# Jet Fuel Quality: What it takes to Fly

**Safe travel on an aircraft takes on a new meaning as aviation engineer John Bagnall describes the critical processes used to ensure quality control for jet fueling. Read about the amazing range of "contami-nants," even creatures, that can turn up in a fuel supply and what it takes to filter out potential problems.**

Making commercial flights safe

While fueling hundreds of jet aircraft a day at a major airport, millions of gallons are uplifted into aircraft fuel tanks by airline personnel and “into-plane” fuel service companies. A common motto of these entities is, “we deliver clean, dry fuel to the aircraft.” Quite a number of measures are taken to ensure that “clean, dry fuel” is provided. However, fuel problems are often one of the initial suspects in airline crashes.

A heavy burden of responsibility is placed on those involved in such a critical industry as aircraft fueling. The specialized knowledge and wherewithal to properly design, construct, operate and monitor these systems are paramount to providing acceptable jet fuel quality and ensuring the safety of the flying public. While previous PE&T articles have addressed certain aspects of airport fueling systems and fuel quality, this article provides a comprehensive, global picture of jet fuel quality assurance measures. These measures contribute to making commercial air travel safer for all of us.

**What is jet fuel?**

Commercial jet turbine fuel, known as Jet A or Jet A-1, is a kerosene-based product comprised of a multitude of different hydrocarbons. It is a remarkably clear fluid resembling water.

In a jet turbine engine, the fuel is continuously burned by injection into rapidly flowing high temperature air. Its properties are similar to diesel fuel, being classified as a Class II Combustible liquid with a very low vapor pressure and a flashpoint above 100 degrees F (compared to gasoline which is a Class I Flammable liquid with a high vapor pressure and a flashpoint below -30 degrees F). Jet A-1, virtually identical to Jet A except for a lower freeze point, is commonly used outside the United States. US military jet fuel grades JP-5 and JP-8 are also extremely similar to Jet A.

**Potential fuel contamination**

The primary contaminants that can be present in jet fuel include water, surfactants, sediment or particulate, microbial growth and even other petroleum products. These contaminants can generate a number of adverse consequences including aircraft and ground-based fuel system corrosion; fouling or disarming of fuel filtration components; failure of aircraft fuel system instrumentation; and potentially, shutdown of fuel supply to engines on an in-flight aircraft.

Water can be considered the most significant contaminant as it is inherently present and must be dealt with. The composition of Jet A allows water to be easily absorbed and held in suspension. If enough water is present in an aircraft fuel system, ice crystals can form at higher altitudes and clog fuel lines or system components, disturbing or stopping the fuel supply to the engine. Additionally, water promotes corrosion of steel and the generation of microbial growth.

A goal of 5 PPM (parts per million) or less of water in the fuel is desired. Fifteen PPM is the maximum recommended by guidelines such as the Air Transport Association (ATA) specification 103, Standard for Jet Fuel Quality Control at Airports. Most authorities consider 30 PPM to be an acceptable limit that is not detrimental to aircraft turbine engines.

Particulate contamination can be introduced into the airport fueling system from a number of sources. Almost anything one could imagine, from rags and two by fours to dead animals, have been found in an airport fuel piping system during the initial system flush following completion of construction.

Winds blow sand or dirt (and water) through storage tank vent openings. Rust, metal shavings and rubber or plastic fragments are introduced by wear and corrosion of system components. System screens and filter elements collect particulate. The “loading” of these elements must be monitored or excessive differential pressures could develop that would rupture them and possibly generate even more particulate contamination.

Surfactants or “surface active agents” are soap or detergent-like compounds that emulsify water and particulate, complicating or preventing their removal. These compounds can be introduced from refinery processes; pipeline or truck cross-contamination with other products or cleansing agents; or from fuel additives. Surfactants can disarm the water-removing ability of critical system filtration.

Microbial growth can occur at a stagnant water-fuel interface. It is hard to believe that living organisms actually “eat” petroleum, but this is indeed the case. Certain bacteria and fungi are capable of existing in the water at the fuel interface and can propagate quite rapidly, producing a sludge-like substance. If present in sufficient quantity, this growth can cause corrosion on both steel and aluminum surfaces such as storage tanks, aircraft fuel tanks and piping. This growth can also foul filters and system instrumentation.

Other products, such as gasoline and diesel fuel, produce what is called “cross-contamination” when accidentally mixed with jet fuel. This can occur when “multi-product” pipelines, ones in which different product batches are shipped back-to-back, are connected to the pipeline(s) feeding the airport.

Gasoline and diesel fuel have accidentally been shipped into airport jet fuel storage tanks. When this occurs, the tank is taken out of service and the product supplier is usually responsible for transferring the “off-specification” product back to its refinery or pipeline terminal. Another problem existing with multi-product pipelines is the use of dyes. Some petroleum products are injected with dye to promote ready identification. The dyes can stick to the walls of the pipeline and be picked up by a later batch of jet fuel. This can result in a discoloration and resultant decrease in the quality of the optimally clear jet fuel.

