Jet fuel filtration

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There are four aspects to the problem of aviation fuel handling where filtration plays a key role in quality. These are:

- At the refinery.
- Through the pipeline.
- Tanks at the terminal.
- Truck transportation (across the road or tarmac and into the plane for airport refuelling).

Before fuel enters the turbine engine, it must be both clean and dry. While it is obvious that poor quality fuel can lead to catastrophic accidents in both commercial and military aircraft, fuel quality is also important in industrial applications, where aeroderivative units are used to generate power, or as a prime mover. In all cases, liquid fuel standards and specifications are extremely important to understand and implement. Engineers involved with ensuring jet fuel quality should be extremely familiar with these requirements and all those published by the supported organisations.

In light of this, one must be aware of specific fuel test methods for both civilian and military aircraft. These product specifications cover the key fuel contaminants, which are: particulates, water, surfactants and microbial growth. This article focuses on particulate removal.

Fluid/particle separation takes place not only at the refinery and pipeline, but also at the terminal tank farm, the fuelling system, and on the trucks or skids that lift the fuel into the aircraft. Filter selection and filter design can be at the submicron level (nominal) or 2 μ (absolute). Furthermore, there are additional fuel filters on the aircraft itself. Just as important as particulate removal, engineers must also address the design of water removal systems and coalescers (hay packs), selection of prefilters and absorbers. The latter can be clay treaters, swelling powders or absorbent fibres.

Where quality begins

Quality begins in the design of the fuel delivery system. A myriad of filtration problems can occur when the wrong construction materials are used (copper pipe, galvanised components or cadmium fittings are unacceptable). Proper pipe drainage is essential to avoid low points where rust or scale can accumulate and lead to large-scale slugging of grit and particulates to the filter. Also, proper drainage is critical to avoid the growth of organisms in the fuel system. These microbes present themselves to the filters as small gelatinous particles that are flexible and difficult to remove, as they can squeeze through filter pores, particularly under pressure. There is no end to system design problems because, over time, fuel pipelines can be shutdown, allowed to sit for two or three years, and then are reactivated. At restart, there are major filtration considerations to clean the system before it sends fuel into the airport's fuel system. These kinds of problems are common at major hubs or terminals. Most importantly, the filter must match the requirements and formulation of the actual jet fuel (Table 1).

Fuel quality

As a rule of thumb, jet fuel should be filtered each time it is moved. Also, standard operating procedures (SOPs) should include complete details of fuel system operations. These would include blending records, filtering operations and test results from normal and spot-check quality control (QC) procedures. The tank farm itself poses particular problems. It is important to recognise that the fuel filter cartridge is integrated as part of a total system: to ensure the proper quality and amount of fuel reaches the aircraft when needed.

This means the removal of all particulates including: dirt, rust and blooms of live organisms. Microbial growth, which develops as a result of stagnant conditions in the fuel system, begins with bacteria or fungi finding suitable breeding conditions. These manifest themselves as flexible particulates that will quickly foul filters, corrode system hardware, neutralise

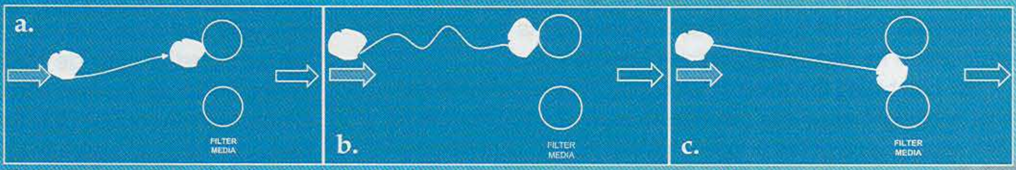

Figure 1. a. Inertial impact. b. Diffusional interception. c. Direct interception.

