reservoir by the lift pump into and out of the pre-fuel filter/water separator. The fuel is pre-filtered through a 10 to 30 micron rated filter which also removes harmful water, thereby protecting the lift pump and injection system. The lift

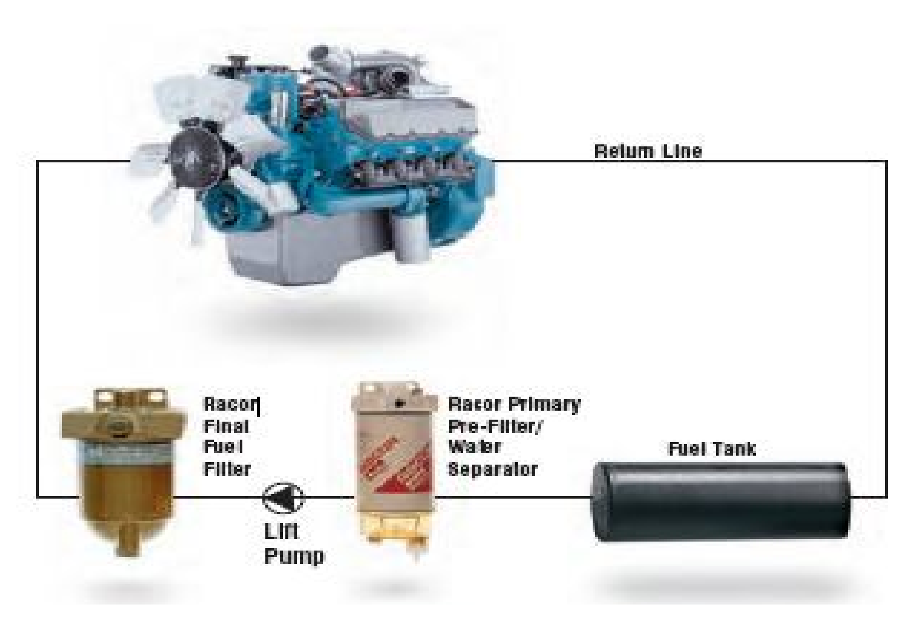


Figure 2.32 Primary (Pre-) Fuel/Water Separator For Vacuum Applications And Final Fuel For Pressure System

pump pressurizes the pre-filtered fuel into the final filter. Fuel is then filtered by a 1 to 7 micron rated filter, ensuring purified fuel is delivered. The combination filtration system design provides superior protection for heavy-duty applications where high levels of contamination and high volumes of fuel require a high filter capacity. Fuel conditioning options (drain, water sensor, hand primer pump, heater, etc.) are usually installed in the primary assembly

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

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 microns. 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 0.74 bar negative pressure should ever be allowed when a new primary filter is first installed.

Recently, 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.

2.3.6.2 Secondary (Final) Fuel Filter/Water Separators For Vacuum Applications

This design integrates the primary fuel filter/water separator and final fuel filter into one system that is installed prior to the lift pump. The single assembly provides total filtration (4 to 7 microns) and water separation for the entire fuel system. This filtration system design provides excellent protection for applications where cost and service constraints are a challenge. Sufficient space for an adequate size combination unit must be available.

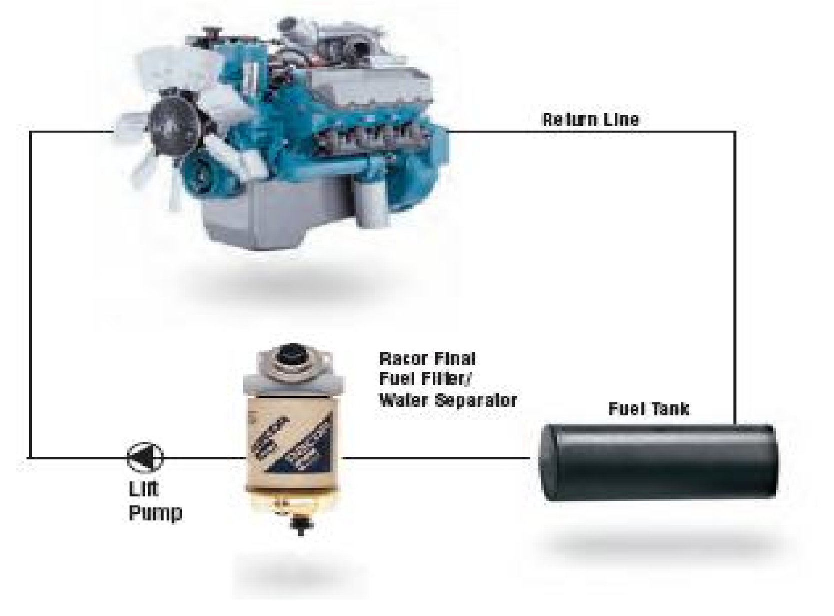


Figure 2.33 Secondary (Final) Fuel Filter/Water Separators For Vacuum System

Secondary (Final) Fuel Filter/Water Separators For Pressure Applications

This design integrates the primary fuel filter/water separator and final fuel filter into one compact system that is installed after the lift pump. Generally, an in-fuel reservoir filter screen (100 to 200 micron) is utilized to complete the filtration system. The final fuel

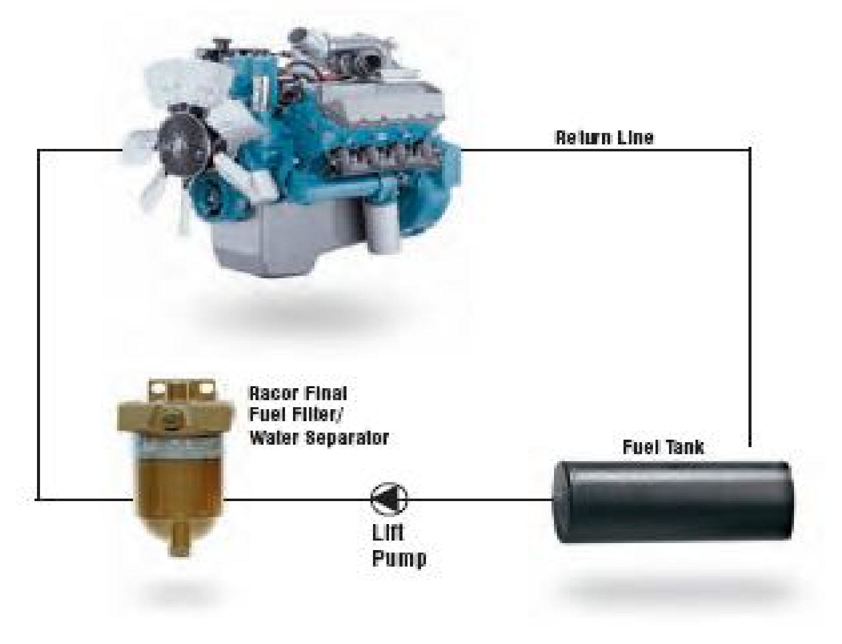


Figure 2.34 Secondary (Final) Fuel Filter/Water Separators For Pressure System

filter/water separator is installed after the lift pump and provides protection (4 to 7 microns) to the high pressure injection system. This filtration system design provides economical fuel injection system protection for small diesel engines, automotive and light-truck applications that already have generally good fuel quality and a relatively low volume of fuel usage.

2.3.6.3 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 cavitations 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.

2.4 Fuel filter types

2.4.1 Fuel Filter Types According to filter element (media) construction types

2.4.1.1 Pleated Filter Element

In a typical filter assembly, a filter element is located within a housing in such a manner that the relevant fluid flows through the filter element and particles are removed there from. In one known type of filter element, the filter media comprises a cylindrical construction of pleated material. The filter element can be coreless (i.e., the media's inner radius is self-supporting and received over a support tube integral with the filter housing) or it can include an integral support tube.

A cylindrical pleated filter media is usually made by folding media material into a plurality of longitudinally-extending pleats. The folded media is then shaped into a cylinder with the end pleats being positioned circumferentially adjacent each other. A side seam is then formed between the end pleats to maintain the media in the cylindrical shape. In this shape, the pleats have radially-inner peaks defining an inner diameter, radially-outer peaks defining an outer diameter, and side walls extending there between. The cylindrical filter media can then be mounted over its inner core (if it has one), and end caps can be attached to the opposite axial ends of the filter media. The fluid to be filtered typically passes radially inward through the filter media and then outward through an opening in one of the end caps to an outlet passage in the housing. This radially inward flow direction is usually the most advantageous for efficient filtering, although it could conceivably be more beneficial for the fluid to pass radially outward through the pleated media in certain filtering and/or coalescing situations.

It is important that the pleats of the filter media be able to withstand the pressure of fluid flowing there through .If the pleats become deformed (e.g., folded-over and/or bunched against one another), the filtering surface area of the pleats is reduced and the useful life of the filter element is significantly shortened. Accordingly, almost all pleated filter media contain some type of support mechanism for preventing deformation of the pleats. The support mechanism have conventionally been pleat able "endoskeleton" layers incorporated into the pleated media (i.e., resin-reinforced, cellulose-fiber, woven mesh layers) and/or rigid "exoskeleton" structures surrounding the pleated media (i.e., metal cages or rings). Non-rigid exoskeleton support structures, such as spiral wraps and flexible sleeves have also been used in conjunction with pleatable endoskeleton layers.

It is also important that the side seam in the filter media remain structurally sound throughout the filter's life. Any rips or tears in this seam provide bypass flow passages for the fluid thereby compromising the filter's efficiency and perhaps even forfeiting its usefulness. That being said, the side seam construction must also be designed to avoid the sacrifice of precious flow area through the filter media. Depending upon the filtering situation, the optimum side seam construction can be accomplished by sewing, gluing, taping, and/or mechanically clipping the end pleats together.

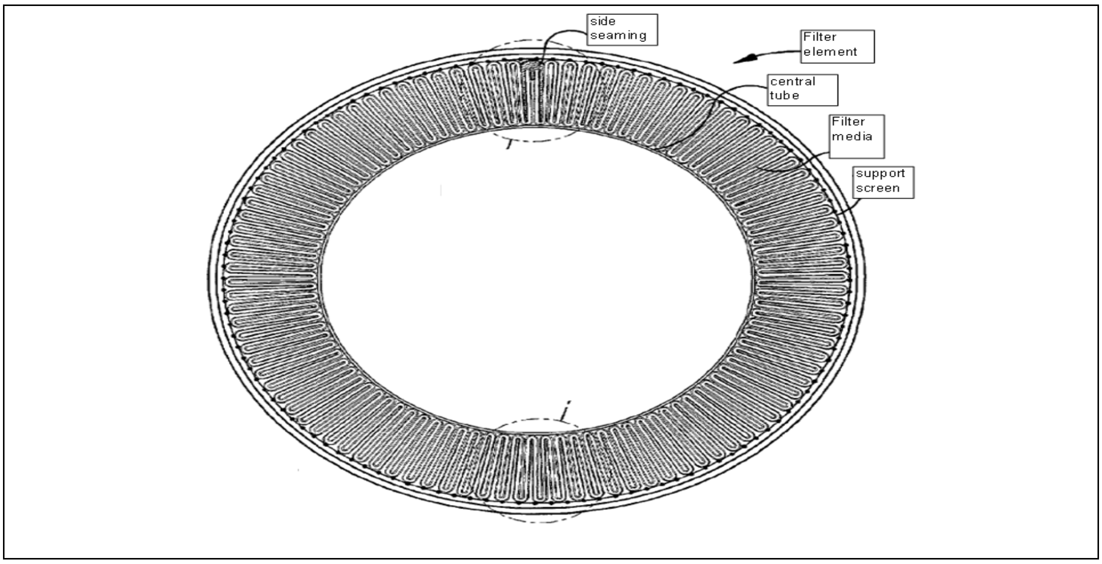


Figure 2.35 Pleated Media

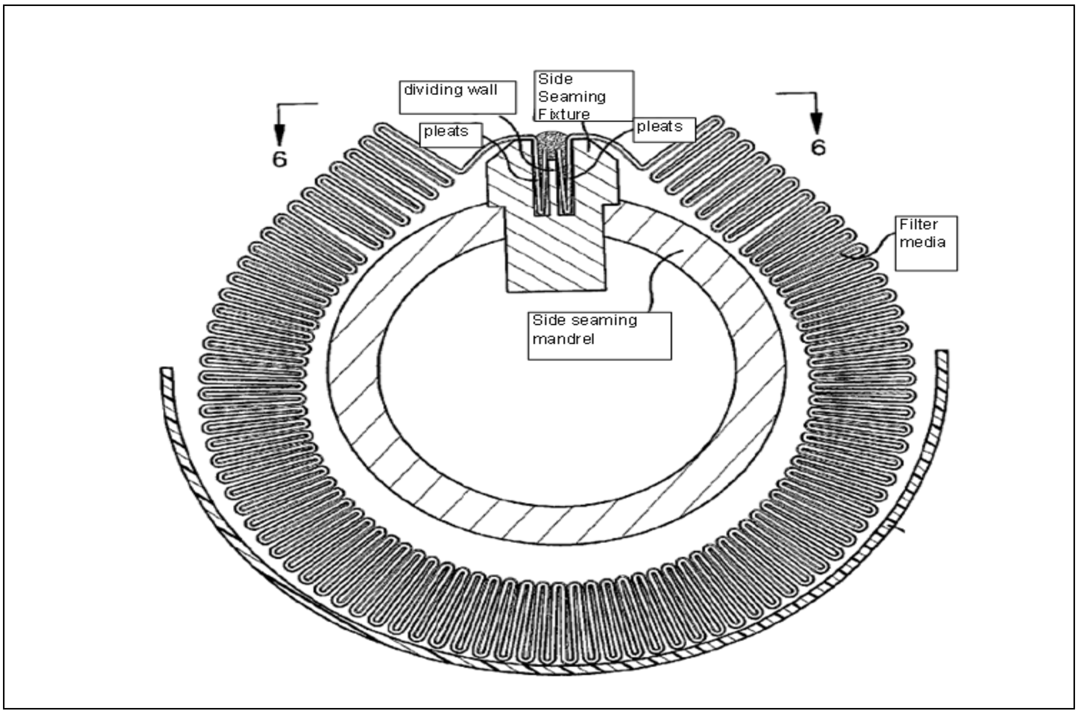


Figure 2.36 Pleated Media side seaming

2.4.1.2 Slot Depth Filter Element

Cartridge Filters are well known for filtration applications and have been constructed of many different types of materials and internal configurations of filter media. The design of many of these filters has become standardized, using a cylindrical filter housing or shell which contains an inserted element of filter media which may or may not be replaceable, depending on the economics of the particular filtration operation. In this type of filter, the fluid flow usually takes a radial path through the filter media and the filtering path is a relatively short one. This is an advantage when high filter throughput is desired, but it also requires the use of filter media which is sufficiently dense to remove fluid contaminants within the short filtration flow path. In the average cartridge filter, little can be done to increase this filter flow path, other than to increase the density of the filter media. This leads to an undesirable increase in pressure drop across the filter with a possibility of early failure due either to plugging or channeling due to the higher pressure which is set up across the filter media. To overcome this situation, a filter element constructed to allow a longer fluid flow path within the filter media is desirable. While this might be accomplished by building filters of larger diameter, this would be impractical for most cases where the filter has been designed to fit into small spaces or where standard filter housings are already in use which will accept only filter elements or cartridges of a standard size. The element should therefore be one which allows a choice of filter media density and fluid flow path while yet per mining the construction of filter cartridges which could mining the construction of filter cartridges which could changes.

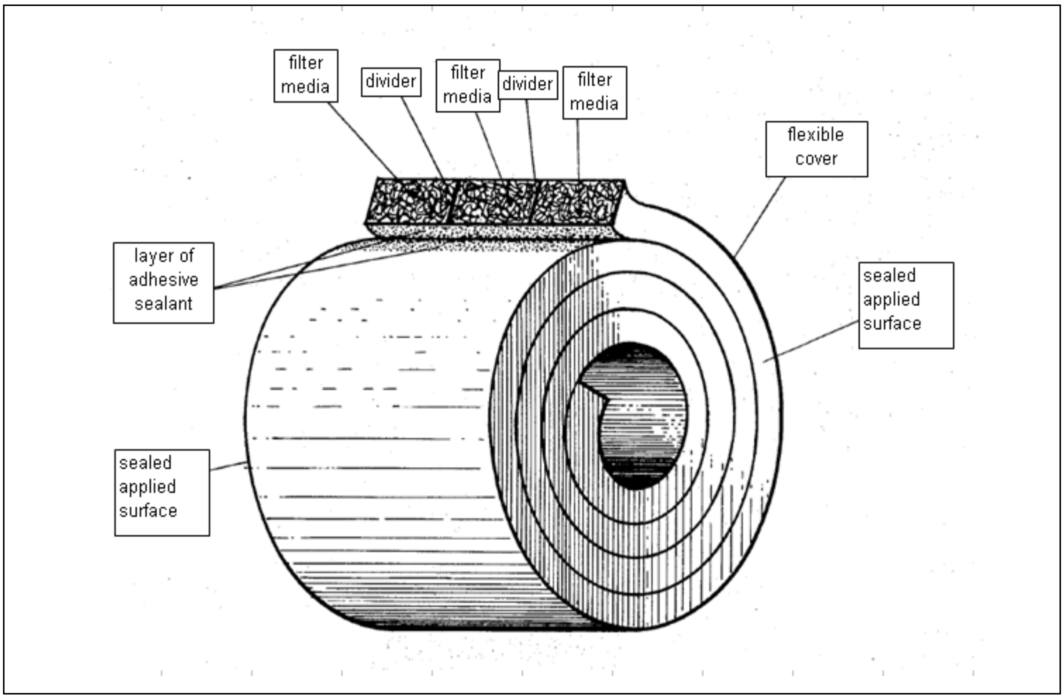


Figure 2.37 Slot Depth Filter Element

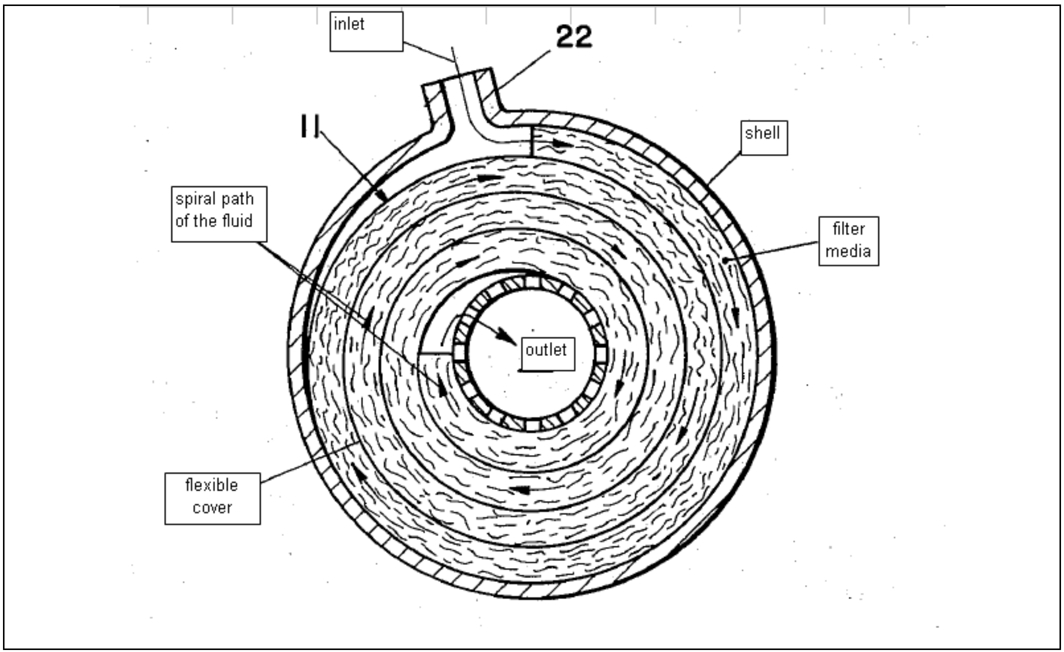


Figure 2.38 Slot Depth Filter Element Fuel Flow

2.4.2 Fuel Filter Types According to Structure

According to Structure 3 type of filters are common

Spin On Filter consist of Filter Head, Filter Can and bowl. Filter media is inside of the filter can. When the filter plugged filter can changed .These design easy to service however storage and recycle used cans is environmental problem.

		
Spin On Filters	Canister/CartridgeFilters	In Line Filters

Figure 2.39 Fuel Filter Types According to Structure

Canister/ Cartridge Filters consist of Filter head, Bowl and filter media. When the filter plugged filter media changed. Less environmental issue, Less service cost. In Line Filters are used small vehicles & engines. When the filter plugged, all filter changed. Less filter life .

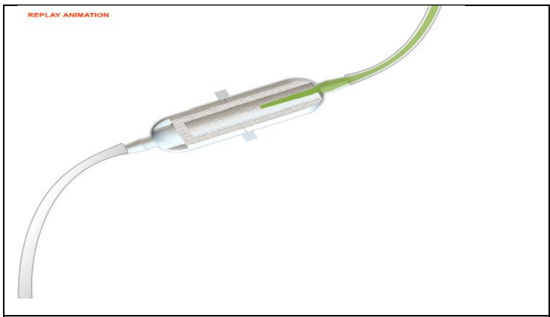
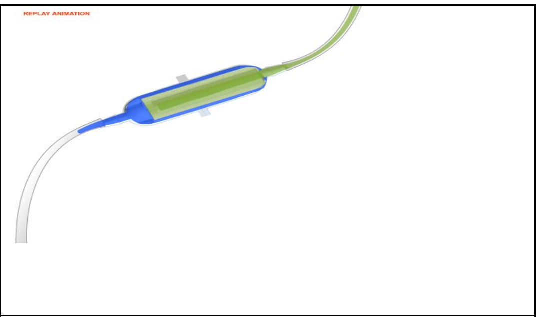
	
In line filter green dirty fuel	In line filter Blue clean fuel

Figure 2.40 In line Filter Filtration

2.4.3 Fuel filter types according to Water Separation

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 section 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.

2.4.3.1 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 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 (Figure. 2.41).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.

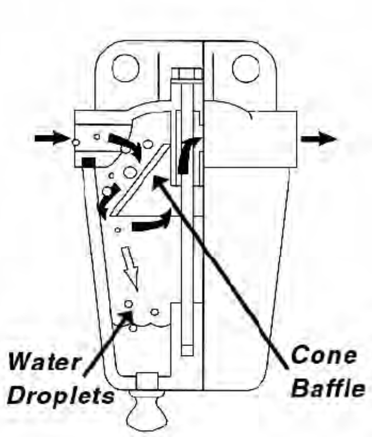


Figure 2.41 This design slows the fuel velocity so water droplets can fall out of the fuel

2.4.3.2 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. 2.42).

Barrier coalescers are relatively sensitive to low fuel temperatures (below 15° C) and also surfactant contaminants. Efficiency can be reduced dramatically at temperatures below 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 add 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.

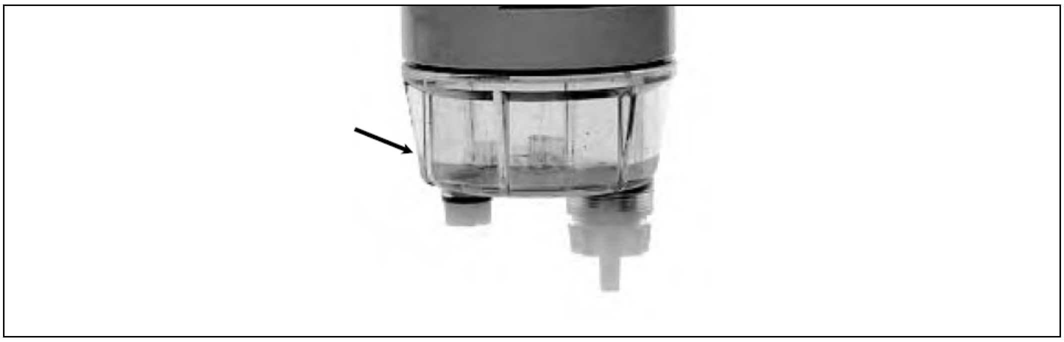


Figure. 2.42 Water is easily visible in the collection bowl.

2.4.3.3 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.

2.4.3.4 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. 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.

2.4.3.5 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.

Figure.2.43 This multi-stage coalescer has a water drain passage between the primary and secondary barriers,

Depth coalescers are very effective under the following conditions:

♦ High Fuel flow rates.

♦ When fuel temperatures are lower than 15°C.

♦ 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.

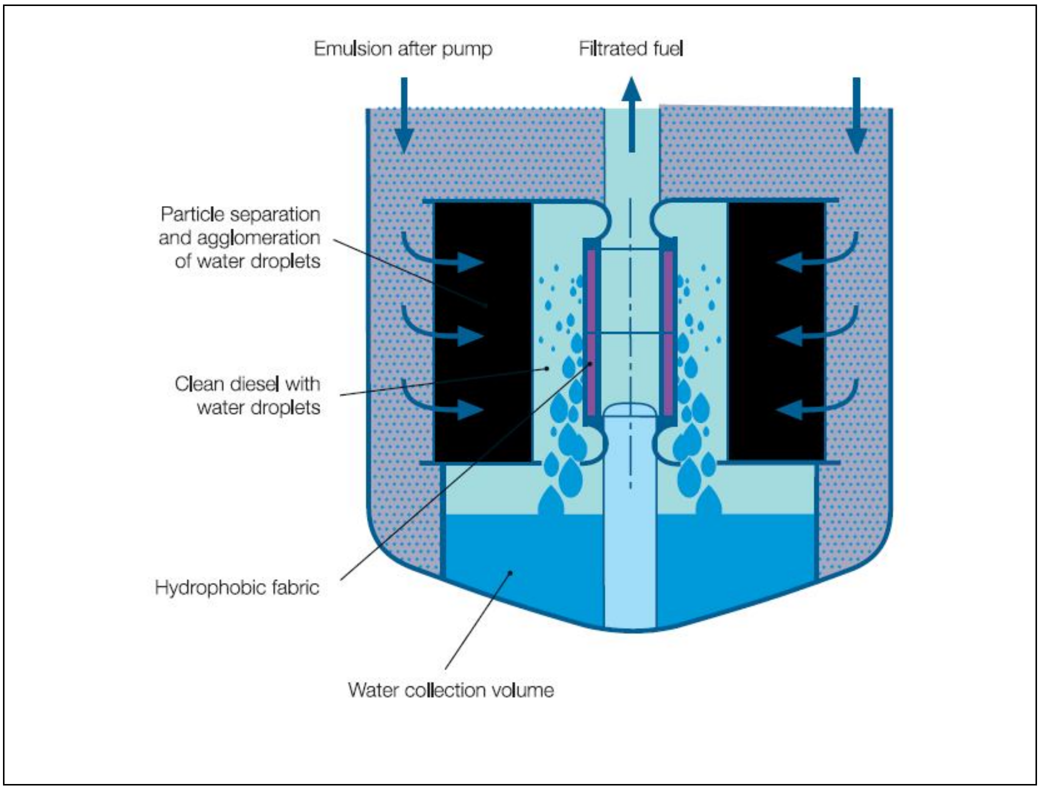


Figure. 2.44 Mechanism of water removal by hydrophopic filter media

The water separating capability of a filter depends on a large number of factors. It essentially depends on the stability of the emulsion which, for its part, is affected by the interfacial tension, the droplet size as well as the fuel pump and its volume flow.Further factors are the pipe arrangement, any non-return flow valves that may be present as well as the design of the filter on the flow side.

