Blow-by and Breather Systems – Part One

Introduction:
This document is an attempt to shed a little more light on what can be the black art of breather system function and design, and why engines need them.

Almost all road going cars since the 1960's, right from the Ford Escort to the McLaren F1, will have a closed breather system that deposits crankcase gases and carried over oil back into the air intake. However for some people, engine tuning or even the mere thought of oil going into the intake has made the idea of a closed breather system unpalatable. This usually results in the adding on of catch cans, atmospheric vents or oil separators, sometimes with very little appreciation of what these parts are actually doing.

Hopefully, this document will put a bit more detail behind the operation of the closed breather system, and allow those who want to modify it to make a more informed decision about how best to go about it.

The data in this document has been taken from personal reference material (the kind of stuff that any self-respecting Engineer has laying around in a few dusty old files), a white paper or two, and personal experience. Where possible, I have credited the source.

Blow-by: What is it?
Blow-by is the gas that enters an engine's crankcase during a normal combustion event or compression stroke. It is composed of unburnt fuel, air, and combustion by-products. Note that at this stage it does not contain any oil. Incidentally, the combustion by-products contained in blow-by gas are corrosive, which is why it is a bad idea to paint the underside of your car with old engine oil as a cheap underseal substitute.

Blow-by happens because the seal around your cylinder is not perfect. It is composed of closely matched metal parts - the piston, rings and cylinder bore. The close sliding fit and tangential load pressing the rings into the bore wall create a good (and variable, as we will see later on) seal, but by necessity there are gaps, and gas will get through them (see figure 1). If left unchecked, this gas entering the crankcase will eventually pressurise it and can cause oil to be blown past the crankshaft and camshaft seals.

I have seen articles on the internet that attribute crankcase pressurisation to the motion of the pistons - a piston descending in the cylinder on the induction or power stroke will pressurise the gas behind it and a piston rising on the exhaust stroke will create a depression behind it. This is not true. In most *common* road car engine configurations there will be an equal number of pistons rising and descending at the same time. Even if slightly out of phase, the overall change in crankcase pressure should be negligible. However, this effect does cause gas to constantly move from one part of the crankcase to the other. The motion of this gas is called *inter-bay breathing*, and can have a knock-on effect to blow-by, which will be covered later.

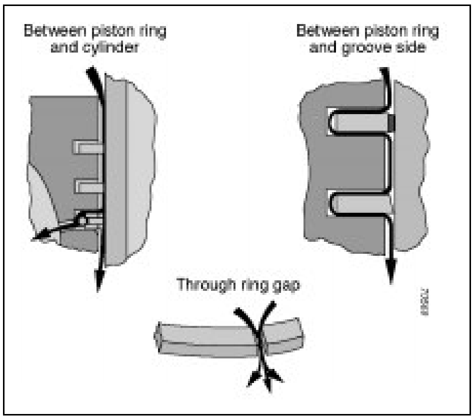

Figure 1: Blow-by flow paths [1].

There are other sources of blow-by: Air leaking into the cam cover via the valve guides and seals in pressure-charged engines, for example. However, we will concentrate solely on piston blow-by for the remainder of this article.

<u>How much of it is there?</u>
The simple answer to this is "it varies". The problem is that it varies depending on so many things that the accurate answer can be a complex one. Thankfully, for the purposes of this article there are some broad simplifications that can be made. Firstly, let us break down blow-by into two variables: The volume of air that your engine is ingesting and the *blow-by rate*.

It is easy to make a simple calculation to roughly determine what volume of air your engine in breathing:

N = engine speed (in RPM)
S = engine displacement (in litres)
V = volume of air being used by engine (in litres per minute)

$$V = \frac{N \times S}{2}$$

Equation 1: Simple volume of intake air per minute.

The other variable, the blow-by rate, is a percentage, which expresses how much of this air leaks past the piston and into the crankcase. It can only really be determined through direct measurement but good rule-of-thumb figures are [2]:

0.5% - New engine, after run-in.
1% - Design target for breather sizing.
2.5% to 3% - Maximum (e.g. for a worn engine, or poor piston ring sealing)

Therefore, we can have a rough attempt at calculating the amount of blow-by gases entering your crankcase by multiplying the air volume by the blow-by rate.

Example: Worn out 1.6 litre engine at 6500RPM

$S = 1.6$
$N = 6500$
Blow-by rate = 3% (0.03)

$V = \frac{1.6 \times 6500}{2} \times 0.03 =$ **156 litres per minute.**

Equation 2: Simple blow-by volume.

Now, let's add some more detail.

The first thing to note is that a normally aspirated engine of *S* volume will not actually ingest *S* litres of air per two crank revolutions (for a four-stroke engine). This is because the engine's *volumetric efficiency* will almost certainly be below 100%.

Volumetric efficiency (VE) is the ratio of the actual air volume actually being breathed to the geometric engine volume. Because of restrictions in the intake system, this will very seldom be 100% for anything but a very highly tuned engine. A good working figure for wide-open throttle (WOT) performance is 90%.