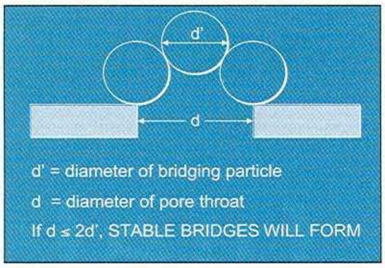

Figure 2. Classic bridging theory.

sensors and disrupt instruments and process control. The presence of water exacerbates microbial growth.

Certain jet fuels, for example, Jet Fuel 'A', are more likely to absorb water and hold it in suspension because of the basic fuel formulation and quantitative analysis. At high altitudes, water in fuel can form ice in the fuel systems and can reduce or actually cut off the fuel supply to the engine. The fact that water also causes corrosion means that water removal is essential.

Table 1. Information on commonly used jet fuel

Type of fuel	Additives*	Comments
Jet-A	Generally none	Commercial fuel; narrow cut kerosene
Jet-A1	Freezing point modifier	High altitude; long haul flights
Jet-B	To lower flash point	Wide cut kerosene
JP-4	For corrosion and anti-icing	Being replaced byJP-8
JP-5	For corrosion and anti-icing	US Naval aircraft
JP-8	Complete additive package	US Air Force

Most of these fuels contain a static depressant.

$$\text{FILTER EFFICIENCY (\%)} = \left[\frac{\beta-1}{\beta}\right] \times 100$$

Figure 3. Filter efficiency equation.

Surfactants also are fuel contaminants. These are present as part of the formulation or are introduced during refinery, pipeline or trucking operations. Surfactants can inhibit filter operation by affecting the pores or by neutralising the effect of water absorbents (activated alumina, non-woven absorbent fibres/powders, atapulgus clay, bentonite, activated carbon, molecular sieves or natural zeolites).

Filtration basics

Particulate removal from jet fuels is generally accomplished using cartridge filtration. As dirt and contaminents build up on the surface of the cartridge, the static pressure increases. At a certain pressure drop across the filter, the cartridge should be changed. The point where additional pressure on the filter no longer achieves any additional throughput is called the 'tiller' point. Filter selection involves choosing a cartridge that can act as a prefilter, as well as the final cartridge element, to achieve the required absolute μ (removal) level. Generally, dissolved solids cannot be removed by filtration without some form of pretreatment. In jet fuel filters, final cartridges may be used to remove particulates down to the submicron level.

The basic mechanisms of filtration are inertial impaction, diffusion interception and direct interception (Figure 1). Since the density of a particle is typically closer to that of a liquid rather than that of a gas, direct interception is the desired mechanism for separating particles from liquids.

By combining the direct interception mechanism with particle bridging theory, it is possible to explain why filter media with specific size pores or openings are able to capture particles with smaller diameters than those of the pores. According to classic bridging theory, a stable bridge will form over a pore if two or more particles with diameters at least one half that of the pore diameter contact the opening at the same time. This newly formed bridge contains even smaller pores that in turn capture smaller particles (Figure 2).

As particles are captured from jet fuel pressure builds up across the filter. Pressure is an indication of dirt accumulation. To alleviate constant change outs, the elements should have a high dirt holding capacity. It is important to note that too much pressure on gelatinous biological particles can force them through filter pores.

Under certain conditions, collected particles can be released from the filter medium and pass downstream. Variations in flow rates and pressure surges are common causes of particle release. Even under ideal flow conditions, filters can release particles if their medium structure is subject to pore enlargement. This is a typical occurrence in string wound filters and low density felt bags whose pore sizes change in response to increased pressure. For aviation fuel, the best filters are designed with filter medium that have fixed pore structures that are not affected by variations in pressure and flow rate.

Filter types

The most commonly used filters in jet fuel filtration can be classified as having either a non-fixed random pore size medium or a fixed controlled pore size medium. Non-fixed random pore size medium filters such as felts, woven yarns, and packed fibreglass contain pores of various dimensions that can enlarge as changes in flow rate and differential pressure occur. These types of filters are subject to particle unloading, channelling, and media migration.

