

Appendix A · Aviation Fuel Distribution and Handling

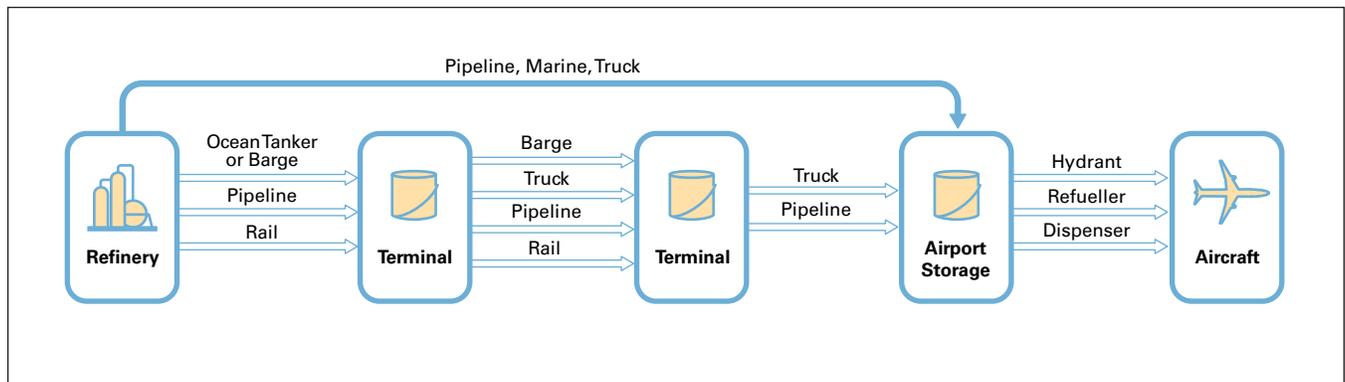
FUEL DISTRIBUTION SYSTEM

A batch of aviation fuel produced at a refinery is tested to ensure that it meets all of the applicable specification requirements. It must then be moved to an airport, and finally, pumped into the tank of an aircraft. The fuel may be shipped directly to an airport fuel storage facility, but usually the distribution chain includes one or more intermediate storage facilities (terminals), as illustrated in Figure A.1. Several modes of transportation may be used: pipeline, ship, barge, railroad tank car, and tanker truck; but not all modes are available for every destination. Quality checks are performed on the fuel at each point in the distribution system to guard against contamination.

Pipelines Pipelines are best suited for transporting large volumes of fuel. Batch shipments (*tenders*) of a product commonly exceed 400,000 gallons (10,000 barrels). For this reason, aviation turbine fuel (*jet fuel*) is commonly moved by pipeline. Aviation gasoline¹ (*avgas*) is usually moved by truck, railcar, or barge because of its smaller volumes.

A few refineries have dedicated² jet fuel pipelines running directly to nearby airports. However, most jet fuel is shipped via common-carrier multiproduct pipelines. That is, the pipelines are available to all shippers that meet their product quality requirements, and they handle tenders of different petroleum products, usually in a predetermined repetitive sequence.

Figure A.1
Jet Fuel Distribution System



1 Another reason to exclude avgas from multiproduct pipelines is the possibility that it could contaminate adjacent tenders of other products with lead. The U.S. Environmental Protection Agency requires that the lead content of motor gasoline not exceed 0.05 g/U.S. gal.

2 A dedicated system is one reserved exclusively for a single product. It has no interconnections to other pipes or storage tanks after the point where batches of fuel are isolated and tested for conformance to specification.

A tender may be produced by a single refiner, or it may be the aggregate of product from several refiners.³ Adjacent tenders of different products usually are not physically separated from one another; the trailing interface of one tender is the leading interface of the next. The intermixing that occurs as the tenders move through the pipeline is confined to a well-defined zone. Heart cuts of the tender may be diverted to terminals along the route of the pipeline. At the terminus of the pipeline, the intermixture (*transmix*) may be segregated and returned to a refinery for reprocessing. More commonly, it is split among the adjacent tenders or incorporated into the tender of the less sensitive (non-aviation) product. The products remain on-test because the transmix volume is a small fraction of the tender volume and because the product sequence is chosen to minimize the differences between adjacent products (see *Figure A.2*).

When jet fuel is passed through a pipeline, it will typically become contaminated to some degree with particulate matter and water. Consequently, jet fuel tenders must be cleaned up at their destination.