Therefore, we can modify equation 1 to include a term that accounts for the engine's VE:

N = engine speed (in RPM)
S = engine displacement (in litres)
VE = volumetric efficiency
V = volume of air being used by engine (in litres per minute)

$$V = \frac{N \times S \times VE}{2}$$

Equation 3: Volume of intake air per minute adjusted for volumetric efficiency.

Note that since the VE is typically less than 100%, this will reduce the amount of blow-by gas by the same factor. However, we can also use the VE term to account for what happens to the blow-by volume on a pressure-charged engine.

Pressure charging compressed a large volume of air at atmospheric pressure into a small volume at atmospheric pressure + boost (gauge) pressure. Broadly assuming ideal gas behaviour, it follows that if this gas were allowed to escape and expand back to atmospheric pressure again it would regain its initial volume. For the purposes of an empirical calculation, we can safely assume that the volume of air being breather into the engine increases by the ratio of the manifold pressure to atmospheric pressure.

Although its not good practise to mix units, in this case we can safely work in bar to keep things simple, since as atmospheric pressure = 1 bar, the ratio = boost pressure + 1.

Therefore the VE term in equation 3 is interchangeable with
(1 + boost pressure in bar).

Example: New 3 litre turbo engine at 6000RPM with 0.75 bar boost pressure.

$S = 3$
$N = 6000$
Blow-by rate = 0.5% (0.005)
VE / boost ratio = 1.75

$$V = \frac{3 \times 6000 \times 0.005 \times 1.75}{2} = \mathbf{78.75\ litres\ per\ minute.}$$

Equation 4: Blow-by volume adjusted for pressure charged engine.

As you can see, the volume of blow by gas entering your crank case can be appreciable, however, while the equations above are a good rule of thumb for initial breather sizing on a new engine, they can be a little over-pessimistic for trying to model real-world behaviour.

In order to refine the model further, we need to take a much closer look at the blow-by rate, which up until now has been picked from a list of rough values.

<u>Blow-by rate versus engine speed and load</u>:
Remember that blow-by gases enter the crank case predominately by leaking past the piston rings. Piston ring sealing effectiveness varies according to the engine's speed and the pressure in the cylinder, which is in turn related to the throttle position, or engine load. Rings tend to seal better at high engine loads when the pressure in the cylinder is high. They also tend to seal better at higher engine speeds. Through measurement at different speeds and loads, a map of blow-by rate can be produced.

Considering figure 2, we can see a clear trend from low speed / low load operation, where the blow-by rate is highest, extending diagonally through the map up to high speed / high load operation, where the blow-by rate is lowest. Reassuringly, this range matches quite nicely with the maximum and minimum values from our "rule of thumb" figures (0.5% up to 3.5 - 4%)

Knowledge of, or at least an educated guess at the maximum volume of blow-by gas produced is essential to the design of an effective breather system. Looking at figure 2 you may conclude that this will occur at the low speed / low load point, but remember that the blow-by gas volume is the blow-by rate multiplied by the actual volume of air being ingested by the engine. Where the engine speed is low, this volume will be low. Where the engine speed is high, this volume will be high.

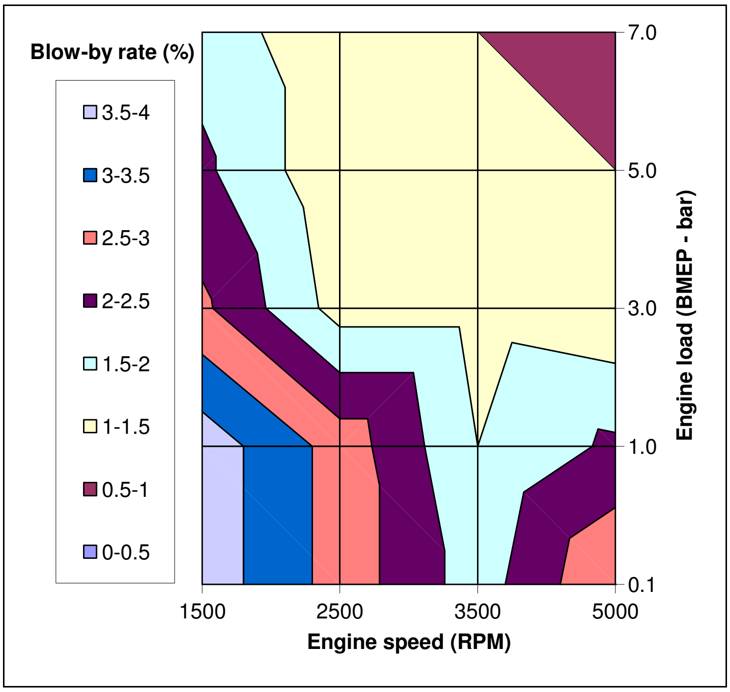

Figure 2: Blow-by rate map for a normally aspirated 1.6 litre gasoline engine [1].

