ICE in the fuel by Joel Ventura…Jan’2020

And I'm not talking about carburetor icing. I'm talking about water suspended or dissolved in gasoline that can turn into ice and stop your engine if freezing conditions are encountered. Many of you are aware of this hazard and can move on to the next post, but I recently spoke to two friends who were unaware and took no precautions against ice in their fuel systems. Since it is that time of year I thought it was worth talking about again. This started out as a much briefer post, however once I did a little homework, it turned out to be a lot more involved than I expected (as usual). This is not the appropriate venue for such a long discussion, however since I felt it was important to get this information out quickly, I'm starting here.

T**he Motivation**
First let me describe the incident that really brought this hazard home to me. About 35 years ago, I was flying my C-150 back home to Boston after visiting my parents in the Washington DC area for Christmas or Thanksgiving.  Shortly after leaving DC, I stopped to fill up my tanks so that I could make the remainder of the trip nonstop. I then climbed to 7500 feet to fly over the Kennedy airport TCA (now class B) airspace.

The weather was bright, sunny, calm, and clear, just about perfect flying conditions. I was enjoying this idyllic flight until suddenly over a period of about two seconds the engine just quit. I immediately pulled full carburetor heat and pumped the throttle just in case, but I knew this was very unlikely to be carburetor icing.  I had experienced that many times before in the C-150, and the loss of power was much more gradual, and in my experience, was never complete.  Besides that, the weather conditions made significant carburetor icing unlikely.

I was just coming up on Kennedy airport, and had way more altitude than I needed to make the field.  Still, the idea of joining the pattern with the SST’s going into Kennedy, declaring an emergency, and totally disrupting operations at a major airport was not very appealing to me. I looked around for an acceptable alternative, and was relieved to find a small airport almost directly below me.

By then, I had also realized that this situation had all the earmarks of fuel line freezing. About an hour ago I had stopped at a small airport and filled my tanks. The fuel came out of the underground tank at around 50°F saturated with water, because there is a layer of water below the fuel pickup in almost all storage tanks.  About 10 or 15 minutes later, the last thing I did before I took off was check the sumps for water, and they were clear. I then climbed to 7500 feet, where the 0AT was well below freezing.  Then one of two things happened. Most likely some of the water came out of solution as the fuel cooled, and collected at the low point in the fuel system, in the fuel line at the bottom of the fuselage before the gascolator where it froze, and cut off the fuel to the engine.  Alternatively, if conditions are right, as the water comes out of solution, it can form ice crystals, and these combined with ice crystals from suspended water droplets, can block the fuel screens.

My plan was to circle over the airport at the minimum sink rate, and hope the ice thawed as I descended into warmer air. If that didn’t happen, I would just make a dead stick landing at the small airport below me.  Fortunately, a couple years earlier I had made some stopped prop gliding tests with this airplane, and I knew that if my airspeed dropped to about 65 mph, the propeller would stop, but if I kept the airspeed around 70 mph, the propeller would continue to windmill.  I knew it was important to keep that prop windmilling, because if it stopped, and I ran the battery down trying to start it, then there would be no way for me to restart the engine in flight even if the fuel line did thaw out.

As I circled down, I had plenty of time to go through my checklists and check the mags. The engine had stopped so suddenly, it sounded like someone had switched off the mags.  Then I had nothing to do for about 10 minutes but listen to  the CTAF for traffic, and monitor my airspeed, my altitude, and the OAT as it so slowly crawled up into the low 30s. When I got down to about 1800 feet, the engine started again just as suddenly as it had stopped, and I immediately had full power available.  I resumed my course to Boston (with a deviation around the Kennedy TCA), but never went above 2000 feet for the rest of the trip, and also made sure I never went below 32° OAT.  The remainder of the trip was stressful, but uneventful.