Other Modes Ships, barges, rail tank cars, and tank trucks are compartmentalized, so in cases of multiproduct transport, different products are physically prevented from intermixing. In some cases, the compartments are dedicated to a single product. In other cases, care must be taken to bring the residue of the product previously transported in a compartment to an acceptable level before a shipment of aviation fuel is loaded.

Intermediate Terminals As noted, in a few cases aviation fuels are transported directly from a refinery to an airport. But more commonly they are distributed by a large multiproduct pipeline or ship or barge to an intermediate terminal from which they are transshipped to nearby airports. Transshipment may employ a smaller dedicated pipeline or tank trucks.

Storage Tanks Aviation fuel storage tanks are typically designed to minimize the effects of particulate and water contamination that occur during fuel transfer, as illustrated in *Figure A.3*. Tanks have a low point on the bottom, a *sump*, where water and particulate are collected and removed. Tanks also use *floating suction* to draw fuel off the top of the tank rather than the bottom where water and particulate concentrate. This, along with adequate settling time, helps prevent some of the particulates and water from being transferred further into the distribution system.

RECEIVING FUEL AT AIRPORTS

A very important step in the fuel distribution system is receipt into airport storage. As fuel is received, tests are conducted to confirm the identity of the fuel and also check for water and particulate contamination. At large

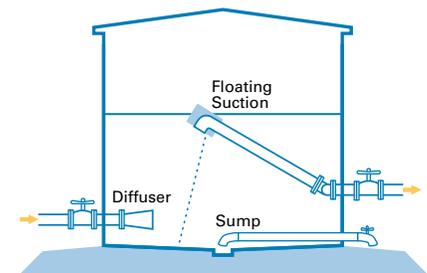
Figure A.2

Typical Multiproduct Pipeline Product Sequence

Unleaded regular gasoline
 Unleaded midgrade gasoline
 Unleaded premium gasoline
 Unleaded midgrade gasoline
 Unleaded regular gasoline
 Jet A
 High-sulfur diesel fuel (dyed red)
 Low-sulfur diesel fuel (undyed)
 (Cycle repeats)

Figure A.3

Fuel Storage Tank



³ The industry uses the term *fungible* to describe products whose batches are interchangeable because they are made to the same specification, although they may be produced at different refineries operated by different companies.

airports, fuel is typically filtered both going into airport storage tanks and also going out of these tanks before being delivered to aircraft.

Airport Fuel Dispensing After the fuel reaches an airport's storage tanks, there are three ways of delivering it to aircraft: *hydrant* system (jet), *refueler* truck (avgas or jet), or a *dispenser* (avgas or jet). The hydrant system is used to fuel jet aircraft at most large commercial airports. A network of underground pipes connects the storage tanks to each gate. A hydrant unit, either a truck or cart, equipped with filtration and volume metering equipment, is used to fuel an aircraft. Hose connections are made between the hydrant and the unit, and the unit and the aircraft. Hydrant trucks typically are equipped with filter/separators or water-absorbing media to provide a final barrier to particulate and water contamination before fuel enters the aircraft's tanks.

The dispenser and refueler are used at smaller airports. Both have pumping, filtration, and volume metering equipment. A refueler truck carries fuel to an aircraft. A dispenser is a pump at a fixed location, similar to the familiar system used to deliver motor gasoline to cars but designed specifically to fuel aircraft.

Regulations Because petroleum products are both flammable and potential air and water pollutants, their distribution and storage are controlled by a multitude of regulations developed and administered by a variety of regulatory agencies. Figure A.4 is a partial listing of the subjects addressed by regulations in the United States. The operator of each facility has the responsibility to understand and comply with all pertinent regulations.

CONTAMINATION AND CLEANUP

Contamination On its journey from refinery to aircraft fuel tank, aviation fuel will spend time in storage tanks and also be transferred one or more times. Each time a transfer occurs, there is a potential for contamination of the fuel to occur. Particulate matter and water are the most common fuel contaminants. Other sources of contamination include: other petroleum products, surfactants, microbes, and dye. This section will describe each type of contamination briefly, and also the procedures and equipment used to remove contaminants from aviation fuel.

Particulate Matter The dominant source of particulate matter is the solid corrosion products that slough off steel pipes and tanks (rust and scale). While protective coatings are being applied to the interior surfaces of more and more tanks, particularly those in critical service, the predominance of steel in industry facilities and the universality of water as a contaminant ensure that almost any distribution process will result in some rust contamination. Other sources of particulate matter are: refinery processing materials (catalyst fines and salts); airborne solids that enter through tank vents or slip past the seals of floating roof tanks (dust and pollen); solids from damaged hoses and filters (rubber particles and fibers); and solids from microbial infestation (cellular debris and microbial by-products).

