Aeration and the Nature of Air in Oil

The ever increasing sophistication of engines, transmissions, gearboxes and, in the case of hybrid or all-electric vehicles, electric motors, has placed severe demands upon the oils that they use.

The primary functions of oil fall into three major categories:

- Lubrication of running surfaces
- Transfer of heat
- Transmission of force

The power densities of engines, transmissions, gearboxes and electric motors have increased markedly during the past decade. Loads on bearings, as well as the amount of heat that must be rejected, have increased right along with them. Also, the use of engine oil and transmission fluid as a medium for transmitting force has added a new wrinkle.

In order for an oil to perform at its full potential, it must be cool, clean and unaerated. The first two should come as no surprise, but the third (aeration…) might.

Much has been written concerning the importance of oil being clean and cool. Unfortunately, relatively little has been written concerning aeration, so let's look at that.

Aeration

Aeration is defined as the presence of undissolved (entrained…) air in oil. The amount of air that is entrained in the oil causes the appearance of the oil to change: a small amount of air will cause the oil to appear to be lighter in color, while a large amount of air will cause foam to form. (How oil can become aerated is covered later…)

Let's look at how aeration affects the three primary functions of oil.

Lubrication of Running Surfaces

In order to minimize parasitic losses, engineers have reduced the numbers, widths and/or the diameters of bearings that are used in various devices. Those facts, combined with increased power densities, place enormous stresses both be bearings and the oil.

When oil becomes aerated, its ability to support a load is reduced. If the oil is too heavily aerated, then the oil film that is supposed to separate two running surfaces can collapse and allow the two surfaces to make contact. In some applications, occasional "touch-down" can be tolerated, but frequent and/or prolonged metal-to-metal contact will inevitably lead to failure.

Transfer of Heat

Features like turbochargers (often multiple turbochargers…) and piston cooling have become common. Both rely upon oil as the primary medium for the transfer of heat.

Aerated oil cannot transfer heat as efficiently as unaerated air can. The difference in efficiency is entirely dependent upon the level of aeration.

Transmission of Force

Melbourne Consultancy
Phone: 603.969.0502 ~ Fax: 603.431.1116
4 Melbourne Street, Portsmouth, N.H. 03801

This is one function that is often overlooked.

In many engines, motor oil is used to transmit force in order to activate devices like chain tensioners, lash adjusters, cam phasers and cylinder deactivation systems. Ideally, the oil is not compressible and the devices and the systems operate as intended. However, if the oil is aerated, then the oil will be "spongy" and those devices and systems will operate in a sluggish or erratic manner. In extreme cases, the devices and the systems may not operate at all.

In conventional automatic and dual-clutch automatic transmissions, the transmission fluid is used to transmit force to clutch packs.

In CVTs, the transmission fluid is used to transmit force to the variator.

When a transmission is not performing properly, the pleasure of the driving experience will be diminished. That is true whether the vehicle is a Honda Civic, Chevrolet Corvette or a Bentley Flying Spur.

How Does Oil Become Aerated?

Two well-known causes of aeration are the ingesting of air and "windage".

Air can be ingested when there is a break in the inlet circuit, when the pick-up becomes uncovered due to vehicle dynamics (acceleration, braking and cornering forces…), vehicle attitude (angle of attack…) and/or poor drain-back.

"Windage" is caused by rotating and/or reciprocating components, which mechanically bond air molecules to oil molecules. Windage trays, scrapers and the like have managed to find their ways into mainstream automotive applications and can reduce the amount of entrained air.

Perhaps the least known cause of aeration involves the liberation of the air that is normally dissolved in the oil.

When motor oil that has been stored in a sealed container is poured into an engine, approximately 7% of the volume is made up of air. The air molecules are relatively small and fit neatly between the relatively large and irregularly-shaped oil molecules. At room temperature and at sea level, the air doesn't cause any problems. It's just there.

How Does Oil become Aerated? (cont.)