**The Jet A fuel goes through one final filtering process during aircraft fueling at O'Hare Airport. This American Airlines pilot discusses the fuel volume with the refueler to ensure that the aircraft will have sufficient fuel for its destination. Photo courtesy of American Airlines**

### The many measures

The many measures that are taken to ensure jet fuel quality encompass all facets of the industry, from fuel manufacture to into-plane operations. A number of established national and international standards and guidelines exist for fuel and fuel systems. The major ones affecting jet fuel quality assurance are identified in the sidebar below.

The airlines, oil companies and companies operating fuel systems have established organizational and procedural structures to ensure fuel quality as well. In addition to the global standards and guidelines, these companies each have their own dedicated fuel quality control (QC) personnel, fuel QC standards, manuals and procedures. Frequent audits are also performed, both by the system operating companies' and airlines' corporate fuel QC staff, to ensure that the standards and procedures are being followed.

### Fueling system design

This is a crucial parameter of maintaining jet fuel quality in that the system must be arranged to minimize the potential for fuel contamination. Present-day practice is to internally line or coat all system piping, storage tanks and major equipment. The exceptions to this are welded pipe joints and smaller pipe fittings, which are left uncoated.

High solids epoxy paint, suitable for hydrocarbon immersion service, is the coating of choice. Due to its slicker surface, the presence of this coating on the vast majority of fuel-exposed surfaces minimizes corrosion and sediment build-up. The use of copper, brass, cadmium or zinc (galvanizing) in fuel-exposed equipment and piping is undesirable because these metals can affect the thermal properties of the fuel or damage engine parts.

The most critical design factors are the adequate sloping of fuel piping and tank bottoms to low points and the provision for draining of accumulated water and particulate from these and equipment low points. As a rule of thumb, as much as one PPM of water can condense from jet fuel per degree of drop in fuel temperature.

Water, being approximately 25 percent heavier than jet fuel, settles to low points (when freed from solution) and must be removed. Failure to provide adequate draining can lead to the problems with microbial growth and freezing described earlier. Also, the system piping should be optimally sized to provide sufficient fuel velocity (typically three to five feet per second or higher) to prevent the accumulation of particulate.

Floating suction piping in airport fuel storage tanks is required by ATA Specification 103. This suction piping arrangement draws fuel from the top of the stored fluid level, rather than from the bottom where particulate and water could concentrate. However, due to significantly improved filtration technology, this requirement has recently been formally waived by the airlines at airports where a good history of received fuel quality exists. At these airports, fixed suction piping is allowed.

**Jet Fuel Quality Standards, Guidelines and Supporting Organizations**

**Organizations**

API American Petroleum Institute
ASTM American Society for Testing and Materials
ATA Air Transport Association of America
IATA International Air Transport Association
NATA National Air Transportation Association

**Jet Fuel Composition**
ASTM D 1655, Specification for Aviation Turbine Fuels
DERD 2494, British Aviation Turbine Fuel Specification
IATA Guidance Material for Aviation Turbine Fuels

Aviation Fuel Quality Requirements for Jointly Operated Systems

**Fuel Quality Control Measures**
API 1500, Storage and Handling of Aviation Fuel at
A irports API 1581, Specifications and Qualification Procedures for Aviation Jet Fuel Filter/Separators
ASTM MNL 5, Manual of Aviation Fuel Quality Control Procedures (This publication references several ASTM standards for individual testing procedures)
ATA 103, Standards for Jet Fuel Quality Control at Airports
NATA Refueling and Quality Control Procedures for Airport Service and Support Operations

**Filtration, filtration, filtration**
As the fuel passes from manufacture to the aircraft, varying levels of filtration are provided to achieve the required level of fuel quality at each point. A common saying is that “this stuff is filtered to death before it reaches the aircraft tank.” I think that most of us would have it no other way! The fuel is filtered at the refinery; filtered as it is received at the airport storage facility; sometimes filtered as it passes from receiving tankage to issue tankage; filtered as it leaves the airport storage facility; and finally filtered before being uplifted into the aircraft. Of course, the aircraft has on-board filtration as well. The diagram to the right depicts one of the different types of filter vessels used.

**Filter elements partially loaded in prefilter (micronic) vessel, clay treater (closed) and filter separator (open). Photo courtesy of Burns & McDonnell**

The most important and necessary unit is the filter/separator. This unit can remove water down to less than five PPM and particulate down to 0.3 micron size with a state-of-the-art coalescer and separator cartridges (based on API 1581, Third Edition, Specifications and Qualification Procedures for Aviation Jet Fuel Filter/Separators). These units are typically present at a minimum of three locations within an airport fuel system: 1) at pipeline and truck unloading receipt facilities; 2) downstream of the fueling system issue pumps; and 3) on the trucks or carts actually fueling the aircraft.