Figure A.4

A Partial List of Subjects Addressed by Regulations Applicable to the Distribution and Storage of Aviation Fuels

Transportation of hazardous materials

Fire protection

Tank overfill prevention

Corrosion protection and release detection (underground storage tanks)

Protection of subsurface and navigable waters

Control of air emissions

Control of wastewater discharges

Storage, transportation, and disposal of hazardous waste

Safety and health of employees and adjacent communities

Emergency response procedures

Water Water in aviation fuels comes from a number of sources. Many refining processes employ water or steam, either directly or as heat exchanger coolant. Any free water picked up during processing is removed before the fuel leaves the refinery.

Because most pipelines are buried, tenders tend to be cooled during transmission. Cooling will cause droplets of free water to form if the jet fuel was close to being saturated with water when it was injected into the pipeline. Even if the jet fuel was dry on injection, it may pick up free water deposited in low spots in the pipeline by the tenders of other products.

Rain water may leak by the seals in floating-roof tanks. Water in moist air may condense in fixed-roof storage tanks, which must be vented. Air flows in and out of a fixed-roof tank as product is added or removed and as the air above the product expands or contracts in response to changes in ambient temperature. When warm, moist air enters during the day and is cooled at night, water may condense and “rain” into the fuel. The amount of water generated by the process depends on the relative humidity of the air and the difference between day and night temperatures; it can be significant for tanks where the climate is humid.

Other Petroleum Products If a batch of aviation fuel is contaminated with enough of another petroleum product to move one or more of the specification requirements off-test, there is no remedy. The batch must be returned to a refinery for reprocessing. So, aviation fuel lines and tanks are rigorously segregated from lines and tanks containing other products in the refinery and in the distribution chain.

There are situations in which small amounts of product mixing may occur:

- At the interface separating two products in a pipeline.
- When aviation fuel is loaded into a compartment of a vessel or truck that previously contained a different product.

These situations can be managed by keeping the relative amount of contamination small enough that it doesn't significantly alter the specification properties. However, even small amounts of contamination can be a problem for aviation fuels if the other product is dyed or contains additives or impurities, that because they are surfactants, degrade water separability.

Surfactants Surfactants (*see page 27*) are polar organic compounds that can stabilize a fuel-water emulsion by reducing the interfacial tension. Surfactants can also degrade the ability of filter/separators (*see page 78*) to remove water, because they, like water, are attracted to and stick to the hydrophilic surfaces of the coalescing medium. Thus the presence of surfactants could potentially allow free water in jet fuel.

Surfactants may come from refinery processing, but these are removed at the refinery by clay treatment before release. Surfactants from other products can adsorb on pipeline walls and pumping equipment in a multiproduct pipeline,

and later desorb into jet fuel. Surfactants may also be introduced from soap or detergent used in equipment cleaning.

Fuel is regularly tested for the effect of surfactants on water separability throughout the distribution system using a device called a microseparometer (*microsep* or *MSEP*) (see page 80).

Microbes Aviation fuels are sterile when first produced because of the high refinery processing temperatures. But they become contaminated with microorganisms that are omnipresent in air and water. Microorganisms found in fuels include bacteria and fungi (yeasts and molds). The solids formed by biogrowth are very effective at plugging fuel filters. Some microorganisms also generate acidic by-products that can accelerate metal corrosion.

Since most microorganisms need free water to grow, biogrowth usually is concentrated at the fuel-water interface, when one exists. Some organisms need air to grow (aerobic organisms), while others grow only in the absence of air (anaerobic organisms). In addition to food (fuel) and water, microorganisms also need certain elemental nutrients. Jet fuel can supply most of these; phosphorus is the only one whose concentration might be low enough to limit biogrowth. Higher ambient temperatures also favor biogrowth.

Microbial contamination in avgas is much less common than with jet fuel, although it does occur. Presumably, the lower occurrence in avgas is due to the toxicity of tetraethyl lead.

The best approach to microbial contamination is prevention. And the most important preventive step is keeping the amount of water in the fuel storage tank as low as possible.

Biocides can be used when microorganisms reach problem levels. But biocides have their limits. A biocide may not work if a heavy biofilm has accumulated on the surface of the tank or other equipment, because then it doesn't reach the organisms living deep within the biofilm. In such cases, the tank must be drained and mechanically cleaned.