The most important parameter for the stability of an emulsion is the interfacial tension. The lower this is, the greater the input required for the water separation. The interfacial tension, for its part, depends on the additives of the fuel. Winter diesel is provided with a greater amount of additives and therefore has a lower interfacial tension than summer diesel

Two separate process stages during water separation: agglomeration of water droplets and separation of the water. The first filter phase consists of a cellulose filter medium with an untreated melt-blown contact surface – a fully synthetic fiber layer for increasing the dirt absorption capacity. Both the base paper and the melt-blown layer optimally cause the many small droplets to coalesce into larger ones. The particle filter designed as a pleat star even agglomerates the finest water droplets.The second filter phase consists of a water separator, whose hydrophobic fabric with a mesh width of 25 µm divides the emulsion now only slightly stable, thus separating the water. As this occurs on the clean side of the filter, it is referred to as a clean-side water separation.

In order to save space, the second filter stage is arranged coaxially inside the pleat star. The prerequisite for this was both a higher efficiency of the filter medium in the first phase as well as the avoidance of a dip tube in the center of the filter used on the pressure-side. In this way, the two-stage filter element combines improved water separating efficiency with durability and a compact package. The filters already used in series protect the injection system reliably against damage resulting from excessively high water contents in the diesel fuel.

2.4.3.6 Water separation with Self-contained devices

Water Separation with Self-contained devices is used for the separation and filtration of low density fluids such as oil, kerosene, diesel fuel, gasoline, and even air, from higher density fluids such as water and particles. The centrifugal force tends to separate the particles and higher density fluid from the low density fluids by urging the high density fluid and particles into a spiral orbit that has a greater radius than the spiral orbit of the low density fluids.

Separation of the fluids begins as the fluid and particles flow spirally downwardly as directed by spiraling flow director flange between sleeve and bowl. As the fluids and particles spiral downwardly, centrifugal force causes the higher density fluid, such as water , and the particles to seek an orbit which has a larger diameter than the low density fluid such as the fuel. Thus, a gradation is established. As the flow director flange does not touch the wall of bowl, the higher density fluid and particles which are located adjacent bowl can begin to settle directly downwardly under the influence of gravity. Additionally, separation of the low density fuel from the higher density water and particles is encouraged when the higher density water and particles under the influence of gravity and centrifugal force are unable to make a 180 degree turn along with the low density fuel, which flows up into the lower end of sleeve. The particles and high density water are collected at the lower end of bowl and can be selectively drained there from by a petcock

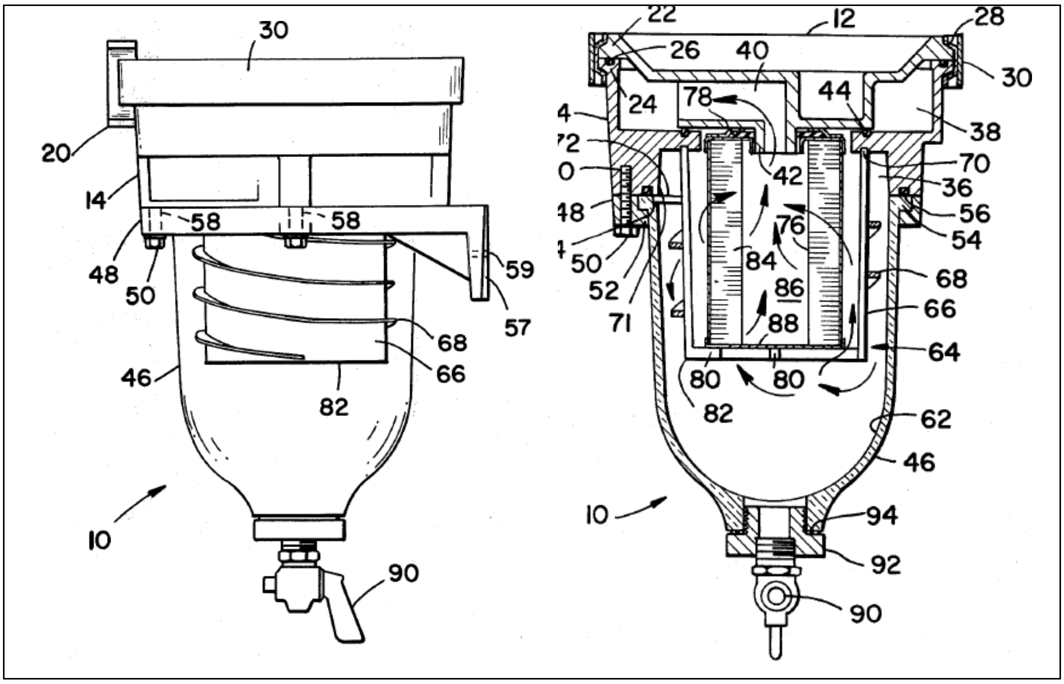


Figure. 2.45 Water removal with centrifugal forces

2.4.3.7 Water Separation with Semi permeable Baffle Fuel Filter

Fuel enters to within the connecting cylinder by way of the tube. Heavy contaminants may drop out of the fuel by passage through the contaminant outlet within the circular ridge. The fuel and remainder of the contaminants pass through the holes, thus leaving the interior fuel zone and traveling towards the exterior fuel zone. As the fuel passes radially outward, the barrier action of the filter media spiral flight preferentially slows the contaminants, while allowing the fuel to maintain a relatively higher speed. As will be readily appreciated, the fuel flow in the radially outward direction includes fuel flow into one side (i.e., the radially inward side) and out an opposite side (i.e., the radially outward side) of the layers of filter media. As the contaminants drop out of the fuel proceeding radially outward, they fall to the bottom of the spiral channel where they settle and take the long circuitous route to the outside of the baffle. Once outside the baffle, the contaminants have slowed significantly relative to the fuel and the contaminants drop from the zone through the contaminant outlet between the end cap and the inner surface of side wall. As the contaminants drop into the exterior annular contaminant collection zone, the fuel has generally kept up its higher speed and may freely pass out of the fuel outlet disposed above the baffle filter.

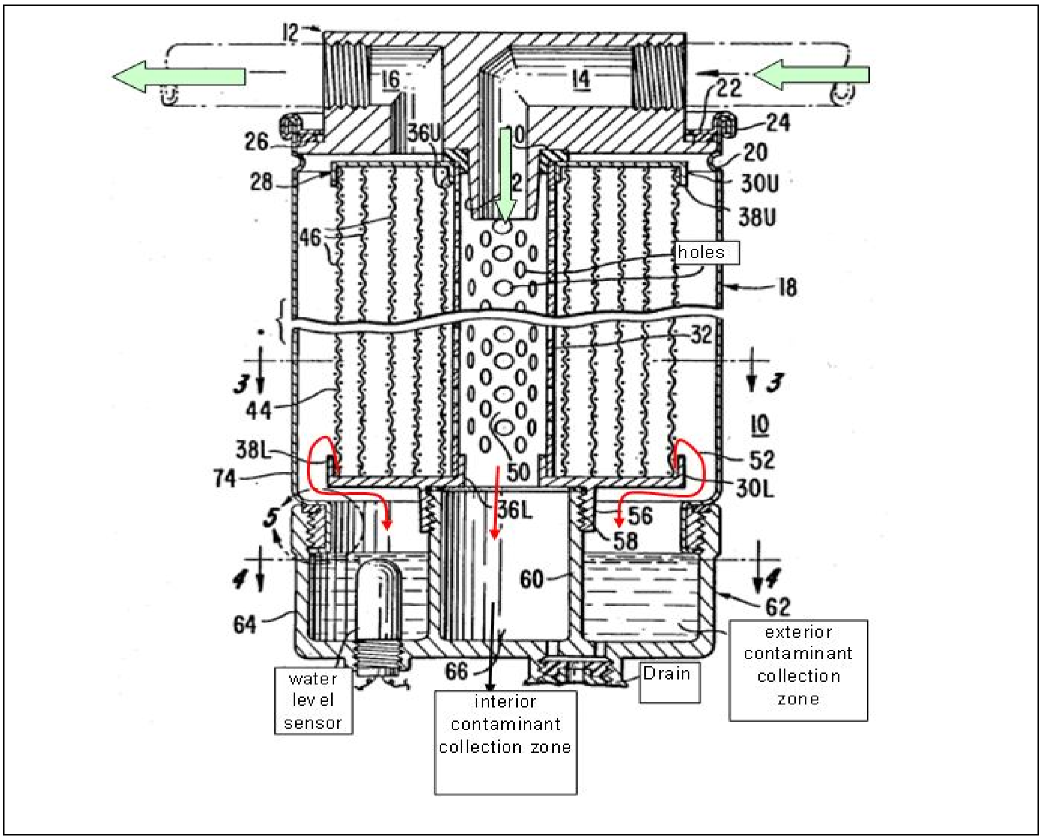


Figure. 2.46 Side view Semipermiable Baffle filter

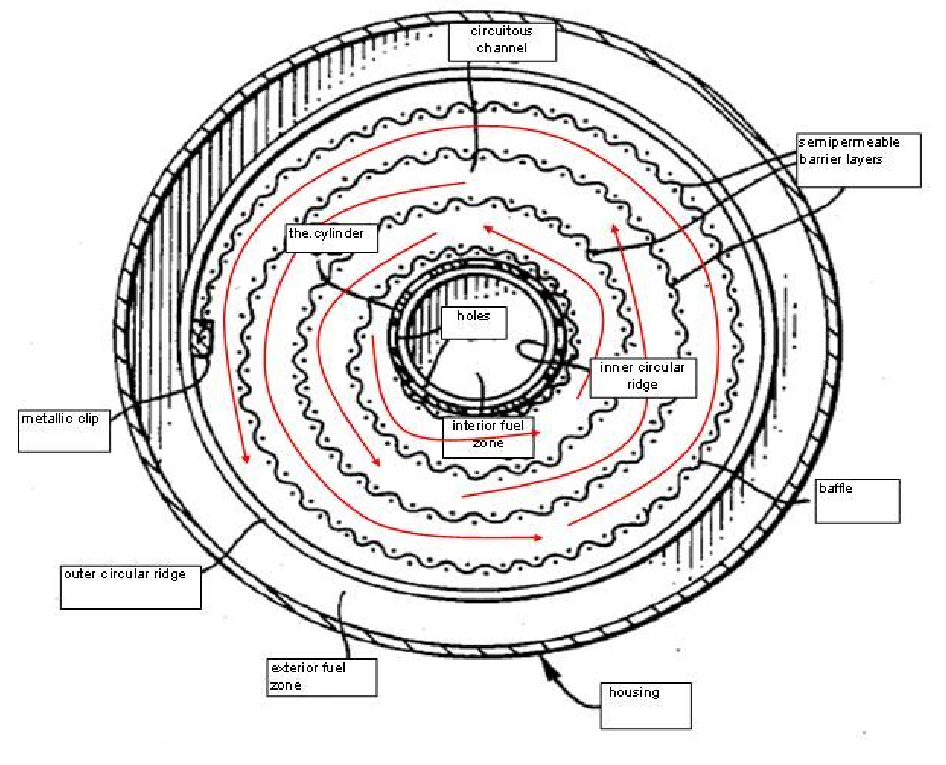


Figure. 2.47 Top view Semipermiable Baffle filter

The spiral baffle arrangement made of semipermeable material allows efficient liquid and solid contaminant separation, while leaving an unrestricted pathway for fuel flow. Thus, there can be a full fuel flow bypass of the filter media without significant flow restriction if the permeability of the filter media decreases. Although failure to change the filter may reduce the effectiveness of the separation of water and other contaminants, it will not cut off the fuel flow. Further, the configuration is particularly resistant to clogging because there is always the fully open unrestricted route or passage to the outside of the baffle. An additional advantage is that separated liquid contaminants slowed by passage through the filter media will drop into the channel and help remove settled solid particulates from the interstitial spaces. The liquid contaminants will help carry the solid paniculate contaminants along the circuitous channel to the outside of baffle whereupon the liquid and solid contaminants may drop into the contaminant collection bowl. The arrangement offers a water removal efficiency comparable to a totally closed filter element, while maintaining the long service life offered by a filterless baffle type of water separator.

2.4.3.8 Turbine Fuel Filter Assembly

Marine Turbine Series filter assemblies are designed to be installed on the vacuum side of the fuel transfer pump for best efficiency and protect precision engine components from dirt, rust, algae, asphaltines, varnishes, and especially water, which is prevalent in engine fuels. They remove contaminates from fuel using the following 3-stage process:

They remove contaminates from fuel using the following 3-stage process:

Stage 1: Separation

As fuel enters the filter assembly, it moves through the centrifuge and spins off large solids and water droplets which fall to the bottom of the collection bowl.

Stage 2: Coalescing

Small water droplets bead-up on the surface of the conical baffle and cartridge element. When heavy enough, they fall to the bottom of the bowl.

Stage 3: Filtration

Cartridge elements repel water and remove contaminants from fuel down to 2 micron (nominal). They are waterproof and effective longer than water absorbing elements.

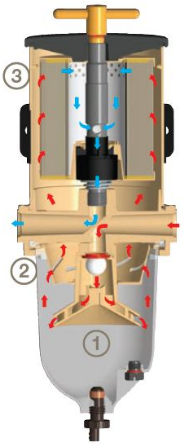


Figure. 2.48 This cut-a-way shows the “Turbine” which generates centrifugal force to separate water

2.4.3.9 Water In Fuel Sensors (WIF)

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. 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. 2.49). They are trouble free, but remember, they will not sense water if it is frozen; ice is an insulator. The probe should be accessible for cleaning when filter elements are replaced.

Figure. 2.49 This Bowl Can Hold Over a Liter of Water

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.

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.

2.4.3.10 Draining Water Removed From Fuel

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 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, and other cartridge types are “Top Loading” (See Figs.2.50 A & B). All of these are readily filled with fresh fuel after draining by simply removing the cover or bowl.

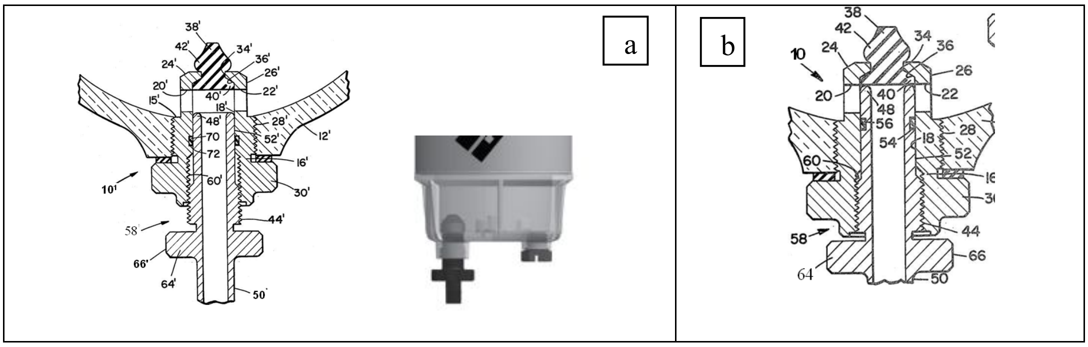


Figure. 2.50. a: Manual drain valve open position, b: Manual drain valve closed position

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. 2.53. 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.

Figure . 2. 51 Top Loading Fuel Filter

Figure 2.52 A simple automatic water drain system.

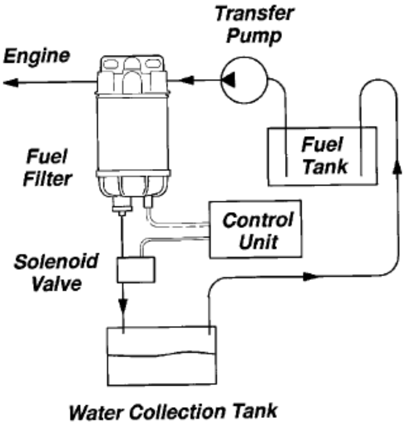


Figure. 2.53 Drawing of A simple automatic water drain system.

2.4.4 Fuel Filter Type According to Fuel Heating

It has long been recognized that hydrocarbon fluids, particularly those used in the operation of diesel engines, must be maintained at a temperature high enough so as to avoid fuel flow difficulties. If the temperature of the fuel is too low (below the pour point) the fuel will not flow due to the increased viscosity of the fuel. For example, number two diesel fuel will not flow below approximately —26° C.

Additionally, even though the diesel fuel itself may flow at temperatures above its "pour point" certain other disadvantages result when operating at such temperatures. Ice crystals and wax form in the diesel fuel at such low temperatures, causing the filter to be coated or otherwise encased, interfering with the operation of the fuel filter, which serves to remove impurities from the diesel fuel. Failure to remove the impurities may result in damage to the engine or the clogging of the fuel lines.

One approach to avoiding the above problems is to use additives to lower the viscosity of the fuel and therefore lower the temperature at which the fuel will flow freely. Common additives are alcohol and gasoline. The addition of additives, however, has not proven to be a practical method of avoiding the problems of fuel flow at low temperatures. The additives do not contain a lubricating agent which is essential for the operation of engines. As a result, the use of fuels with an additive results in the rapid wear of ejectors and pumps, and other parts of the engine

The concept that the fuel be heated in some manner has long been recognized and various attempts to provide heating units, of one kind or another, for avoiding the icing, waxing or failure of the fuel to flow have been proposed in the past. One such method has been to use the exhaust of the manifold for heating the fuel and preventing its icing and waxing at low temperatures after the engine has been wanned up, and is not useful be viscous.

2.4.4.1 PTC (Positive Temperature Coefficient) Electric Fuel Heaters

PTC Most Widely Used.(positive temperature coefficient (PTC) semiconductor). 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. PTC's are usually disc shaped heating elements that are attached to a heat sink plate which transfers the generated heat to the surrounding fuel 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.

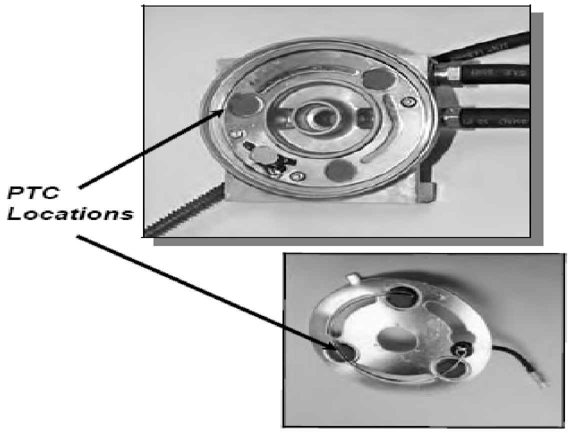


Figure .5.54 PTC Heaters Attached to Heat Sink Plates

2.4.4.2 Fuel Heating by Resistance Element (Calrod Type Heater)

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.

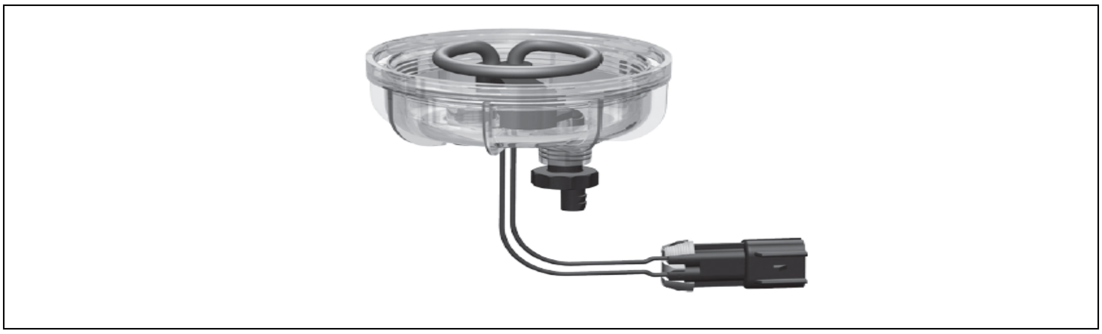


Figure 2.55. Bowl Heater

Calrod type heaters are located in the clear plastic water collection bowls, or internal of the filter housing. 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 filter 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.

Bowl fuel heater is a critical filter component for cold weather operation. An electric relay allows a switch to control the heater operation. The fuel heater turns on when fuel temperature drops below 45°F (7°C), and off when fuel temperature reaches 85°F (29°C).During operation, the in-bowl heater provides convective heat directly to the surface of the filter to melt clogging paraffin wax crystals and allow the fuel to flow.In-bowl heater and relay kits are available in 12 and 24 volt DC configurations. These kits are used to preheat the filter by turning the ignition switch to the accessory position and waiting a minimum of 5 minutes before starting the engine. After the engine starts in extreme cold weather, full power may not be available until warm re-circulated fuel returns to the fuel tank

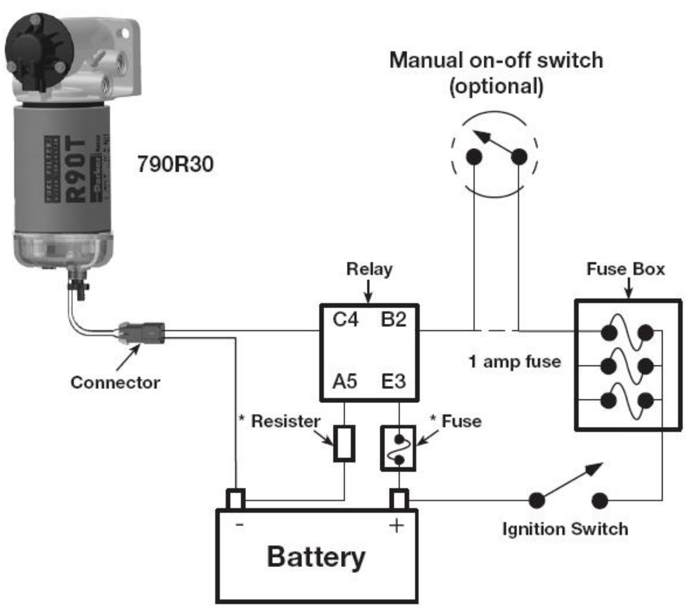


Figure 2.56. Bowl Heater Electrical Connection

2.4.4.3 Fuel Heating by Filter Head Heater

While initially heaters were adapted to preexisting filter devices with bowl heater, it has now become commonplace to incorporate the heater as an integral part of the filter assembly and to achieve an efficient heat transfer with the fuel being passed to the filter element.

The apparatus of the instant heater is an improvement over these types of devices in providing a heater structure which is located in the filter head of a filter assembly, which filter assembly includes a compound spin-on element comprising a casing for a filter element subassembly together with a removable threaded collection bowl. This form of structure is particularly suited for the spin-on type of filter element in providing a convenient and safe mechanism for accommodating the element exchange and also providing an efficient heat transfer relationship between the fuel heater and the diesel fuel passing through the filter apparatus

The fuel heater is an annular can structure having a central mounting aperture adapted to receive the threaded tube and consisting of an upper insulating housing and a lower conductive plate which is in electrical connection with the threaded tube. A feed-through electrical contact and thermostat assembly provides electrical power to a pair of PTC-type heater elements disposed on the conductive plate. A circuitous fuel path is established so that a suitable heat transfer relationship is achieved with the heater elements

Heater assembly is shown in more detail in the views of Figure 2.56 as comprising an annular container formed essentially of an upper insulating cover and a lower conductive cup which are joined at their margins and staked in place to provide a fuel heater enclosure of generally annular configuration. Upper insulated cover is depressed at the central portion thereof to form the inner margin of annular enclosure and is received on a central stud in filter head for securement in inlet chamber . Lower conductive cup is depressed at two locations about its lower wall, spaced 180° apart for receipt of a pair of heater element discs which are the devices which supply the thermal energy for warming of the diesel fuel passing through heater assembly . Heater discs are positive temperature coefficient (PTC) semiconductor elements which are commonly employed for similar purposes and which have a self-regulating thermal capability due to their relatively high positive temperature coefficient. This provides regulation of the electrical input and thus, the power output of the heater discs. A conductive plate of generally half-ring configuration is joined to the inner end of feed through connector and thermostat to supply electrical power to one side of heater discs by means of a plurality of spring fingers depending from conductive plate at the location of each of discs . As noted, lower conductive cup is in contact with threaded tube which in turn is threaded into filter head , and with all of these devices made of highly conductive metal, this arrangement provides an efficient ground connection for the heater assembly .

The in-head heater is a cold weather aid and is thermostatically controlled when power is provided. The heater will automatically turn on if the fuel temperature drops below 7°C and will automatically turn off at 24°C. Heat is supplied directly below the inlet port to melt the wax crystals and allow fuel to efficiently pass through the element. The heater is operated by turning the ignition switch on for a minimum of five minutes prior to starting the engine.

