Reducing the Amount of Entrained Air and Gasses in Oil, Dry-Sump Systems

In an earlier posting, I discussed aeration and the nature of air in oil. (See "Aeration and the Nature of Air in Oil", which appears in the Archive section.) By their nature, dry sump systems cause the oil to become heavily aerated, or more precisely, entrained with both air and blow-by gasses. In order for the oiling system to perform at optimum levels, the amount of entrained air and gasses must be reduced to levels which can be tolerated by the application.

In a typical dry-sump system, the oil supply resides in a specially designed tank, which is usually located remotely from the engine. After being ingested and discharged by the lube pump/section, the oil passes through the engine, where gravity takes over and most of the oil drains back to a shallow sump for scavenging. Oil that does not/cannot find its way back to the sump must be scavenged separately. One, or more, scavenge pumps (or scavenge sections…) ingest a mixture of oil, air and blow-by gasses and then transports the mixture to the oil tank, where the air and the gasses leave the oil and the oil cools. In a perfect world, starting and operating an engine goes something like this:

- At start-up, the bulk of the oil resides in the oil tank.
- When the engine starts, the lube pump/section creates a partial vacuum.
- Atmospheric pressure within the oil tank pushes the oil through an oil line and its associated fittings to the inlet side of the lube pump/section.
- The oil enters the inlet side of the lube pump/section.
- The pumping elements transport the oil to the discharge side of the lube pump/section.
- The oil passes through a network of fittings, lines, drillings and/or cast passages, the oil filter, the oil cooler and then through the engine itself.
- The network, as well as the various features and hydraulic devices within the engine present resistance to the discharge flow, causing pressure to build.
- Assuming that the lube pump/lube section of the fixed-displacement type and that it is driven by the engine, an increase in operating speed will cause both oil flow and oil pressure increase proportionally.
- After the oil has circulated through the engine, most of the oil drains back into the sump, but some oil may become trapped elsewhere in the crankcase of the cylinder head(s).
- Each scavenge pump/section creates a partial vacuum and atmospheric pressure within the crankcase and other locations and pushes a mixture of oil, air and blow-by gasses into the inlet side of each scavenge pump/section.
- The pumping elements transport the mixture to the discharge side of the scavenge pump/section.
- The mixture is returned to the oil tank, where the air and the gasses escape and the unaerated oil cools.
- At some elevated speed, the lube pump/section's rate of output exceeds the engine's rate of demand for oil and a pressure regulating valve opens, causing the predetermined system pressure to be maintained throughout the rest of the engine's operating speed.

Up until now, I have avoided using the term "deaeration". That is because both air and blow-by gasses will be entrained in the oil. So, before examining methods for reducing the amount of entrained air and gasses in the oil, let's address true aeration from the following sources:

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- The liberation of air from oil by way of excessive vacuum in the inlet port of the lube pump/section
- Windage by way of oil striking rotating and reciprocating components
- The ingesting of air by way of the scavenge pump(s)/section(s)

Liberation of Air at Inlet of Lube Pump/Section

Like any other lube pump, the lube pump/section of a dry-sump system must be allowed to ingest oil from the tank with a minimum amount of resistance (a/k/a pressure drop…). If the resistance is excessive, then some, much, or most of the air that is normally dissolved in the oil, will come out of solution and become entrained as foam. (Oil normally contains approximately 7% air, but the air molecules are relatively small and fit neatly between the larger oil molecules. When liberated, the air molecules agglomerate and create foam.) Simply put, this should be thought of as a change in the state of air that is always in the system.

Care must be taken to minimize the amount of aeration that is created in the inlet port of the lube pump/section, because the volume that is occupied by the air will displace an equal volume of oil, effectively reducing the output of oil. When the air reaches the discharge side of the pump, some, much or most of the air will be driven back into the oil, which will generate heat.

Windage and the Ingesting of Air and Blow-By Gasses via Scavenge Pump(s)/Sections(s)

Unlike wet-sump systems, dry-sump systems employ one, or more, scavenge pumps/sections. When multiple pumps/sections are used, they can scavenge oil, air and/or blow-by gasses from various locations within the engine. The pumps/sections that scavenge the crankcase ingest oil, but even greater amounts of air and blow-by gasses.

In relatively small, simple engines that are not subjected to extremes in g-forces and/or extremes in roll and pitch, a single scavenge pump/section whose output is as little as 25% greater than that of the lube pump/section can be sufficient.