API 1581 specifies three different performance classes of filter separators: Class A, B and C. Class A units can handle heavy contaminant loads such as may be encountered at the refinery. Class B units are suitable for moderate contaminant loading—these are provided within airport fuel systems. Class C filter separators are for mobile use and light contaminant loads; they are used as the final filtration on vehicles fueling aircraft. All three classes typically use the same type of elements, but in different quantities.

Filter separators in airport fuel systems are equipped with a water defense system. If high water levels are reached in the vessel water collection sump, a “water slug valve” closes and shuts down the flow though the unit. A high water level alarm is also sent to the system operator. The other filter units described in the next few paragraphs are typically equipped with high water level alarms as well.

Fuel received into airport storage by pipeline may contain particulate and surfactants, and, in some cases, it may have an above average water content. In these cases, additional filtration is provided and may include prefilters, water coalescers and clay treaters. Truck unloading facilities may also be equipped with prefilters and clay treaters.

**This diagram shows Two-Stage Vertical Filter Separator and water slug valve. Diagram courtesy of Facet USA.**

A prefilter, or micronic filter, contains pleated paper cartridges and removes particulate. It is much cheaper to replace these paper elements than elements found in the other filtration vessels if such vessels were to be fouled with particulate. Water coalescers, or “haypacks,” contain wafers of excelsior or a synthetic hay, which assist in removing gross amounts of water from the fuel. This water can result from a “water plug” used to separate different products in a multi-product pipeline or it can be residual water remaining after periodic pressure testing of the pipeline with water.

A clay treater removes surfactants from the fuel, preventing the downstream filter separators from being disarmed and unable to remove water. The clay treater contains canisters or bags filled with very fine clay granules, also referred to as “fuller’s earth,” that adsorb (collect, adhere to) surfactants on a molecular level.

**Construction and flushing operations**

Proper measures taken during fuel system construction promote the ability to maintain good fuel quality. Fuel piping stored onsite should be kept as clean inside as possible; this piping should have the ends covered with heavy plastic caps at all times to prevent the introduction of dirt and debris.

Partial in-trench piping installations need to be provided with water-tight plugs or “nightcaps” to prevent water, mud, debris and even animals from entering the pipe. In instances where nightcaps were not used, piping systems have been filled with mud and water (and animals). As a result, costly steam cleaning of the piping has been required in some instances. In others, the flushing operations have been long, drawn-out affairs, involving significant additional cost.

Adequate flushing of the new system piping is critical to fuel quality. Fuel—not water—should always be used as the flushing fluid since water is a major contaminant as described in this article. Practically speaking, all of the water could not be drained and entirely removed after flushing with it, due to pockets and recesses that exist in piping systems, fittings and components.

**Pipeline receipt filtration vessels—-prefilters, haypacks, clay treaters and filter separators—-being installed for the four incoming Jet A pipelines at Los Angeles International Airport. Photo courtesy of Burns & McDonnell.**

An adequate flushing fluid velocity must be maintained, typically 10 feet per second or higher. Typically, it takes three to five fluid volumes of fuel to adequately flush the pipe. The flushed fuel is routed to either tank trucks, larger portable tanks or system storage tanks temporarily dedicated to the flushing operation.

Towards the end of a system flush, the fuel is sampled, visually inspected and tested by standardized methods that are described in more detail later in this article. Testing and visual inspections include those for color (clearness), odor, particulate, water and surfactant content, and also for the presence of microorganisms.

For the piping system to be accepted and put into service, the samples must pass the visual inspections and meet guideline criteria, such as the five PPM water maximum and a very low allowable particulate and surfactant content. The five PPM water guideline requirement is the goal for an initial, placed-into-service condition, even though it is below the 15 PPM operational requirement described earlier.

Flushing operations are repeated until all of the sampling criteria are met. When piping is added to an existing fuel system (e.g., to provide fuel to new aircraft parking positions or gates), this piping must also be flushed, samples taken and the same sampling criteria met.

If fuel used for flushing were substantially contaminated, it could, of course, be rejected and subject to recycling at the refinery, or downgraded for other uses such as heating oil. Such contamination might arise from unsatisfactory construction or flushing practices, such as contaminated tank trucks or excessive piping sediment or debris.