After this experience, I was paranoid about fuel system ice for about a month. I would no longer put fuel directly into my fuel tanks. Instead I would put it into 6 gallon  containers, and would leave them outside for a few days in cold weather to allow at least some of the water to come out of solution.   I frequently saw water collect at the bottom of these translucent containers by putting a strong light underneath the container. I would then pour the fuel off into my fuel tanks and discard the water.  I did this even though I had taken more reasonable anti-icing precautions. Eventually my trauma faded, and I could fuel my plane more normally, but I never again flew my airplane into conditions where encountering freezing temperatures was reasonably possible without putting an anti-icing agent in the fuel, or what is more generally called a Fuel System  Icing Inhibitor (FSII), or de-icing agent.  I felt a little foolish, because I did have plenty of warnings.  Periodically I would drain small amounts of water out of the sumps, and sometimes the fuel drains would freeze shut, but I ignored those warnings. After that, I conscientiously put Prist in my fuel during the winter for over 10 years, and I never again had a fuel flow problem, or frozen fuel drains.

Many people think water is not soluble in gasoline, and it is not very soluble, only about .01% by weight (see ref 1, and there is much more detail in ref 2). But .01% of 25 gallons is .32 ounces or about 2 teaspoons of water. Assume half of that comes out of solution as the fuel cools in the aircraft tanks, and that is more than enough to block the fuel flow if the water in the low point freezes.

Besides dissolved water, there is probably even more water in suspension in the fuel (see ref 3), much of it in droplets so small that they can be indefinitely held in suspension by Brownian motion.

Fuel System Icing Inhibitors (FSIIs) commonly come in two main varieties; ethers or alcohols (see ref 4 for more information). The original ether used was ethylene glycol monomethyl ether (EGME).  In 1994 this was replaced by diethylene glycol monomethyl ether (DEGME).  Both of these ethers are strong solvents, impact the environment, are flammable, and are highly toxic, though the second is less toxic than the first. The first one also damages the male reproductive system.  Both of these ethers are often referred to by the genericized trade name Prist, because they had the largest advertising campaign.  Now only DEGME is readily available.  I was told by a Prist representative that the switchover to DEGME was driven by the military for fire safety considerations since DEGME has a higher flashpoint than EGME, which is an important factor in aircraft carrier operations.  The military is their main customer for this product, and orders it by the thousands of gallons for both jet fuel and avgas.

**DEGME**
DEGME has limited solubility in fuel, but is highly soluble in water, and will quickly leave the fuel to dissolve into any free water it contacts. This lowers the freezing point of the water to about -45° F (-43° C). To be effective, the FSII must be thoroughly mixed into the fuel. So unless you have some means of completely mixing the fuel inside your tanks, the DEGME and fuel must be mixed together as they are poured into the tank. Pouring the FSII into the tank before or after the fuel is added is not adequate. Most manufacturers make this relatively easy to do by supplying DEGME in aerosol cans, usually 20 ounce. The cans come with a small metal clip that attaches to the end of the fuel dispensing nozzle, and a couple of feet of 1/16 inch plastic tubing that connects the can to the clip.  The mixing process is simply to press the button on the top of the can, then begin fueling the airplane at the maximum rate provided by the pump. When the desired fuel quantity has been dispensed, release the nozzle trigger, and then the button on the top of the can.  Then invert the can and press the button again to empty the plastic tube. You don't want any DEGME dribbling out on your skin, since toxic amounts can be absorbed through the skin. The recommended DEGME volume percentage range in the fuel is .1% to .15%.

Aerosol cans come in two varieties; 1) 8 oz LO-FLO cans designed to be used with avgas pumps with a flow rate of 15 to 20 gallons per minute, or 2) 20 oz HI-FLO cans designed to be used  with jet fuel pumps with a flow rate of 30 to 45 gallons per minute. It is the same DEGME in both kinds of cans, so HI-FLO can be used with avgas, but you will have to pulse the can button to get into the range of the right DEGME/fuel ratios.  Many FBO's and aviation stores only carry HI-FLO cans. It is also available in five and 55 gallon drums, but that might be a little more than you need, and it is harder to properly mix with the fuel. DEGME is a stable compound with no shelf life.