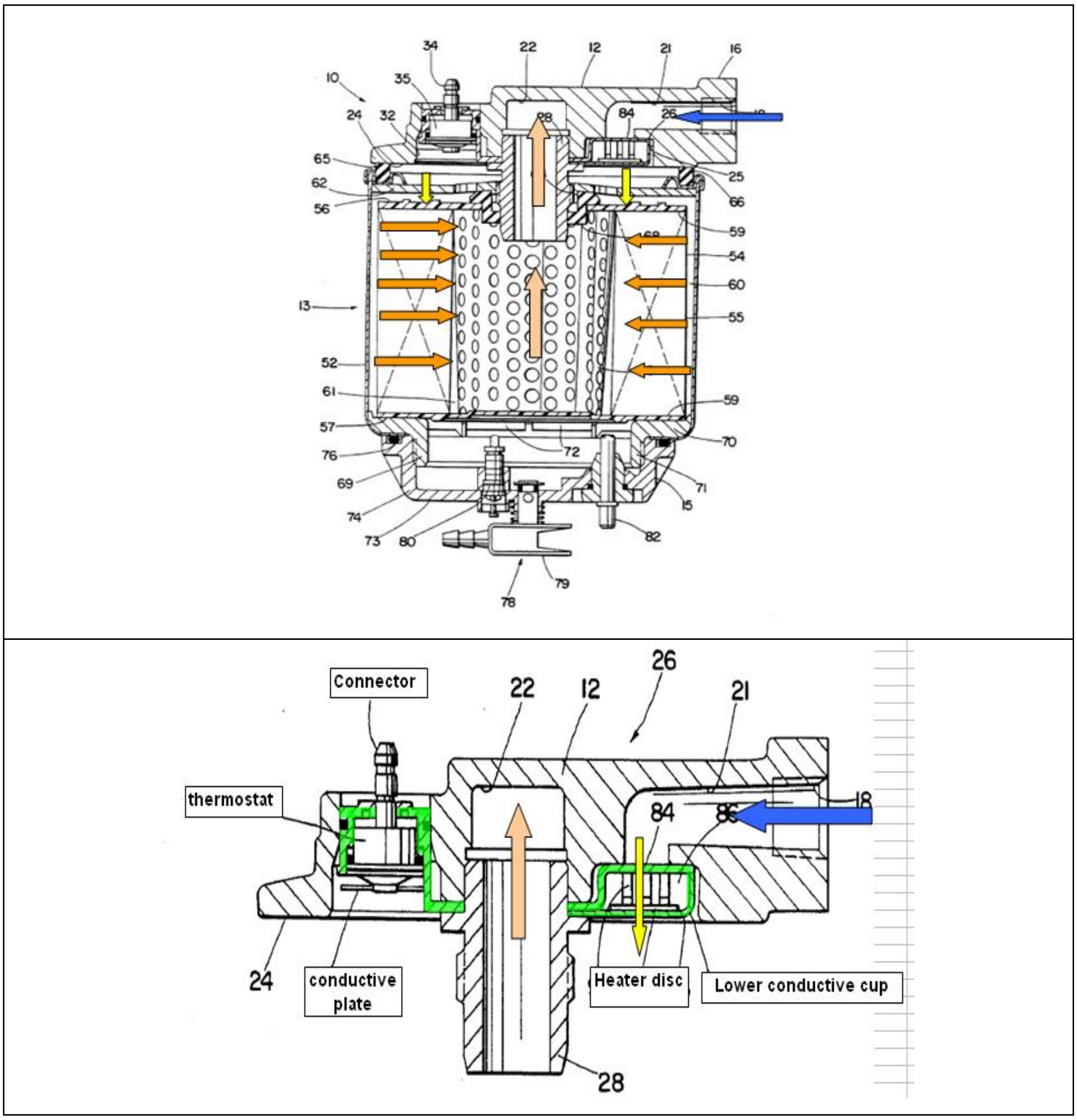


Figure.2.57 PTC Heaters Attached to filter head

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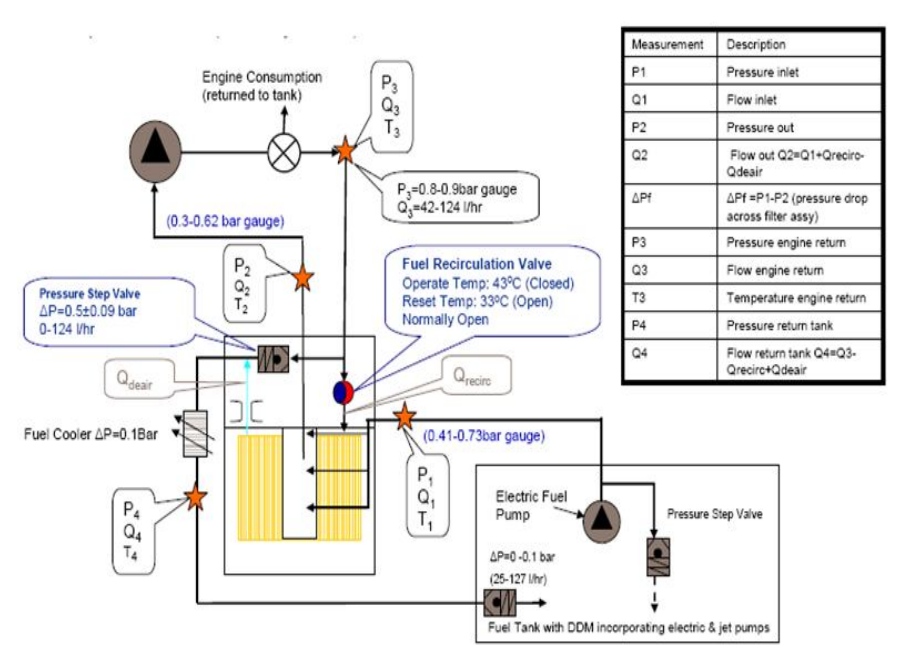
2.4.4.3 Fuel Heating by using engine return fuel as a heat exchange source (return fuel in the dirty side of filter)

These type of fuel heating system generally used in common rail injection systems where engine return fuel temperature is high. Fuel filter head has bypass ports ans thermal recirculation valve.Engine return fuel enter the filter ,there is a theramal recirculation vale on the filter head, valve is normally open position so that hot return fuel enter the filter at dirty fuel ide and heat the fuel.If fuel temperature inside the filter getting hidh such as 43ºC , thermal recirculation valve closed . Therefore engine return fuel bypass the filter and return the fuel tank.



Measurement	Description
P1	Pressure inlet
Q1	Flow inlet
P2	Pressure out
Q2	Flow out Q2=Q1+Qreciro-Qdeair
ΔPf	ΔPf =P1-P2 (pressure drop across filter assy)
P3	Pressure engine return
Q3	Flow engine return
T3	Temperature engine return
P4	Pressure return tank
Q4	Flow return tank Q4=Q3-Qrecirc+Qdeair

Fig.2.58 Fuel heater with engine return fuel

2.4.4.4 Fuel Heating by using engine return fuel as a heat exchange source (No direct contact with return fuel and fuel in the filter)

Stage 1. Fuel enters the Filter through the cover's center port. The fuel travels down the isolator tube, pushing the check ball down, then passes through fuel slots on the bottom. The fuel changes direction and travels up and around the diffuser plate. The entire time it is being warmed by the surrounding hot water jacket

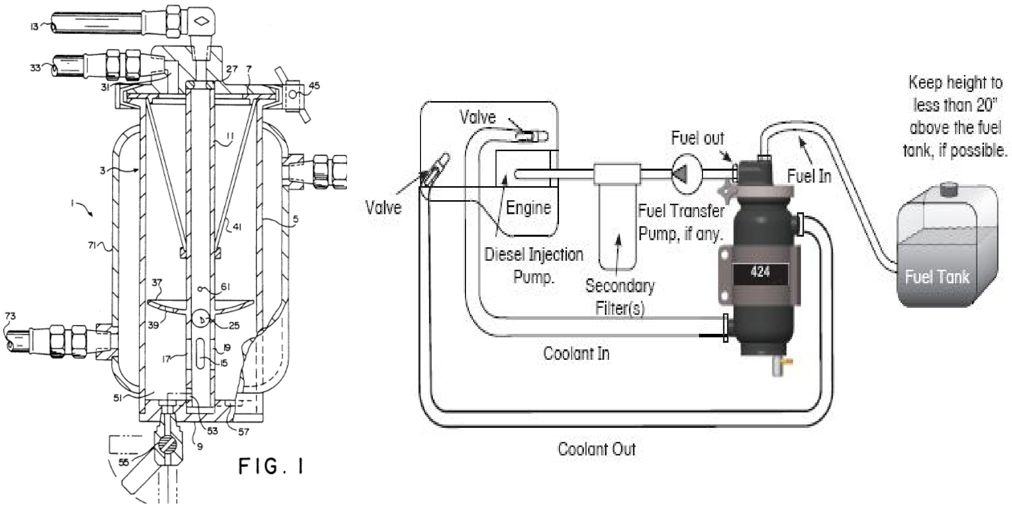


Figure 2.59 Fuel heating system by using engine return without direct contact

Stage 2. Fuel then passes through the self flushing stripper screen where the contaminants and water are left behind to fall to the top of the diffuser plate. Their, the contaminates settle below incoming fuel and collect at the base of the unit, were the contaminants and water are drained.

Stage 3. Finally the clean, dry, and warm fuel exits the Filter unit through the cover's side port and than is ingested by the engine.

2.4.5 Fuel Filter Priming Pumps

2.4.5.1 Manual Type Priming Pumps

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.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 2.60). Special 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

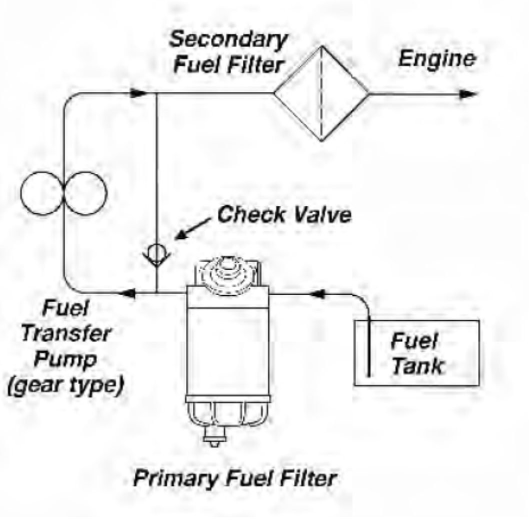


Figure.2.60 A Bypass Around A Gear Pump Is Needed to Prime the Secondary Fuel Filter

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.

2.4.5.2 Priming Pumps Piston Type

Figure .2.61 A Piston type priming pump

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. 2.61.)

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.

2.4.5.3 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.2.62). They generally have displacement volumes of about 15 cc per stroke. All diaphragm pumps have a spring return.

Figure.2.62 A Diaphragm type priming pump

Figure..2.63 A Piston type priming pump

2.4.5.4 Automatic Priming Type

Two-stage filtration and repriming system featuringba 12 volt solid-state controlled electronic primingpump, a vent valve to purge air, a 100 micron prefilter screen, a 30 micron Aquabloc spin-on element,a water sensor probe, a clear collection bowl and a weather proof control box. This complete fuel management system isolates contaminants present in diesel fuels and traps them prior to reaching the fuel injection system, protecting the engine’s fuel system from costly and premature failure.

Figure.2.64 Automatic Priming pump

2.4.6 Special Filters

2.4.6.1 Fuel Filter with Dual Filter Media and By-Pass device

Through use, the filter media can become dirty and clogged. When the filter media becomes clogged, resistance to flow increases and the filter element must be replaced. Indicators such as pressure and water sensors have been used which provide the operator with an indication that a filter element needs to be replaced. However, since the self-propelled vehicle is not always in a position or location to be stopped and the filter element replaced, by-pass devices have been developed for allowing the fuel filter to continue operating in at least a reduced capacity until an appropriate time and location are found to replace the element.

One such filter which prolongs the use of the vehicle has a by-pass valve in the filter element which opens at a predetermined pressure to allow fuel to flow around a clogged filter media. The by-pass valve in the filter element opens a fuel flow path which entirely circumvents the clogged filter media. While this type of fuel filter enables a fuel system to remain in operation, the fuel which passes through the by-pass valve is entirely unfiltered and can adversely effect the fuel system.

In order to prevent these unfiltered effect, a second filter media, separate from the first filter media, is provided in the flow path from the by-pass valve. The back-up filter media is not normally in the fuel flow path and hence is not used when the primary filter media is functional. The second filter media captures at least a minimal amount of impurities in the fuel until the filter element can be replaced.

It is therefore an object of the present filter to provide an improved fluid filter assembly for gasoline and diesel fuel which continues to separate and filter impurities in the fuel when the filter element is exposed to contaminants such as tar and asphaltenes, and which warns the operator that the filter element needs to be replaced when water begins to pass through the filter element to the fuel system.

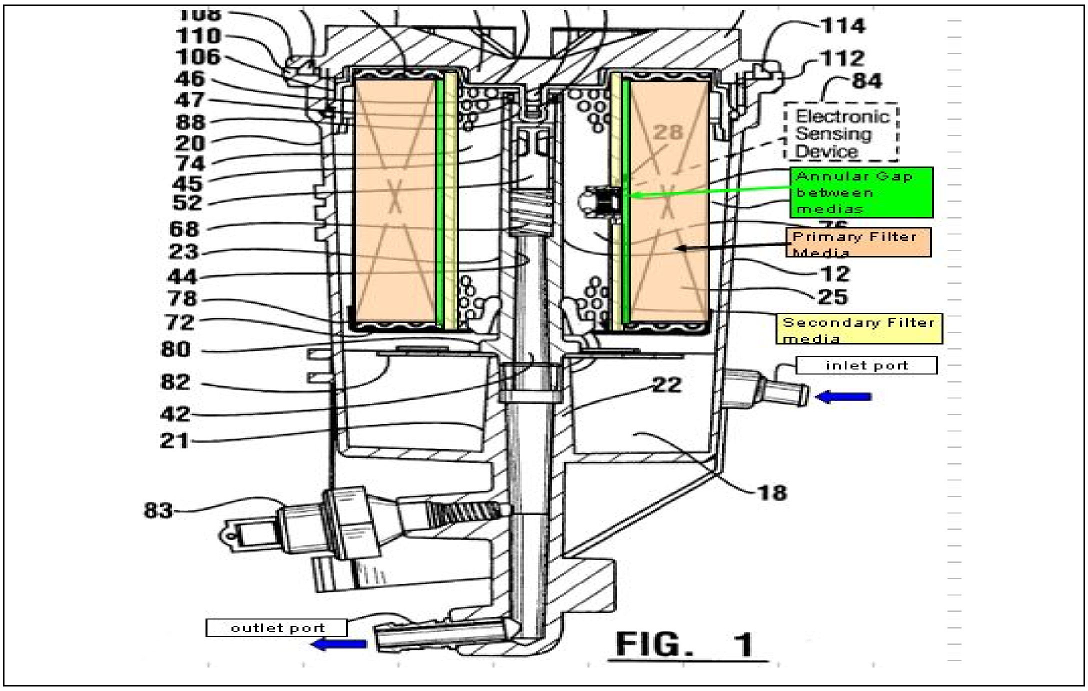


Figure.2.65 Special Filter with dual filter media & bypass device

The improved fuel filter assembly includes a replaceable filter element with dual filter media and a by-pass device disposed within a filter housing. The dual filter media includes an outer, primary filter media and an inner, secondary filter media. The outer primary media is formed from a water-coalescing medium, while the inner secondary media is formed from a dimensionally-expanding, water absorbing medium. The primary and secondary media are each arranged in the form of a sleeve or tube. The primary media is located around the secondary media and is concentric therewith. An annular gap is provided between the primary media and the secondary media for fuel flow therebetween.

Input and output flow paths are provided in the housing such that the fuel flows radially inward through the primary media to the secondary media. The primary media has a particle filtration efficiency which normally filters or separates substantially all the particles of a predetermined micron size in the fuel passing through the filter element. Further, the primary media coalesces water in the fuel, which beads and falls downward into a collection sump. The filtered fuel then flows radially inwardly through the secondary media and passes through to a central perforated tube. The secondary media normally allows the fuel to pass through the filter element without restriction.

If the primary media becomes degraded from contaminants such as tar or asphaltenes, and water begins to permeate to the secondary media, the secondary media absorbs the water. The secondary media initially prevents the water from entering the fuel system. As the secondary media absorbs water in the fuel, the secondary media expands and begins to restrict the fuel flow through the filter element, which increases the pressure differential across the secondary media. When the pressure differential across the secondary media reaches a predetermined level, a pressure sensor provides a remote signal to notify the operator that the filter element should be replaced. Additionally, the by-pass device opens or otherwise allows fluid to circumvent the clogged secondary media such that fuel continues to be supplied to the fuel system at an appropriate level.

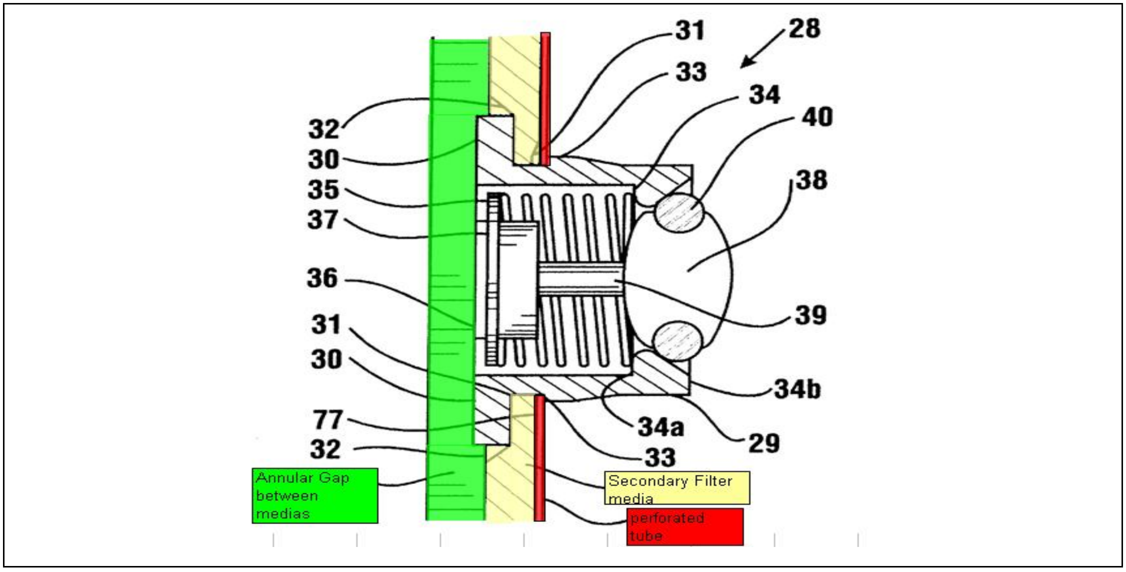


Figure 2.66 Bypass Device

2.4.6.2 Fuel Filter with Fuel Line Valve device

A popular type of filter and/or separator construction is a type that has a filter head to which a replaceable "spin-on" element is attached. The head is a permanent part of the fuel system of the vehicle and includes inlet and outlet connections to the fuel lines. The element may be readily removed from the filter head and a new one attached without opening the fuel line connections to the filter head.

Another popular type of fuel filter construction is one that has a housing which encloses a replaceable filter element.

Problems may arise such filter elements are replaced. Periodic replacement of the element ensures that the filter element will not become so loaded with impurities that fuel flow is restricted. Replacing the element also ensures that impurities are removed from fuel before it is delivered to other fuel system components such as fuel injection pumps and fuel injectors, where such contaminants may cause severe damage.

One common problem associated with changing filters is fuel spillage. The fuel lines and element are often under pressure. When the element is removed the pressure is relieved and the fuel spills out. This can present a fire hazard as well as a waste clean up problem. Air can also enter the head and pass downstream to the remainder of the fuel system. This can cause rough operation of the engine during start-up, as well as damage downstream components In order to prevent this effect; valve was added to filter system to close the fuel lines.

2.4.6.3 Spin On Fuel Filter with Fuel Line Valve device

Fuel is prevented from draining out of the filter head and air is prevented from entering the head, when an element is removed. The filter head can also only be used with a specific filter element, and the filter will not operate without such a filter element installed

The filter head has inlet and outlet ports. An annular inlet chamber is provided in the base of the head, and is fluidly connected to the inlet port. A threaded nipple is centrally located and projects axially away from the base. The nipple includes an internal flow passage fluidly connected to the outlet port. A valve assembly including elongated, spring-biased valve member is located in the flow passage of the nipple. The valve member is normally biased upwardly into a closed position—preventing flow through the passage. A portion of the valve member projects outwardly from the nipple. The outwardly-projecting portion includes a series of threads.

The filter element of the present filter includes a cylindrical housing enclosing a ring-shaped filter media. The housing preferably includes an open first end, and a second end. The second end can be closed, or can be open and include means to allow attachment of a collection bowl. End caps are provided at each end of the filter media, with an annular portion of each end cap fixed (e.g., adhesively bonded) to the respective end of the media. A tap plate encloses the filter element in the housing, and is secured to the open end of the housing. The tap plate includes a central threaded opening, and a series of peripheral openings spaced radially outward from the central opening. The central tap plate opening cooperates with the threaded nipple on the filter head to allow the filter element to be screwed on (spun-on) to the filter head. The peripheral openings are located for receiving fuel from the inlet chamber of the filter head when the element is attached to the filter head.

The filter element supports a threaded sleeve internally of the element, co-axially aligned with the central opening in the tap plate. The threaded sleeve cooperates with the threaded valve member of the filter head when the filter element is screwed onto the head to cause the valve member to move to an open position. The thread pitch (angle) on the valve member/sleeve combination is preferably greater than the thread pitch of the nipple/tap plate combination, which causes the valve member to be pulled or drawn axially outward from the nipple as the filter element is threaded onto the filter head, allowing flow through the nipple threaded sleeve can be supported on a radial end wall at the internal end of an annular wall extending axially inward into the media from the upper end cap, or by other means that rigidly supports the sleeve centrally in the filter element. Fluid can pass through the openings in the radial end wall the radial supports to the central passage in the nipple and then to the outlet in the filter head when the filter element is installed. The threaded sleeve, radial end wall and annular internal wall are preferably formed integrally (and more preferably, unitarily) with the annular portion of the end cap.

As described above, the screwing of the filter element onto the filter head causes the valve member to move to an open position. This enables fuel to flow out of the filter element to the outlet of the filter head. Disengagement of the filter element allows the valve member to move to a closed : position. This prevents air entering the head and passing downstream to the remainder of the fuel system when the element is removed. This also prevents fuel draining out of the head during an element change.

The threaded sleeve on the filter element is sized and configured so that only a sleeve having a certain length, diameter, and thread pitch will properly engage the threads on the valve member to draw the valve member to an open position. The sleeve may have different configurations with various elements, each of which corresponds to a particular filter head. Further, the valve assembly is constructed such that if an improper element is installed, fuel normally forces the valve member into a closed position, which prevents the valve element from opening during high pressure situations. As a result, only a proper filter element will operate in conjunction with the filter head, and the filter head will not operate without a proper filter element installed.

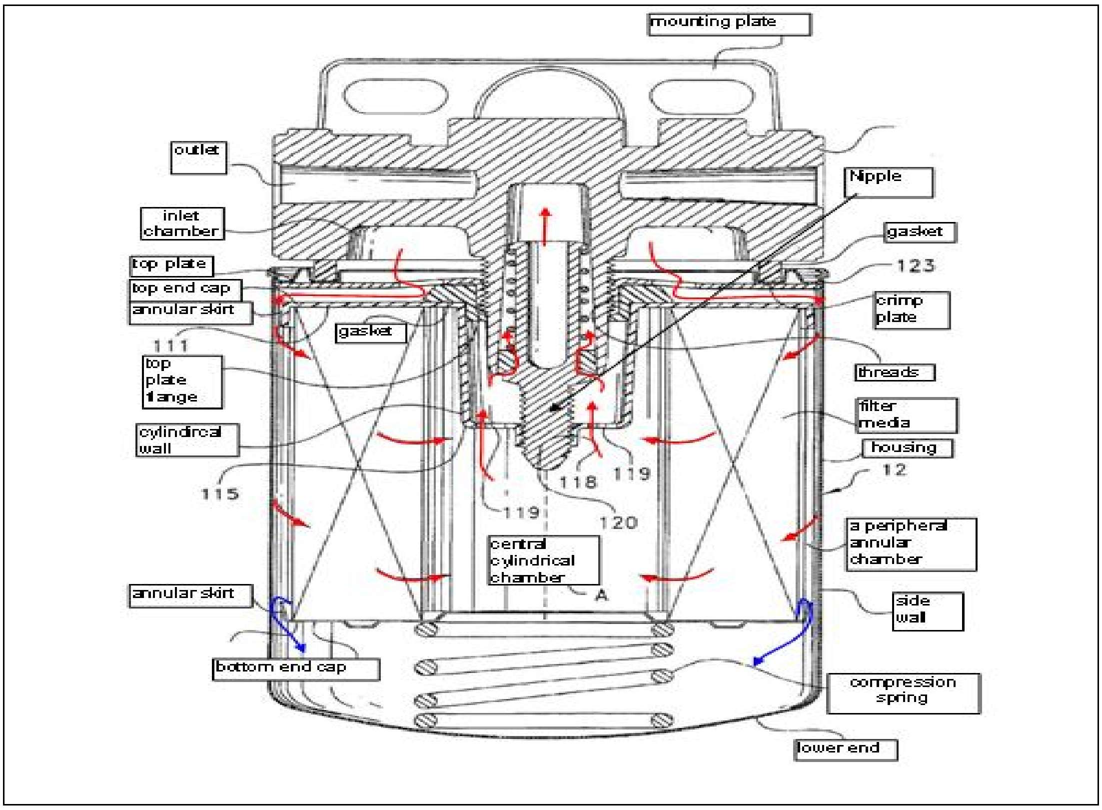


Figure.2.67 Spin On Fuel Filter with Fuel Line Valve device

2.4.6.4 Replaceable Fuel Filter with Fuel Line Valve device

The first embodiment further includes a filter head with a nipple portion which attaches the element to the head. The nipple portion includes a valve element therein. The valve element is positioned in the fuel passage in the nipple portion and is biased by a spring to a closed position.

Attachment of the element and the head causes the actuating projection in the nipple portion to engage and move the valve element therein to the open position. This enables fuel to flow out of the filter element. Disengagement of the element causes the valve element to move to the closed position so that air may not readily enter the head or the remainder of the fuel system. Further, the closure of the valve element prevents fuel from flowing out of the head through the nipple portion.

