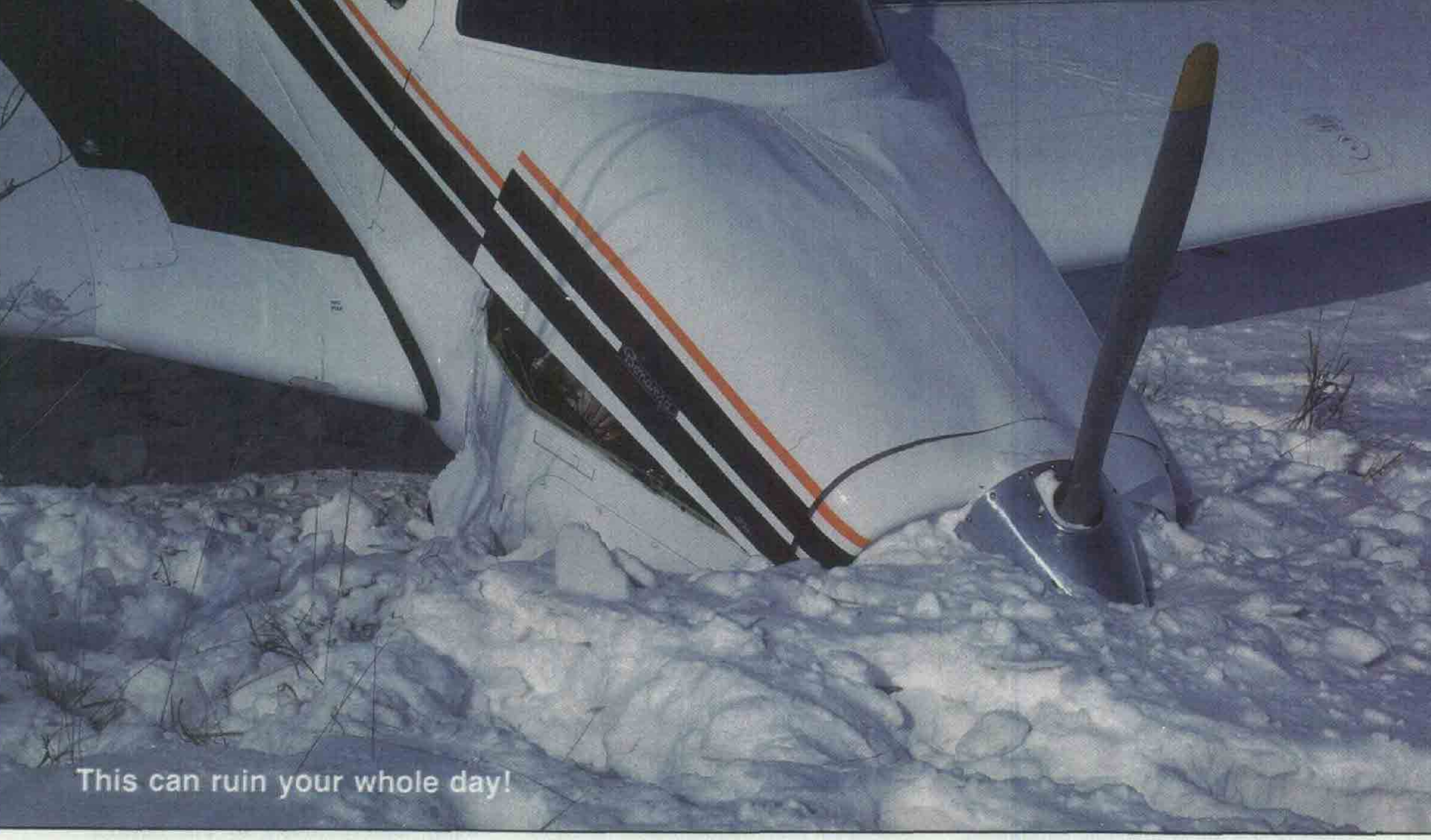

MIXING WINTER FLYING WITH OIL, FUEL AND WATER

by ***Niel Petersen, EAA 35302***
11227 Farm Lane
Hopkins, MN 55343

Photos by Verdon Kleimanhagen

Winter flying mysteriously increases the chances of aircraft engine problems and failures. Cold weather flying advice has belabored a number of subjects, but the low temperature properties of oil and fuel remain two poorly understood winter flying hazards. The purpose of all this is not to tell you how to run your engine (only your lawyer should do that!), but rather give you my insight into a couple of serious winter gotchas. My interest in this subject started 14 years ago on a bitterly cold January day when our old reliable 172H quit 10 seconds after take-off. Miraculously, we got it all down in one piece with a FAST 180, a vertical bank, and full flaps all at the same time — whew! Afterwards no one was able to tell me why it quit in the first place.

First . . . Do You Have Enough Lubrication For Cold Operation?

In the SAE lube oil ring system, viscosities are measured in Saybolt Seconds Universal (SSU). This is the time required for gravity to cause a certain quantity of oil to dribble through a small diameter tube at 100 degrees F. Alternately, tests run instead at 0 degrees F. have the additional "W" designator added. With mineral oils, the SSU viscosity numbers change so radically with temperature that the ASTM gave oils arbitrary numerical ratings, like the "SAE 20" line shown in Figure 1, according to whichever SSU vs. temperature curve fit best on this standard chart. Since then, modern additives, new oil types and synthetics have created oils with different slope lines on the standard SSU vs. temperature chart. The rating system was modified to use the dual reference points of 0 degrees F. and 210 degrees F. to allow us to relate to the familiar SAE