An analogy that I like to use involves basketballs and golf balls. In the analogy, the oil molecules are represented by basketballs and the air molecules are represented by golf balls.

If you were to partially fill a room with basketballs and then add 7% as many golf balls as there are basketballs, then the golf balls will fill the spaces between the basketballs and the level of the basketballs will not change.

Now, moving back to actual oil…

As the pressure that is acting upon the oil is reduced, the oil's ability to contain the air molecules is reduced.

Another analogy that I like to use, involves carbonated beverages. Carbonated beverages, like soda pop, contain carbon dioxide gas. When the pop is sealed in its bottle, the contents are under pressure and the carbon dioxide gasses are dissolved in the pop. If the bottle is transparent and is sitting on a countertop, then

Melbourne Consultancy
Phone: 603.969.0502 ~ Fax: 603.431.1116
4 Melbourne Street, Portsmouth, N.H. 03801

you cannot see the gas bubbles. However, when the cap is removed, the pressure that was acting upon the pop is reduced, bubbles emerge, float to the top and form foam.

What do basketballs, golf balls and soda pop have to do with an oil pump?

Contrary to popular belief, oil pumps do not suck oil. The repeated expanding of the pumping chamber's at the inlet side of the pump creates a partial vacuum. When that partial vacuum becomes great enough, atmospheric pressure (the pressure in the crankcase, sump, gearbox, etc…) then pushes the oil through the inlet circuit (pick-up strainer, pick-up pipe, fittings, lines, drillings, cast passageways, etc…) and into the pump.

So, by definition, the oil is exposed to a partial vacuum as it is entering the pump. If the level of vacuum is too great, then the air molecules are liberated from the oil. That is when the trouble begins.

For the sake of discussion, if all of the oil becomes liberated, then it will agglomerate and create foam. That foam will displace oil and reduce the theoretical displacement of the pump by approximately 7%. When the foamy oil reaches the discharge side of the pump, some, but not all of the air molecules will be driven back into the oil. That action consumes power and generates heat.

Preventing/Minimizing Aeration

Great care must be taken when designing the inlet circuit of an oil pump. The circuit must be capable of allowing oil to pass with a minimum amount of restriction (a/k/a pressure drop…). Fortunately, the pressure drop can be calculated.

Preventing/Minimizing Aeration

Variables involved in calculating the pressure drop through an inlet circuit include:

- gap between bottom of sump and inlet strainer
- perimeter of inlet strainer
- effective open area of inlet strainer
- cross sectional area of pickup tube
- number of bends in pick-up tube
- radii of bends
- change in direction of flow due to bends in pick-up tube
- inside diameters of fittings
- number of fittings
- inside diameter of line(s)
- inside diameters of drillings
- change in direction of flow due to intersection(s) of drillings
- cross sectional area of cast passageways
- net lift or head
- total developed length of run
- rate of oil flow
- viscosity of oil
- atmospheric pressure in crankcase, sump, gearbox, etc.

Yes, a fair amount of work is involved, but investing the time will prevent, or at least minimize aeration. I have a suite of programs that I wrote specifically for that purpose. The programs allow me to calculate the pressure drop through individual sections and then determine the total pressure drop through the circuit. The ability to

Melbourne Consultancy
Phone: 603.969.0502 ~ Fax: 603.431.1116
4 Melbourne Street, Portsmouth, N.H. 03801

calculate the pressure drop through individual sections of the circuit, allows trouble spots to be identified very quickly.

The programs are used on a regular basis during the analysis of existing systems (for troubleshooting…) as well as the design of new systems (for the avoidance of trouble in the first place…). It is not unusual for clients to take advantage of the capability to benchmark competitors' products.

If you believe that you have an application which would benefit by being subjected to this kind of analysis, then contact me directly at marcdesign@comcast.net for a free consultation.

Melbourne Consultancy
Phone: 603.969.0502 ~ Fax: 603.431.1116
4 Melbourne Street, Portsmouth, N.H. 03801