I found an 8 oz can of LO-FLO on SkyGeek for $8.37.  A 20 oz can of HI-FLO costs $9 to $15 depending on the manufacturer and supplier. However that 20 oz can will treat 104 to 156 gallons of fuel, so it will only increase your fuel costs by $.06 to $.14 per gallon depending on the manufacturer and supplier. Premixed fuel is also available at many FBOs.

**Iso-propanol**
An alternative anti-icing agent is anhydrous isopropyl alcohol (IPA), sometimes called aviation IPA. This is not the drugstore variety of IPA, which can be 35% water. Anhydrous IPA is at least 99% alcohol. This product is not as readily available at FBO's, and the recommended concentration in fuel is 1% by volume. That is 10 times the minimum recommended concentration of DEGME. However, unlike  DEGME, IPA is less toxic and is totally soluble in fuel, and therefore the mixing requirements are much less stringent. It can simply be poured into the fuel stream by hand as the tank is being filled.  Another mixing procedure is given in the C-172S POH, in addition to a good graph on volume of additive vs volume of fuel for both types of anti-icing agents (see ref 5, page 8-17).

I found a gallon of anhydrous IPA online for $23, and one gallon will treat 100 gallons of fuel, so that adds $.23 per gallon to the cost of your fuel. That can be as much as four times the cost of using DEGME, plus it is less convenient, and not as readily available, so it is easy to see why DEGME (commonly called Prist) dominates the FSII market.

**DEGME vs IPA**
I have already mentioned that DEGME is cheaper, more readily available, and easier to carry than IPA, but it requires more care in mixing with the fuel and is much more toxic, so you might not want to be exposed to it if you hope to have children someday. There are other disadvantages.  First, it is a much stronger solvent than IPA, and will damage fuel system components at much lower concentrations, notably fuel tank bladders. As with all FSII agents, it is always a compromise between adding enough agent to deal with the reasonable range of dissolved and suspended water that may be encountered, but at the same time limiting the concentration to prevent damage to fuel system components.  The IPA concentration is limited to 1% not only to prevent damage to the fuel system, but unlike ethanol, at higher concentrations it also reduces the octane rating of the fuel.

20 years ago there was a statement on the Prist website that, if used as directed, Prist could be used in the fuel system of any certified aircraft, including those with fuel bladders. That statement is no longer there. Instead they say that the use of Prist is approved by Lycoming, but that the pilot should check with their individual engine and airframe manufacturers for suitability. Of particular interest to us is the compatibility of DEGME laced fuel with our fiberglass epoxy fuel tanks. I called Prist about this 10 or 15 years ago, and was told that an expert would get back to me. He never did. Recently I emailed them, and was told that there would be no problems with my underground composite tanks. I know they use especially resistant epoxies in those tanks tanks, and emailed back that I really wanted to know about the compatibility with structural epoxies used in aircraft tank construction. I never got a reply to that email. I called again and am still waiting.

The recommended dose of DEGME is so low, that I would not expect it to damage our composite fuel tanks, but I'm no expert in this area, so I will defer to Gary and others on the subject. However, even when used as directed, there are still at least four situations that can result in exposing your tank to higher than recommended concentrations.

1. When you add a deicing agent to your fuel tank, rarely will you be doing it to an empty tank. And when you are adding fuel to a tank partially filled with untreated fuel , you don't want to add just enough agent to have the proper concentration in the fuel you added, but you want to add enough so that the final mixture in the entire tank is appropriate. Therefore, if there are 10 gallons of untreated fuel already in the tank, you would want to add double the recommended concentration to the fuel being added, so that the final concentration will be appropriate. But again, since DEGME has limited solubility in fuel, it can only migrate through the fuel by two mechanisms. The first is thermal diffusion which is very slow, and the second is through mechanical dispersion caused by the varying accelerations of the aircraft in flight. Though usually more efficient than diffusion, both of these mechanisms together will still take a long time to reach equilibrium. In the meantime the concentration of DEGME in the lower part of the tank is too low, and the concentration in the upper part is too high. This is much less of a problem with IPA, since again, it is completely soluble in fuel, and therefore in addition to the above two mechanisms, there will be a "solubility pressure" that will drive the IPA from areas of high concentration to areas of low concentration, and therefore result in a much more rapid mixing.