ratings. For example, a 20W50 oil will behave like a 20 (actually 20W) weight oil at 0 degrees F. and like a 50 weight oil at 210 degrees F., as also shown in Figure 1. Notice in particular though, the tremendous range of the SSU viscosity numbers between these typical start-up and operating conditions.

Multi-grade oils have an improved Viscosity Index (VI), meaning the viscosity doesn't change as much with temperature as a traditional mineral oil. These had been achieved with additives, but some of these tended to deteriorate under service and lose their effectiveness. More recently, improved VI's are achieved by substituting a synthetic base stock (i.e. oil made in a chemistry lab) for some or all the mineral base stock. Synthetic base stocks have less viscosity change with temperature. As an additional benefit they are more resistant to high temperature breakdown.

Other ASTM specs spell out the absolute cold start capability of oil in simple temperature terms. For example, the "pour point" is the lowest temperature at which an oil will flow at all. Below this temperature, oils begin to have the properties of a solid — i.e., able to support sustained shear without movement, rather than a fluid which cannot. Just because the lube oil is above the pour point temperature doesn't mean an engine can be safely started.

The lubrication system in an airplane engine uses a positive displacement gear pump to suck oil from a sump and force it into a few critical bearings. The output pressure is limited by a bypass relief valve to protect the pump, filter, oil cooler and other components from excessive pressure buildup. When the engine is cold the engine bearings, etc., are unable to absorb much flow and most of the pump flow is bypassed over the relief valve. Unfortunately, the design of most engines is such that this bypassed oil flow never gets to warm