To find the worst case condition, essential for the proper design of a breather system, it is necessary to use this map to find the actual volume of blow-by gases. This can be done by applying equation 2 (or equation 4 if we want to include VE effects) to each speed / load point.

Note that for the purposes of producing the map in figure 3, VE was varied from 75% to 90% according to engine speed, with the peak at 3500RPM – the assumed maximum torque speed.

We can clearly see that for full load performance, the WOT breather system must be able to handle gas volumes of between 10 to 30 litres per minute. The part throttle breather could be expected to have to handle up to 100 litres per minute in the high speed / low load regime (i.e. on the overrun). This volume tails off quite rapidly as the engine load increases, and it is quite possible that for this extreme condition any blow by design targets for the engine would be relaxed.

Considering breathing at low speed / low load (i.e. idling) the volume is still in the region of 30-40 litres per minute, and not far away from that is an island of 40-50 litres per minute.

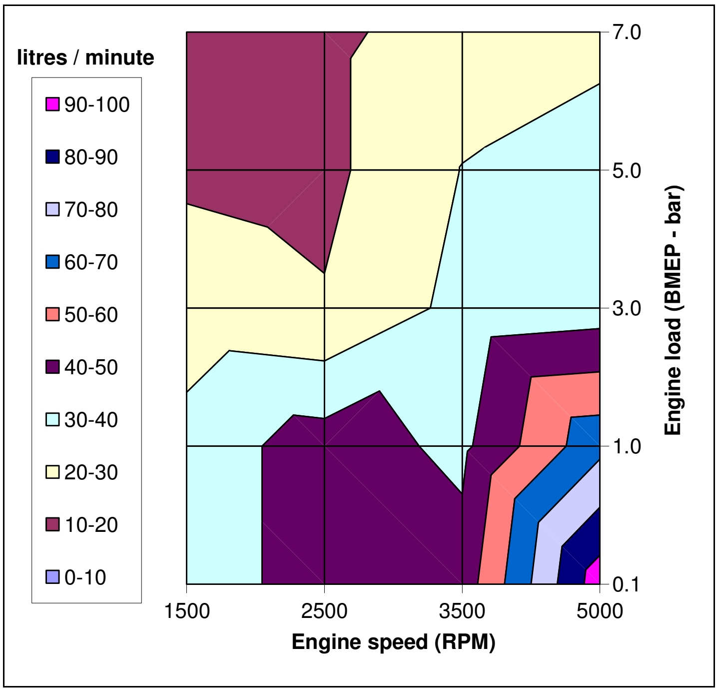

Figure 3: *Blow-by volume map for a normally aspirated 1.6 litre gasoline engine*

Now, compare this with the rough guideline calculations from earlier in this article:

First of all, consider the "design point" of 1% blow-by rate:

S = 1.6
N = 5000
Blow-by rate = 1% (0.01)
VE = 90% (0.9)

$$V = \frac{1.6 \times 5000 \times 0.01 \times 0.9}{2} = \textbf{36 litres per minute.}$$

Equation 5: Blow-by rate calculation assuming good piston ring sealing and high engine speed.

In this case we can see that the simplified calculation agrees well with the blow-by volume derived from the map. Now, consider a "worst case" scenario:

S = 1.6
N = 5000
Blow-by rate = 3% (0.03)
VE = 90% (0.9)

$$V = \frac{1.6 \times 5000 \times 0.03 \times 0.9}{2} = \textbf{108 litres per minute.}$$

Equation 6: Blow-by rate calculation assuming poor piston ring sealing and high engine speed.

Again, there is a good correlation between with the map values at the worst piston ring sealing regime (low speed / low load).

Summary:

- Blow-by is predominantly the leakage of combustion gases into the crankcase past the piston rings on the compression and power strokes.
- The amount of blow-by can be determined from the volume of air being breathed by the engine, the VE (or boost pressure), and the blow-by rate.
- The blow-by rate varies according to engine speed and load.
- Rough calculations based on assumed blow-by rates can be valid tools for breather system sizing.

Blow-by and Breather Systems – Part Two

Introduction:
So far we have seen that an internal combustion engine produces gases that enter the crankcase via leakage past the piston rings. This gas flow can be considerable (up to 100 litres per minute in a normally aspirated engine).

If left unchecked, this would cause a build up of pressure in the crankcase, the result of which would be oil being pushed past the shaft seals at the front and rear of the crankshaft. Also, since the cylinder head and cam cover are linked to the crank case by oil drain galleries which allow lubrication oil from the valvetrain to return to the oil pan under gravity, this pressure can also pressurise the cylinder head and push oil past the camshaft seals. In extreme cases, the pressure can rise to a point where it is sufficient to push these seals out of their housings.

This section deals with the system that prevents this from happening – the *closed breather system*.

History:
The obvious solution to pressure build up in the crank case is simply to incorporate an atmospheric vent into the cam cover, and up until about 1960 this is exactly what was done – the so-called *open breather system*. Unfortunately for the environment, blow-by gases contain a proportion of unburned fuel, oil and combustion products, which would get dumped into the atmosphere. As soon as legislation to govern vehicle emissions started to come into play, the open breather system's days were numbered.