The actuating member is sized and positioned longitudinally so that the actuating member inside the element engages and opens the valve element in the nipple portion when the element is attached to the head. The actuating member may be positioned within various element types at different longitudinal positions each of which corresponds to a particular configuration of a nipple portion. As a result only the proper element will operate in conjunction with the filter head. This assures proper filtration which provides optimum engine performance and prolongs engine life

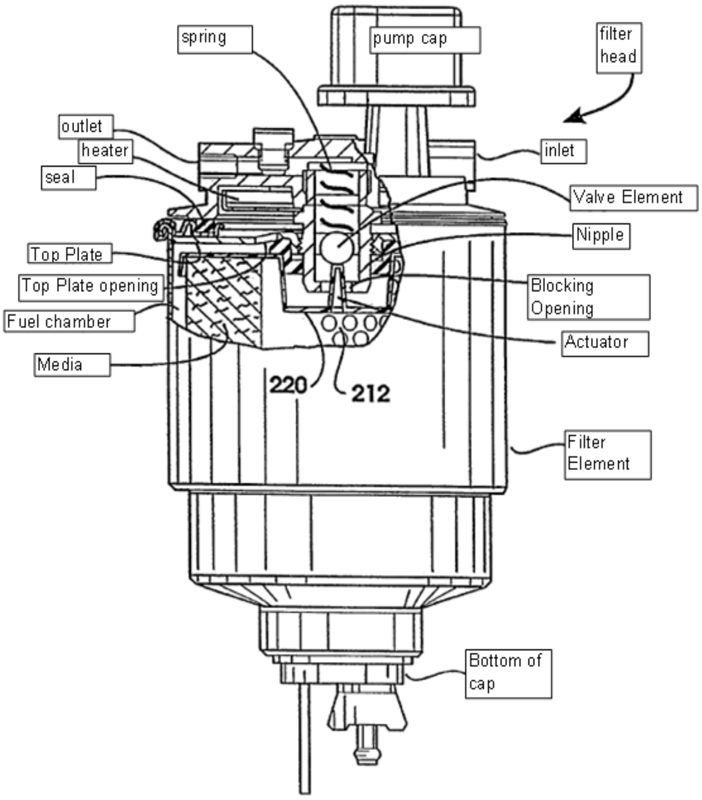


Figure 2.68 Replaceable Fuel Filter with Fuel Line Valve device

Another Valve application in replaceable fuel filter; The element includes a dividing means that includes a lip portion. The lip portion engages the annular wall between the aperture that is in fluid communication with the outlet, and the aperture that is in fluid communication with the inlet, when the element is positioned in the housing. The lip portion also engages the one-way check valve in the inlet aperture when the element is positioned in the housing and moves the check valve to an open position. The dividing means also bounds an intermediate area through which fluid may flow to the aperture in fluid communication with the outlet

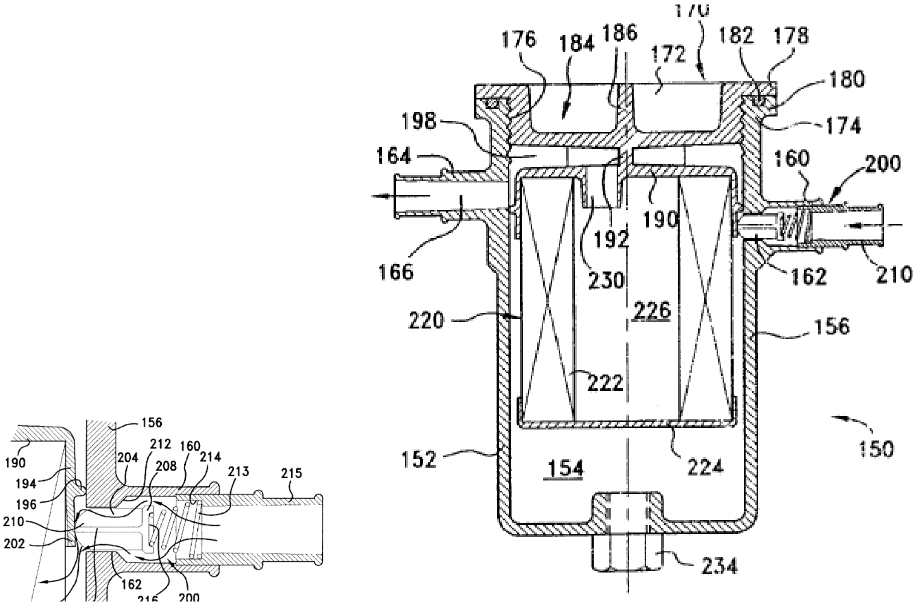


Figure .2.69 Replaceable Fuel Filter with Fuel Line Valve device

2.4.6.5 Double Pass Fuel Filter Assembly

Vehicle fuel systems typically have a fuel tank for holding a supply of liquid fuel for delivery to an engine. The fuel system also includes a lift pump for pumping fuel from the tank to the engine. Some engines, particularly those that have fuel injection, also have an injection pump which raises fuel pressure beyond that produced by the lift pump so that the fuel may be injected at high pressure into the combustion chambers

Fuel filters are included in fuel systems to remove contaminants such as dirt and water from the fuel before it reaches the engine. Fuel filters are positioned in the fuel system either on the vacuum side or the pressure side of the lift pump. Each position for the fuel filter in relation to the lift pump has advantages and drawbacks

If the fuel filter is positioned on the vacuum side of the lift pump, it has the advantage of removing contaminants before the fuel reaches the lift pump. This protects the lift pump from contaminants and prolongs its life. The drawback associated with this position of the fuel filter is that the amount of pressure available to push fuel through the filter is limited to atmospheric pressure. As a result, severe contamination may block flow and starve other fuel system components causing damage. Loss of flow may also occur in cold temperatures when wax or ice crystals form in petroleum fuels and block flow through the filter. Fuel heaters are needed in these situations to minimize the risk of problems

A further problem associated with placing the fuel filter on the vacuum side of a lift pump is that lift pumps sometimes fail and generate contaminants. If these contaminants are carried downstream in the fuel they may cause damage to the high pressure/fuel metering pump or the fuel injectors

An alternative fuel system configuration is to place the filter assembly on the pressure side of the lift pump. In this position more pressure is available to push fuel through the filter which reduces the risk of fuel starvation. Also, the heat energy imparted to the fuel by the lift pump tends to make fuels flow easier. In this position the high pressure pump and fuel injectors are protected from damaging debris from failure of the lift pump

The drawbacks of positioning the fuel filter on the pressure side of the lift pump is that the lift pump is exposed to the contaminants which may shorten its life. Further, the pumping action tends to entrain the contaminants in the fuel which makes it more difficult to filter them out when they eventually reach the fuel filter assembly

Thus, there exists a need for a fuel filter assembly that provides better filtration while reducing the drawbacks associated with positioning the filter on only the upstream or downstream sides of the lift pump.

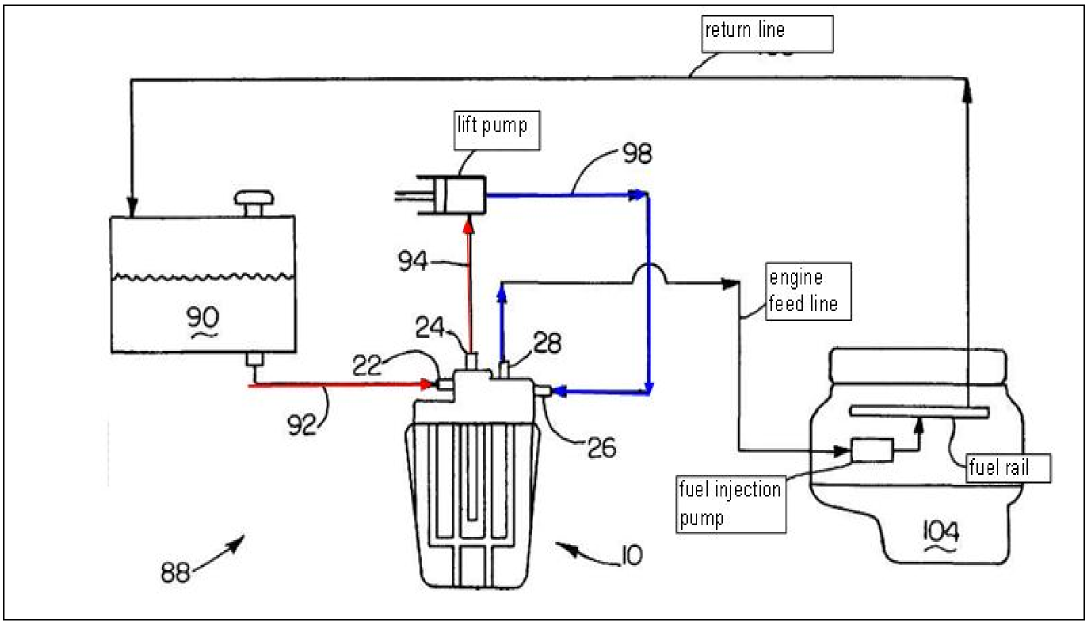


Figure.2.70 Double Pass Fuel Filter , filtration layout

The operation of the fuel filter assembly is now explained with respect to the components of the fuel system shown in Fig 2.70 Fuel delivered from the fuel tank enters first inlet port due to suction force of the lift pump or head pressure from the fuel in the tank. The fuel passes into recess in the head portion and flows downward around nipple into first fluid inflow area . The fuel passes through screen which serves as first media means. As the fuel passes from the outside to the inside of the screen, large contaminants and slugs of water are removed from the fuel. These impurities collect at the surface of the screen and fall downward into the first sump area

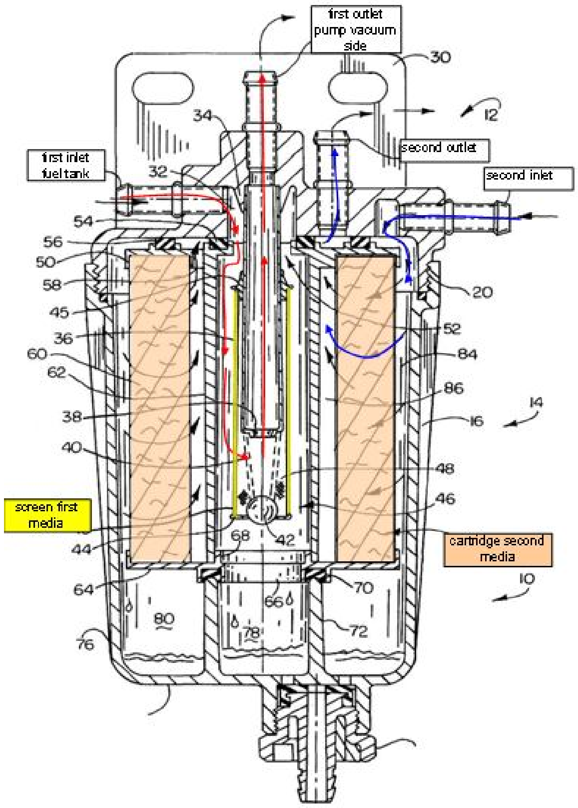


Figure.2.71 Double Pass Fuel Filter Assembly

The fuel which has undergone initial filtration by passage through the screen flows in the fluid outflow area and upward through the inside of tube. The fuel leaves the head portion of the filter assembly through first outlet port. The fuel is drawn out of first outlet port by the suction produced by lift pump .In severe contamination conditions, the surface of perforated screen may become clogged with impurities. In this case the suction force of the lift pump is designed to overcome the force of spring on relief ball. If flow through screen is substantially blocked, ball will be pulled upward off its seat in cap, allowing fuel to enter the first outflow area therethrough. This avoids fuel starvation of downstream components and vehicle stoppage

Fuel that is delivered out of the fuel filter assembly through first outlet port passes through the lift pump and is returned to the fuel filter assembly by way of second inlet port .The fuel then flows into second fluid inflow area and flows through media loop. As the fuel passes through media loop from the outside to the inside, it is cleansed of small impurities.The impurities that are captured by the media loop fall downward and are collected in second sump area .

After passing through media loop the clean fuel flows through second fluid outflow area and passes upwardly through fluid opening in upper end cap. The fuel then flows circumferentially in the area between seals and leaves the fuel filter assembly through second outlet port

A fuel filter assembly has the advantage of providing filtration prior to fuel passing to the lift pump. This minimizes the risk that large and potentially damaging impurities will reach the lift pump. The design also serves to remove large impurities before they are broken up or emulsified by the pumping action of the lift pump. These large impurities are captured in the first sump area and may be periodically drained or dumped out of the housing when the cartridge is replaced.

A further advantage of the fuel filter assembly of the present invention is that by having the fuel undergo primary filtration before reaching the lift pump, the life of the fine filter media in loop is prolonged.

The outer media loop is preferably of a conventional paper media type and adapted to provide removal of fine particulate material and water that could prove harmful to components such as fuel injection pumps and fuel injectors. The position of media loop on the downstream side of the lift pump also serves to capture materials that may enter the fuel system due to deterioration of components of the lift pump. As a result, potential damage to downstream fuel system components is minimized,

CHAPTER 3

PRELIMINARY TESTS FOR DESIGN

3.1 Introduction to preliminary tests

During the fuel filter design about 20 to 36 tests should be completed.

Table 3.1 Preliminary Fuel Filter Tests and Scope

Test	Scope of Test
Air under Water Test	to verify that the filter housing, casting, and seals will not leak fuel
Filter and Parts Cleanless Test	to determine the level of cleanliness of either finished filter products or parts used in the production of filters.
Restriction clean filter	To measure flow resistance through a clean filter to determine flow capacity acceptability at a given flow, temperature, and fluid viscosity
Multi-Pass Particle Retention Efficiency	to measure the filters effectiveness in removing particles from fuel by multi pass method
Single-Pass Particle Retention Efficiency	to measure the filters effectiveness in removing particles from fuel by single pass method
Contaminant, Clogging Capacity Test	To determine to establish the quantity of contaminant required to block a test filter to a pre-determined differential pressure
Element Collapse Pressure Test (Element Rupture Strength)	to ensure that a filter element will withstand the anticipated maximum differential pressure without bypassing due to loss of seal ,distortion , breakage of element or a collapsed element.

Table 3.1 Preliminary Fuel Filter Tests and Scope continue

Test	**Scope of Test**
Breaking Torque Test	to establish the torque required to break a component from its particular locking mechanism or screw thread
Hot Soak Test	to verify that the materials and seals used in the test filter can withstand attacks from diesel or specified fluid and high temperature encountered in service.
Cold Soak Test	to establish that component functionality is retained after being exposed to cold conditions for a prolonged period of time.
Thermal Cycle Test	to establish whether a varying thermal cycle will damage either the operation or physical casing of a component
Vacuum Decay Test	detects small vacuum leaks as the result of test filter defects under cold and hot conditions.
Differential Pressure Drop Test	to determine the pressure loss which will result when fuel is passed through a filter element under standard conditions of flow, temperature and fluid viscosity
Environmental Corrosion Resistance Test	for spin on type filters. Filter can paint resistance to corrosion tested
Vibration Test	to determine the mechanical resistance to vibration under normal service condition
Jet Wash , Degree of Protection Test	The purpose of this test is to establish the level of protection provided by a components casing when it is exposed to harsh environmental effects
Resistance to chemicals , Chemical Compatibility Test	to verify that the materials and seals used in the test filter can withstand attacks from chemicals encountered in service
Diesel Soak, Diesel Resistance Test	to verify that the materials and seals used in the test filter can withstand attacks from diesel
Water separation efficiency Test	to evaluate and compare the efficiency of fuel/water separators.

Table 3.1 Preliminary Fuel Filter Tests and Scope continue

Test	Scope of Test
WIF Probe Test	Measures the electrical resistance curve and the electrolytic corrosion of Water In Fuel (WIF) probe while submerged in tap water
Hand Primer Pump Operation Test	to verify the efficiency and operation of a filter head mounted hand priming pump used to purge air and fill a filter element assembly with fuel.
Hand Primer Pump Life Cycle Test	to determine if a hand operated priming pump can withstand environmental conditions and operation that may be encountered under vehicle operating conditions over time.
Electric Connector Pull Test	to ensure that an electrical connector can withstand forces that may be encountered in actual service and not disengage or break the electrical connection.
Solenoid Valve Operation Test	to verify the operation of a solenoid valve to drain fluid from filter assembly bowl.
Solenoid Valve Endurance Test	to determine if a solenoid drain valve can withstand environmental conditions and operation that may be encountered under vehicle operating conditions over time
Heater Efficiency Test	to determine heater efficiency and performance
Heater Electrical Continuity Test	to verify that an electric fuel filter heating device is functional
Heater Life Cycle Test	to determine if the heater and thermostat withstands accelerated environmental conditions that may be encountered under vehicle operating conditions during the life of the vehicle.
Engine Test (Dynamometer)	To determine filter assembly structural integrity under conditions encountered in service. To determine acceptability of filter assembly with respect to established fuel filter change periods.
Vehicle –On Road Test	to verify that There is no functional and Performance issue about filter on road conditions. Test the filter service life.

Table 3.1 Preliminary Fuel Filter Tests and Scope continue

Test	Scope of Test
Dynamic, Pressure Pulsation (Mechanical Strength) Test	To determine filter assembly structural integrity under conditions designed to simulate maximum dynamic pressure pulsation's and maximum vibratory forces encountered in service.
Drop Test	to establish the level of damage caused by releasing a component into free fall 1 metre above a solid surface.
Burst (Hydrostatic Strength) Test	to ensure that spin-on lube filters will withstand the specified burst pressure without failure due to distortion, breakage or gasket blowout
Water In Fuel Signal Level Test	to determine the level of water in a fuel filter/water separator bowl needed to activate water in fuel probe signal.

3.2 Single-Pass Particle Retention Efficiency

This test specifies a test procedure for evaluation of the initial efficiency, the efficiency evolution during clogging and the retention capacity of a fuel filter for internal combustion engines submitted to a constant flow rate of test liquid. It applies to filters having a rated flow from 50 l/h to 250 l/h. By agreement between filter manufacturer and customer, the procedure, with some modification, may be used for fuel filters with higher flow rates. ISO13353 is a single pass test, i.e. the contaminated fuel passes through the filter once only

Note: ISO standards do not call for measurements below 4 micron , the reason for this is the laser particle counters can not read particles below 4 micron in size.

Standard test Method:

- ISO/TS 13353: Diesel Fuel & Petrol Filters for Internal Combustion Engines - Initial Efficiency by Particle Counting Or
- SAE J 1985: Fuel Filters - Initial Single Pass Efficiency Test Method

Principle

The procedure uses a test fluid with a low concentration of contaminant. The initial efficiency of the filter is evaluated by particle counting upstream and downstream of the filter, allowing on-line particle counting without dilution.

3.2.1 Test Equipments

3.2.1.1 Test Fluid

Hydraulic fluid with a viscosity of 10 mm2/s min. at 40 CC

3.2.1.2 Test contaminant

The test contaminant shall be ISO 12103-A3 (ISO medium test dust) in accordance with ISO 12103-1

3.2.1.3 Laboratory equipments

3.2.1.3.1 Automatic particle counter

Particle removal efficiency was measured upstream & downstream of the filter by ACM20 particle counters. The counter or counters shall be calibrated and validated in accordance with ISO 11171 and ISO 11943.

Particle counting based on the principle of light obscuration is otherwise known as light blockage or light extinction, where an object passing in front of a light source creates a shadow of a particle suspended in a fluid and is measured by voltage drop across a light sensitive diode. The signal generated as a result of the shadow is dependent on the size of the particle and the speed at which it passes through the light. This voltage drop equates to a known particle size as a result of calibration via ISO 11171 calibration procedures.

When the particle counter start to take measurement, it takes 4 consecutive test of measurement results. Than it discard the first measurement and take the average of following 3 measurements. The reason for this the contamination in a fluid is heterogeneous distribution.

Count time: 50 s; Hold time: 10 s

Micron channels analysis - solid particulate (4µm+, 6µm+, 14µm+, 21µm+, 25µm+ & 30µm)

Analysis range ISO 7 to 22 % by volume / Viscosity range 0.5 to 250 cSt.

Fluid operating temp. +5°C to +80°C

Particle Counters calibrated in accordance with ISO 11171, 11943 through principles to ISO 4406:1999 bring laboratory standard equipment into the field for precise, quick and reliable results.

Performance :

+/- 1 % # of particle at 4 micron

+/- 1 ISO code depend on stability of flow. (+/- 0.1 particle according to ISO4406:1999) > 4 micron

Reproducibility / Repeatability : Better than 1 ISO code

3.2.1.3.2 Test Stand

Bonavista test stand has been used. Bonavista test stand has The main reservoir have a conical bottom with an included angle of not more than 90° and with the fluid entering below the fluid surface. The total volume, of the test fluid in the circuit is 6 liter

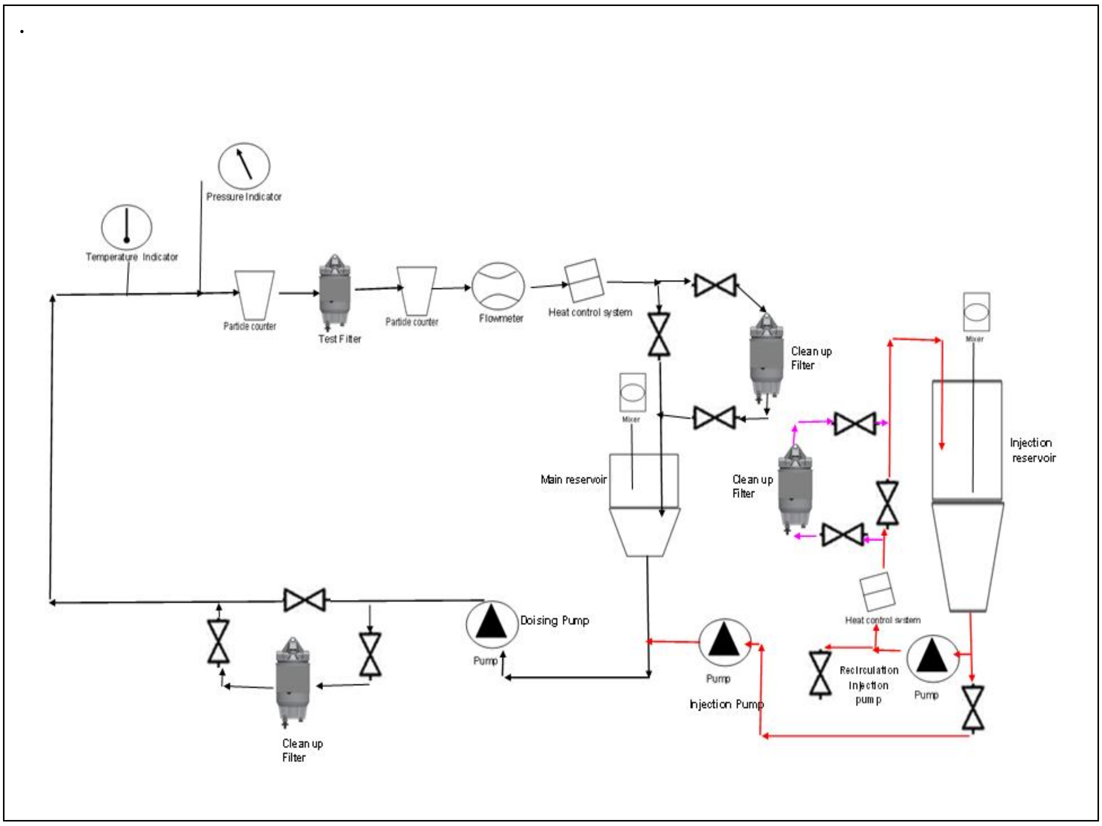


Figure .3.1 Schematic diagram ISO TS 13353 standard single pass efficiency, Black side test rig , red side is injection system

The main pump, with a variable rotational frequency, is insensitive to the contaminant and does not alter the contaminant's particle size distribution. The pump shall not induce excessive flow pulsations (less than 1 % of mean pressure).

Clean-up filters (black line located before main reservoir and after dosing pump) shall be capable of providing an initial contamination level of less than 30 particles per milliliter of a size greater than 4 um.

Upstream and downstream ACM20 particle counters in accordance with ISO 4021 shall be provided.

All pipes and the reservoir shall be chosen so as to avoid particle settling or segregation. For the test flow rates applicable to this Technical Specification, pipes of a 6 mm inside diameter. Pressure gauges, temperature indicators, flow meters and controllers shall be able to ensure the test condition accuracy given In Table 3.2

3.2.1.3.3 Injection System

The injection tank have a conical bottom with an included angle of not more than 90° and with the fluid entering below the fluid surface. The volume of the tank is 50 litre. The injection tank is equipped with a recirculation pump and stirrer (mixer). the recirculation pump is a centrifugal type pump .

The contaminant injection pump have a variable rotational frequency. The injection flow rate shall be maintained at 100 ml/min max. (accuracy in accordance with Table 3.2).

3.2.1.4 Test condition accuracy

Set up and maintain the test condition accuracy in accordance with Table 3.2.

Table 3.2 Test condition accuracy

Test condition	Allowable deviation from actual value
Flow, flow rate	±2%
Pressure	±2%
Temperature	±2°C
Volume	±2%
Test dust	± 0,5 mg

3.2.2 Test Preparation, Cleaning of Injection & Test System

Use the Automated Cleanup procedure to clean both the Injection System and the Test System. This is the preferred “finishing” technique (as opposed to simply cleaning up the injection system and test system individually) because it purges the injection diversion line and the sample lines.

Set the Automated Cleanup to clean to < 15 particles / ml at 5 μm(c)
Set the maximum time to 60 minutes.

3.2.3 Calculations:

Efficiency of filter (%) :

$$\frac{(\#\text{ of particles Upstream} - \#\text{ of particles Downstream}) \times 100}{\#\text{ of particles Upstream}} \qquad (1)$$

3.3 Contaminant, Clogging Capacity Test

3.3.1 Scope:

The purpose of this test is to determine to establish the quantity of contaminant required to block a test filter to a pre-determined differential pressure.The contaminant holding capacity is defined as the amount of contaminant removed and held by a filter before a specified differential pressure is reached. (in grams)

3.3.2 Test Equipments:

Circulation System

1. Conical sump; approximately 18 liters, 45° tapered walls to bottom outlet
2. Circulation pump; positive displacement, 8-12 lpm
3. Method to measure flow. Digital paddle flow meter
4. Bypass control valving, valves
5. Circulation system cleaning filter 2 μm
6. Heat control system
7. Temperature Indicator
8. Test Filter

9. 0-15 psi differential pressure measuring device, 0.25% accuracy at full scale

a. All piping approximately 1/2 inch inner diameter

b. Test fluid #2 diesel

Contaminant Addition System,

10. Contaminant peristaltic pump; variable speed control, Viton hose, 10-50 ml per minute. Normal setting is 33ml/min

11. Conical container, approximately 12 litres, 45° tapered walls to bottom outlet with stir motor; strong continuous duty. 1/30 hp, 1500 rpm or equivalent

12. Clean up filter for contamination addition system

13. recirculation pump

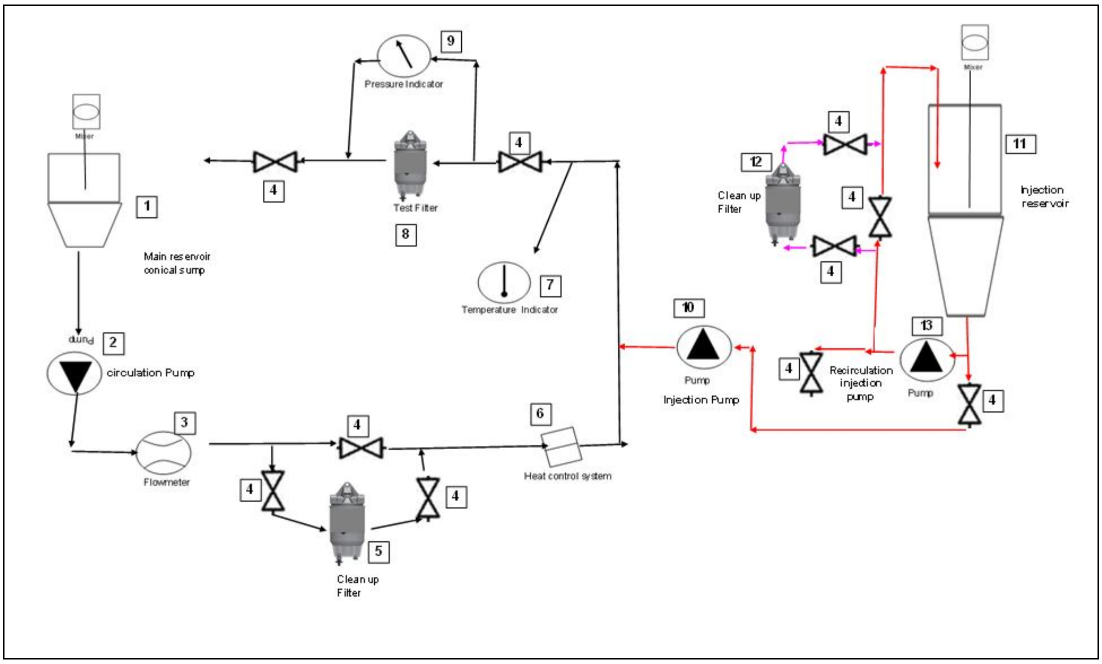


Figure 3.2 Clogging capacity Test Schematic diagram

Test materials and conditions

a. The test unit, filter with housing or spin-on base; means of mounting

b. #2 diesel

c. Organic – Statex n660 carbon black. Lubrizol 8040B dispersant added at 10cc per gram

d. Inorganic – Mira M2 dust OR Mira M3, M4, M5 dust

e. Temperature 23 ±5°C (80 ±7°F) in test loop

f. Flow rate at unit rated or as specified, constant throughout test

Standard test Method:

For Multi-pass Test

ISO 19438: Diesel Fuel & Petrol Filters for Internal Combustion Engines - Filtration Efficiency using Particle Counting & Contaminant Retention Capacity

For Single-pass Test

ISO/TS 13353: Diesel Fuel & Petrol Filters for Internal Combustion Engines - Initial Efficiency by Particle Counting
Or SAE J 1985: Fuel Filters - Initial Single Pass Efficiency Test Method

To do this switch on the main circulation pump and place the injection outlet pipe from the peristaltic pipe placed in the main tank. The differential pressure, time and temperatures are recorded at this initial point. The readings are then taken at 2, 4, 8 minutes etc and every 4 minutes until the pre defined differential pressure is reached at which point the test is complete.