And even if the biocide effectively stops biogrowth, it still may be necessary to remove the accumulated biomass to avoid filter plugging. Since biocides are toxic, any water bottoms that contain biocides must be disposed of appropriately.

Dye In the United States, diesel fuel may be dyed red for one of two reasons: to identify high sulfur diesel fuel intended for non-highway applications in EPA regulations, or to identify fuel that is not subject to the federal excise tax in Internal Revenue Service (IRS) regulations. If a tender of red-dyed diesel fuel is transported next to a tender of jet fuel in a multiproduct pipeline, the interface between the products will contain some amount of dye. If the cut between the jet fuel and the interface is not made properly, some of the red dye will contaminate the jet fuel.

As mentioned in Chapter 4, only additives that are specifically approved may be added to jet fuel. The presence of red dye in this situation is considered an unapproved additive in jet fuel, apart from the small amount of diesel fuel contamination it represents. A visual test of jet fuel appearance is done throughout the distribution system. Any pink or red color resulting from dye contamination is grounds for rejection of the fuel.

An industry sponsored program is being conducted to determine the effect of trace levels of red dye on jet fuel properties and also on the performance of critical turbine engine components.

Cleanup Contamination with particulate matter, and to a lesser extent, with water is unavoidable during distribution. Therefore, the aviation fuel distribution system includes processes to remove these contaminants:

- Filtration to remove particulate matter.
- Filter/separator, water-absorbing media, and salt drier to remove water.
- Clay treatment to remove surfactants.

One or more of these processes may be used at each stage in the distribution chain: at the refinery, at the inlet or outlet of terminal tanks, at the inlet or outlet of airport storage tanks, and in equipment dispensing fuel into aircraft.

Filtration Passing a petroleum product through a filter with a pleated paper or synthetic fiber medium removes solids with particle sizes larger than the pore size rating of the filter.⁴ Typically, filters with a nominal pore size of five micrometers (*microns*) are used for avgas and one micron or two microns are used for jet. These filters are commonly called *pre-filters*, because they are typically used before filter/separators, or *micronic filters*, because they are rated by the size of particulate removed, e.g., two microns.

The filter elements are hollow cylinders that screw into a base plate in the filter vessel, as shown in Figure A.5. Clean fuel flows out of the center of the filter elements into the bottom of the vessel.

In most fuel cleanup systems, particulate removal precedes water removal for cost reasons. If the particulate matter isn't removed, it would shorten the life of media used in the subsequent water removal process. Particulate removal media are less expensive than water removal media.

Salt Drier A salt drier is a vessel containing a bed of salt particles, usually sodium chloride, but calcium chloride is also used. As the fuel flows upward through the bed, free water in the fuel combines with the salt to form a concentrated salt solution (*brine*), as shown in Figure A.6. Droplets of brine, being much denser than the fuel, collect in a sump at the bottom of the vessel.

Figure A.5
Particulate Filter

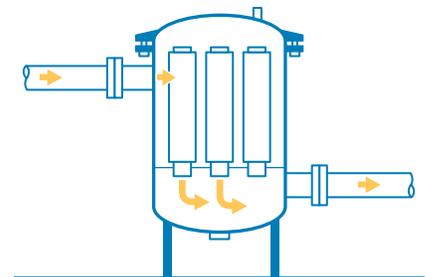
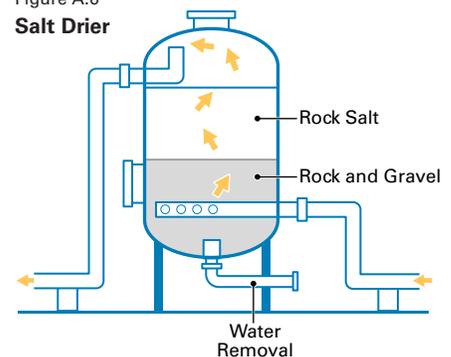
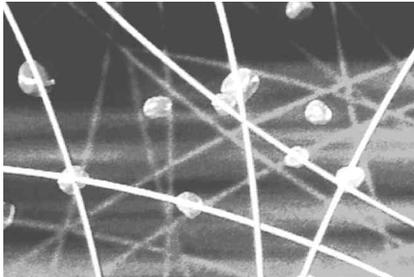


Figure A.6
Salt Drier

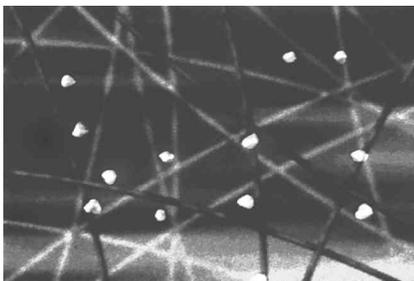


⁴ Particulate filters are designated by a nominal pore size or an absolute pore size, whichever is smaller. Typically, a filter captures 50 percent (by count) of particles the size of its nominal rating but 99 percent of particles the size of its absolute rating.