Thus the closed breather system was born. The hose that was previously routed to atmosphere was connected to the engine's air intake so that the engine effectively ingested its own blow-by gases and all that they contained. Over the years, the closed breather system has evolved into a complex part of the modern-day engine.

A simple closed breather system:
In any breather system the crankcase (where the blow-by gases are created) is linked to the cam cover via either a chimney cast into the crankcase and cylinder head, or an external pipe. This chimney has two functions: Firstly, it allows blow-by gases to leave the crankcase to equalise pressure in the top and bottom of the engine. Secondly, it gives any oil that may be being carried along with the gas time to "drop out" and return to the oil pan under gravity. Note that depending upon the dimensions of the chimney, the velocity of the blow-by gases can be quite high. For this reason, it is bad practise to use a cylinder head oil drain as a blow-by chimney, as the oil and gas moving in opposite directions can interfere with each other – more on this later.

Once the blow-by gas has made its way up into the cam cover, it needs to be fed back into the intake system. The obvious way to do this is to link the cam cover to the intake plenum with a small pipe. In this way, the vacuum in the plenum will draw the gases off and maintain the crankcase at slightly below atmospheric pressure. In practise things are not quite so simple.

At low engine loads, the throttle plate will be almost fully closed, leading to a low pressure in the plenum. This is ideal for drawing the blow-by gases out of the cam cover. However, at high engine speeds and low loads (i.e. on the overrun this vacuum can be very high – to high in fact for the purposes of just maintaining the crankcase at slightly below atmospheric pressure. The solution is to introduce a restriction (typically about 1 to 2mm in diameter) into the link pipe between cam cover and plenum to limit this vacuum.

Conversely, at high engine loads, the throttle plate will be almost fully open and so the plenum will be at almost atmospheric pressure – no good for a vacuum source. Therefore, a second connection off the cam cover is used which uses the pressure drop across the air filter as a vacuum source.

This is the essence of the closed breather system – a restricted connection into the plenum which creates a vacuum under part throttle, and a second connection upstream of the throttle plate which creates a vacuum at wide open throttle (WOT). These two connections are referred to by various names, but in this document we will call them the *part-throttle breather* and the *WOT breather*.

<u>Operating modes of the simple closed breather system:</u>
As the engine moves through its speed and load range, the way the breather system behaves varies. If blow-by volume is low and load is low, then the part-throttle breather will tend to draw a higher vacuum than is required to draw off the pressure in the crankcases. Therefore the WOT breather will tend to suck in fresh air.

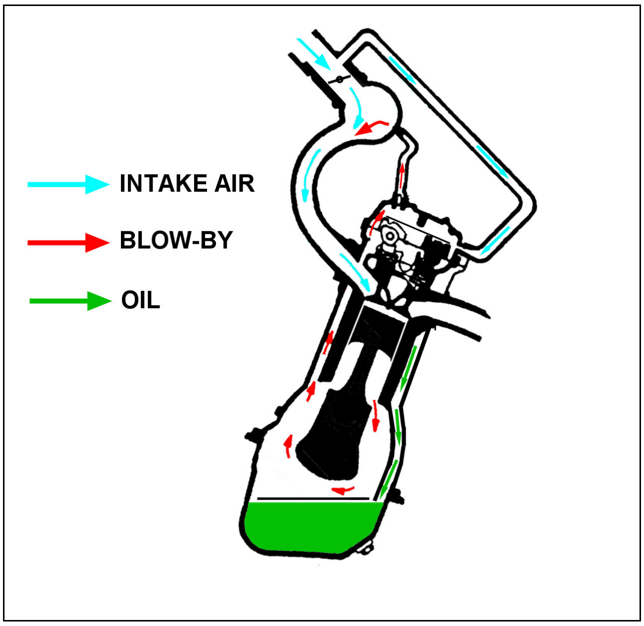

Figure 4: Low blow-by / low load breather flow.

Where blow-by production is high but load is low, the part-throttle breather will draw off all the gases and there will be little or no flow through the WOT breather.

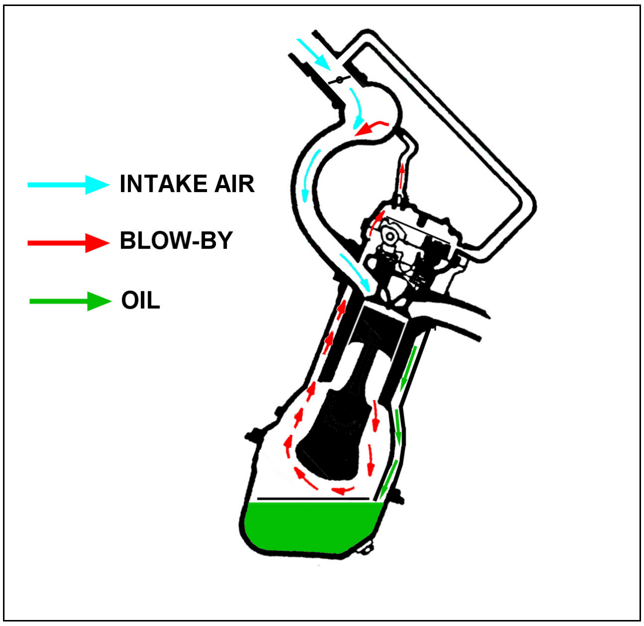

Figure 5: High blow-by / low load breather flow.