3.4 Water separation efficiency Test

The purpose of this procedure is to evaluate and compare the efficiency of fuel / water separators.With this test, it is possible to determine the quantity of water separated by the filter from a water-oil dispersion. This test only applies to filters which are claimed to separate water.
Standard : DIN ISO 4020 or ISO 16332
Requirements:

Filter is to have time averaged overall efficiency of not less than 95% at specified test flow rate, or as required

3.4.1 Test Equipments

3.4.1.1 TestStand Water Separation Stand

1. Main tank with a test fluid (diesel) capacity of 50 l
2. Flow metre ,with a measuring range of 0l/h to 200 l/h
3. Distilled water tank capacity of 2 l
4. Flow meter ,with a measuring range of 0 l/h to 4 l/h

5. Valve

6. Main pump ,diaphragm type ,capable of generating consistent water droplet size distribution:

Static pressure (no flow) :34.5 kPa to 55.1 kPa above atmospheric pressure

Displacement per stroke : 8.5 cm^3 maximum

Movement up :2.72 mm maximum

Movement down : 2.84mm maximum

Fuel flow through 3 mm orifice 1 500 min^{-1} cam speed : 90 l/h minimum

Valve orifice diameter : 10mm

Diaphram effective diameter : 60mm

Cam rotational frequency during to test :1 425 min^{-1} ±26 min^{-1}

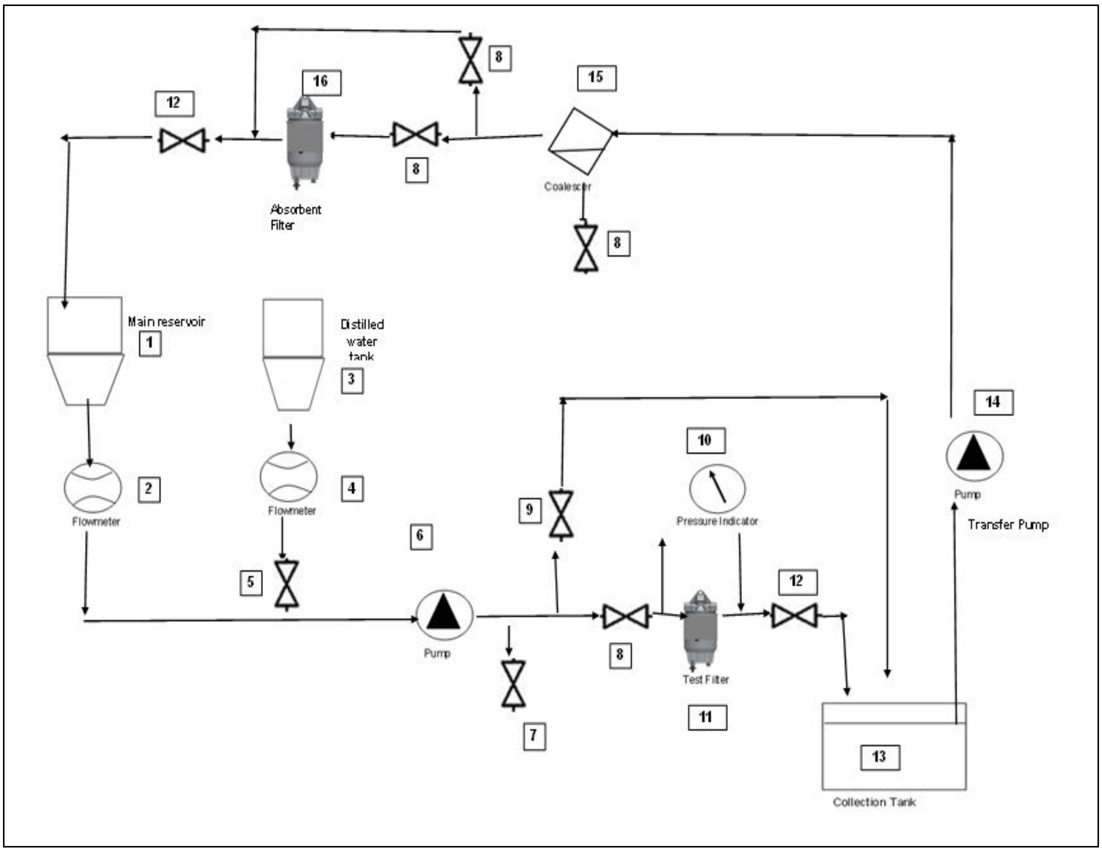


Figure 3.3 Water Separation Efficiency Test Schematic diagram

7. stopcock for sampling

8. stopcock ,on/off,

9. Bypass Valve

10.Manometre with a measuring range of 0 kPa to 40 kPa

11.Test Filter
12.Adjustable Valve
13.Collection Tank Capcity of 10 l
14. Transfer pump ,min flow rate 200 l/h
15.Coalescer ,capable of reducing free water content to less tham 300 mg/l
16. Absorbent filter,

3.4.1.2 Interfacial Tensiometer

DuNouy Tensiometer with a accuracy of ±0.05 dynes/cm

3.4.1.3 Karl Fischer Titration equipment;

It is used to determine ppm of water .Measurement range 100 ppm...100%.Repeatability 0.3% at >10 mg $H2O$

3.4.1.4 Test Fluid:

CEC Legislative Diesel Fuel RF-06-99 , 27±1 dynes/cm surface tesnion. Test Fluid should maintained 23°C ± 5°C

3.4.2 Test Preparation:

a. Ensure that test stand has been fully purged, cleaned and new clean fuel introduced at the begining of any new series of tests.

b. Ensure that clean up filters have been replaced and that all free water has been purged from the system.

c. Engage clay filter and re-circulate the system untile the interfacial tension has reached the desired level (as described in the individual test standards), then disengage the clay filter.

f. Replace filter element on the test filter for a new clean element.

g. Purge the differential pressure gauges to ensure accurate readings.

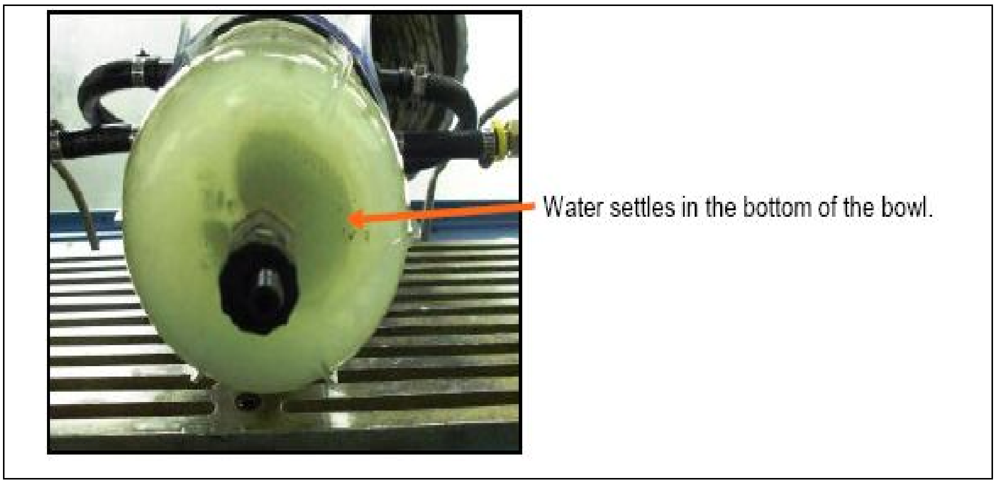


Figure 3.04 Water Test Sample

3.4.3 Test Procedure for SAE J1488, SAE J1839:

a. Set fuel flow rate to desired level, and set all valves to the specified path for the test to be performed (as per Stand instructions).

b. Pressurise water injection system, set water injection flow rate to required level (based on **0.25%** injection level required by the test at the specific flow rate).

c. Start the stopclock.

d. Take down stream samples in a clean sample bottle at specified intervals. Introduce a weighed proportion of the sample into the titration machines to obtain the ppm of water in the sample. Log ppm, time and differential pressure for the **2 hour test** duration.

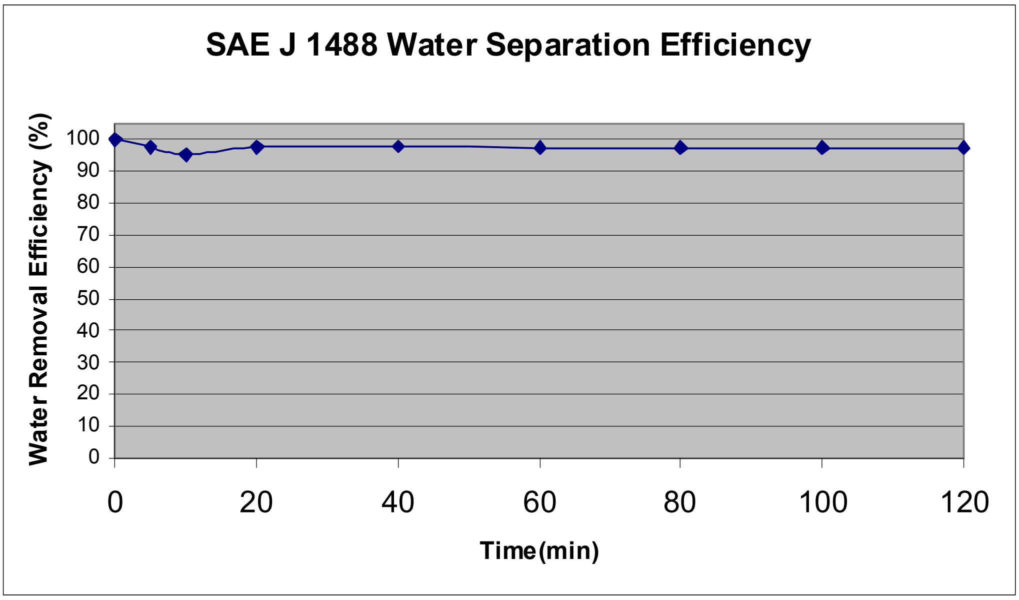


Figure 3.5 SAE J1488 Water Separation Efficiency Test Result Example

3.4.4 Test Procedure for ISO 4020:2001 :

a. Set fuel flow rate to desired level, and set all valves to the specified path for the test to be performed (as per Stand instructions).

b. Pressurise water injection system, set water injection flow rate to required level (based on 2.0% injection level required by the test at the specific flow rate)

c. Start the test clock.

d. Take down stream samples in a clean sample bottle at specified intervals. Introduce a weighed proportion of the sample into the titration machines to obtain the ppm of water in the sample. Log ppm, time and differential pressure for the 1 hour test duration.

PARAMETERS					
TEST FUEL	INTERFACIAL TENSION (dynes/cm)	INLET HOSE SIZE	INJECTION RATE ml/min (2%)	FLOW RATE (lpm)	TEST FLOW (OUTSIDE IN or INSIDE OUT)
Legislative grade RF-06-99 diesel	27.0	3/8	52	2.63	Outside In

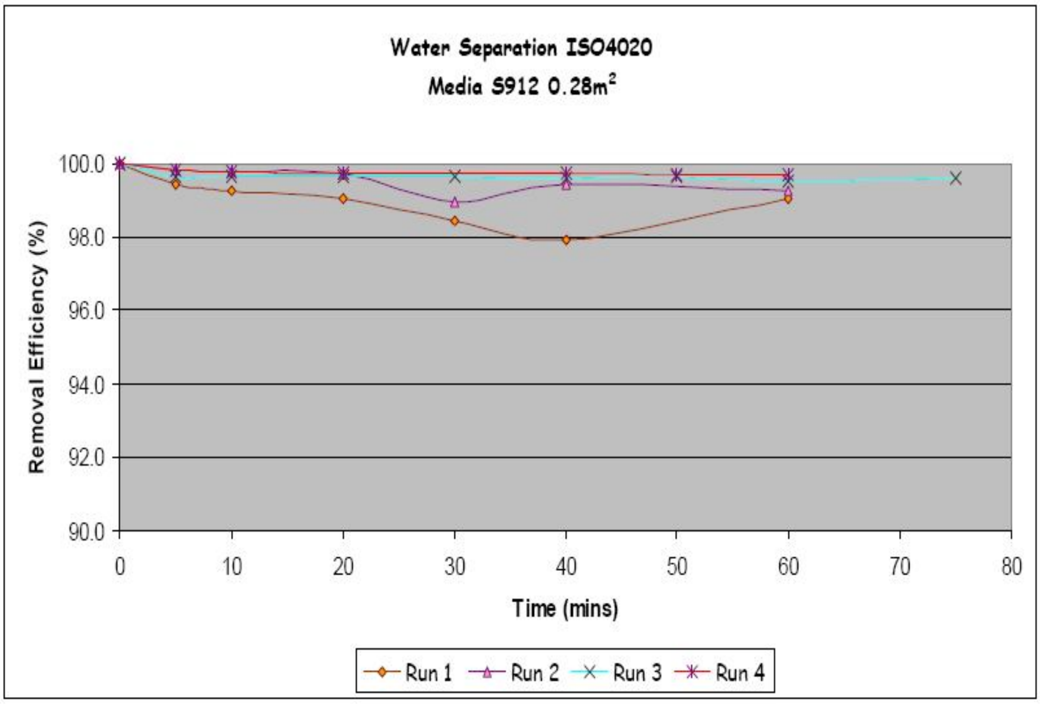


Figure 3.6 ISO 4020 Water Separation Efficiency Test Result Example

3.4.5 Calculations:

Water Removal Efficiency of filter (%) :

$$\frac{(\text{Upstream Water ppm} - \text{Downstream Water ppm}) \times 100}{\text{Upstream Water ppm}} \qquad (2)$$

CHAPTER 4

FILTER DESIGN

4.1 Stage 1.System Analysis

Filtration system based on concept of fuel water separation on pressure side. Pressure of the Fuel at tank increased by electric Fuel pump up to (0.4-0.73 gage bar pressure). Then pressurized fuel enter the fuel filter, filtration and water separation process completed. During these stage filter pressure drops (0.3-0.62 gage bar). After that, clean fuel pumped to the injection system. Unused fuel returns to recirculation line. It is decided to use return unused fuel to heat the filter. Thermal valve is normally open, when the temperature of filter increased up to 43ºC than it is closed to prevent overhead the filter. There is a bypass line which has pressure step valve so that allows the fuel flow from return to fuel tank

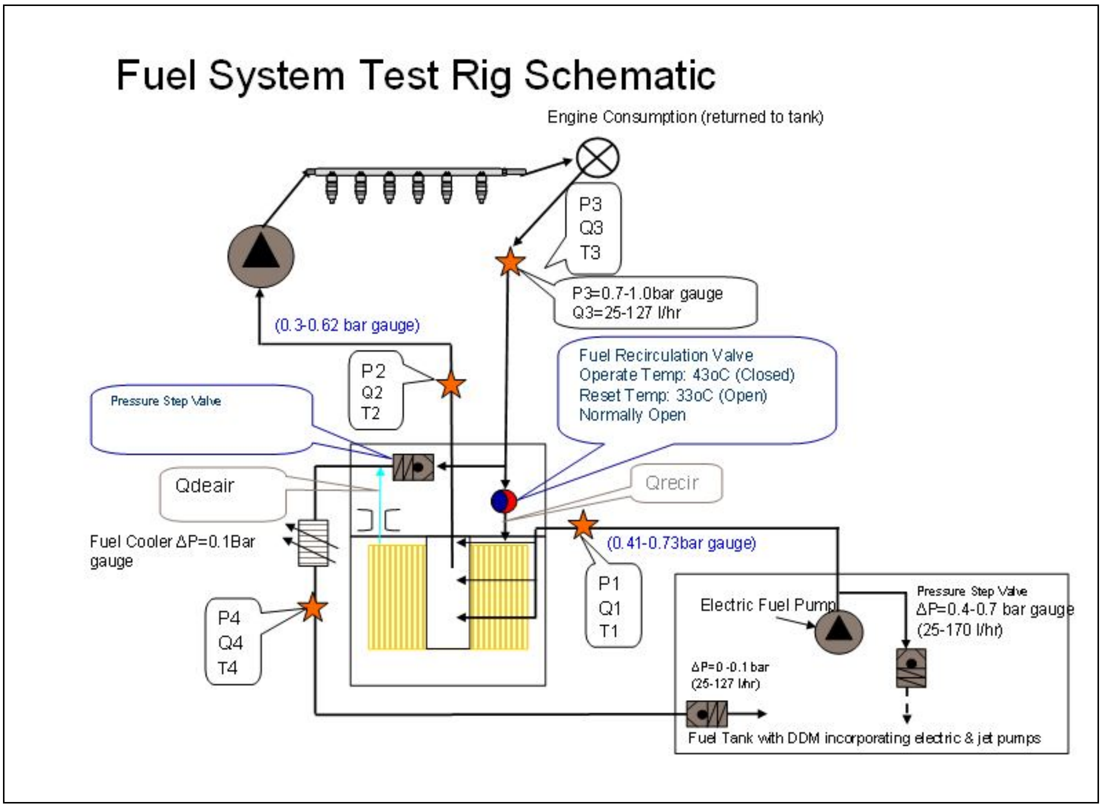


Figure 4.1 Sample filtration system

P1	Pressure Inlet	P3	Pressure Engine Return
Q1	Flow Inlet	Q3	Flow Engine return
P2	Pressure Out	T3	Temperature Engine Return
Q2	Flow out Q2=Q1+Qrecirculation-Q deair	P4	Pressure Return tank
ΔPf	ΔPf=P1-P2 (pressure drop across filter assy)	Q4	Flow return to tank Q4=Q3-Qrecircle+Q deair

4.1.1 Pressure Step Valve Selection:

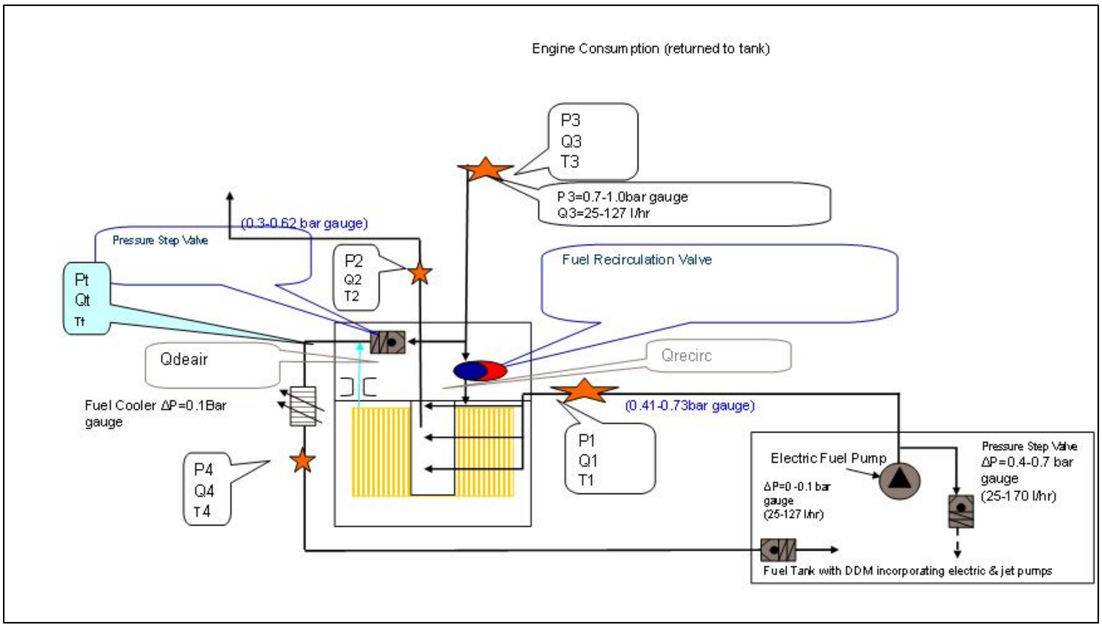


Figure 4.2 Step valve section of sample filter system

In order to get good de-aeration and good return pressure to tank , pressure step valve selection is important. Selected pressure steep valve should create;

- De-Air ΔP = P1-Pt (> 0.1 bar) .There should be at least 0.1 bar pressure difference
- P4=Pt-0.1 (> 0.1 bar gauge) . Tank return pressure should be higher than 0.1 gauge bar

Different step valve 0.3/0.4/0.5/0.6 added to system than De-Air ΔP and P4 Tank return pressure for P1 and P3 pressure tolerances is calculated.

Engine Return P3 =between 0.7-1.0 gauge bar

Filter in P1=between 0.41-0.73 gauge bar

Tank Return Pressure =between 0-0.1 gauge bar

Overall ΔP of StepValve = 0.6 bar						
	P3 gauge	P1 gauge	Step Valve ΔP	Pt gauge = P3- Step Valve ΔP	DeAir ΔP = P1-Pt (> 0.1 bar)	P4=Pt-0.1 (> 0.1 gauge bar)
Mins	0.70	0.41	0.60	0.10	0.31	0.00
Max's	1.00	0.73	0.60	0.40	0.33	0.30
P3 Min-P1max	0.70	0.73	0.60	0.10	0.63	0.00

Overall ΔP of StepValve = 0.5 bar						
	P3 gauge	P1 gauge	Step Valve ΔP	Pt gauge = P3- Step Valve ΔP	DeAir ΔP = P1-Pt (> 0.1 bar)	P4=Pt-0.1 (> 0.1 gauge bar)
Mins	0.70	0.41	0.50	0.20	0.21	0.10
Max's	1.00	0.73	0.50	0.50	0.23	0.40
P3 Min-P1max	0.70	0.73	0.50	0.20	0.53	0.10

Overall ΔP of StepValve = 0.4 bar						
	P3 gauge	P1 gauge	Step Valve ΔP	Pt gauge = P3- Step Valve ΔP	DeAir ΔP = P1-Pt (> 0.1 bar)	P4=Pt-0.1 (> 0.1 gauge bar)
Mins	0.70	0.41	0.40	0.30	0.11	0.20
Max's	1.00	0.73	0.40	0.60	0.13	0.50
P3 Min-P1max	0.70	0.73	0.40	0.30	0.43	0.20

Overall ΔP of StepValve = 0.3 bar						
	P3 gauge	P1 gauge	Step Valve ΔP	Pt gauge = P3- Step Valve ΔP	DeAir ΔP = P1-Pt (> 0.1 bar)	P4=Pt-0.1 (> 0.1 gauge bar)
Mins	0.70	0.41	0.30	0.40	0.01	0.30
Max's	1.00	0.73	0.30	0.70	0.03	0.60
P3 Min-P1max	0.70	0.73	0.30	0.40	0.33	0.30

Step Valve can be chosen either 0.5 bar or 0.4 bar. Step valve has tolerances ±0.09 bar.

For step Valve 0.5 bar upper tolerance 0.59 bar lower tolerance 0.41 bar

Overall ΔP of StepValve = 0.59 bar						
	P3 gauge	P1 gauge	Step Valve ΔP	Pt gauge = P3- Step Valve ΔP	DeAir ΔP = P1-Pt (> 0.1 bar)	P4=Pt-0.1 (> 0.1 gauge bar)
Mins	0.70	0.41	0.59	0.11	0.30	0.01
Max's	1.00	0.73	0.59	0.41	0.32	0.31
P3 Min-P1max	0.70	0.73	0.59	0.11	0.62	0.01

Overall ΔP of StepValve = 0.41 bar						
	P3 gauge	P1 gauge	Step Valve ΔP	Pt gauge = P3- Step Valve ΔP	DeAir ΔP = P1-Pt (> 0.1 bar)	P4=Pt-0.1 (> 0.1 gauge bar)
Mins	0.70	0.41	0.41	0.29	0.12	0.19
Max's	1.00	0.73	0.41	0.59	0.14	0.49
P3 Min-P1max	0.70	0.73	0.41	0.29	0.44	0.19

For step Valve 0.4 bar upper tolerance 0.49 bar lower tolerance 0.31 bar

Overall ΔP of StepValve = 0.49 bar						
	P3 gauge	P1 gauge	Step Valve ΔP	Pt gauge = P3- Step Valve ΔP	DeAir ΔP = P1-Pt (> 0.1 bar)	P4=Pt-0.1 (> 0.1 gauge bar))
Mins	0.70	0.41	0.49	0.21	0.20	0.11
Max's	1.00	0.73	0.49	0.51	0.22	0.41
P3 Min-P1max	0.70	0.73	0.49	0.21	0.52	0.11

Overall ΔP of StepValve = 0.31 bar						
	P3 gauge	P1 gauge	Step Valve ΔP	Pt gauge = P3- Step Valve ΔP	DeAir ΔP = P1-Pt (> 0.1 bar)	P4=Pt-0.1 (> 0.1 gauge bar)
Mins	0.70	0.41	0.31	0.39	0.02	0.29
Max's	1.00	0.73	0.31	0.69	0.04	0.59
P3 Min-P1max	0.70	0.73	0.31	0.39	0.34	0.29

At 0.4 bar step valve , lower tolerance which is 0.31 , De air ΔP is not enough .