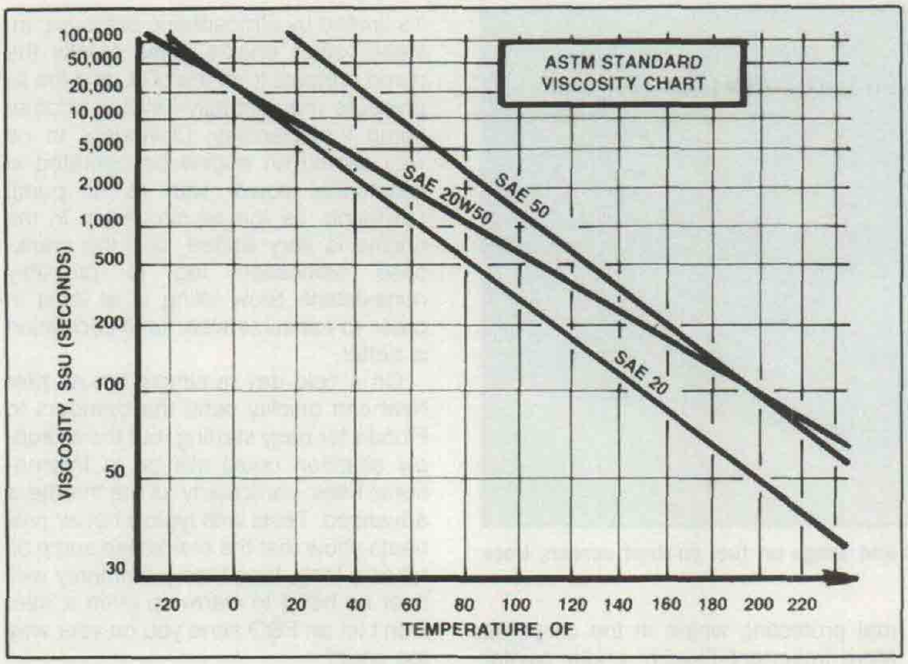

Figure 1

parts of the engine. Instead it is returned directly to the sump with no opportunity for any temperature rise. Thus, when the lube system is cold and needs heat to reduce viscosity and improve circulation, the oil has poor access to the heat of the engine. This suggests why oil temperatures are so strangely and dangerously slow to rise compared to cylinder head temperatures.

When an engine is warm and has properly thin oil, much of the oil pump flow leaks out the sides of the main and connecting rod bearings and sprays around, fogging the crankcase with oil and carrying cylinder and piston heat back to the pan or sump. Sliding surfaces, such as cylinder barrels, camshaft lobes, etc., also rely on the incidental spray for lubrication. Some oil dribbles from small holes in the valve train for rocker arm and lifter lubrication. Preferably some of the oil pump flow should be left to blow over the relief valve, or otherwise the cruise oil pressure will tend to fall excessively when hot.

If the rod and main bearing leakage follows viscous fluid capillary leakage laws, the spray lubrication flow will be proportional to the pressure (which is fixed by the relief valve), to the 3rd power of the bearing clearance (which commonly varies from 0.0015 to 0.005 in.), and inversely proportional to the viscosity. From Figure 1's viscosity figures, it is obvious bearing leakage and spray can easily be reduced by a factor of 1000 or more in a cold engine from viscosity effects alone! When this is combined with clearance effects (cubed yet!), the bearing spray rates could easily be reduced by a factor of 10,000 or more comparing a cold tight engine with thick oil vs. a loose warm engine with thin oil. The worst combinations of these factors initiate expensive cold start damage problems.

New engines with tight bearings will be more sensitive to cold start damage than loose engines near their TBO. Mechanics shouldn't even THINK of assembling an engine with bearing clearances below minimums, as the spray goes as the third power of the clearance. Operators of new engines should be extra careful to preheat and be sure to lean towards lighter oils — especially for those unnamed engine models susceptible to valve train lubrication problems.

The main (but not the rod) bearing clearances are further reduced in a cold engine due to differential expansion between the steel crankshaft and the aluminum case. In really cold weather, this will reduce the main bearing clearance by about an additional 0.001 in., possibly causing a tightly fitted main bearing shell to rotate in the case on start-up. This is a financially traumatic affair, as it causes the oil feed holes to become mismatched. The bearing is starved, and over the next few hours, fills the screens with metal, etc.

Cold start lubriation related damage may also show up as either piston/cylinder scoring (probably first on the top side of the right cylinders for a CCW rotation engine), or as general scoring on the cam and cam lifter faces. Lubrication of a cam/cam follower interface is characterized by a very thin oil film — much thinner than, say, a bearing journal. Once scoring begins on such a highly loaded sliding surface, the detailed lubrication mechanism is interrupted, as the necessary mirror finish surface geometry is lost. The oil film will become progressively less able to support normal operating loads even with

