Separator or Condenser?

Air-oil separators 101.

BY DAN HORTON

Next time you're hanging out on the FBO porch with the boys, casually announce your intention to install an oil separator with a sump return line. Chances are at least one will swear it's a bad idea, and offer a dire warning about returning water to the engine along with the captured oil.

Is he right, or wrong? Let's look at the details.

Blow-by-Blow

Crankcase outflow originates in the combustion chambers. The piston rings don't seal perfectly, and some of the hot combustion gas leaks past them into the crankcase. We call this leakage "blow-by," a nicely descriptive term. Without some way to escape, blow-by would increase crankcase pressure until it became high enough to blow out an oil seal. The escape path is the crankcase breather outlet.

The hot combustion gas is, not surprisingly, similar to ordinary exhaust outflow: in ballpark terms, about 71% N_2, 14% CO_2, 13% H_2O, with the remaining few percent being NO_X, CO, unburned hydrocarbons, and trace compounds. The rings also leak on the compression stroke; compression blow-by is mostly ordinary air spiced with gasoline. The resulting "crankcase atmosphere" is hot, so constituents with high vapor pressures (notably water and fuel) are in the form of a gas, not liquid.

The crankcase is full of whirling parts and flying oil droplets. Lubricating oil has a very *low* vapor pressure and thus does not easily evaporate, even at high temperatures. In consequence, although the oil droplets get smacked and smashed until broken down to aerosol size, they remain in liquid phase. The

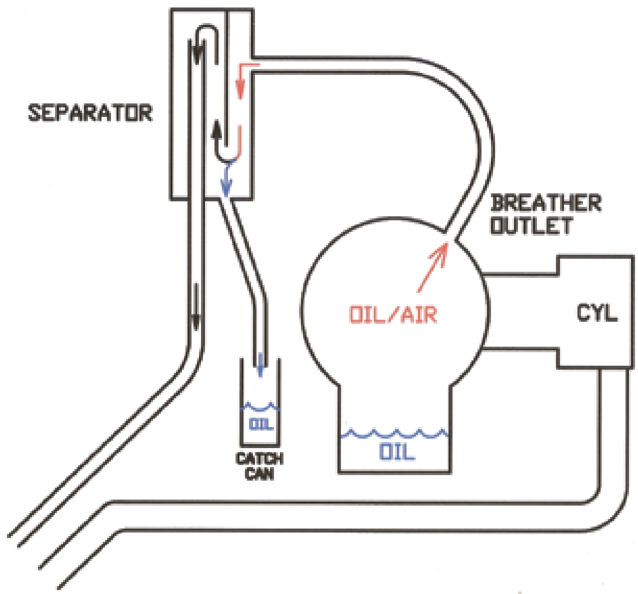

Figure 1: Oil separator with catch can, ambient pressure system, overboard dump.

result is a breather outflow consisting of tiny liquid oil droplets floating in a hot mixture of gases.

In a traditional aviation installation, the breather outlet is simply vented overboard at the base of the firewall, and the liquid oil tends to spread itself along the belly. If the outflow temperature remains high enough, water and fuel remain in the vapor state and pass to the atmosphere. However, if outflow temperature is reduced to the respective dewpoints of the water and the fuel, they will condense into liquids within the breather hose. Normally both re-evaporate when released into the atmosphere, although ice formation (and blockage) at the end of the hose is a distinct possibility if outside air temperature is low enough.

Separators

Let's add an oil separator. Traditional aviation separators generally work by directing the breather flow against the inside surfaces of a can, then vertically to an outlet. The oil droplets, having mass, can't follow the rapid changes of flow direction. They splatter on the surfaces, coalesce into larger drops, drain to the bottom of the can, and exit via a drain line. In a simple system the hot outflow gases continue overboard as before, but now without the liquid oil.

Almost everyone likes a separator. The debate centers on what to do with the oil drain line. Quite a few separators have been installed with a catch can intended to store the separated oil until drained at some maintenance interval (Figure 1). Owners and mechanics often report that the can collects a milky emulsion of oil and water, usually described as "slime." The condensed water generally includes some miscible acids and oxidizers; the reported pH is in the range of 4.6 to 3.85, which is about the same as ketchup, canned peaches, or a Bartlett pear. Regardless of content, it's not attractive. Owners don't like the idea of returning slime to the engine sump.

However, slime isn't universal. Other operators report nothing but oil in their catch cans. The slime faction figures them for tall tales and white lies (they're pilots, right?), but that's unfair. It is far more likely that the slime-free installations simply operate at higher temperatures.