Therefore ; Step valve with ΔP =0.5±0.09 bar has been selected

4.1.2 Final system analysis:

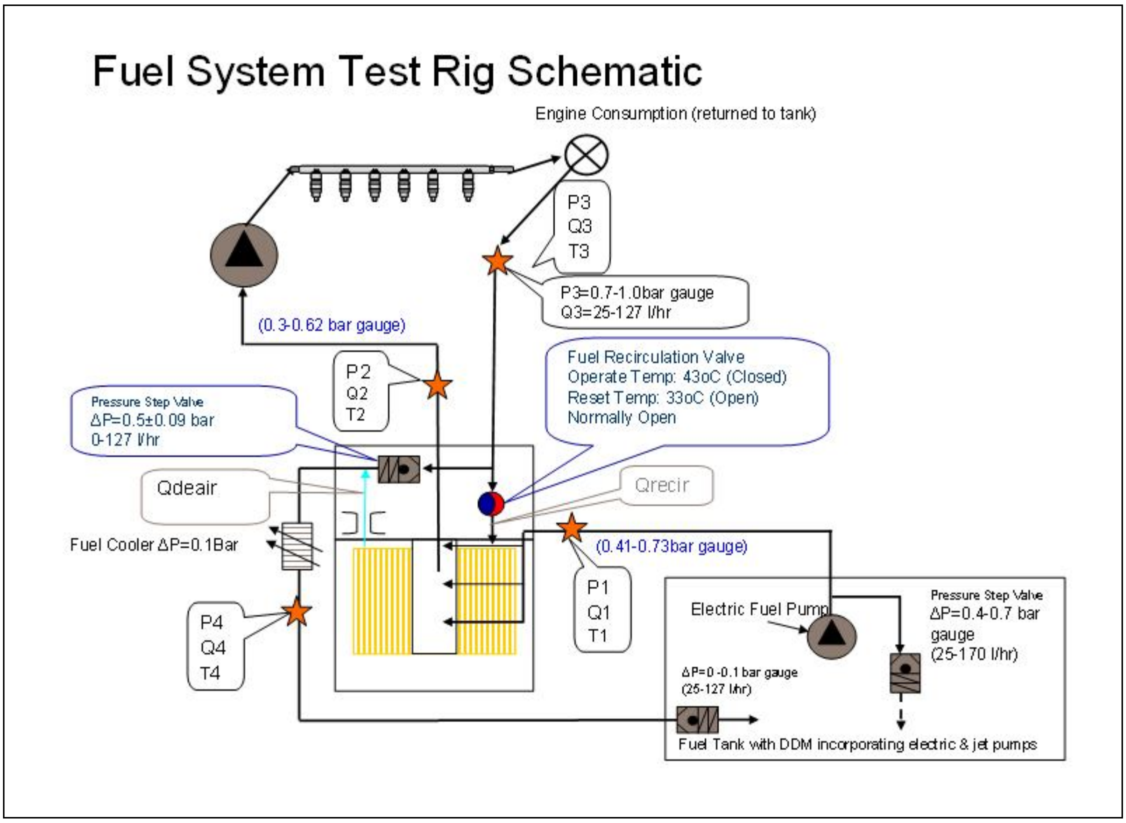


Figure 4.3 Finalized Filtration System

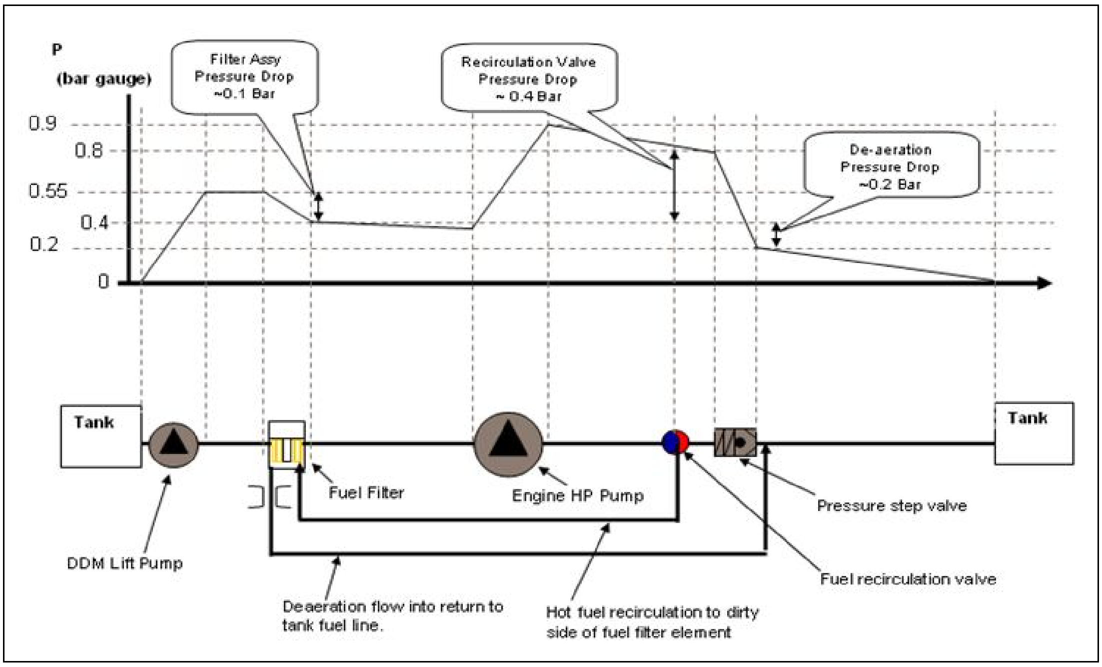


Table 4.01 Pressure change in the filtration system

4.2 Filter Paper (Media) Selection:

Customer Requirement :

- Required initial filter efficiency according to ISO 19438 > 98.5% for particle size of 6 µm
- Filter replacement min in 3 months

First step is take 3 different filter paper prepare sample filters and test them according to ISO 16948

Filter efficiency tests

Table 4.2 ISO 19438 Efficiency Test Results of 3 sample filter paper

Particle size (micron)	Sample 1 Stanadyne 5mic	Sample 2 Stanadyne 2mic	Sample 3 S912
4	96.69	99.32	96.70
5	98.16	99.38	99.30
6	98.80	99.39	99.80
7	99.09	99.39	99.90
8	99.22	99.40	100.00
9	99.31	99.40	100.00
10	99.65	99.41	100.00
12	99.92	99.92	100.00
15	99.95	99.95	100.00
17	99.97	99.99	100.00
20	99.99	99.99	100.00
25	99.99	99.99	100.00
30	99.98	99.62	100.00
40	99.98	99.46	100.00
50	99.98	99.79	100.00

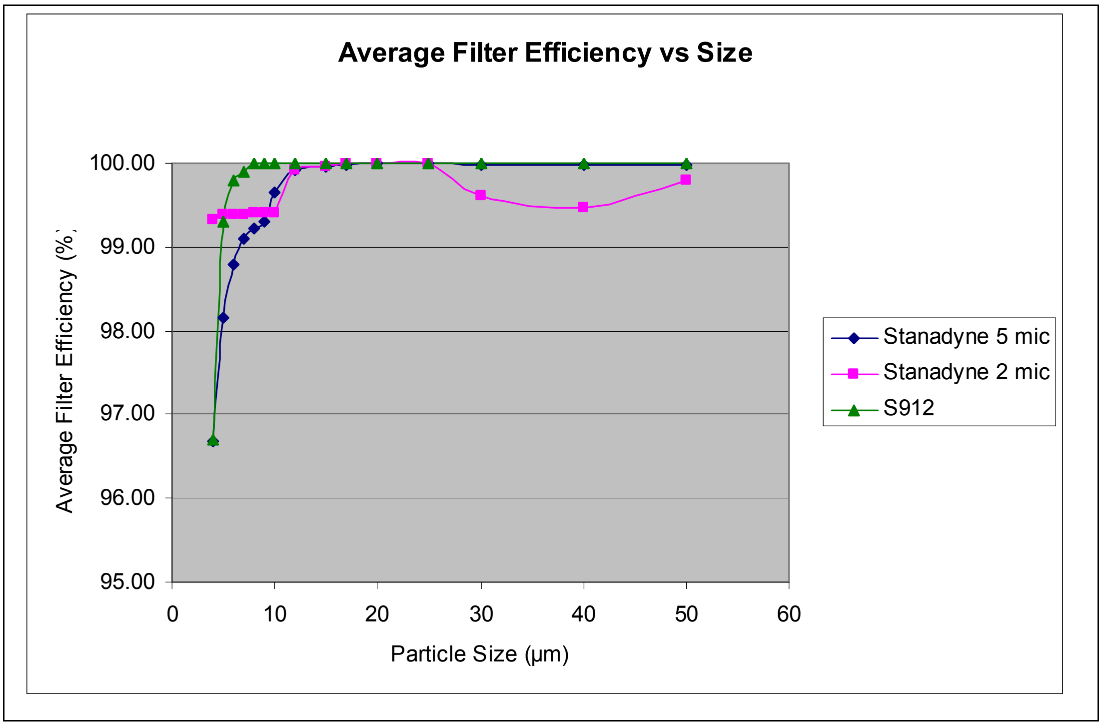


Figure 4.4 Filter efficiency versus particle size for 3 different filter media

- These 3 filter media has higher efficiency than customer expectation according to ISO 19438 > 98.5% for particle size of 6 µm

In order to choose best filter media Dirt holding capacity of these three media should be tested for dirt holding capacity according to ISO 4020

Table 4.3 Dirt holding capacity test results of sample filter papers

Stanadyne 5 micron Flow @ 1.5 l/min				Stanadyne 2 micron Flow @ 1.5 l/min			
t/mins	dP/bar	T/^{o}C	g dirt @ 2.5 g/min	t/mins	dP/bar	T/^{o}C	g dirt @ 2.5 g/min
0.00	0.00	24.7	0.00	0.00	0.00	25.8	0.00
2.00	0.01	25.3	5.00	2.00	0.02	26.4	5.00
4.00	0.24	26.0	10.00	3.80	0.30	26.5	9.50
4.20	0.30	26.2	10.50	4.00	0.39	26.8	10.00
5.25	0.50	26.6	13.13	4.90	0.50	26.9	12.25

Table 4.3 Dirt holding capacity test results of sample filter papers continue

S912 Flow @ 1.5 l/min

Time	ΔP	Temp	Dirt Injected
t/mins	dP/bar	T/°C	g dirt @ 2.5 g/min
0.00	0.00	25.9	0.0
2.00	0.02	25.2	1.0
4.00	0.03	25.0	2.0
8.00	0.04	24.8	4.0
12.00	0.05	24.6	6.0
16.00	0.06	24.5	8.0

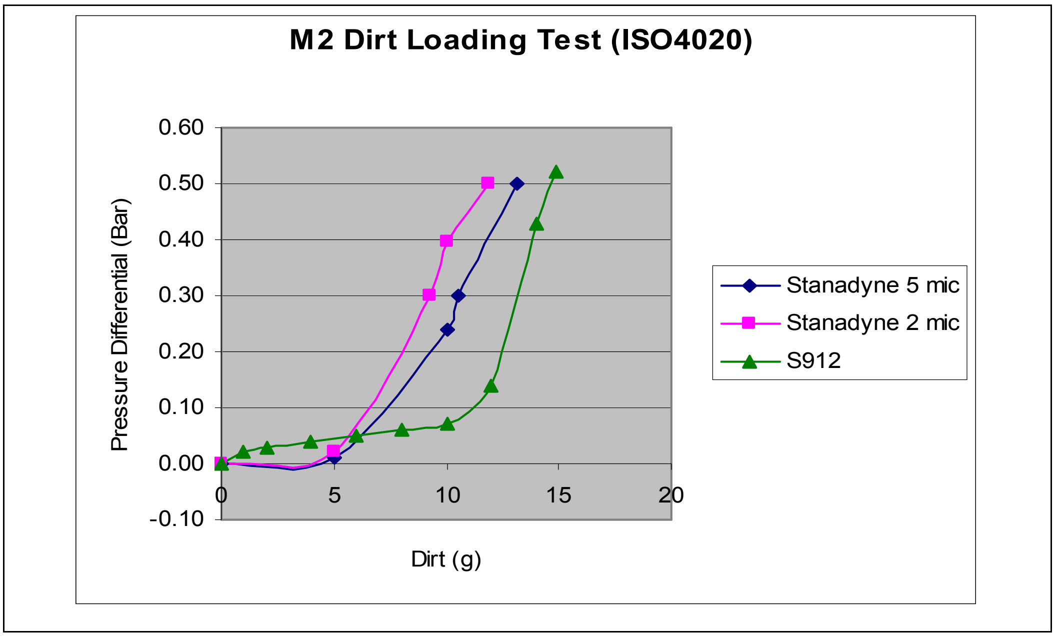


Figure 4.5 Dirt loading test of 3 different media

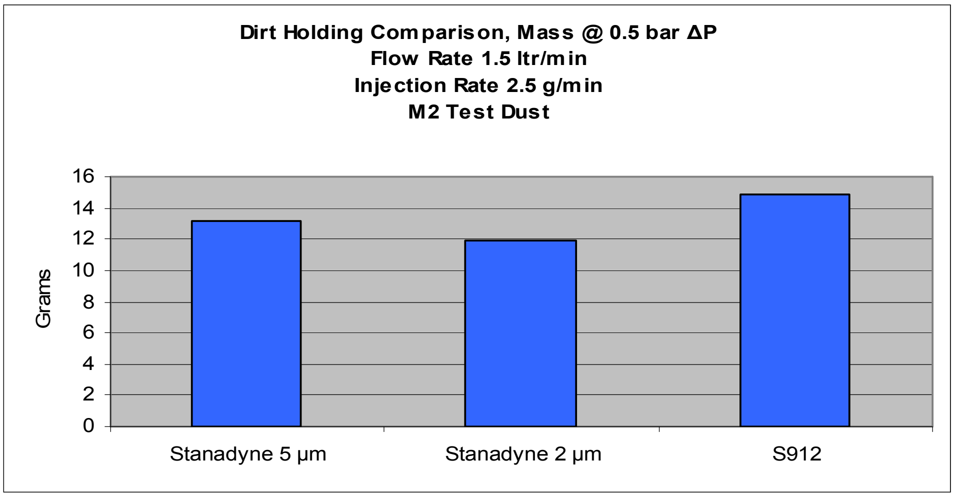


Figure 4.6 Dirt holding capacity comparison of 3 different media

According to Dirt holding test Results best option is use S912 media which has highest dirt holding capacity

4.3 Filter size selection:

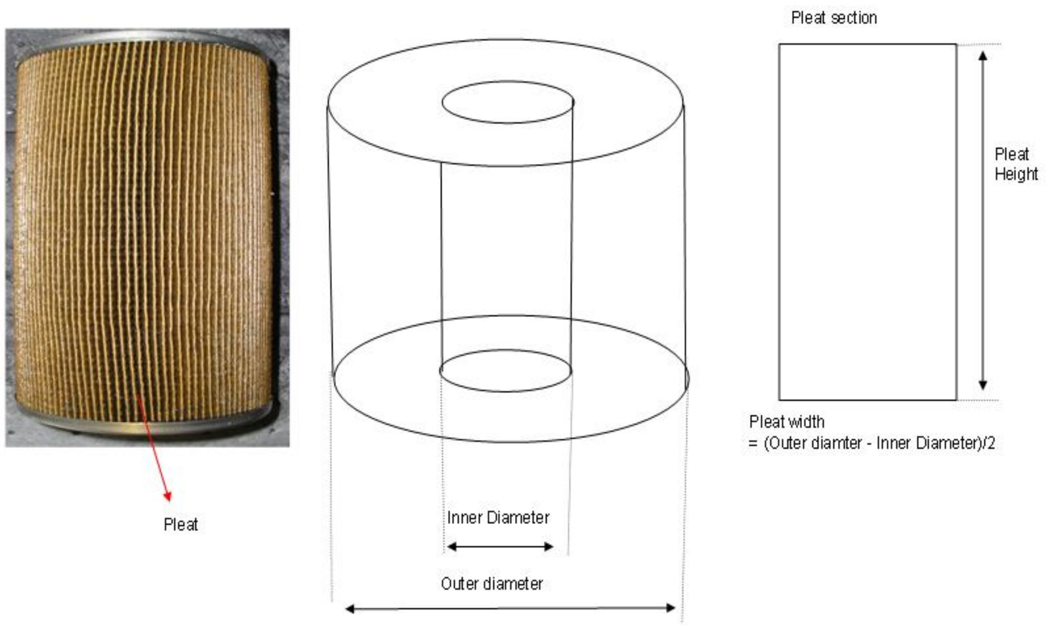


Figure 4.7 Filter dimensions

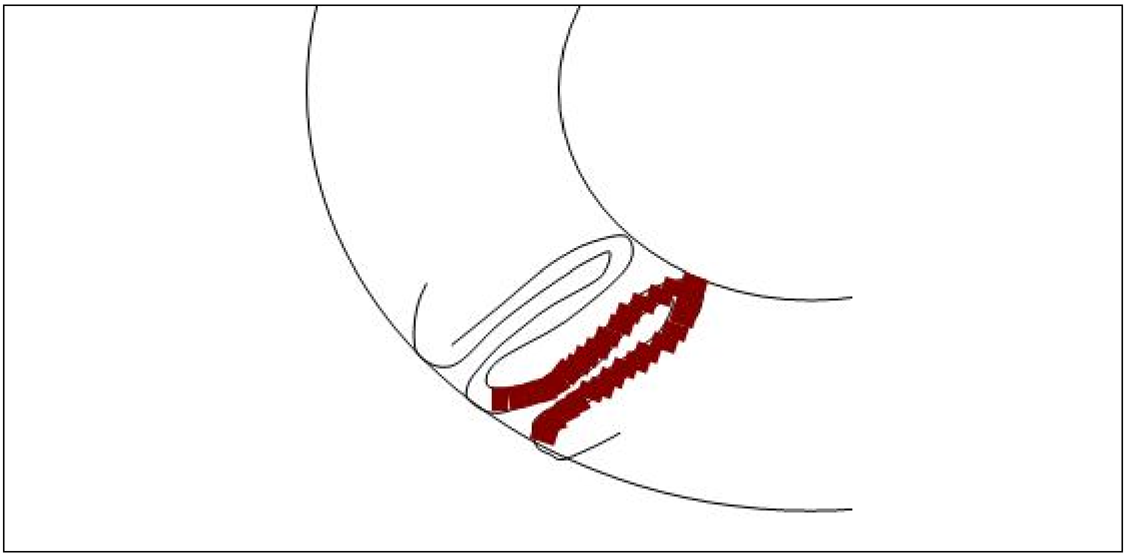


Figure 4.8 Pleat consist of one in and one out section.

Filter can be used two different engine

Flow rate of engine A 158 l/hr, 2.63 l/min	Flow rate of engine B 190 l/hr, 3.17 l/min

Step 1: Prepare sample filter for water test

Prepare sample filter than test water separation efficiency according to ISO 4020 test
Sample filter Dimensions :

Media, Filter paper : S912
No of pleats : 65
Pleat width : 25.4 mm
Media height : 125 mm
Length of media area : Pleat with x No of pleat x 2 = 3302 mm
Area : Length of media x Media Height = 0.413 m^2

Sample filter tested customer requirement is 95%> water separation efficiency ,

Table 4. 4 Water Separation efficiency Test Results for Different flow rates according to ISO 4020

Flowrate 2.63 l/min Injection Rate 52.6 ml/min

Time / mins	Downstream Water / ppm	Temperature ^{o}C	Upstream Water / ppm	% Removal Efficiency= (Up pp-Down ppm)/ Up ppm
0	0	23.1	20000	100.0
5	38	23.2	20000	99.8
10	43	23.3	20000	99.8
20	50	23.3	20000	99.8
30	53	23.3	20000	99.7
40	55	23.2	20000	99.7
50	60	23.2	20000	99.7
60	64	23.2	20000	99.7

Flowrate 3.2 l/min Injection Rate 64 ml/min

Time / mins	Downstream Water / ppm	Temperature ^{o}C	Upstream Water / ppm	% Removal Efficiency= (Up pp-Down ppm)/ Up ppm
0	0	23.0	20000	100.0
5	66	23.1	20000	99.7
10	66	23.1	20000	99.7
20	82	23.2	20000	99.6
30	86	23.3	20000	99.6
40	104	23.2	20000	99.5
50	138	23.2	20000	99.3
60	149	23.1	20000	99.3
75	220	23.3	20000	98.9

Flowrate 3.8 l/min Injection Rate 76 ml/min

Time / mins	Downstream Water / ppm	Temperature ^{o}C	Upstream Water / ppm	% Removal Efficiency= (Up pp-Down ppm)/ Up ppm
0	0	22.3	20000	100.0
5	75	22.4	20000	99.6
10	105	22.5	20000	99.5
20	268	22.7	20000	98.7
30	682	22.8	20000	96.6
40	724	22.9	20000	96.4
60	867	23.2	20000	95.7

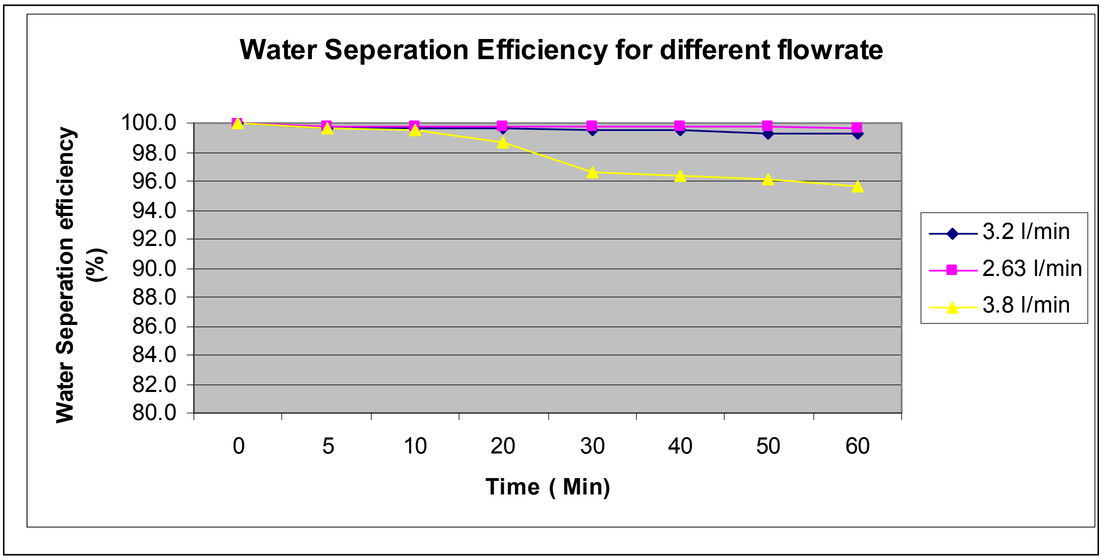


Figure 4. 9 Water separation Efficiency for different flow rates

According to test ; flow rate of ≤ 3.8 l/min , can get these requirement

Therefore

Face velocity = Flow rate / Media Area

Face velocity = 3.8 lt/min / 0.413 m^2

Face velocity = 9.2 lt / (min*m^2)

These face velocity will be used to determine required filter size for our engines

Engine A

Filter size (Media Area) =Flow rate / Face velocity

Filter Area = 158 lt/hr / 9.2 lt / (min*m^2)

Filter Area = 0.286 m^2

Engine B

Filter size (Media Area) =Flow rate / Face velocity

Filter Area = 190 lt/hr / 9.2 lt / (min*m^2)

Filter Area = 0.344 m^2

In order to meet two engine water separation specification. Designed filter area should be equal or higher than 0.344 m^2

- Thickness of Selected Media = 0.79 mm
- Define filter Media height = Selected Effective Media Height as 90 mm
- Pleat width is something related with pleating machine standard pleat widths are 1.5”,1”, 7/8”, ¾”, ½” ..etc
- Filter effective Area (m^2)= pleat width (25.4 mm or 22.23 mm) x number of pleats x effective media height (90mm)

Table 4 .5 Filter effective Area (m^2) versus number of pleats for different pleat width

Number of pleats	Pleat width 1” (25.4 mm)	Pleat width 7/8” (22.2 mm)
88	0.402 m^2	0.352 m^2
87	0.398 m^2	0.348 m^2
86	0.393 m^2	0.344 m^2
85	0.389 m^2	0.340 m^2
84	0.384 m^2	0.336 m^2
83	0.379 m^2	0.332 m^2
82	0.375 m^2	0.328 m^2
81	0.370 m^2	0.324 m^2
80	0.366 m^2	0.320 m^2
79	0.361 m^2	0.316 m^2
78	0.357 m^2	0.312 m^2
77	0.352 m^2	0.308 m^2
76	0.347 m^2	0.304 m^2
75	0.343 m^2	0.300 m^2
74	0.338 m^2	0.296 m^2

Lets select pleat width 25.4 mm therefore required number of pleats is 76

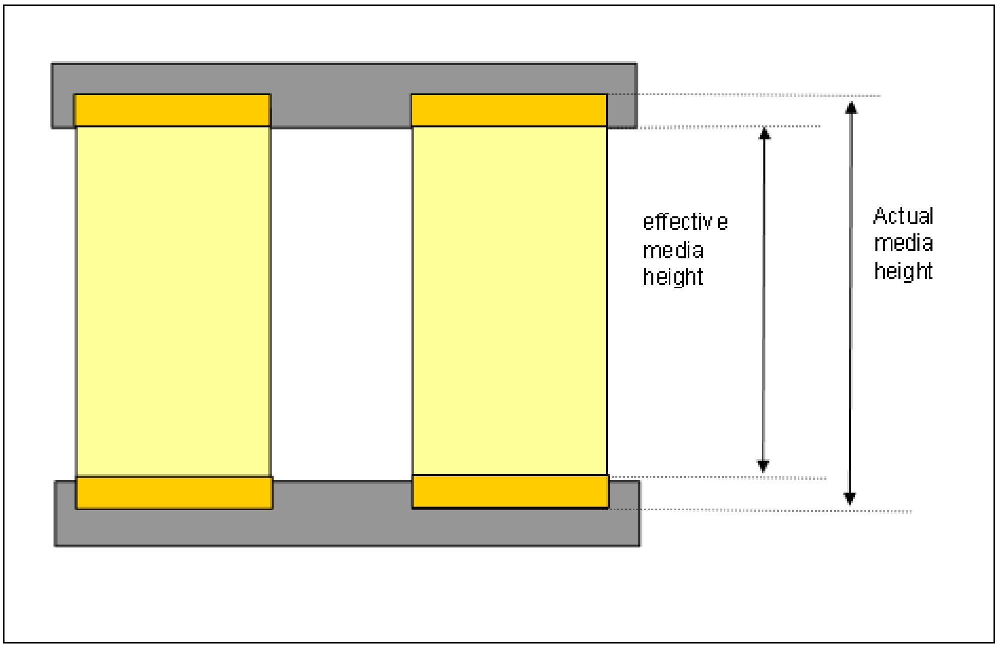


Figure 4 .10 difference between effective media height and actual media height

Actual media height = Effective media height + loss due to bounding

Lets assume 5% loss on actual media height due to bounding

Actual Media Height = Effective media height / 0.95 = 90 mm/ 0.95

Actual Media Height = 94.74 mm ~ 95 mm for easy production

Inner Diameter = Outer diameter – 2x Pleat width

Inner Diameter = 90 mm- 2x 25.4 mm = 39.2 mm

Check Inner Diameter

Aim is to see whether we can put number of pleats in these inner diameter or not

Check Diameter =2 x Number of pleats x Thickness of media/ 3.14

Check Diameter = 2x 76 x 0.79 mm / 3.14

Check Diameter = 38.24 mm

Since

Inner diameter > check diameter

39.2 mm > 38.24 mm

Therefore 76 pleats of media can be produced at inner diameter of 39.2mm

As a result media Dimension;