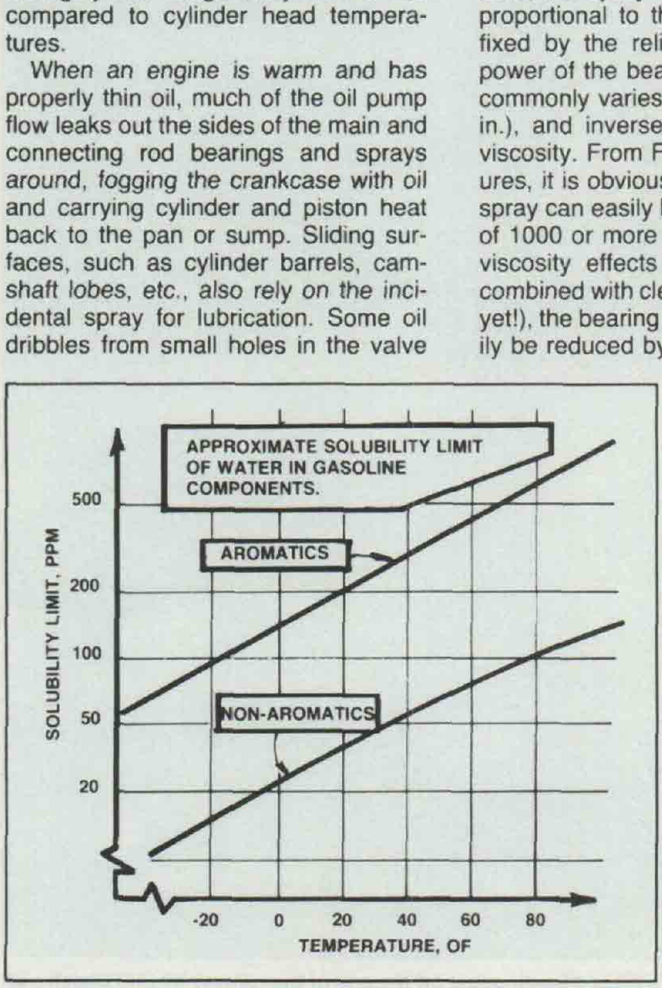

Figure 2

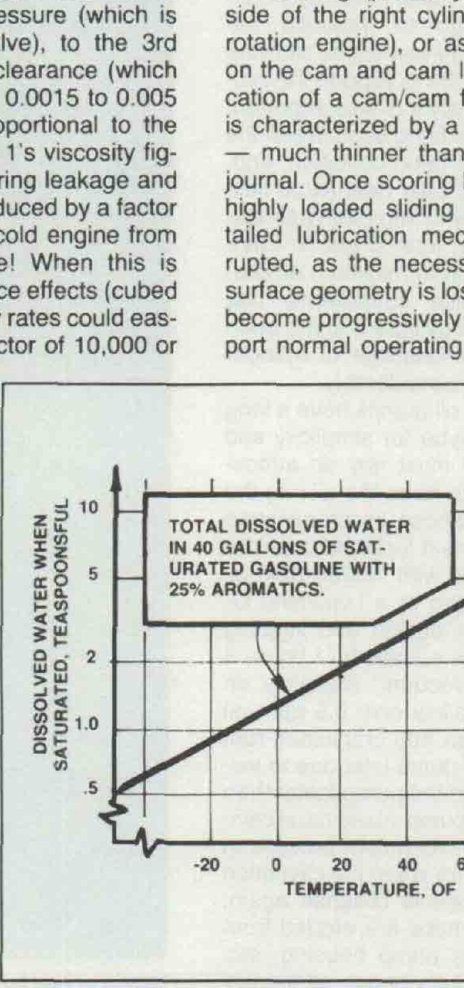

Figure 3

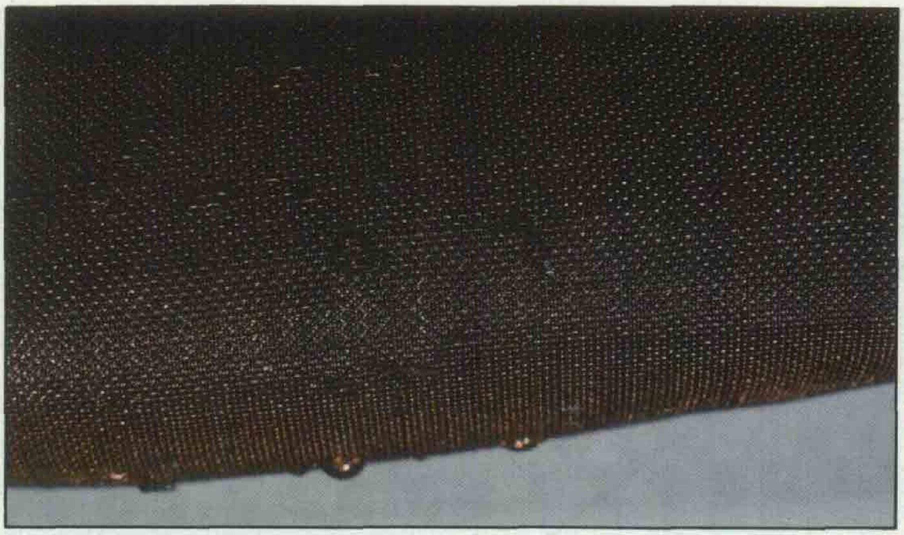

Figure 4 — Ice crystals precipitate from fuel and lodge on fuel strainer screen. Note fine wire mesh.

normal lubrication later on, and metal particles will again start to show in the filters and screens, if they don't simply settle in the crankcase. There is no healing recovery of the surface condition with normal operating time, and a premature cam and/or follower failure occurs.

Cylinder scoring can also be caused by primer fuel dilution of the cylinder lubricating oil. The first few seconds of operation should be confined to minimum power until the cylinders warm up enough to vaporize the gasoline on the cylinder walls, allowing the remaining oil film to support the sliding loads. Obviously it is also important to get all cylinders firing soon. Keep the ignition system in good condition, and, if necessary, use carb heat (what little bit there is at idle) to improve vaporization. If necessary, lean to get all cylinders firing ASAP with minimum oil dilution. If an engine consistently has trouble getting all cylinders to fire soon after starting, the chances of cylinder scoring increase considerably.

Aircraft engine oil pumps have a long suction tube (maybe for simplicity and "low" cost?) and must rely on atmospheric pressure to force the oil into the pump intake. Suppose as an example we push our preheat luck and consider starting an engine with 10,000 SSU oil in the pan. Looking at a Lycoming O-235 lube system design and juggling some messy flow equations, I figure a 10 psi "suction vacuum" (certainly an upper limit) will allow only 0.5 gpm oil — that's less than 300 crankshaft-rpm