At high loads there will be little or no flow through the part-throttle breather but the WOT breather will now be drawing the blow-by gases out of the cam cover.

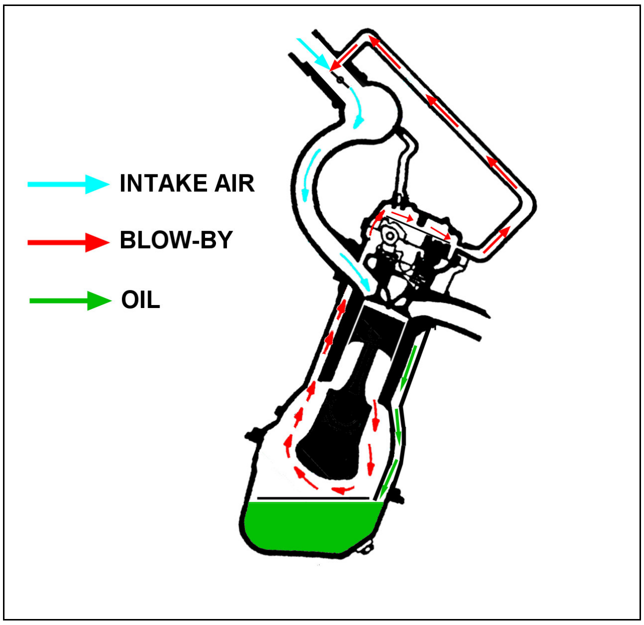

Figure 6: High blow-by / high load breather flow.

Therefore, as load and blow-by gas production increases, the flow through the part-throttle breather tends to stop, and the flow through the WOT breather changes from sucking air into the cam cover to venting blow-by gases out.

The part-throttle breather restrictor and PCV valves:

As mentioned earlier, a restriction is used in the part-throttle breather to limit the vacuum produced at low loads, but there is another reason for this restriction. Note that in the low load / low blow-by regime the WOT breather is sucking air into the cam cover to equalise the pressure. This air exits the cam cover again through the part-throttle breather and so enters the plenum, *bypassing the throttle*. If this flow of air is allowed to get too large, then amongst other things idle speed will be high. This means that there is an upper limit to the size of the part-throttle breather restrictor. Anything too large and it becomes difficult for the people calibrating the ECU to control the engine idle speed. Anything too small, and you risk not pulling enough vacuum in the low-load condition where blow-by production can be high due to poor piston ring control. You can also have too large a depression in the crankcase at part throttle, which can cause air to be sucked in through the crank and camshaft seals.

Usually, a fixed-orifice restriction can be tuned so as to give acceptable performance in all engine operating regimes, however, the quest for better control over crankcase depression lead to the development of the *Positive Crankcase Ventilation* – or PCV valve.

A PCV valve is a device that varies its flow according to the pressure difference across it. When placed in the part throttle breather line, low load the valve will be tuned so as to provide just enough negative pressure to evacuate the blow-by gases without drawing too high a vacuum in the crankcase. As the load increases and the available vacuum in the plenum decays, the valve will open more to allow a higher flow rate. Finally, at high load, the valve will close almost completely to allow proper functioning of the WOT breather circuit.

Additionally, the PCV valve allows proper functioning of the closed breather system on pressure charged engines. Where a turbo or supercharger is employed, on medium to high load the pressure in the plenum will go higher than atmospheric. In a normal fixed orifice part throttle breather, this would allow boost pressure to enter the crankcase, which would have to be vented out of the WOT breather together with the blow-by gases, effectively adding to the problem. However, a PCV valve can be rigged so as to close under positive pressure from the plenum side and allow the WOT breather to come into play.

Both PCV and fixed orifice system are still in use today. Some On-Board Diagnostic (OBD) systems are required to monitor the integrity of the closed breather system, as failure is an emissions related issue. This can be done by checking the pressures in the system against a map of known values to check for deviations that may be caused by leaking or blocked hoses. This is much easier to do with a fixed orifice system than for one using a PCV valve.