Remember, when the engine is operating, the crankcase outflow is hot… usually somewhat hotter than indicated oil temperature. At that level all the volatile liquids (water, some acids, and fuel) are in vapor phase. If they remain in vapor phase, they pass right through the separator with the other gases; only liquid droplets collect on the walls. To

Photos and illustrations: Dan Horton

maintain the vapor phase, the separator and its associated plumbing must be kept at some temperature above the dew point of the vapor constituents.

With that in mind, there are two causes for water in a catch can. The first and most obvious is that the breather hose and/or the separator housing is being chilled enough to act as a *condenser*. The cowl may be the type that is largely open to the air stream (think J-3 or similar), or includes several blast tubes, or is just poorly sealed. Leaking baffle seals can allow a *lot* of cool air into the accessory area; NASA Report CR 3405 reported 38% of total cooling mass flow bypassed the engine fins in a relatively new installation. That unheated leakage significantly lowers temperatures in the firewall area.

The second cause is accumulation following cold start. When the engine is started after a period of inactive storage, liquid water droplets condensed inside the crankcase are blown out through the breather in the same manner as liquid oil droplets. Since both the initial outflow gas and the separator system are cold, the liquid water cannot reach vapor phase, and is thus collected by the separator and drained to the catch can. Note that if cold-start liquid water is returned to the engine, it evaporates as the engine reaches normal operating temperature, and is ejected as vapor in due course.

Temperature Considerations

It is physically impossible to return water to the crankcase if breather gas temperature is held above the dewpoint until downstream of the separator can. Dewpoint is dependent on percent water saturation (or relative humidity, to use a common term). The quantity of H_2O in the breather gas is a function of combustion chemistry (fixed by the number of available hydrogen atoms in the fuel) and the contribution of atmospheric water in the intake air. I wasn't able to obtain research literature that specifically measured breather gas H_2O saturation. However, there is no shortage of information about exhaust gas constituents, including water content, and the dewpoint calculations can be borrowed from flue gas engineering. The resulting dewpoint appears to be between 125° and 145° F.

Take a Breather

There are a number of successful breather and separator systems, but they're not all alike. Let's explore the differences.

Ambient Pressure System

Here "ambient" refers to a system operating at normal crankcase pressure, usually 1 to 3 inches of water (0.0735 to 0.22 inches Hg) above atmospheric. Examples would include a classic breather hose dumping overboard, and the separator system shown in Figure 1.

Positive Pressure System

Perhaps the best known is the Walker separator system (Figure 2), now produced and marketed by Airwolf. The notable features are the separator can size (promoted as larger than competitors') and the "venturi tube" (manufacturer's term) at the sump return fitting. This system operates at significant positive pressure because it is connected to either the vacuum pump output, or to upper cowl pressure. It appears the purpose of the venturi tube is to assist sump oil return, perhaps necessary in some installations. The Walker/Airwolf system dumps breather outflow directly to the atmosphere.

Negative Pressure System

Many experimenters have adopted negative pressure systems using crankcase evacuation (Figure 3). The idea is to reduce atmospheric density inside the crankcase in order to reduce pumping losses, which are significant. Auto racers take it to extremes, using powered vacuum pumps to pull as much as 15 inches Hg negative. For the less radical aviation application, a reed valve capable of withstanding moderate temperatures is attached to a port welded or clamped to an exhaust pipe, then connected to the separator's air outlet. Normal exhaust wave physics generate substantial alternating positive and negative pressures in the pipe. The reed valve closes against the positive pressure peaks and opens for the negative pressures, allowing the entire breather and crankcase volume to be pulled below atmospheric. A reduction of -2.5 to -3.5 inches Hg is common, as measured with an ordinary manifold vacuum gauge (mechanical averaging), or with a digital manometer connected through a line restrictor.

A different approach to a low-pressure source is seen on the 6-into-1 Sky Dynamics exhaust system popular with aerobatic and Red Bull competitors. The pressure tap is inserted into the high velocity area in middle of the collector. Published reports state negative pressure is on the order of 3 inches Hg at 2700 rpm with this system.

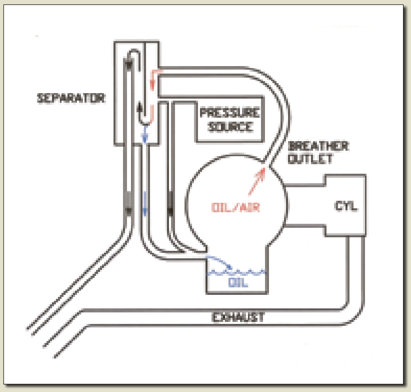

Figure 2: Airwolf (Walker) separator, positive pressure system.