Media: S912 Gesner 2 micron

No of pleats = 76

Pleat width = 25.4 mm

Media height = 95 mm

Inner Diameter = 39.2 mm

Outer Diameter = 90 mm

Media loss due to bounding 5%

Effective Media height = 90.25 mm

Length of media area : Pleat with x No of pleat x 2= 3860.8 mm

Area : Length of media x Effective Media Height = 0.348 m^2

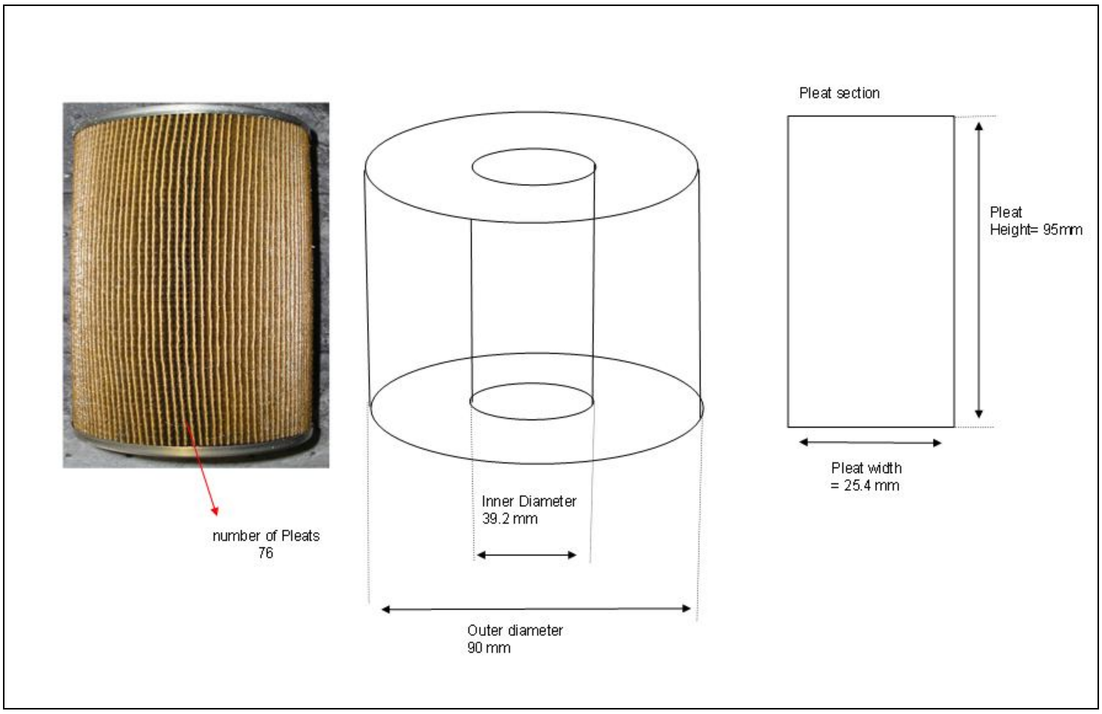


Figure 4.11 Designed filter dimensions

CHAPTER 5

VIBRATION EFFECT ON FUEL FILTER EFFICIENCY

5.1 Introduction

Currently all filtration efficiency test conduct according to two ISO standards, both these tests are the industry norms;

- ISO13353 is a single pass test, i.e. the contaminated fuel passes through. The filter once only,
- ISO19438, is a multi-pass test, here the contaminated fuel passes through the filter a multiple number of times

However these tests don't cover vibration effect on the filter efficiency. Therefore there is no standard test for investigate vibration effect on filter efficiency. There are some studies such as Experimental and Modeling Studies of the Stream-Wise Filter Vibration Effect on the Filtration Efficiency investigate Vibration effect on air filters however these study doesn't cover amplitude change .In real word , vehicle are subjected to vibration and amplitude changes.

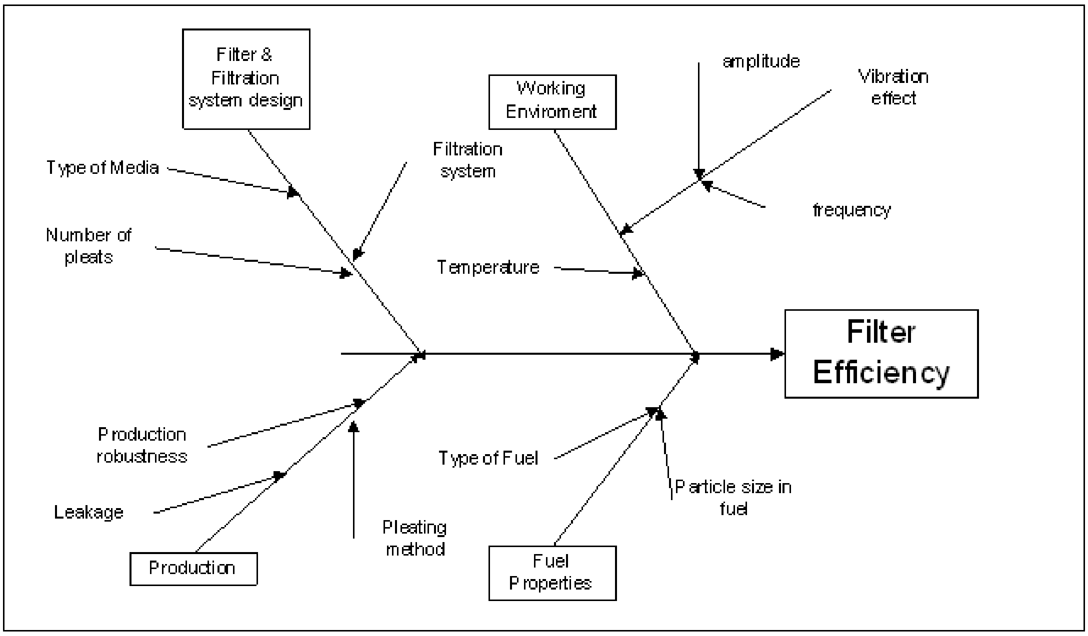


Figure 5.1 Fishbone of filter efficiency

It is decided to investigate vibration effect on fuel filter efficiency.

Y= F(x) Y is response , X is the factors

Where Y is filter efficiency

X1 = Particle Size, X2= Frequency, X3 = Amplitude

Therefore

Y= F(X1,X2,X3)

5.2 Vibration Analysis on fuel filter on the field conditions:

It is required to understand characteristic of vibration on fuel filter at field condition. Vibration is measured at engine with different rpm and according to these measurement results test set up was prepared;

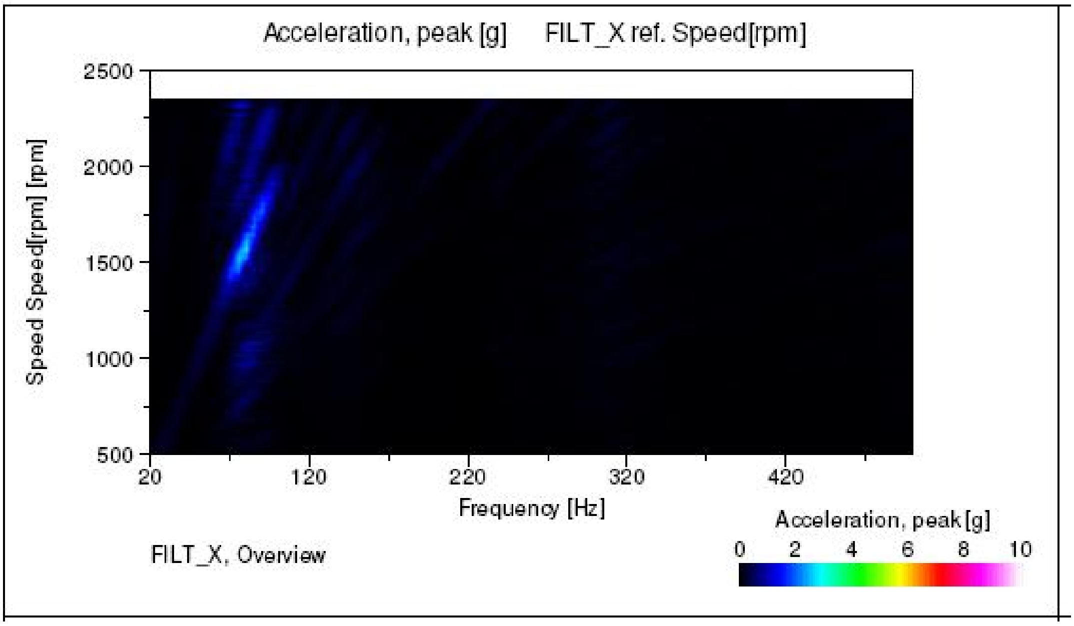


Figure.5.2 Vibration analysis on X direction

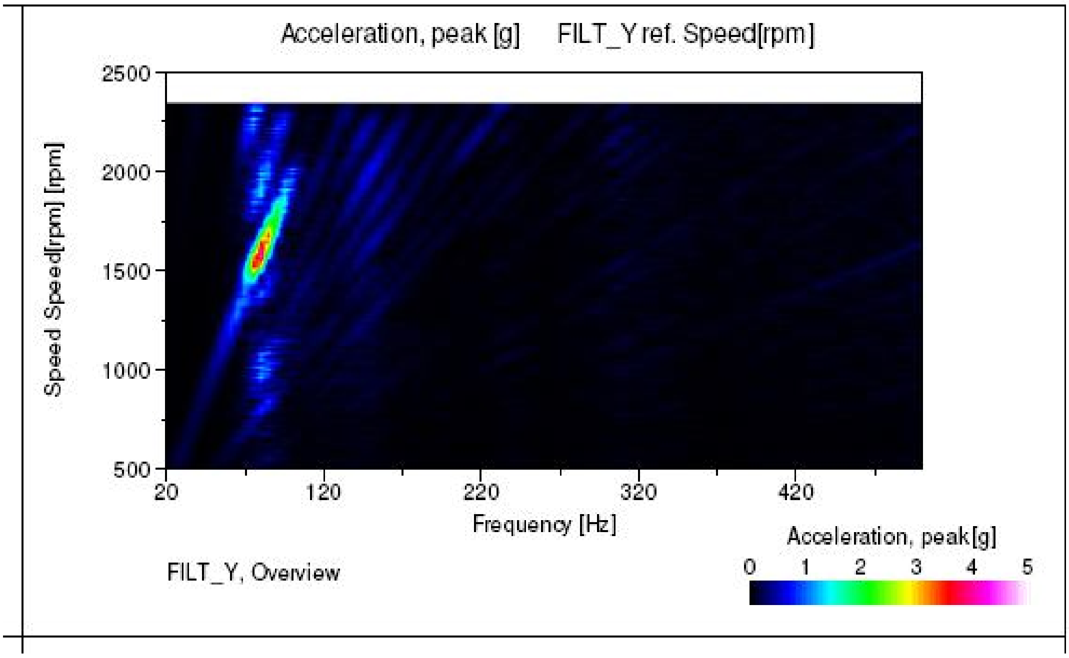


Figure.5.3 Vibration analysis on Y direction

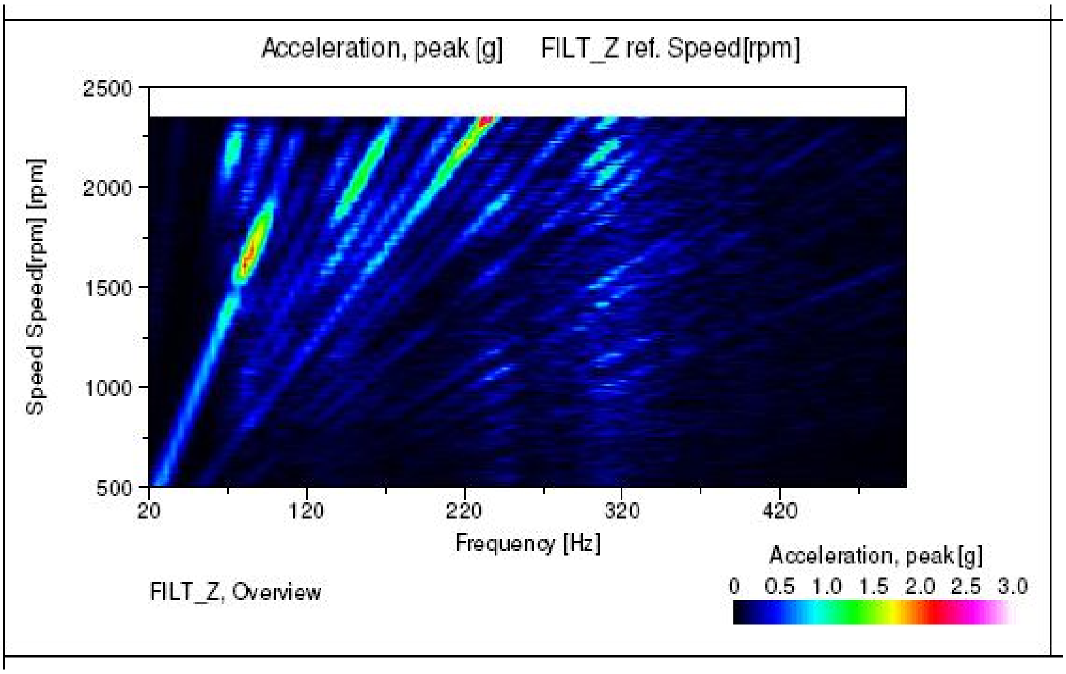


Figure.5.4 Vibration analysis on Z direction

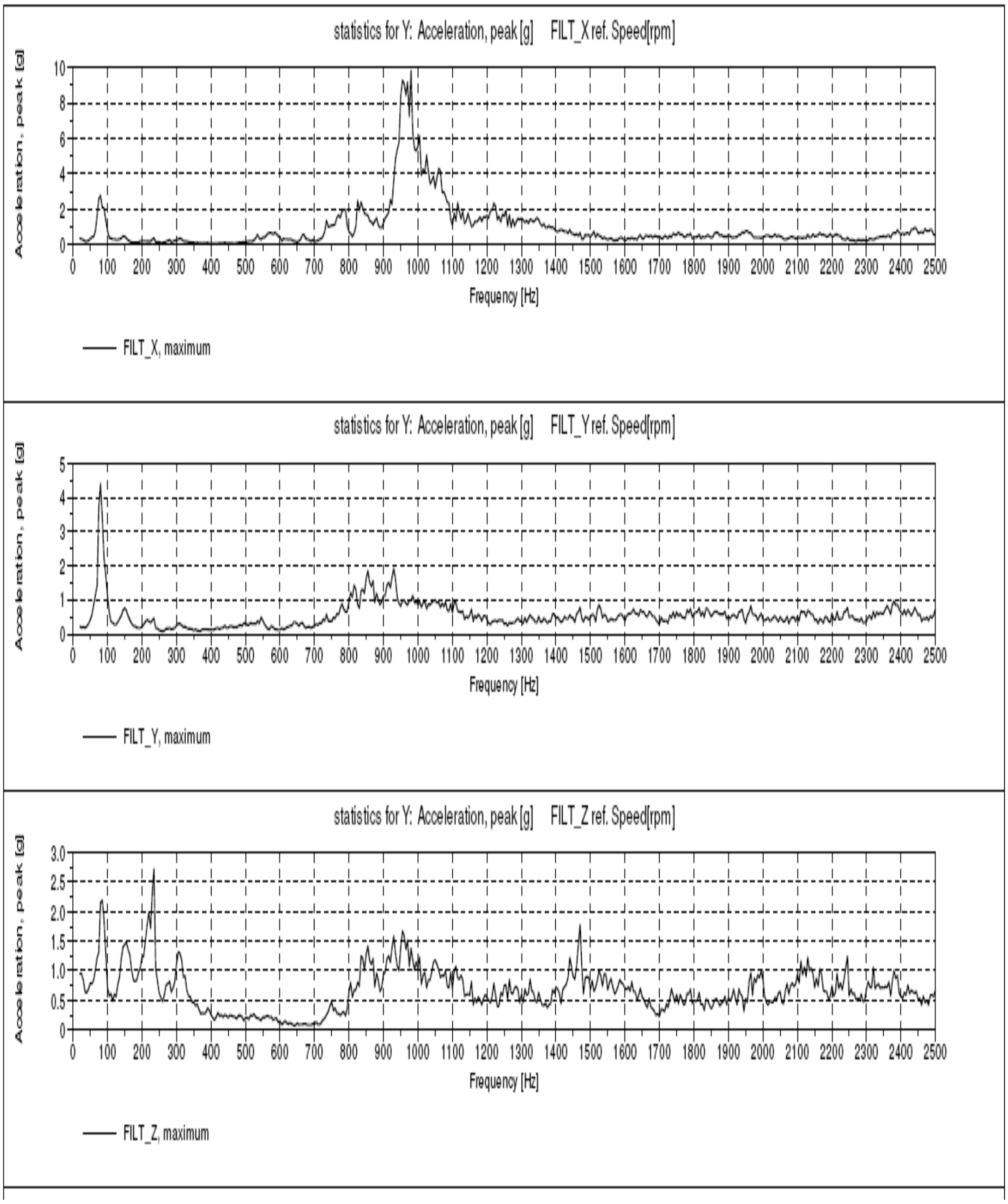


Figure 5.5 Vibration analysis on X,Y,Z directions

5.3 Test Setup:

Existing ISO 13353 test system (Section 3.2 Single-Pass Particle Retention Efficiency) is used. Temperature was maintained at around 17°C. Flow rate used is 252 l/h. Contaminant (ISO Medium test dust) was added into the fuel tank at an injection rate 33 ml/min. Particle removal efficiency was measured upstream & downstream of the filter by ACM20 particle counters.

5.3.1 Vibration Test Rig Modification

Existing ISO 13353 test system modified by adding test rig shake table. Tests performed on the vibration test rig shake table, power from an amplifier and driven by a Dactron Shaker Controller System with data collection by a PC.

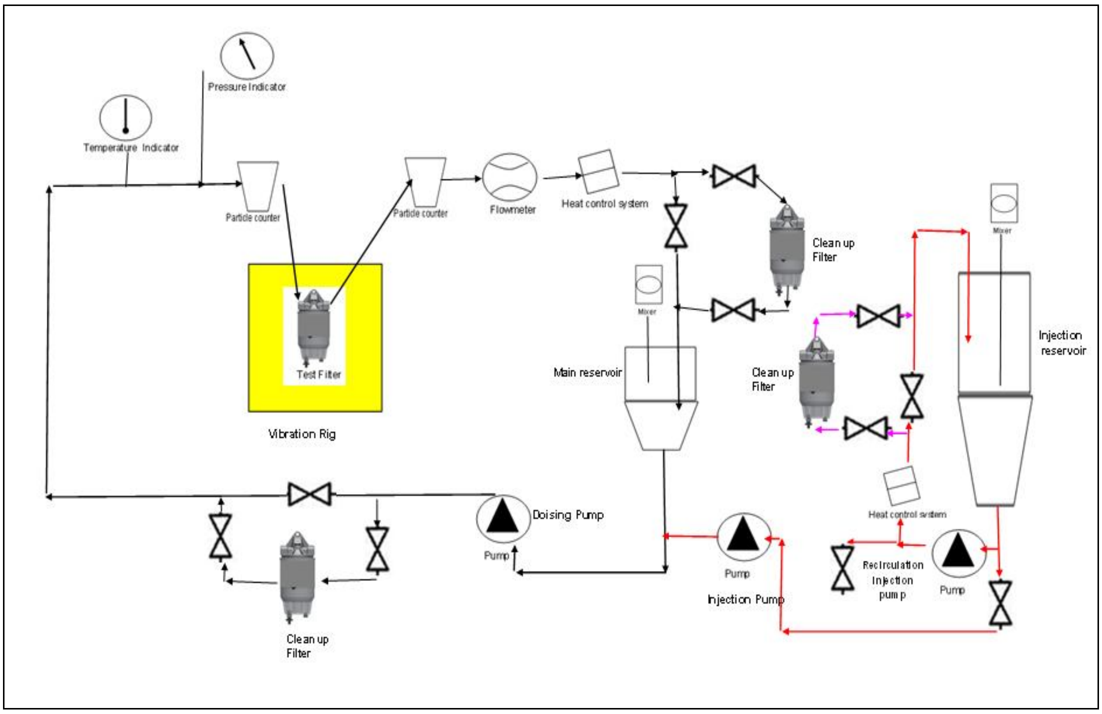


Figure .5.6 Schematic diagram ISO TS 13353 standard single pass efficiency test rig with vibration rig modification.

Figure 5.7 ISO 13353 Test Stand with vibration rig modification

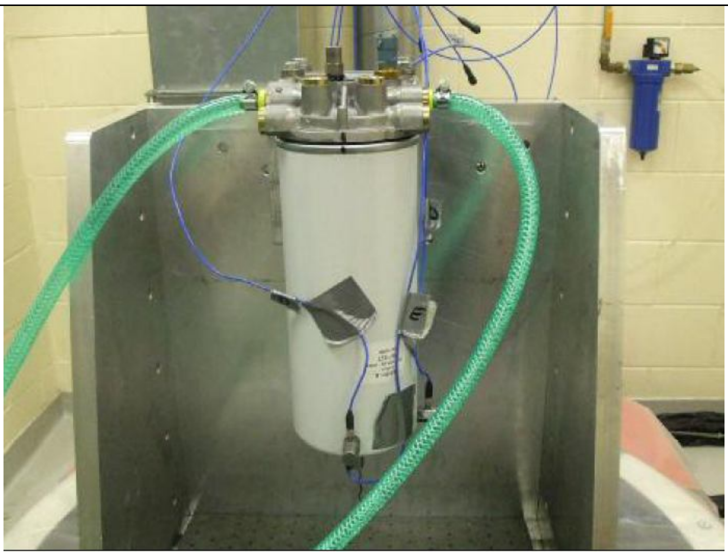


Figure 5.8 Filter connection on Test system

Figure 5.9 Particle counter connection with Test System

5.3.2 Preparation of Vibration rig

a. For the Z direction of vibration on the test components, suitable fixtures mounted onto the shaker table. The fixtures torqued to 35Nm .The test Filter is attached the fixture

b. Attach the control accelerometer to the fixtures & filter then monitor accelerometers to test pieces in agreed positions. Use Superglue to ensure no detachment of the accelerometer during the test.

c. Switch on the air supply.

d. Switch on main power supply to amplifier. Switch on amplifier and turn the gain up to 100% (slowly or it will blow the fuses)

e. Adjust the load support to ½.

f. Turn on the PC, select software and switch on Dactron Shaker Controller.

5.4 Test Results Analysis:

The test regime began with no vibration and then vibration frequency and *g* load (acceleration) was gradually increased, concluding with no vibration again. Efficiency readings are taken at 5 min intervals at channels >4μm, >6μm, >14μm, >21μm, >25 μm , >30μm

Table 5.1 Vibration effect on filter efficiency Test Results Table

Test Particle Dia (μm)

1. No vibration	4μm	6μm	14μm	21μm	25μm	30μm
Upstream	10562.9	3769.9	216.6	38.3	15.1	6.1
Downstream	841.7	68.6	0.1	0.0	0.0	0.0
Efficiency (%)	92.0	98.2	100.0	100.0	100.0	100.0

2. 1g 15Hz	4μm	6μm	14μm	21μm	25μm	30μm
Upstream	10759.7	3852.5	224.6	39.3	15.5	6.3
Downstream	857.3	72.9	0.1	0.0	0.0	0.0
Efficiency (%)	92.0	98.1	100.0	100.0	100.0	100.0

3. 1g 30Hz	4μm	6μm	14μm	21μm	25μm	30μm
Upstream	10587.2	3797.4	233.6	43.5	17.4	6.8
Downstream	839.1	70.7	0.0	0.0	0.0	0.0
Efficiency (%)	92.1	98.1	100.0	100.0	100.0	100.0

4. 2g 30Hz	4μm	6μm	14μm	21μm	25μm	30μm
Upstream	10344.9	3697.1	215.6	41.3	16.0	6.5
Downstream	843.6	70.7	0.1	0.0	0.0	0.0
Efficiency (%)	91.8	98.1	100.0	100.0	100.0	100.0

5. 1g 80Hz	4μ	6μ	14μ	21μ	25μ	30μ
Upstream	10941.9	3910.0	237.6	40.0	15.0	6.1
Downstream	909.5	80.9	0.1	0.0	0.0	0.0
Efficiency (%)	91.7	97.9	100.0	100.0	100.0	100.0

6. 2.5g 80Hz	4μm	6μm	14μm	21μm	25μm	30μm
Upstream	10849.9	3885.1	232.4	42.8	14.8	6.3
Downstream	961.1	87.3	0.1	0.0	0.0	0.0
Efficiency (%)	91.1	97.8	100.0	100.0	100.0	100.0

7. 4.5g 80Hz	4μm	6μm	14μm	21μm	25μm	30μm
Upstream	11086.9	3962.7	242.9	44.5	17.1	5.4
Downstream	1249.6	131.1	0.5	0.0	0.0	0.0
Efficiency (%)	88.7	96.7	99.8	100.0	100.0	100.0

Table 5.1 Vibration effect on filter efficiency Test Results Table continue

8. 1g 230Hz	4µm	6µm	14µm	21µm	25µm	30µm
Upstream	11091	3986.5	246.7	44.6	18	6.1
Downstream	942.6	80.8	0.1	0	0	0
Efficiency (%)	91.5	98	100	100	100	100

9. 3g 230Hz	4µm	6µm	14µm	21µm	25µm	30µm
Upstream	11114.8	3975.1	236.7	43.4	16.8	7
Downstream	1175.2	115.1	0.2	0	0	0
Efficiency (%)	89.4	97.1	99.9	100	100	100

10. 2g 950Hz	4µm	6µm	14µm	21µm	25µm	30µm
Upstream	11550.7	4098.4	251.9	47.9	18.7	6.7
Downstream	1003.2	80.4	0.1	0	0	0
Efficiency (%)	91.3	98	100	100	100	100

11. 10g 950Hz	4µm	6µm	14µm	21µm	25µm	30µm
Upstream	11274.9	3988	250.8	48.6	21.8	8.9
Downstream	1152	100.5	0.2	0.1	0	0
Efficiency (%)	89.8	97.5	99.9	99.8	100	100

12. No vibration. Finish	4µm	6µm	14µm	21µm	25µm	30µm
Upstream	11400.6	4066.7	252.6	49.1	20.1	7.4
Downstream	1010	79.5	0	0	0	0
Efficiency (%)	91.1	98	100	100	100	100

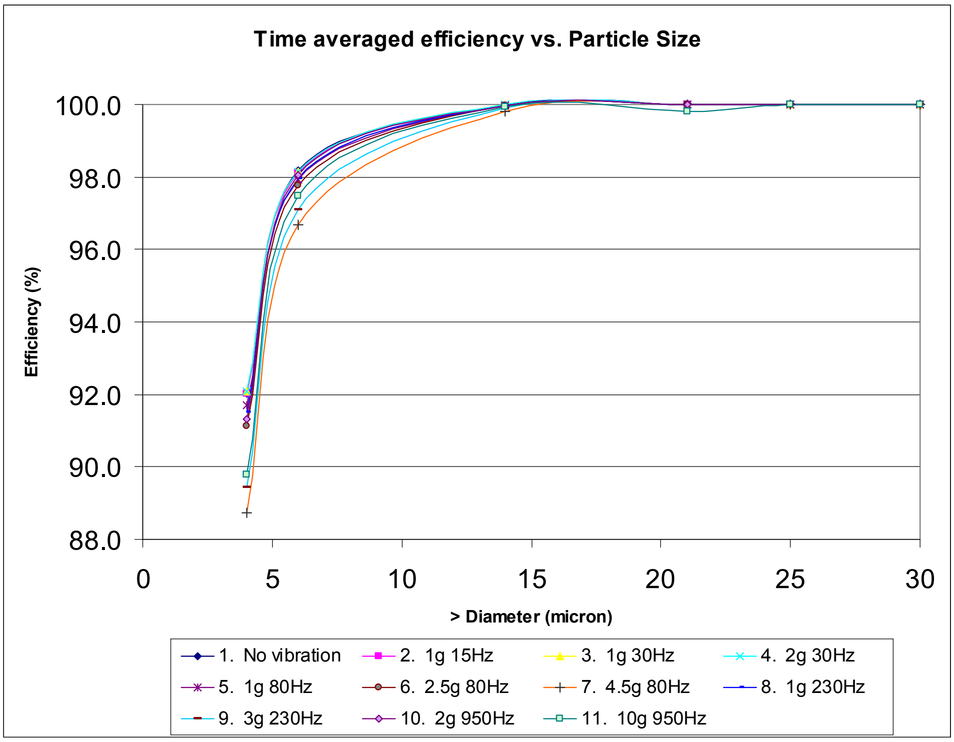


Figure 5.10 Vibration- efficiency change on different particle size

It is shown that vibration doesn't effect filter efficiency when we talk about filtration more than 10 µm particles. However for efficiency less than 10 µm ,affected by vibration.