worth — into the pump inlet due to viscous losses. Drive the pump faster than 300 rpm and the pump intake must cavitate. This is a micro-violent process in the pump gears, for when the cavitation bubbles are forced to collapse again, tiny particles of metal are eroded from the edges of the pump housing, etc. This destructive activity can commonly be heard on a cold engine by an abnormal protesting whine in the oil pump. More important though, under cavitating conditions, the pump is unable to deliver its normal full flow rate of oil due to intake restrictions. Accelerating the engine can't increase the flow either as it's limited by atmospheric pressure. Instead, other engine noise masks the pump protests from the pilot, and the oil pressure may actually fail due to other pump inefficiencies. Obviously, in no way should an engine be operated at substantial power with its oil pump cavitating, as the oil circulation in the engine is very limited, and the crankcase lubrication fog is probably nonexistent. Slow idling is at least in order to minimize wear until circulation is better.

On a cold day, a simple hot air preheat can quickly send the cylinders to Florida for easy starting, but the oil supply situation could still be in International Falls, particularly as the throttle is advanced. Tests with typical hot air preheats show that the crankcase sump oil takes a long, long time (commonly well over an hour) to warm up even a little. Don't let an FBO send you on your way too soon!

An oil pan preheater more directly addresses the real cold start lubrication problem. Some have suggested that leaving it on all winter may cause corro-

Result of fuel cut off is a forced landing just off the end of the runway by this Beechcraft A-36.