Fixed controlled pore size medium filters are constructed such that the pores are prevented from enlarging under pressure and flow changes. Although these filters contain pores of varying sizes, their overall structure is controlled during manufacturing to ensure quantitative removal of particles larger than a given size. With this type of filter, any particles released during impulse conditions should be smaller than those designated by its removal rating.

Removal ratings

Various systems exist for rating filter removal efficiency. Two of the most common are the nominal rating and the absolute rating systems. Unfortunately, each manufacturer is free to utilise variations of the different testing procedures to assign the nominal or absolute ratings of their specific filters.

A nominal filter rating is defined as a μ value. This value is based on a percentage of particles removed by weight, where the particles are a given size or greater. Common percentages used by various manufacturers include 98, 95, and 90%. This rating system bases results on gravimetric testing rather than actual particle counting. Problems associated with the system include a poorly defined test procedure, variation in removal percentages with manufacturer, test data is not usually reproducible, and larger downstream particles than the micron rating of the filter.

An absolute filter rating is generally defined as the diameter of the largest hard spherical particle that will pass through the filter under specific test conditions. Several recognised tests exist for establishing the absolute rating of a filter and may vary with manufacturers. However, in all tests, the filters are subjected to a particle challenge by pumping a known contaminant through the filter and measuring upstream and downstream particle counts. Only fixed controlled pore size medium filters can have an absolute rating.

Beta ratios

Beta ratios were originally developed for evaluating the performance of hydraulic and lubricating oil filters. Today, these ratios are very useful in measuring and predicting the performance of absolute rated filters under specific test conditions, in a variety of liquids (Figure 3). Beta ratios are particularly important in large volume filtration operations such as those

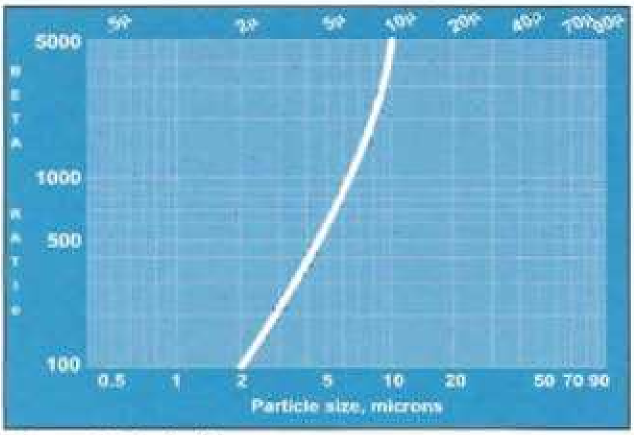

Figure 4. Typical beta curve.

$$E = \frac{P}{H} + \frac{L}{H} + \frac{D}{H}$$

D = Disposal Cost/Filter
H = Dirt Holding Capacity in Pounds
L = Labor Cost/Filter
P = Filter Price

$$\text{ALHA FACTOR } (A) = \frac{\text{FILTER PRICE } (P)}{\text{DIRT HOLDING CAPACITY } (H)}$$

$$E = A + \frac{L}{H} + \frac{D}{H} \Rightarrow E = A + \frac{L + D}{H}$$

handling jet fuels at major airports.

The beta ratio concept involves measuring total particle counts at several different μ levels in both the influent and effluent streams. These counts provide a profile of the filter efficiency at the different μ levels and can be plotted as a beta curve for the given filter (Figure 4).

Filter selection

Many factors must be taken into consideration when choosing the filtration system for aviation fuels. These include chemical and temperature compatibility, flow rate, acceptable pressure drop, degree of filtration, and overall filtration cost. Depending upon the size of the airport and the amount of fuel being handled, engineers may select a high capacity cartridge filter (HCCF) with large dirt holding capacity. These are normally made of polyester, fibreglass or cellulose.