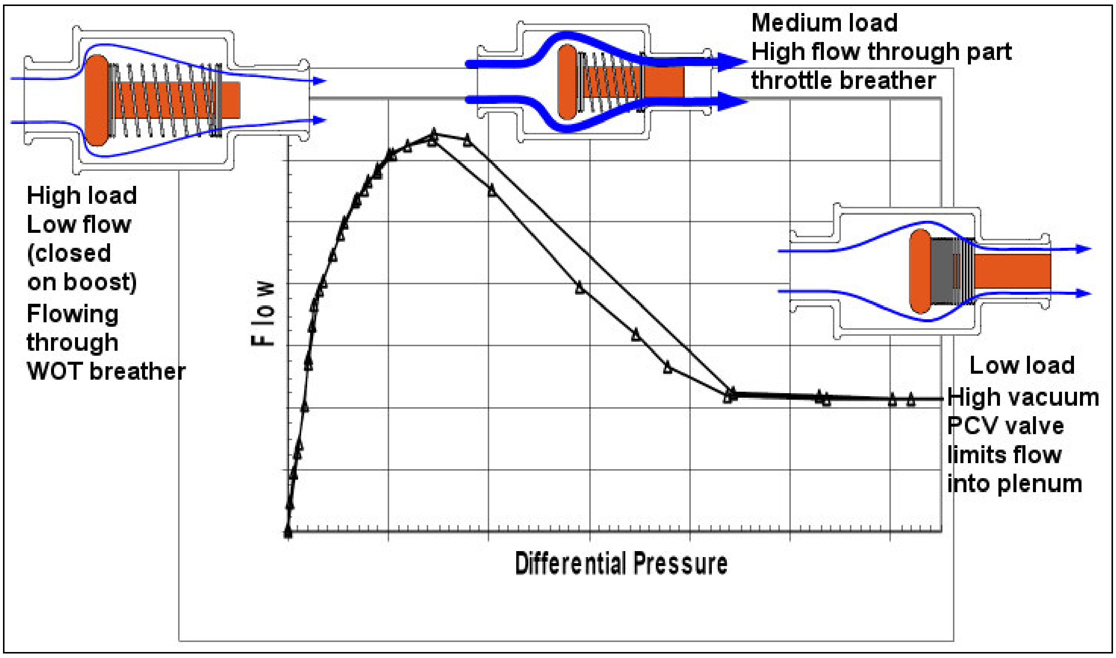

Figure 7: Typical PCV valve flow versus pressure [3].

<u>Oil carry-over:</u>
So far all we have talked about is the production of blow-by gases and their passage through the engine as the closed breather system works to maintain the crankcase pressure at just below atmospheric. However, even though the pressure in the crankcase may be under control, there may be side effect of the closed breather system that is just as undesirable.

The space inside the crankcase is not just full of air and gases. It is full of oil mist. The oil pump supplies oil under pressure to the crankshaft and connecting rod bearings, which falls out of the clearance gaps between the bearings and the crankshaft. There may be oil cooling jets aimed at the bottom of the pistons. Oil is also supplied to the cylinder head to lubricate the valvetrain. All of this oil is left to find its own way back into the oil pan under gravity. However, on its journey back the oil is very likely to encounter the rotating crankshaft, which will whip the oil into a fine mist. Inter-bay breathing (the motion of pressure pulses between the underside ascending and descending cylinders) will pull the oil back and forth. In short, the conditions inside the crankcase are not conducive to letting the oil return to the oil pan.

Engine designers do their best to make the oil return path as trouble-free as possible. The addition of oil drain galleries that run as far down the sides of the crankcase as possible keep the oil returning from the cylinder head well separated from the crankshaft. In the cross-section of the engine being used in the figures for this article, note that the clockwise rotation of the crankshaft naturally promotes blow-by gas flow up the breather chimney, while drawing oil down into the oil pan. The addition of an oil "baffle" in the oil pan tried to makes sure that once the oil is back in the pan, it *stays there*. A "bladed" crankshaft design with streamlined counterbalance webs will help minimise the turbulence created as it rotates. Inter-connecting passages and space around main bearing panels will give as much room as possible for inter-bay gas motion. Finally, the oil circuit will be designed so as to deliver as little oil around the engine as is necessary for the system to survive.

However, the crankcase is still full of airborne oil particles, and these will get swept along with the blow-by gases and carried up into the cam cover.

What happens in the cam cover is the first attempt at oil separation, which is a topic that will be covered in a lot more detail later. As with the oil pan, there is a baffle in the cam cover, which separates off the uppermost part of it into an empty chamber with the rotating valvetrain below. It is into this chamber that the blow-by gases enter.

What should happen in this chamber is that through one of the several possible methods of oil separation, the airborne oil will fall out of suspension and drop onto the baffle. There, carefully positioned drain holes will allow the oil to run back into the lower part of the head, avoiding the valvetrain, and from there it can enter the oil return circuit and make its way back towards the oil pan. The blow-by gases, now free of oil, exit the cam cover in the methods already discussed.