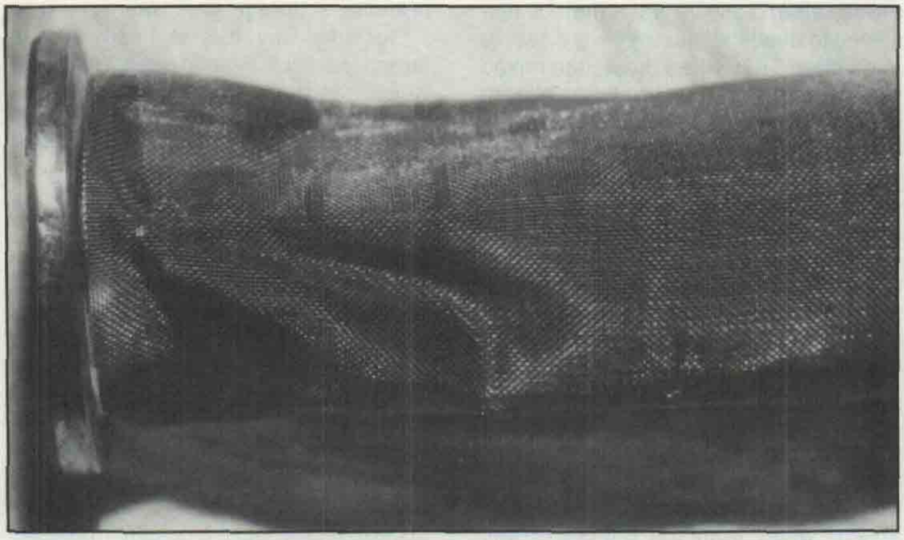

Figure 5 — As ice crystals clog fuel filter, fuel pump collapses the screen and fuel flow is cut off.

sion products in the oil to be distilled onto the cylinder surfaces. A partial saving grace is that the cold temperatures also reduce the chemical reaction corrosion rates about 50% for every 20 degrees of temperature drop.

The engine manufacturers seem to have established a maximum no-preheat winter start-up viscosity of about 20,000 SSU, **assuming winter grade oil**. If so, summer weight oil also has to be approached carefully in cooler temperatures as cold start problems can occur in surprisingly moderate temperatures. For example, from Figure 1, SAE 50 oil below about 45 degrees F. is near the same viscosity limit as 20W50 at about 5 degrees F. Don't get too carried away with initial rpm on a cooler fall day. Identify and observe the pump cavitation limit.

In very cold conditions with summer oil, it may not be possible to preheat enough for safe flying as there may be too many cold surfaces in the lube system on which oil may congeal and not return to the sump properly. Under these circumstances the only thing to do is to patiently preheat the oil enough to change it BEFORE flying.

Make it a habit to check the oil pressure trend during the initial take off roll in cold weather to make sure the pump is taking in oil properly. Pump intake cavitation will show by a mysterious pressure reduction as the power is advanced. Use an oil which will free flow at low temperatures. The synthetics or partial synthetics are a real plus to engine life, but only use them after break-in. If you have to span an excessive temperature range (like going to Sun 'n Fun), it is probably better to err on the side of too thin oil than too thick.

Consider the manufacturer's cold weather oil recommendations and preheat requirements as more than just suggestions to be followed only when convenient. Rather, they are a maximum start-up viscosity design limit (from the parts supplier!), which already assumes winter oil grades, above which one is inviting very serious trouble.

Why do aircraft oils have to be so thick when car engines routinely start in much colder conditions without preheat? Automobile engines rarely cavitate when cold as they have a less restrictive oil pump intake system. The engines run at much lower outputs, have more mass, thermal inertia, and thermal equalization capability with water cooling, and are consequently able to tolerate thin oils under what is otherwise light-service operating conditions. On the other hand, an aircraft-equivalent operating scenario for a car would be for every trip to the corner store begin with a flat out drag race through the gears at maximum power before settling down for a few minutes of 90 mph freeway driving. How long do you think the family sedan would last in that operating mode? Notice, for example, Dave Blanton's heavy oil recommendations for auto engines used in aircraft.

Gasoline, Water and Winter

As I found out the hard way, the biggest winter gotcha with gasoline is simply inflight ice blockage. No, it's not the frozen gas line like shown on TV with deicer commercials (I don't think they have it right either). I have never seen the nature of the problem clearly explained by others, but my harrowing experience 14 years ago, and engineering background, has led me to these observations and conclusions.

My college chemistry prof noted that water is a universal solvent. Given enough time and quantity, it will dissolve anything, or conversely dissolve minutely in anything.