These HCCF cartridges generally utilise a staged pleated filter that is highly efficient and high capacity (HE/HC). These maximise dirt holding capacity in order to ensure maximum time between change out (MTBC). The filtration operation in jet fuel can be hazardous, so producers try to keep the units online as long as possible. This is particularly true in large pipelines and in cases where toxic additives are used. The HE/HC cartridges feature segregated flow channels and flow chambers to optimise the alpha factor (A) (a key factor in determining total cost of filtration operations). Maximum dirt holding capacity is obtained by combining this design with the technique of pleating several different filter media together in a pack. This design permits the use of many different types of filter media, which is essential for a wide range of fluid and temperature applications. A cross sectional view details the basic design and flow paths of an HE/HC filter (Figure 5). This unique design works with either an 'outside in' or an 'inside out' flow path and is not limited to three rows of media.

As mentioned previously, material selection is very important in jet fuel filtration. Since fuels vary in composition, it is not always possible to designate a filter medium that is suitable for every purpose. Other complications can arise from the additives used in the fuel. Generally, cellulose and/or fibreglass is acceptable. However, operating temperature and the presence of certain surfactants in the fuel can affect filter choices.

The size of filter housings and pumps is usually dictated by the desired flow rate, pressure drop limitations, and the required level of filtration. The recommended flow capacity of a filter element is used to determine the total number of elements required for the desired flow rate. Housing size relates directly to the number of filter elements. Sufficient pump pressure must be provided to ensure the desired flow rate through the filter element as it clogs, so as to fully use the effective dirt holding capacity of the filter.

Filtration costs

It is not unusual for operators to underestimate the true cost of a filtration operation. Total filtration costs must include both capital cost and daily operating costs. Indeed, most engineers understand capital costs, but the cost of operations and maintenance of the filtration system is often underestimated. This includes cost of labour, installing and removing the element, and the actual costs of disposing of the element. In cases that require special breathing apparatus and protective clothing, the total cost of the filtration operation can be quite high. The cost of the filter element may be nominal compared to companion costs. It therefore becomes obvious that extending the MTBC is desirable.

Filtration cost efficiency (E) is defined as the total costs, direct and indirect, that are associated with removing 1 lb of solids from a process stream. Direct cost is filter price and indirect costs include labour and disposal. A lower total cost results in a better efficiency rating. If we disregard equipment depreciation, we can express this relationship by the following rule:

Jet fuel filtration is both a batch and a continuous operation depending upon where the filter is located in the fuel distribution system. Consequently, one must recognise that the actual dirt holding capacity in pounds (H), can dramatically influence the true cost of the filtration operation. However, by knowing dirt loading, the filter is sized accordingly. One also matches the filter housing to the flow requirements.

Filter price and dirt holding capacity are the dominant components in operating cost. The relationship between these two items is defined by the following rule and is the alpha factor (A).

Combining the alpha factor formula with the filtration cost efficiency formula provides an interesting result.

The indirect costs shown in the equation are reduced as the dirt

Figure 5. Highly efficient, high capacity filter showing flow pattern.

holding capacity of the filter increases. Therefore, the alpha factor becomes the dominant number in the equation. The lowest alpha factor results in the lowest filtration cost.

$$\text{FILTER LIFE INCREASE} = \frac{Le}{Lo} = \left(\frac{Ae}{Ao}\right)^N$$

Le = Extended Filter Life
Lo = Original Filter Life
Ae = Expanded Filter Area
Ao = Original Filter Area
$1 \leq N \leq 2$

Maximising filter life

Filter life is directly related to a filter's dirt holding capacity. It can be defined as the total volume of fluid that passes through a filter before reaching the maximum operating differential pressure.

Under a constant flow rate, the life of most absolute rated filters is significantly increased when their effective surface areas are increased. This property of filter life is a direct result of the relationship between flow density (gallons per minute per square foot) and the resulting differential pressure across the filter area.