2. When water comes out of fuel as it cools, it will tend to join with water already in suspension in the fuel, and together this free water will tend to settle out to the bottom of the tank. In the process, DEGME will preferentially dissolve into this water, greatly increasing its concentration in the water. The fuel tank is now exposed to areas with much higher than recommended concentrations of DEGME.  Note that this water is now very toxic, and should be treated and disposed of appropriately when drained out.

3. The specific gravity of DEGME is 1.023 making it much more dense than the fuel.  And since most of the DEGME is only mixed with the fuel and is not in solution, over time it will tend to settle out of the fuel, raising the concentration at the bottom of the tank.  DEGME treated fuel should not be stored in the aircraft's tanks for weeks or months.  This is not a problem with 1% IPA, since it does go into solution, and will not come out at the temperatures of interest to us.

4.  Finally, there are reports of the epoxy topcoat peeling off the walls of the aluminum fuel tanks in B-52s  and other military aircraft (ref 6).  This happens in the airspace above the fuel, a.k.a. the ullage area of the tank. The proposed mechanism is that the DEGME evaporates from the fuel, and then condenses on the walls of the ullage area, and this high concentration causes the epoxy to swell and separate.  One would expect our tanks to be less susceptible to this mechanism than the military aircraft mentioned since our aircraft don't fly as high, and the foam fiberglass structure is a much better thermal insulator than the aluminum tanks used in the military aircraft. However, when I post cured my tank, I made some thermal conductivity measurements of the strake, and they were much higher than expected. So though short-term ice in the fuel and condensation problems should be reduced, they are not eliminated.

In spite of successfully using Prist for over a decade in my C-150, I have decided to use IPA in my Longez, because I cannot get a straight answer out of Prist, and there is just too much uncertainty about the compatibility of DEGME with composite tanks.  In addition, there are situations mentioned above, in which much higher concentrations of DEGME will come in contact with the tank surfaces, even if used as directed.  For me it's just not worth taking a chance.  I don't expect any problem with 1% IPA since it is a weaker solvent and the concentration is so low, but I again defer to Gary and company.

**Final Thoughts**
1. First, the use of anti-icing agents as described above should protect you from the amount of water normally dissolved and suspended in the fuel. They will not protect you if you have bad fuel cap seals or other leaks or sources that put much larger amounts of free water into your fuel. These problems must be fixed first.

2. We have all heard the old adage to keep our fuel tanks full to reduce the amount of condensation that occurs with changing temperature. I am not a big believer in this advice.  First of all, I have never seen any data to support it. And secondly, because of the poor takeoff and climb performance of the C-150, I rarely kept my tanks full unless I needed the range. If this adage were true, then I would expect to find most of the water in my tanks in the spring and fall when there can be humid conditions and large temperature changes. But the only time I found significant water in my fuel sumps was in the winter, when the temperature was well below 50° F, and the air was usually very dry. So I believe a more important source of free water in the fuel is the water that comes out of solution when the fuel is brought aboveground. My own tests using translucent containers also show that there was significant water in solution in fuel in underground storage tanks. There may be less dissolved water in aboveground tanks and in fuel trucks since the fuel temperature will be lower, and some of the water may have already come out of solution.
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 3. If you don't use an anti-icing agent in your fuel, there is another scenario that's particularly dangerous. Over a very calm cold night, the fuel can become supersaturated with water. As the fuel slowly cools some of the water normally comes out of solution and sinks to the bottom of the tank, but if the fuel is not mechanically disturbed, it is possible for the water to remain in solution 10 or more degrees below freezing. Once the fuel is disturbed, a large amount of water will suddenly come out of solution in the form of a blizzard of ice crystals. These crystals can block the fuel filter, and kill the engine just as the aircraft is taking off, and is low and slow. You often hear about mysterious engine failures shortly after takeoff in the winter. This is another hazard you don't have to worry about if you put an FSII in your fuel. If you do not use an FSII, you should vigorously shake the airplane from the wingtip, and then drain your sumps. If the fuel looks dull and milky rather than bright and clear, then don't fly until a warmer day.