In relatively large, complicated engines that are subjected to extremes in g-forces and/or extremes in roll and pitch, may require as many as, say, five scavenge pumps/sections. In a standard pump module that contains one lube section and five scavenge sections, the combined outputs of the scavenge sections can be as much as 600% greater than that of the lube section. (In this example, the scavenge ratio is 6:1.)

As you can see, where a lube pump/section changes in the state of the air from dissolved to entrained, the scavenge pump(s)/section(s) actually add air and blow-by gasses to the system.

Fortunately, dry-sump systems can include passive and/or active features and/or devices, which can reduce the amount of air and gasses that are entrained in the scavenged oil. (I stress that the amount of entrained air and gasses can be reduced. However, for all practical purposes, the entrained air and gasses cannot be completely eliminated.)

The problems that are associated with aerated oil are not unique to motor vehicles. Virtually every machine that uses oil for lubrication, for cooling or to transmit force can suffer from the ill effects of aeration.

The problems that are associated with aerated oil are so common, that there are literally thousands of designs for devices that deaerate oil. (If you are curious, then Google "oil dearator". When I did, I got 120,000 results…)

All of the methods that can be used to deaerate oil fall into one of two categories: passive and active.

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Passive Methods of Separating Air and Gasses from Oil

Devices that utilize passive methods of deaeration are not machines per se. An oil tank is the best example of a passive deaerating device. Oil tanks rely upon the clever application of simple principles of physics in order to do their jobs. Those principles are:

- Time
- Surface area
- Centrifugal force

<u>Time</u>

Given enough time, a well-designed oil tank will allow some of the entrained air will go back into solution with the oil, with the rest of the air and gasses entering the atmosphere within the tank as free air and gasses. The tanks also allow air and gasses to escape to the external atmosphere by way of a filtered vent and catch can. (Street applications may require the emissions to be controlled. Check with local, state or federal authorities for information concerning the control of emissions.)

If time is the only principle that is employed, then too-high of a turnover rate may not allow enough residence time for much more than partial deaeration to occur. ("Turnover Rate" appears after "Centrifugal Force" section.)

<u>Surface Area</u>

Encouraging the aerated oil to fan-out over a relatively large surface, allows some of the entrained air to go back into solution. The balance of the air, along with the gasses, will enter the atmosphere as free air and gasses within the oil tank and be vented to the outside atmosphere. (Again, street applications may require the emissions to be controlled.)

Most often, the large surface area is provided by the inside surface of the tank, as well as particular arrangements of plates and/or baffles.

It takes time for the oil to pass over the all of the surfaces that are located inside the oil tank and join the oil that has settled at the bottom of the oil tank. That being the case, the combined effects of time and surface area are in play. The net result is that providing a generous amount of surface area is a great deal more effective at deaerating oil than simply relying upon time. However, high turnover rates and/or the percentage of entrained air may still not be enough to deaerate the oil to acceptable levels.

<u>Centrifugal Force</u>

Due to their differences in density, centrifugal force causes the oil to become separated from the air and the gasses.

Note that in oil tanks, the centrifugal force is created by introducing the oil/air/gas mixture tangentially to the inside surface of the oil tank under moderate pressure and at a high speed. This is a principle that has been used in swirl pots for quite some time.

When the principle of centrifugal force is combined with the principles of time and surface area, an oil tank's ability to separate air and gasses from the oil is increased significantly.

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Turnover Rate

"Turnover rate" is something that is foreign to many within the powertrain community. That's a shame, because, in this case, understanding the turnover rate of a particular oil tank provides a great deal of insight as to what is happening to the oil.

By definition, an oiling system must be in equilibrium when it is operating. In order to attain and maintain equilibrium, the rate at which the lube pump/section delivers oil to the engine and the rate at which deaerated oil settles to the bottom of the oil tank must match the engine's rate of demand. That sounds pretty simple, but what happens in the middle must be understood, or problems will most certainly arise.

To keep the math simple, let's work with the following conditions:

- Engine operating speed = 5000 rev/min
- Engine's rate of demand at 5000 rpm = 30 lit/min
- Lube pump/section output at 5000 rev/min = 30 lit/min
- Scavenge ratio = 6:1
- Total volume of oil in system = 30 liters

Based on the preceding conditions, the total capacity of scavenge pump(s)/section(s) is 180 lit/min.