Figure A.7
Coalescence



Good coalescence – large drops of water



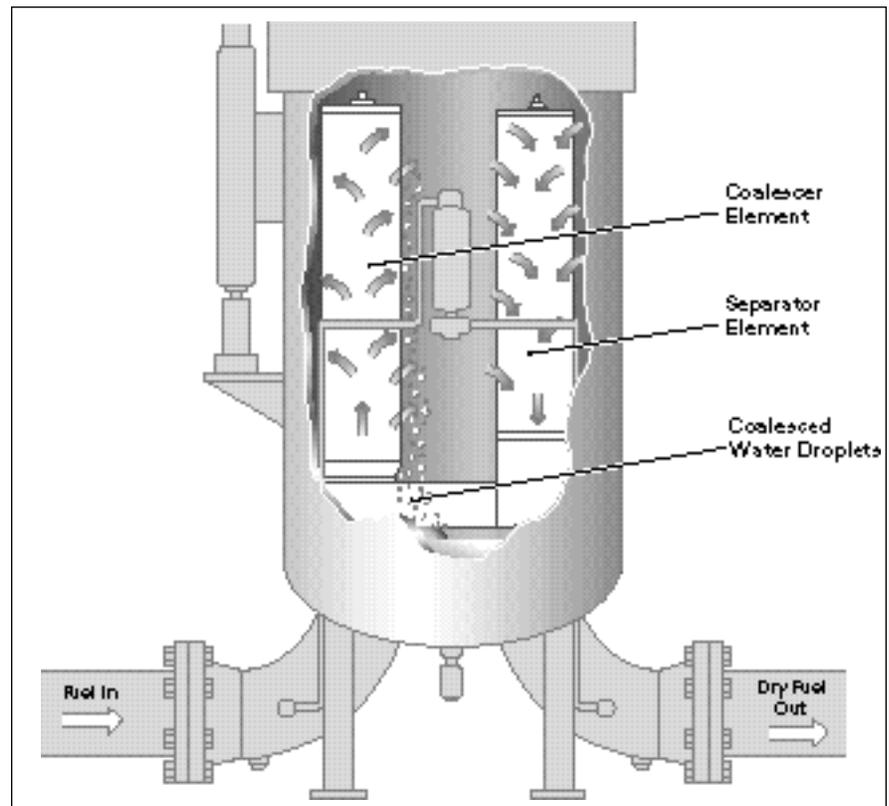
Poor coalescence – small drops of water

Courtesy of Velcon Filters, Inc.

Salt driers are most suitable for drying large volumes of fuel and therefore usually are installed at refineries or at high-volume terminals and airport storage facilities.

Filter/Separator The filter/separator is the workhorse of the processes used to remove free water from aviation fuels. Two media are involved. First the fuel passes through a water-coalescing medium, which is composed of fibers with a hydrophilic surface that serves to combine small drops of water into larger drops (see Figure A.7). Then it passes through a water-separation medium, which has an outer hydrophobic surface that rejects the larger water droplets. The rejected water is collected in a sump. A filter/separator does not remove dissolved water. Figure A.8 is a cutaway drawing of a typical filter/separator.

Figure A.8
Filter/Separator



Courtesy of Velcon Filters, Inc.

The filter/separator media will remove particulate matter larger than the pore sizes of the media, but, as noted above, this is not a cost-effective use of these materials.

The American Petroleum Institute (API) and the Institute of Petroleum (IP) have issued joint performance specifications for filter/separator (*API/IP Specification 1581*), as has the U.S. Defense Department (Mil Specs).

Water-Absorbing Media Water-absorbing media, sometimes called a *filter monitor* or *fuse*, are designed to shut down a fuel system when free water is present. Filter monitors contain water-absorbing material that removes free water. As the water-absorbing material picks up water, it expands in volume, which reduces and finally stops the flow of fuel. The reduced flow warns the operator that the current batch of fuel may be unusually wet, and that the media should be replaced.