 4.  Though DEGME and IPA may be effective against carburetor icing in higher concentrations, they are not significantly effective against carburetor icing in the concentrations typically used as an FSII, and some of the manufacturers of DEGME have that disclaimer on their websites.

5.  Low concentrations of low molecular weight alcohols, especially methanol, ethanol, and IPA are effective de-icing additives that are often used in the volume percent range of .05 to .25% (see ref 7, page 68),  but the only alcohol combination blessed by the FAA is 1% anhydrous IPA, presumably because it gives the best combination of advantages and disadvantages. Of course, experimental aircraft can use whatever they want, and if you fly with five or 10% ethanol auto fuel, your FSII needs are more than covered. This suggests, that if nothing else is available, one could use 1 gallon of 10% ethanol auto fuel for every 9.1 gallons of avgas, and end up with a 1% ethanol fuel that has adequate anti-icing properties. But of course, that assumes the ethanol in autofuel is anhydrous.

I flew for many years without any FSII in my fuel without incident, so it may seem like a lot of trouble to go through for a very unlikely event. But over the years, hundreds of people have been killed because they did not have an anti-icing agent in their fuel. And once your engine gives you the silent treatment, you will be more than willing to take any reasonable precautions to keep it talking to you in the future (assuming you are as lucky as I was and survive the lesson).

Finally, my training is in physics, not chemistry, so I would appreciate any corrections to errors I may have made in this discussion.
Happy Flying! --Joel
Others have made good responses to this question, but I also want to comment on that and respond to other questions.

Unfortunately, most auto fuel available in the United States is contaminated with 5 or 10% ethanol, and although this causes a wide variety of  problems in engines not designed for it, especially in  older non automotive fuel systems, it does solve the ice in the fuel system problem..  Normally, to prevent fuel system icing, alcohol is added in the range of .05 to .25% by volume, and this is adequate to deal with dissolved and suspended water in gasoline that is normally encountered.  Therefore, assuming the ethanol is anhydrous to begin with, adding 10% to gasoline can protect one from an even much larger fuel system icing problem.   Cars running on fuel with these large amounts of ethanol should not have this icing problem.  The fuel systems and engines are designed to tolerate a relatively large amount of water in the fuel.  They will not tolerate nearly as much ice.  The FAA, and aircraft engine and airframe manufacturers all recommend a maximum of 1% iso-propanol (IPA).  This is a conservative compromise on how much water they can deal with, while still keeping the iso-propanol concentration low enough to prevent damage to fuel system components, and prevent detonation that may result from higher levels of IPA.

I got a couple emails from canard pilots who said they have flown for 20 or 30 years, and almost never find any water in the fuel.  One said he did not believe water in the fuel was a problem with canard aircraft if they use avgas, unless it leaks past the filler cap, but it certainly could be if mogas/ethanol is used.  My response is water in the fuel is a problem for all aircraft, because even if there are no fuel cap leaks or condensation, water is pumped into your tanks with the fuel.  This water is dissolved and suspended in the fuel, and you can not detect it by normal sump draining. I repeat that small amounts of water in the fuel will not usually be a problem, because the fuel system is designed to deal with that, and the engine will tolerate  small amounts in the fuel stream.   When I first got my LongEz, I found the gascolator almost completely filled with water, but the engine ran fine. The problem is that water can turn to ice when it gets cold enough, and the fuel system and engine are not tolerant of that.

If you use mogas with ethanol in it, you will in most cases be protected from that problem.  But even if the auto fuel has no anti-ice additive in it, fuel system icing is still much less likely in cars than in aircraft because of the much more rapid altitude and temperature changes that aircraft are routinely exposed to.