Most people incorrectly assume that gasoline and water won't mix with each other. Obviously, they don't freely mix in any proportion, but depending on the gasoline constituents, gasoline will dissolve small but significant quantities of water to the approximate saturation limits shown in Figure 2. In particular, note how the saturated mutual solubility between gasoline and water decreases by half about every 50 degrees F. temperature reduction. What happens to dissolved water when things cool off? As long as the saturation limits are not exceeded, nothing. But if the water concentration exceeds the saturation limit, the water condenses and precipitates out of solution, sort of like rain out of the atmosphere, and that's when we have to begin to pay attention.

Normally the amount of available dissolved water is insignificant. However, a typical aircraft fuel system design is such that the engine can be stopped with maybe a teaspoonful of water if it happens to be in the form of ice crystals accumulating and blocking the gascolator screens. Since a 40 gallon gas tank contains about 20,000 teaspoonfuls of gasoline, it doesn't take very many PPM (parts per million) of water coming out of solution and freezing, to create a dangerous blockage potential.

Gasoline is not an exact chemical compound. Rather it is a hodge-podge of thousands of hydrocarbons blended together to meet a performance spec that defines its suitability for use in engines. Thus the Figure 2 water solubility chart is deliberately vague and approximate because the range of water solubilities for various gasoline components varies enormously. Typical components of gasoline can be classed, however, into a couple of broad types for water solubility estimating purposes. Most important are the aromatics, commonly used for octane boosting, because their molecular structure absorbs on the order of 6 times as much water as conventional saturated chain type hydrocarbons. Typically, unleaded regular gasoline will contain 25% aromatics as an octane booster. The specs for 100LL avgas don't limit the use of aromatics except an indirect one that practially also limits it to about 25%. Some manufacturers don't use aromatics in 100LL to minimize water solubility (and for other reasons) but that's not universally true, nor is it prohibited by the specs.

Figure 3 shows the maximum possible dissolved water vs. temperature for 40 gallons of 25% aromatics gasoline. From the plot, it is obvious many teaspoonsful of water can precipitate out of solution, very much like rain out of a cloud when a saturated mixture is chilled. This water (along with any inexcusable rain water) collects at low points in the fuel system for us to drain. This is called condensation by most, but I have trouble accepting the idea of dew in the gas tank. Think for a minute — why

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doesn't condensation collect in other interior places in your airplane?

I believe that except for fuel cap water leakage, a lot of fuel sump water is dissolved water coming out of solution with the gasoline as the mixture is chilled. Fortunately most gasoline is not delivered to you in a water saturated condition — at least as long as it's kept warm. In addition, gascolators can accumulate several teaspoonsful of liquid water before it has to spill over into the engine. If it doesn't come through in a big slug, some water could even pass through the system with only a rough engine.

This mutual solubility effect between gasoline and water is much more hazardous though, when the fuel is chilled below freezing temperatures. The chances of the gasoline being saturated with water increase sharply as the gasoline is chilled below its previous manufacturing and storage temperatures. Also, just as rain forms above freezing and snow forms below freezing, the dissolved water now comes out of solution as fine ice crystals. They look like daiquiri mix as shown completely surrounding a fuel strainer in Figure 4. Worse yet, the amount of water it takes to stop an engine is much less if it is in the form of fine ice crystals plugging a gascolator screen. Figure 5 shows the effects of a hard working fuel pump to force fuel through an ice blocked strainer.

When might accumulated ice crystals most likely cause a fuel strainer blockage? After a long cold cruise — or worse, on a take-off when the fuel flow demands. Finer fuel screens used with fuel injection systems are possibly more prone to blockage, although the fuel pump system is more powerful. The old reliable gravity feed fuel systems could also be more blockage prone since the available pressure overhead is very limited compared to an installation with a fuel pump.