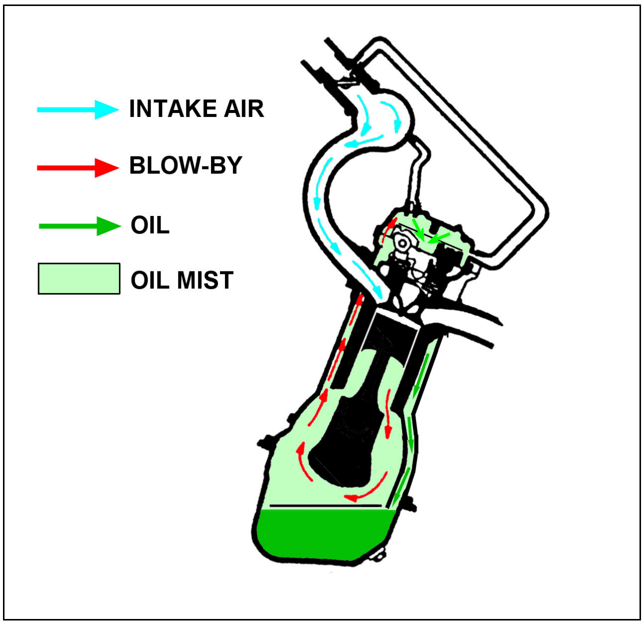

Figure 8: Oil mist and oil return circuit.

However, if there is a lot of blow-by, a lot of oil mist, or the oil separation methods employed in the cam cover are ineffective, oil can get carried through the part throttle or WOT breather system and back into the intake system. This is called *oil carry over*, and (in excess) is an undesirable side effect of the closed breather system.

<u>Oil separation:</u>

If the engine exhibits excessive blow-by or poor oil circuit design, oil separation is the last line of defence against oil carry-over. The goal is to remove the airborne oil from the blow-by flow before it enters either the part throttle or WOT breather pipes, and gets re-ingested into the air intake.

There are three main methods of oil separation:

Volumes and chambers:
This is the simplest, and if the engine designers have the luxury of space to create a proper system, usually the best kind of system for a road-going engine. The main characteristic of the blow-by flow that retains the oil within it is the speed at which it travels through the engine. The speed is proportional to the blow-by volume, and inversely proportional to the cross-sectional area of the channels that it flows through. Rule-of-thumb design says that if you can get this speed below 1m/s then gravity will take over and the oil will fall out.

Therefore, instead of narrow chimneys connecting the crankcase with the cylinder head, if there is space to design in a large, wide chamber, then the majority of the crankcase oil will never actually make it into the cam cover. If there is still oil in the space above the baffle in the cam cover, then making the cam cover as large as possible will help oil drop out here, too.

Unfortunately, the one thing that modern engine designs are always short of is space, and packaging large empty volumes just for oil separation is very difficult, but there are possibilities. On an engine with chain driven camshafts, the chain enclosure makes an excellent breather chamber because the chain enclosure has to be large, and it links the crankcase with the cam cover.

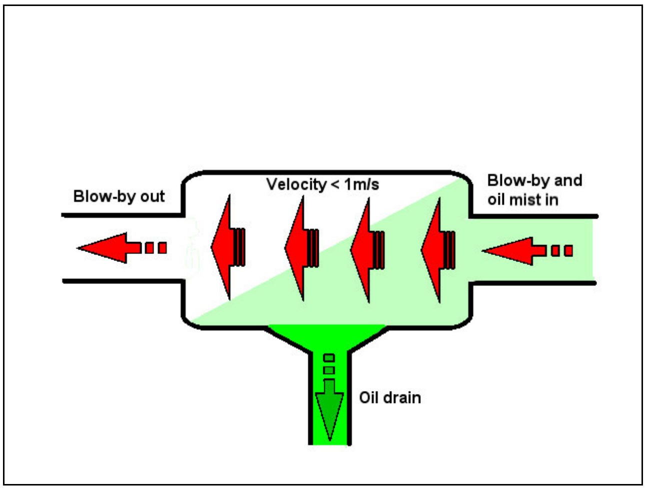

Figure 9: A simple oil separator volume.

Labyrinths:
Labyrinths work by forcing the blow-by gases to repeatedly change direction through a maze of narrow passages. The theory is that as the gas changes direction it also slows down. Also, the oil droplets will impact upon the walls of the passages during the turns and drop out. The labyrinths have oil drain holes in the bottom to allow the trapped oil to drain. In some systems fine gauze is used, although this can become loaded with oil, obstructing the breather system. However, if gauzes are used in the WOT breather, the flow reversal during part-throttle operation can effectively make the oil separator self-cleaning by purging the trapped oil back into the cam cover[2].

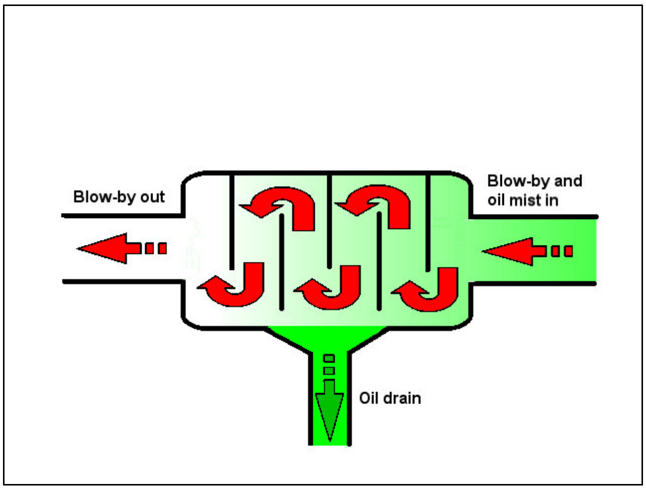

Figure 10: A simple labyrinth oil separator.