Under ideal conditions the maximum increase in filter life is equal to the square of the increase in effective surface area. Doubling the effective filter surface area can increase filter life up to four times.

An easy way to increase filter life using an existing housing is to replace depth filters with HE/HC pleated filters. In the following diagrams, the surface area of the cylindrical depth element is much less than that of the pleated element.

In large jet fuel operations, engineers should obviously consider the savings associated with filter housing costs. Many plants design their filtration systems based on a maximum flow rate. If a 2.5 in. OD or 3.75 in. OD cartridge is used in the base flow rate calculations, a larger vessel will be required to meet the maximum flow requirements. Using an HCCF design will minimise the filter vessel size (and costs) required for specific flow rates. The design can also result in significant cost reductions when high pressure filter vessels are required. A typical filter system is shown in Figure 8.

Fuel handling and filtration

The improper operation and maintenance of a jet fuel delivery system places additional burdens on the separation and filter components of the unit. For example, at many airports, daytime to night time temperatures can change by as much as 40 F. In the process, water can condense into piping, nozzles or bypass components. Consequently, in the morning, before fuel is sent to aircraft, a certain amount of fuel must be recirculated back into the storage tank to alleviate water being sent into the plane. Also, if delivery piping has not been operated for a while, particulates may lodge in the bypass valve of a pump and can move their way through the pipe, causing contamination. This action places additional requirements on the final filtration step, the one just prior to fuel entering the aircraft.

Filter elements can also be damaged during shipping and/or installation, especially when improper installation procedures are followed. Poorly trained personnel can damage a filter, absorber or coalescer simply by being careless in removing it from its shipping box.

Filters are changed out when the differential pressure between inlet and outlet reaches the manufactures recommendation, approximately 35 pounds per square inch (psi). Obviously, utilising an HE/HC cartridge enhances overall economics tied to MTBC. However, in standard paper or string wound cartridges, pressure surges can actually rupture a filter element. System pressure can also affect the vessel closure seal. Consequently, bolted closures should utilise a torque wrench to ensure the closure can withstand the internal filter system pressure. Monthly maintenance procedures should include retesting and resetting of the bolt closure using a torque wrench.

Figure 8. Skid mounted jet fuel filter, 36 in. diameter.

While pressure testing and bolt torquing may appear obvious to assure a filter is operating properly, other facets of fuel system quality control are not so obvious, but can affect the quality of the jet fuel. One of the most overlooked concerns is cleanliness of the tanker fleet. Jet fuel tankers should not be used to transport other liquid petroleum products. Fuel handlers should also perform daily preventative maintenance sump checks on any sump that has the potential to build-up particulates. Flushing and cleaning each sump can ameliorate MTBC.

Additives and filters

Certain pipeline additives/surfactants are used as flow enhancers for petroleum products and can be removed in the jet fuel filtration system. Static dissipaters (surfactants essential to the fuel formula) are often removed by clay filters and certain absorbers. Consequently, static depressors are usually added in upstream pipeline locations to assure they remain in the jet fuel as it is loaded into the aircraft. Excess amounts of anti icing additives in the fuel system can affect the filtration system, especially the coalescer. Their use, or omission, can affect water absorption, similar to the way corrosion inhibitors can influence particulate removal.

Conclusion

In conclusion, jet fuel deserves close attention to ensure overall economical operation and to maximise an operator's return on investment (ROI).

- A filter element's alpha factor is easy to calculate. The lowest alpha factor results in the lowest filtration cost.
- An increase in effective surface area will result in a significant increase in filter life.
- Beta ratios provide a profile of a filter's efficiency at different μ levels.
- Filter elements used in jet fuel systems should be selected based on media that contain fixed controlled pore sizes.
- Total filtration operating cost must include equipment depreciation, filter element cost, labour cost, and element disposal cost.

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