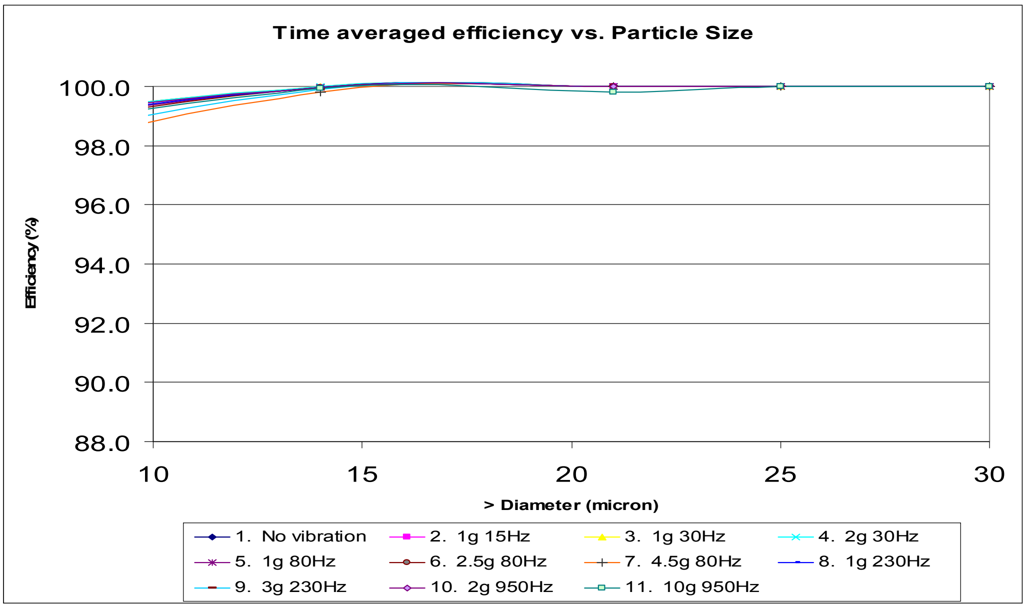


Figure 5.11 Vibration- efficiency change on particle size> 10 µm

According to Figure 5.11 it is required to focus on less than 10 µm particle test results to understand vibration effect on filter efficiency. It seems that efficiency drop with vibration

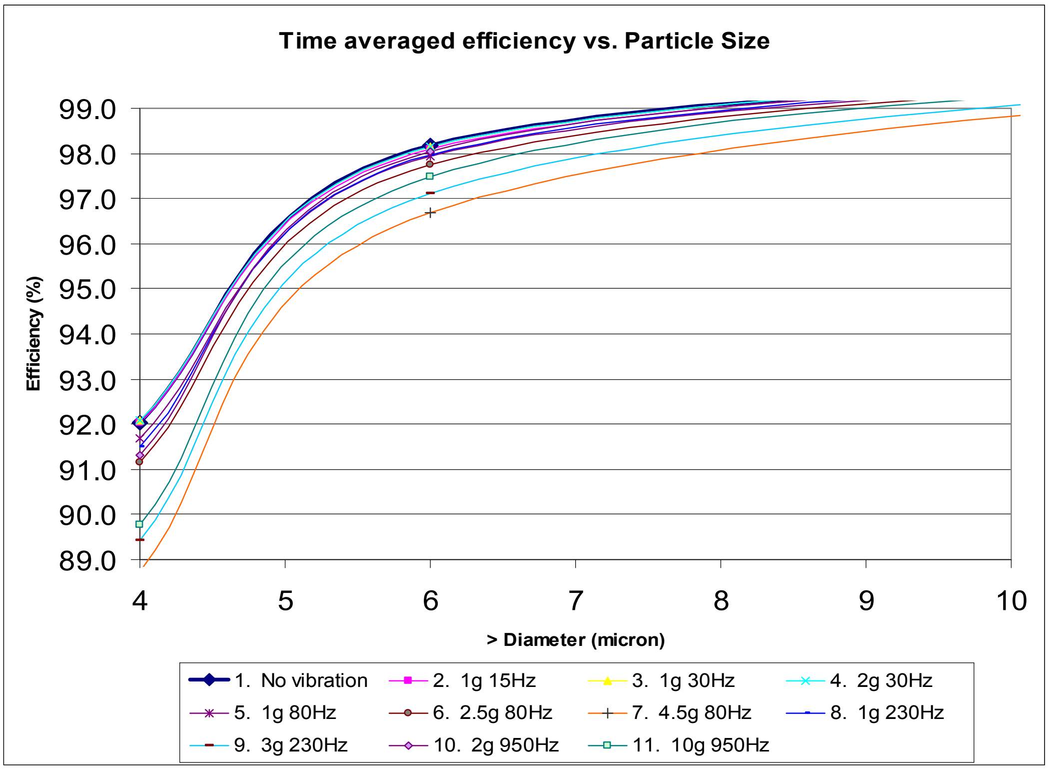


Figure 5.12 Vibration- efficiency change on particle size< 10 µm

It is observed that under 10 µm particle change in vibration effects the filter efficiency.

Y= F(x) Y is response , X is the factors

Where Y is filter efficiency

X1 = Particle Size, X2= Frequency, X3 = Amplitude

In order to understand vibration effect , it is decided to focus test results below 10 µm.

Anova Analysis Method is used to investigate effect of test data on filter efficiency.

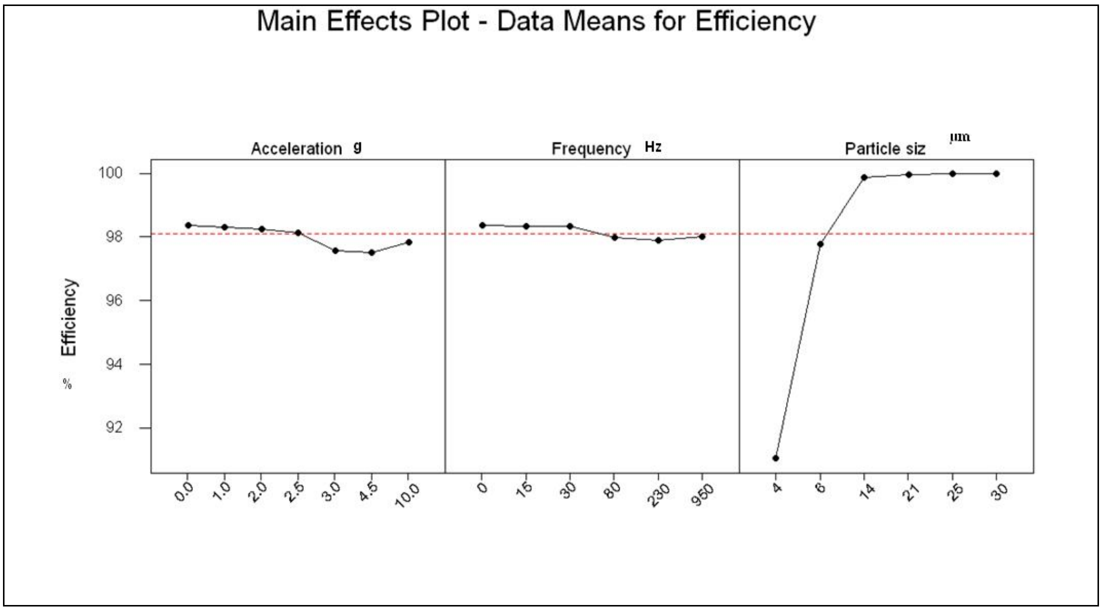


Figure 5.13 Main Effect diagram shows that filter efficiency effected by Acceleration (g), Frequency & Particle Size.

It seems that Filter Efficiency effected particle size, Frequency & acceleration. In order to get more detailed response and factors analysis, Regression method is used.

- Regression analysis will provide the coefficients for the prediction equations
  - Mean
  - Standard deviation

With these method 3D surface model that fits the test result created.

The analysis was done using coded units.

"The original measurement units for experimental factors can be transformed into coded units. Measurement scales as diverse as degrees, seconds or grams are transformed into a common, coded scale.

For each factor level measured in the original scale, the coded unit is obtained by calculating {Original factor level - [(Max. factor level + Min. factor level) / 2]} / { (Max. factor level - Min. factor level) / 2}."

Regression surface created according to inputs where inputs are " Particle size, frequency & Acceleration"

Filter E = Actual test filter efficiency

Fit= Regression surface best fit data for filter efficiency

Residual = Difference between Actual and regression data

ST residual = Standard deviation of residual

Table 5.2 Regression Analysis Results Table

Observation	Filter E	Fit	Residual	St Residual
1	92.000	92.084	-0.084	-0.20
2	98.200	98.711	-0.511	-1.23
3	100.000	100.383	-0.383	-0.96
4	92.000	91.668	0.332	0.75
5	98.100	98.347	-0.247	-0.56
6	100.000	100.229	-0.229	-0.52
7	92.100	91.619	0.481	1.08
8	98.100	98.297	-0.197	-0.44
9	100.000	100.171	-0.171	-0.39
10	91.800	91.184	0.616	1.42
11	98.100	97.916	0.184	0.42
12	100.000	100.007	-0.007	-0.02
13	91.700	91.466	0.234	0.52
14	97.900	98.138	-0.238	-0.53
15	100.000	99.989	0.011	0.02
16	91.100	90.832	0.268	0.61
17	97.800	97.585	0.215	0.49
18	100.000	99.761	0.239	0.55
19	88.700	89.672	-0.972	-2.71R
20	96.700	96.533	0.167	0.45
21	99.800	99.143	0.657	1.95
22	91.500	91.100	0.400	1.01
23	98.000	97.755	0.245	0.61
24	100.000	99.535	0.465	1.18
25	89.400	90.418	-1.018	-2.46R
26	97.100	97.181	-0.081	-0.19
27	99.000	99.394	-0.394	-0.95
28	91.300	91.486	-0.186	-0.62
29	98.000	98.109	-0.109	-0.31
30	100.000	99.767	0.233	1.34
31	89.800	89.873	-0.073	-0.24

Table 5.2 Regression Analysis Results Table continue

Observation	Filter E	Fit	Residual	St Residual
32	97.5	96.929	0.571	1.6
33	99.9	100.319	-0.419	-2.42R

R denotes an observation with a large standardized residual.

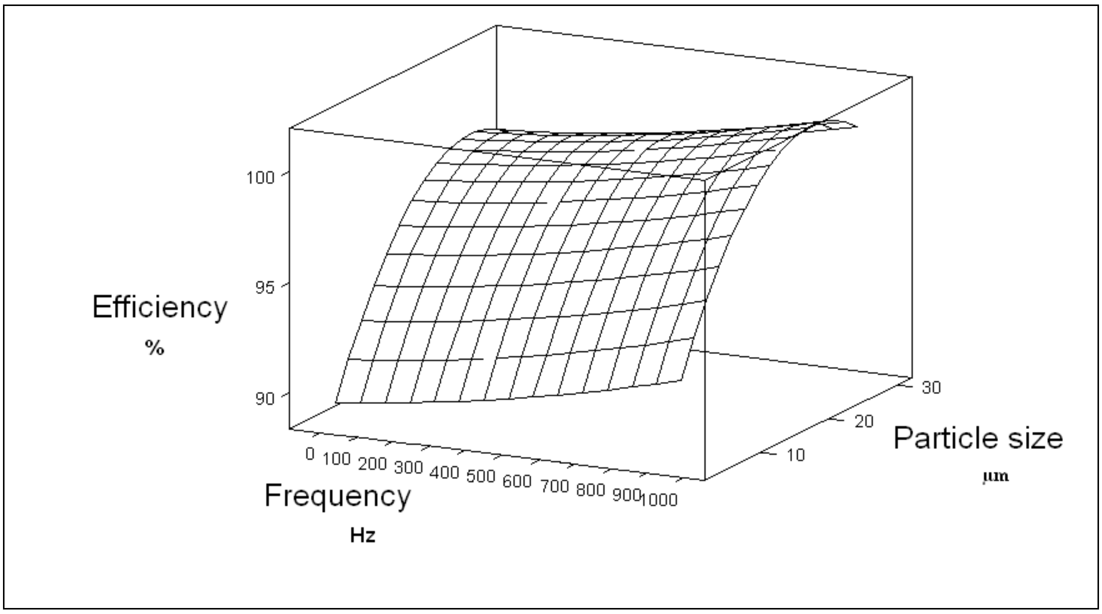


Figure 5.14 Regression surface shows relation between Filter efficiency, Frequency & Particle size

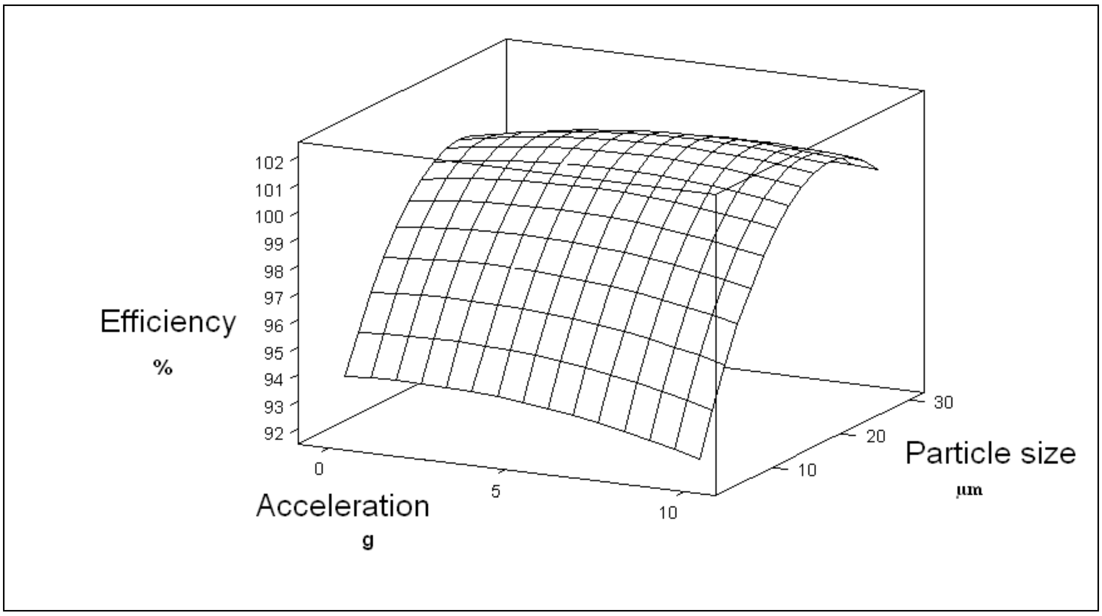


Figure 5.15 Regression surface shows relation between Filter efficiency, Acceleration (Amplitude) & Particle size

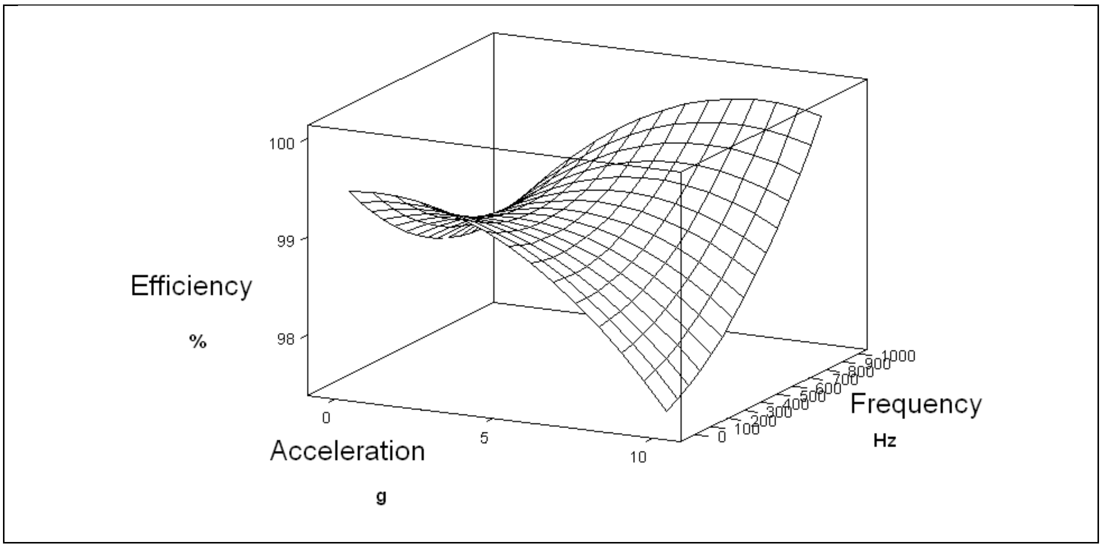


Figure 5.16 Regression surface shows relation between Filter efficiency, Frequency & Acceleration (amplitude)

Analysis of Variance Method help us to understand relationship between Y (response) and X (inputs)

The p-values is used (P) to determine which of the effects in the model are statistically significant. Before you look at the individual effects in the regression table, you should look first in the analysis of variance table at the p-values for the omnibus F-tests for all linear, all squared and all interaction effects. After you identify a significant set of effects (for example linear effects, or interaction effects), use the regression table to evaluate the individual effects.

If the analysis of variance table suggests significant squared or interaction effects, you should look at them first because they will influence how you interpret the linear effects. To use the p-value, you need to:

- identify the p-value for the effect you want to evaluate.
- compare this p-value to your a-level. A commonly used a-level is 0.05.
- if the p-value is less than or equal to a, conclude that the effect is significant.
- if the p-value is greater than a, conclude that the effect is not significant

Analysis of Variance for Filter E

Table 5.3 Analysis Of Variance Table Results

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	481.464	481.464	53.4961	232.80	0.000
Linear	3	312.871	290.013	96.6709	420.69	0.000
Square	3	165.799	162.499	54.1663	235.72	0.000
Interaction	3	2.795	2.795	0.9315	4.05	0.019
Residual Error	23	5.285	5.285	0.2298		
Total	32	486.750				

These means that

Regression p=0000 < 0.05 Regression method is applicable

Linear p=000 < 0.05 there is linear relationship between input and Y(i.e

Y =ax)

Square p=000 < 0.05 there is square relationship such as $Y = a X^2$

Interaction p=0.019 < 0.05 there is interaction relationship such as $Y= aX_1*X_2$

For the test data, the regression table shows the following:

·**Interaction effects**:

The model contains a 3 two-way interaction (Acc*Frequency, Acc* Particle; Frequency*particle).

Interaction	P	
Acc*Frequency	0.141	> 0.05 No Significant Effect
Acc*Particle	0.009	< 0.05 Significant Effect
Frequency*Particle	0.428	> 0.05 No Significant Effect

·**Squared effects:**

The model contains 3 squared effects (Acc*Acc; Frequency*Frequency and Particle*Particle). Squared terms are used to evaluate whether or not there is curvature (quadratic) in the response surface. Because the squared terms were identified as significant in the analysis of variance table ($p = 0.000$) you can look at each of the terms individually.

Interaction	P	
Acc*Acc	0.403	> 0.05 No Significant Effect
Frequency*Frequency	0.068	> 0.05 No Significant Effect
Particle*Particle	0.000	< 0.05 Significant Effect

The p-values for both squared effects (Frequency*Frequency= 0.068 and Particle*Particle = 0.000) are less than 0.05. Therefore, there are significant quadratic effects. That is, the relationship between Vibration and Filter Efficiency, and Particle Size and Filter efficiency follow a curved line, rather than a straight line.

·**Linear effects**:

The model contains 3 linear effects (Acc, Frequency and Particle size),

Interaction	P	
Acc	0.014	< 0.05 Significant Effect
Frequency	0.130	> 0.05 No Significant Effect
Particle	0.000	< 0.05 Significant Effect

Table 5.4 Estimated Regression Coefficients for Filter E by using coded units

Term	Coef	SE Coef	T	P
Constant	102.206	0.4139	246.941	0.000
Acc	-1.528	0.5774	-2.647	0.014
Frequency	0.959	0.6115	1.569	0.130
Particle	4.687	0.1367	34.294	0.000
Acc*Acc	-1.124	1.3190	-0.852	0.403
Frequency*Frequency	0.698	0.3641	1.917	0.068
Particle*Particle	-7.761	0.2927	-26.515	0.000
Acc*Frequency	1.646	1.0786	1.526	0.141
Acc*Particle	0.677	0.2369	2.856	0.009
Frequency*Particle	-0.140	0.1736	-0.806	0.428

S = 0.4794   R-Sq = 98.9%   R-Sq(adj) = 98.5%

R^2 and adjusted R^2 represent the proportion of variation in the response that is explained by the model.

- R^2 (R-Sq) describes the amount of variation in the observed responses that is explained by the model.

For the catalytic reaction data, 93.0% of the variation in yield is explained by model.

- Adjusted R is a modified R that has been adjusted for the number of terms in the model. If you include unnecessary terms, R can be artificially high. Unlike R, adjusted R may get smaller when you add terms to the model.

For the catalytic reaction data, the adjusted R is 87.0%.

Note You can make R artificially high by including too many terms in the regression model. If you add unnecessary predictors to the model, the R usually increases even if you gain no additional information about the response. Because the adjusted R takes into consideration the number of predictors in the model, it is more appropriate than R for comparing models with different numbers of predictors.

Coded Units Equation :

Y(Filter Efficiency) = 102.206 -1.528 Acc +0.959 Frequency+ 4.687 Particle-1.124 Acc^2 +0.698 Frequency^2 – 7.761 Particle^2 + 1.646 Acc* Frequency+0.677 Acc* Particle -0.140 Frequency* Particle (3)

Table 5.5 Estimated Regression Coefficients for Filter E using data in uncoded (actual) units

Term	**Coefficient**
Constant	71.3782
Acc	-0.429109
Frequency	-0.00385325
Particle	6.41816
Acc*Acc	-0.0449410
Frequency*Frequency	3.092639E-06
Particle*Particle	-0.310455
Acc*Frequency	0.000693143
Acc*Particle	0.0270689
Frequency*Particle	-5.89436E-05

Result indicate:

Y(Filter Efficiency) = 71.3782 -0.429109 Acc +0.00385325 Frequency + 6.41816 Particle-0.044941 Acc^2 +3.0926 E-06 Frequency^2 – 0.310455 Particle^2 + 0.000693143 Acc* Frequency +0.0270689 Acc* Particle -5.89436 E-05 Frequency* Particle (4)

5. 5 Conclusion:

In these study Frequency and amplitude effect on filter efficiency investigated with different particle sizes on Fuel Filter. Test results has been analyzed by using Regression, Anova and Analyze of Variance methods by using Minitab software.

Frequency and amplitude doesn't have any big effect on filter efficiency when we talk about filtration of particle size higher than 10µm.

However, it is observed that Frequency and amplitude effected the filter efficiency. Amplitude (acceleration) increase, decreases the filter efficiency, it has negative effect. For filtration of particle size less that 10µm. On the other hand frequency increase, increases the filter efficiency, it has positive effect.

Our test results on frequency effect is similar with study on HVAC glass filters "*Experimental and Modeling Studies of the Stream-Wise Filter Vibration Effect* on the Filtration Efficiency ". However in these reference amplitude effect wasn't included.

Test results on amplitude effect is similar with study on oil filters "*How Flow and Vibration Affect Filter Performance - Inside and Outside the Laboratory*" .

According to regression formulation amplitude (acceleration) has bigger effect than the frequency. Combination of amplitude and frequency can reduce the filter efficiency.

Considering Frequency and amplitude effect on selection of suitable fuel filter is important .Specially for engine like Common rail system which are require high filter efficiency.

Frequency increase, increases the filter efficiency, it has positive effect;

- due to the increased relative velocity between the particle and the filter fiber
- due to the increased diffusion intensity from turbulence around the filter fiber

Amplitude (acceleration) increase, decreases the filter efficiency, it has negative effect

- A steady flow of fluid through a filter will cause correspondingly steady accumulation of solids and rise in pressure drop mentioned as cake filtration The effect of amplitude on flow is to loosen the finer particles held in the filter cake, and so to allow them to pass through the filter and on into the filtrate. Therefore filtration efficiency for small particle drops .

Fuel filter should be positioned on vehicle to avoid vibration. When designing new fuel filtration system acceleration and frequency should take care .

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