This is where things start to get interesting…

We know that oil enters the engine at the rate of 30 lit/min. After having done its work, the oil eventually finds its way down into the bottom of the crankcase or is captured elsewhere in the engine. The total capacity of the scavenge pump(s)/section(s) is 180 lit/min. If we subtract the oil that has passed through the engine at the rate of 30 lit/min from the scavenge capacity 180 lit/min, we are left with 150 lit/min.

A relatively small portion of the 150 lit/min that is being scavenged contains air and gasses. The additional scavenging capacity creates a partial vacuum in the crankcase, which reduces pumping losses due to the rising and falling of the pistons and also improves the sealing of piston rings. Both of these effects are welcome. (Crankcase vacuum is a subject that is far too complicated to cover here, but it is worth noting that it is possible to over-scavenge. Excessive levels of vacuum, by way of over-scavenging, can lead to all sorts of trouble. Keep your eyes open for a follow-up article that will deal with the unintended consequences of over-scavenging.)

For the sake of this exercise, let's assume that at any given moment, 4 liters of oil are in the engine doing work (not sitting in the sump…). In order for the system to be in equilibrium, at any given moment, there must be 4 liters of deaerated oil sitting in the bottom of the tank. (The other 26 liters are in the crankcase, in the lines that feed the scavenge pumps/sections, in the scavenge pumps/sections themselves, in the tank (as foam/mist…), in the line that feeds the lube pump/section, in the lube pump/section, in the line that delivers pressurized oil to the engine.

If the engine's rate of demand of 30 lit/min is divided by the tank volume of 4 liters, then the result is a turnover rate of 7.5 times per minute. Or, looking at it another way, virtually none of the oil resides in the tank for a period that is longer than 8.0 seconds. That's not a lot of time.

For more detailed information concerning the construction and sizing of oil tanks, visit Peterson Fluid Systems at www.petersonfluidsys.com and Armstrong Race Engineering at www.drysump.com.

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Standalone Passive Deaerating Device

If the mixture of oil, air and gasses that exit the scavenge pump(s)/section(s) passes through a standalone, passive deaerating device and an oil cooler prior to entering the oil tank, then the work that must be done by the oil tank can be greatly reduced.

For more information concerning the selection and installation of standalone, passive deaerating devices, visit Armstrong Race Engineering at www.drysump.com or at www.spintric.com.

Active Methods of Deaeration

Active deaerating devices are becoming increasingly more common in dry-sump systems.

I think that it is fair to say that centrifugal force is the most popular principle that is employed.

Centrifuge Integral to Scavenge Pump/Section

One way of implementing active deaeration in an oil pump is by adding a centrifuge stage to the discharge end of a scavenge pump/section. In this case, the oil is deaerated to some degree before it enters the oil tank.

The expression "to some degree" is important because the efficiency of a centrifuge is a direct function of its operating speed. Within reasonable limits, for a given impeller diameter, higher operating speeds yield better results.

Most scavenge pump(s)/section(s) operate at some fixed percentage of engine speed. As engine speed increases, so does the efficiency of the centrifuge. Fortunately, aeration increases as a function of engine speed as well, so the duty cycles are reasonably well-matched.

For more detailed information concerning scavenge pumps/sections that contain integral centrifuges, visit Auto Verdi at www.autoverdi.com and Dailey Engineering at www.daileyengineering.com

Centrifuge as Standalone Device

Another way of implementing active deaeration is by passing the oil/air/gas mixture through a standalone centrifuge.

One interesting device that is currently in development at Dailey Engineering is an electrically- powered centrifuge. Being powered by electricity, the centrifuge can be located in any orientation, anywhere between the outlet from the scavenge pump(s)/section(s) and the oil tank. Also, the speed of the centrifuge can be optimized for the application and remain constant, independent of the operating speed of the engine. (One could take the next leap and imagine a "smart" centrifuge, in which its operating speed would vary, based upon the amount of entrained air and gasses…)

Conclusions

Dry-sump systems present their own, unique challenges concerning both the generation and the reduction of entrained air and gasses in oil. Fortunately, there is a wide selection of devices that are available to help control the situation. Furthermore, there are quite a few, highly reputable sources for both the devices and information concerning their use. I encourage you to contact them directly concerning your specific application.

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