One advantage our canards do have over our aluminum brethren is that our fuel tanks are made of a foam-fiberglass sandwich, which provides much better thermal insulation for the fuel than in aluminum aircraft.  After I refueled my C-150, it only took about an hour flying in 20 degree air, for fuel system icing to occur.  In our canards, it may take 3 or 4 hours.  However, our aircraft have unusual range.  We can fly 6 or 7 hours legs (if your bladder is big enough).  So the  possibility of fuel system icing still exists.  Besides that, if you do not use an anti-icing agent in your fuel, and you park your airplane fueled and ready for flight overnight in twenty degree weather, then you are just as vulnerable to the lethal dangers of supersaturated fuel described in Point 3 of the Final Thoughts section of my Remediation post.

Finally, one person asked why I did not land and drain my fuel system before continuing home as a more reasonable precaution.

1. First and foremost, I was 99.44% sure the engine failure was due to ice in the fuel system.  All the evidence pointed to that.   I thought if I stayed above 32 degrees F for the rest of the trip, that was one very effective solution to this problem.

2. I had just checked my sumps and gascolator drain for water before I last took off and found none.  I knew that any small amount of water that came out of solution and suspension during the flight could easily be handled by the fuel system and engine, and finally,

3.  I was circling above a small airport with unknown resources.  It was likely that I would find nothing wrong.  But what if I was wrong about why the engine failed?  Then I would take off from an airport on a relatively short runway, where I could be faced with an engine failure while I was low and slow.  I much preferred looking for an emergency landing site from 2000 ft, rather than from 200.  I wanted my next take off to be from a runway over a mile long, and I had that at my home field.  However,  I did continue to circle the airport  for a while, and tried various attitudes and power settings in case the power restoration was only temporary,  before I resumed my flight home.

I agree that the wisdom of deciding to continue flying rather than making an immediate precautionary landing at an airport is debatable and may not have been the best decision.  However, in hindsight and  knowing what I know now, in those conditions,  I would still make the same decision today.

--Joel

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**Jay Skovbjerg:**

*“I am having serious doubts about you claims of dissolved water in Avgas which goes through a phase transition to fill up your gascolator when it gets “cold enough”. It simply does not make any logical sense to me.*

*- Water cannot dissolve into a fuel composed of hydrocarbons. So, for there to be water dissolved in the fuel there will have to be some hygroscopic contamination in the fuel. Of course, fuels that are within specification for use in aviation are free from such contaminants.*

*- if water is pumped into the tank as you claim, (to be drained later) it will have to come in separate from the fuel and not as dissolved. THAT of course would be a big issue... how many times have you seen pilots drain their tanks after fueling up? Not to mention paying big bucks for water...*

*- The freeze point of Avgas is -57 C. That is the temperature at which all crystals (typically wax components) which might have formed at even lower temperatures “melt” back into solution. That gives you an idea about operational temperature range.*

*Also, from a practical / operational point of view:*

*- how can pilots in Alaska operate at all in winter time if dissolved water drops out of the fuel right and left? The water would drop out, freeze and stay somewhere as ice cubes... does not make any sense... Yes... I have 21 seasons on the Cozy and never drained a drop of H2O out of it.”*

**Mike Garmon:**

*“Actually, he is correct. I am a chemical engineer who works with all types of hydrocarbons and I can say that almost any hydrocarbon has some capability to dissolve water, see the attached link for a solubility curve of avgas and other jet fuels.*

[*https://www.researchgate.net/figure/Water-solubility-profiles-of-petroleum-derived-jet-fuels-and-avgas-sample-with-reference\_fig2\_322453716*](https://www.researchgate.net/figure/Water-solubility-profiles-of-petroleum-derived-jet-fuels-and-avgas-sample-with-reference_fig2_322453716)

*However, each tank full would only have the capability to hold about 0.07 lbs of water or about 0.25 ounces. It would also take a huge swing in temperature. This is more likely to be noticeable in the FBO tanks than in our tanks.”*

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