Water dryers — such as aviation grade isopropyl alcohol (don't even think of using methanol based deicers since they're corrosive) — would much, **much** rather dissolve water than be dissolved in gasoline, but they will dissolve into either. Thus when dryers are mixed with gasoline, they will quickly absorb most of the dissolved water from the gasoline, and then separate out from the gasoline as an alcohol/water mixture, with the freezing point of the separated mixture very depressed. If necessary, this precipitate can gradually be fed in liquid form through the engine, though the carburetor will be reluctant to pass it and it won't actually burn. The problem is that the drier remaining in the gasoline (and any other traces of alcohol deliberately blended into the fuel) will, over a period of many days or weeks, gradually absorb more moisture from the air. Worse, it will immediately absorb water from the bottom of any storage tank. Consequently, alcohol driers are best used in the aircraft fuel tank, and preferably within a few hours of flight time. It doesn't take a lot (I use only a couple of ounces per tankful), but be sure to drain out any alcohol/water residue that can be found in the sumps before flight. Any extra alcohol that doesn't manage to find water to mix with will stay dissolved in the gasoline, ready to absorb any more water or ice which may become available to the solution.

Don't get suckered into using drug store isopropyl rubbing alcohol as the stuff already contains about 30% water. The best part of its deicing capability is not only all used up, it even adds more water to your system!

If practical, organize your fueling so that non-aircraft filters trap as much slush ice by chilling fuel before straining it. Don't fly with "snow" or ice crystals in the aircraft tanks or you may end up using all the limited filter capacity of the gascolator to remove these ice crystals! Use isopropyl alcohol deicers before flight to reabsorb any moisture or ice that has gotten as far as the airplane. Drain any alcohol-water mixture out of the sumps before flying. If a lot is gotten out, add extra deicer to keep the gasoline "charged up" and ready to absorb more water.

As a general rule, avoid adding unnecessary deicers to a ground storage tank in order to prevent otherwise dry fuels from absorbing moisture. If there is any separated water in a storage tank, figure out a way to drain or suck it out, then use a tiny amount of deicer to also precipitate out any inevitable remaining dissolved water, and suck the precipitate out, too. Be careful of this fuel if it is stored for very long, as it will still be prone to picking up additional moisture. For that same reason, stay away from gasohol (for other reasons, too), as it really attracts water, and you have no way of knowing how much of the octane boosting alcohol has been leached out by past contact with someone else's storage tank water.

Consider any fuel in fixed storage tanks (particularly underground ones) which has been treated with deicer as definitely second class fuel, the use of which has to be monitored more carefully to make sure it isn't picking up more water. On the other hand, if water is encountered in a storage tank, it's probably better to use deicer than having a lot of dissolved water present in it waiting to trap someone who hasn't read this article. Ideally though, save the use of deicer for aircraft fuel tanks — again preferably just before flight.

Be especially careful of non-treated fuel which has been severely chilled in the aircraft tanks since it has last been filtered. The slush ice induced gascolator blockage problem may take a while of flying to show up, but it will tend to show at a most awkward time (it sure was for me!).

Even in the middle of a Minnesota winter, fuel comes out of underground tanks at about 40 degrees F., as cold as it has ever been since it was made, and very possibly saturated with water. Putting such warm fuel in a cold airplane is definitely asking for trouble from accumulated ice crystals. Filtered fuel from a prechilled above ground tank or truck is not as likely to need as much deicer, but it may take a couple of days for it to reach ambient temperature. Those handling their own autogas can take advantage of things and see the ice crystals by chilling your fuel outside overnight before filtering and pouring it in the airplane (you do use a filter screen, don't you?).

If you experience a snow-in-the-gascolator induced engine fadeout and failure, in desperation you may be able to get partial power back for a few minutes by closing the throttle for a few seconds to allow the carburetor bowl to fill before advancing the throttle to a reduced power.

Again, why don't automobiles seem to have these problems? They do, but we don't place such severe operating demands and expectations on the fuel delivery system. Auto gas suppliers have been putting trace amounts of alcohol driers in fuels for years, and the consumption is high enough that the storage tanks rarely accumulate enough water to saturate the small amount of alcohol used. Recent gasohol useage though has taken years of accumulated storage tank contamination and moved it into our cars (and airplanes if you happen to get some of it).

Aircraft fuel is supposed to be dry. The FAA has not yet officially declared it mandatory to use deicers in gasolines. Unfortunately, fuel can easily become water saturated by normal handling or storage events, with possibly tragic consequences.