**Clay canister carousel ready to be loaded into clay treater vessel. There are 150 canisters stacked three high in this 5-foot diameter vessel rated at 1000 GPM. Photo courtesy Burns & McDonnell**

**Piping and pipe fittings stored on-site during recent fuel system construction at Dallas-Ft. Worth International Airport—Piping with protective plastic caps (right), internally epoxy-coated pipe fittings (left). Photo courtesy Burns & McDonnell.**

### Fuel quality assurances

As pointed out earlier, various operational procedures are in place for assuring fuel quality. These procedures are carried out on a formally scheduled basis and range from daily activities to annual requirements. The procedures include those for sampling and testing at various fuel system locations; removal of settled water and particulate from the fuel; and preventative maintenance provisions such as tank inspection/cleaning, filter element replacement and fuel reclaim procedures.

Sampling and subsequent testing of the jet fuel is performed during pipeline and truck receipts. This is done downstream of filter vessels to ensure their continued effectiveness and at other selected monitoring points throughout the system, including inside the storage tanks.

Samples are typically removed through special, permanent sampling connections located in the piping systems. These sampling “probes” allow fuel samples to be taken from the center of the flow stream, which is more indicative of the average fuel condition. Tank samples may be taken through the tank roof using a special sampling “thief,” which can be opened and filled at different levels within the stored product.

Testing and inspection of the fuel is done both locally at the sampling location and remotely. Many major airports have onsite fuel “laboratories” where controlled testing can be performed. Lab testing can be almost a full-time job at the busier airports. At some locations, samples are sent out to a professional laboratory for detailed analysis prior to allowing the fuel to be uplifted onto aircraft.

Local sample inspection and testing may include the “clear and bright test,” the “white bucket test,” the filter membrane test, an API gravity check and checking of odor. Additional local testing, using manufactured test kits, can be performed to determine water and surfactant levels; however, these are more commonly accomplished in a lab as described later.

• The “clear and bright test” involves placing a sample into a clear glass container and observing it for a “clear and bright” condition. The sample is swirled, creating a vortex. Visible particulate will appear at the lower tip of the vortex and free water will settle into a lower layer after the swirling has stopped. A hazy or cloudy sample indicates contamination.

• The “white bucket test” is similar to the “clear and bright” test and indeed involves filling a special white-painted bucket with approximately eight inches of fuel, and allowing the fuel to stabilize. The fuel is visually checked for clarity and the presence of water, particulate or surfactants, which can be readily identified against the contrasting white background. A shiny copper coin is dropped into the bucket and if its features can be easily seen, the fuel is considered clear. Free water can also be observed, when present, as “bubbles” at the bottom of the pail.

• The filter membrane test measures particulate levels. It uses a test kit consisting of plastic tubing, a circular, flat filter membrane and a split plastic and/or metal casing, which can be readily disassembled. The membranes have a pore size of 0.8 microns and are used only once. From one to three gallons of fuel are passed through the membrane, sampled from a flowing pipe through a special connection as described earlier.

Once used, the membrane is removed and allowed to dry. The color of the dry membrane is checked against a reference chart of standard sample color shades and graded. Typical acceptable ratings would be A2, B1 or G2; A, B and G being different reference color scales.

A more scientific method that is sometimes used involves weighing the membranes. This is done following the sampling to determine how much particulate has been collected. A pre-weighed membrane is typically used in this case. Very sensitive measuring equipment is used to ensure that the maximum collected particulate content of the fuel does not exceed 0.5 milligrams per liter.

• API Gravity measures a hydrocarbon’s density, and differs from standard specific gravity. API Gravity is measured in “degrees”—the higher the number, the lighter the product. Jet A must be in the range of 37 to 51 degrees, which corresponds to a standard specific gravity of 0.84 to 0.78 (water being 1.00). Checking for API Gravity is commonly done with a glass bulb hydrometer. This device is a sealed, floating vertical tube resembling a thermometer, with graduated markings corresponding to different API Gravities. The hydrometer will float at a level consistent with the product density. API Gravity is read at the fuel surface level. An API Gravity reading outside the acceptable range typically identifies contamination of the fuel with another petroleum product.

| **Detected Contaminant** | **Test Kits** |
|---|---|
| **Water** | Shell® water detector, Exxon Hydrokit®, Metrocator |
| **Surfactants** | Microb Micro-separometer (MSEP rating) |
| **Flash Point** | Setaflash Closed Tester |
| **Microbes** | Monitor Test,<br>Hum-bug Detector Kit |

**With four pipelines supplying fuel to Los Angeles International Airport, an on-site fuel lab is provided, complete with analysis equipment and fumehood**

Odor can be a telltale sign of fuel contamination. Although the smell of “healthy” jet fuel is not “pleasant” to all of us, fuel tainted by certain contaminants is readily discernible. Contaminants producing odors include gasoline, ammonia, stagnant water (microbial growth) and hydrogen sulfide (rotten eggs).

Tests performed in a local fuel storage facility lab typically use manufactured test kits and apparatus specifically designed for the application. Samples are drawn and placed in clear glass containers, such as mason jars, sealed and taken to the lab. Equipment that can be used for the various lab tests includes:

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