Unlike filter/separators, filter monitors are not disarmed by surfactants. For this reason, filter monitors are most often used at the point where fuel is loaded into an aircraft's tanks. Recent developments have shown that excess di-EGME (*see page 28*) in the fuel can adhere to the water-absorbing media, interfering with the water-absorbing process.

The API and the IP have issued joint performance specifications and qualifications for water-absorbing media in *API/IP Specification 1583*.

Clay Treater Clay treatment is used to remove surfactants (*see page 27*) from fuel. As noted above, surfactants can disarm coalescers and thus allow water to pass through. In a refinery, a clay treater is a large vessel containing tons of activated clay. As the fuel flows through the bed, the surface active compounds in the fuel are attracted to and held by (adsorbed) on the surface of the clay particles. In the fuel distribution system, smaller clay treaters are used that contain the clay in canisters or cloth bags for easier handling, as shown in Figure A.9, but they work in the same way as the larger refinery units.

QUALITY CONTROL

Because of the critical nature of aviation fuel use, the industry has developed several quality control guidelines. These include: Air Transport Association of America *ATA 103 Standards for Jet Fuel Quality Control at Airports*, *IATA Fuel Quality Control and Fueling Service Guidance Material*, Joint Inspection Group (*JIG*), and other guidelines.

These guidelines are designed to help ensure that only clean, dry, uncontaminated fuel is delivered to aircraft. They recommend practices for receiving fuel into airport storage and delivering it to an aircraft. They also recommend equipment for airport fueling facilities, facility system checks, and quick field tests to detect various forms of contamination.

ASTM has issued a *Manual of Aviation Fuel Quality Control Procedure, MNL5*. The manual contains information on many field test methods and operational procedures designed to assess fuel quality (*see Figure A.6*). It also contains general information on filtration equipment and recommended practices for its use, as well as a section on microbial contamination. Many individuals with extensive experience in all aspects of aviation fuel handling contributed to this valuable document.

Figure A.9
Clay Treater

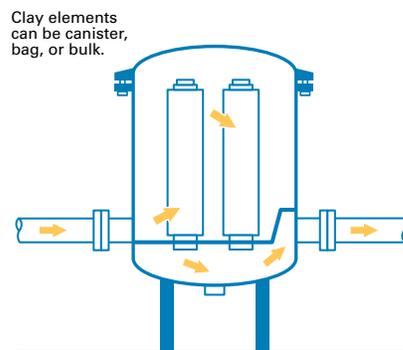


Figure A.10

Frequently Used Aviation Fuel Field Tests

Property	Standard Test Method	Description
Visual Appearance	<i>White Bucket Test</i>	The sample is placed in an 8-liter (8-quart) white porcelain enamel bucket and the bucket is swirled to create a vortex in the sample. (Particulates tend to concentrate at the center, or foot, of the vortex.) The sample is inspected visually for clarity and color, and the bottom of the bucket is inspected for the presence of solids or water droplets.
	<i>ASTM D 4176 – Test Method for Free Water and Particulate Contamination in Distillate Fuels</i>	The sample is placed in a clean, transparent, dry glass bottle and the bottle is swirled to create a vortex in the sample. The sample is inspected visually against a light background to determine whether its condition is “clear and bright.”
Density	<i>ASTM D 1298 – Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method</i>	Fuel is transferred to a cylindrical container and a hydrometer is carefully lowered into the cylinder and allowed to settle. After the temperature of the sample has equilibrated, the value on the hydrometer scale positioned at the surface of the sample and the sample temperature are recorded. The hydrometer value can be converted to density at 15°C using standard tables.
Particulate Matter	<i>ASTM D 2276 – Particulate Contaminant in Aviation Fuel by Line Sampling</i>	Fuel from a field sampler is fed through a membrane with a pore size of 0.8 micrometers. The membrane is compared to examples in a rating booklet to rate its color and color intensity.
	<i>ASTM D 5452 – Particulate Contamination in Aviation Fuels by Laboratory Filtration</i>	Fuel from a field sampler is fed through a pair of matched-weight membranes with a pore size of 0.8 micrometers. The membranes are dried under standard conditions and weighed. The weight difference between the two membranes is a measure of the particulate content of the sample.
Water Separability	<i>ASTM D 3948 – Determining Water Separation Characteristics of Aviation Turbine Fuels by Portable Separometer</i>	Using a semiautomatic Micro-Separometer instrument, a fuel sample is mixed with water, forced through a fiberglass coalescing medium, and rated. The MSEP rating indicates the relative ease of coalescing water from the sample. The instrument is first calibrated with a sample of the fuel to be tested.