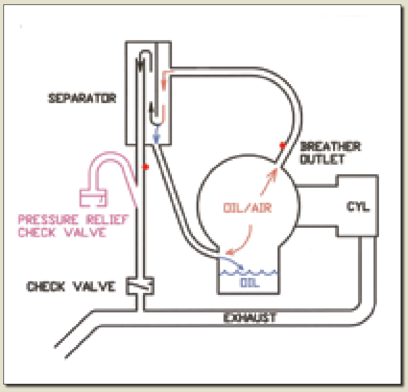

Figure 3: Separator with sump return and evacuator, negative pressure system.

My RV-8 is equipped with a pair of very useful roving temperature sensors (National Semiconductor LM135's) on long leads in the engine compartment. In order to establish operating temperatures, one sensor was inserted into the main breather line just outboard of the accessory case port, and the other into the outflow line just after the separator (red dots, Figure 3).

The resulting measurements are interesting. Breather outflow at the accessory case averaged 200° F, or about 15° F higher than indicated oil temperature. Separator outlet temperatures averaged 40° F less than breather port temperature. A 200° F average breather outflow and 160° F separator outflow are enough to stay above the assumed dewpoint.

However, a similar separator system may run colder under certain circumstances, and there is no downside to increasing the margin between separator outflow and dewpoint. So, the next step was to insulate the breather system and recheck temperatures. Surprisingly, breather can insulation (1/16-inch Fiberfrax felt under aluminum foil tape) didn't change outlet temperature very much. However, insulating the breather hose with a length of ordinary firesleeve raised the separator outflow to between 170 and 175° F, a nice increase in margin over dewpoint.

Oil Analysis

Several aircraft owners were kind enough to forward their recent reports from Blackstone Laboratories, the very popular oil analysis firm. The reports show no change in water content after the addition of a sump return separator. The systems were installed on RV-type aircraft, which, being fully cowled, tend to maintain moderate to high undercowl temperatures. However, there was no effort to insulate the separator systems and increase dewpoint margin.

Bottom line? It appears that warnings about returning water and slime to the sump have basis in physical reality, but only if the owner/installer fails to ensure adequate operating temperatures. The apparent physics do not allow water return to the sump when the breather-separator system is operating above the dewpoint. If you're not sure about separator outflow temperature, measure it. One measurement can be worth a great many front porch opinions.

Several certified installations pipe the separator outflow directly to a tap in the tailpipe, without a reed valve. These systems probably operate with some negative pressure, although certainly not as negative as reed valve and collector tap systems.

There are six benefits to a negative-pressure system. First, germane to water removal, negative pressure slightly lowers the dewpoint temperature. Second, the engine tailpipe becomes the overboard vent, incinerating both liquid and vapor volatiles before they can foul the belly. Third, negative case pressure tends to halt or slow the kind of weepy oil leaks common to aviation engines. Fourth, the entire system is contained within the lower cowl, where temperatures make ice blockage impossible. Fifth, reduced air density means less ability to support aerosol oil droplets. Last, even a small reduction in pumping losses is welcome. Airplanes usually become efficient through steady, incremental improvement.

Danger, Will Robinson!

No system is perfect. The critical issue with any engine breather ported to the exhaust is the buildup of coke deposits in the exhaust tap. When the tap becomes clogged, the breather gas has nowhere to go, and case pressure skyrockets to a level that can easily blow out the front crankshaft seal. The result is massive oil loss, followed by a forced landing. At the time of this writing, no one has firmly established a method of preventing eventual blockage. Users of such a system *must* clean the exhaust tap at regular intervals.

What is "regular"? Anti-Splat's system for the muffled RV-10 seems to have the worst record, with a time-to-blockage of 30 to 35 hours. Tornado Alley Turbo's tailpipe tap breather system for the turbo-normalized Cirrus SR-22 has a recommended cleaning interval of 50 hours (SI08-01 rev. A), while a similar Mooney cleaning interval is 100 hours (SB M20-312). The author's shop-built system for an RV-8 has gone as much as 140 hours between cleanings, and at least one Long-EZ owner reports no cleaning, ever. The differences *appear* to be the tap location in the exhaust system, but there is no firm conclusion. For now, be aware that an evacuator tap must be cleaned regularly, using a schedule based on careful observation of that particular system. Just pull the hose or reed valve, and run a scraper and wire brush through the exhaust tap.

As a safety measure, builders may wish to tee a second reed valve (Figure 4, and magenta, Figure 3) into the separator outflow line, between the separator and the exhaust tap. The auxiliary reed opens if system pressure becomes positive, thus eliminating any chance of a blown seal. The worst case then becomes oil mist deposited on the firewall and belly, much like a conventional open breather. The safety valve is cheap insurance if you're not absolutely sure of the required cleaning interval.

—D.H.

Figure 4: Safety valve.