Centrifuges:
There are two types of centrifuge: Driven and non-driven. A driven centrifuge is a cylindrical, motorised chamber that spins as the blow-by gas passes through it. Oil droplets are separated out to the walls and run down to a drain at the bottom. This is an extremely effective method of oil separation, but almost totally impractical for a road car engine installation.

A non-driven centrifuge is again a cylindrical chamber where the blow-by gas enters at a tangent. The idea is that the circular flow of the gas around the chamber creates its own centrifugal force that throws the oil against the chamber walls in the same way the that the driven centrifuge does.

In practise, blow-by gas flows are seldom fast enough to create sufficient angular velocity to create an efficient centrifuge, but the tangential entry of blow-by gases into a volumetric separator remains good design practise.

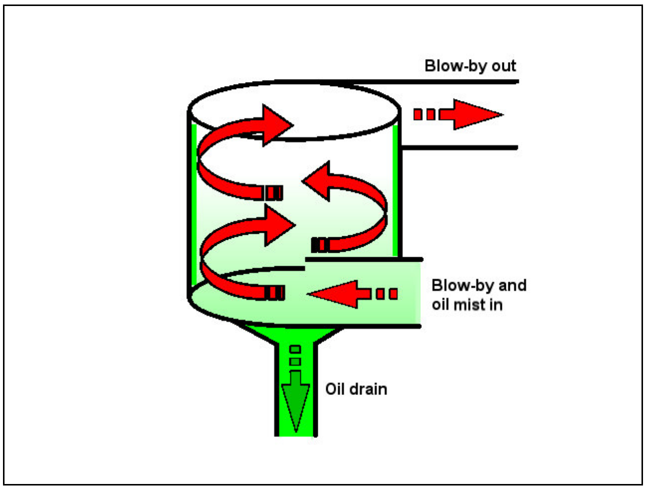

Figure 11: A simple non-driven centrifugal oil separator.

Note that an oil separator's job is to return the airborne oil back to the oil pan. This requires an oil drain, which is connected to the oil pan. Since the oil separator is also connected to the breather system it is possible that blow-by gases could be drawn up this drain and into the separator, thereby reducing its effectiveness. For this reason, gas velocity in the drain must be kept low by using a large diameter drain tube. If the oil separator is effective, any oil mist that enters via the drain should drop straight back out again before it gets to the breather connection.

Internal and external oil separators:
It should be the engine designer's goal to incorporate the oil separation mechanism into the engine components. As mentioned above, if the package space is generous enough, effective volumes can be included in the crankcase and cam covers. Labyrinth separators are sometimes used just before the breather connection in cam covers where space is tighter. However, if the engine design does not permit internal oil separation, and if the root causes of the excessive blow-by or airborne oil cannot be corrected, there is little alternative but to add a dedicated oil separator to the outside of the engine.

An external oil separator is generally a mixture of the non-driven centrifugal and volume designs, and they are plumbed into the breather system as shown in figure 12.

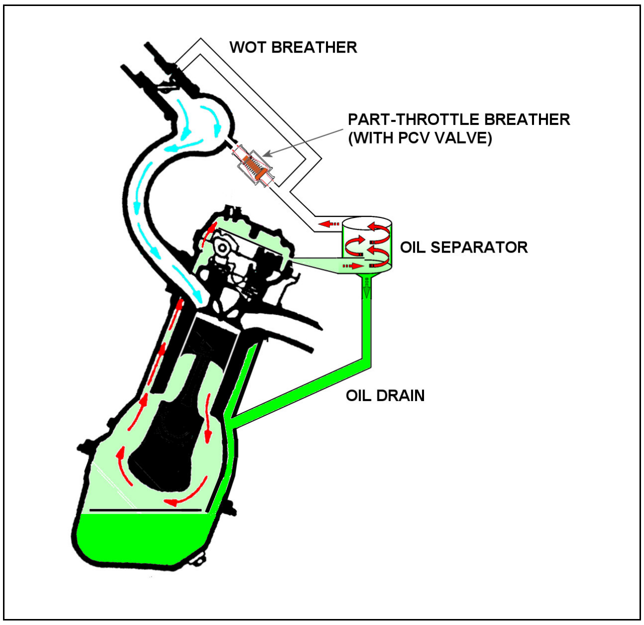

Figure 12: An external oil separator.

Catch cans:
There is another type of oil separator which has a similar purpose, but a different usage and necessarily different design features, and should not be confused with oil separators: *Oil catch cans*.

A catch can's job is to separate the oil from the blow-by gases, but instead of returning it to the oil pan, it retains it in a chamber which must be emptied periodically.

For obvious reasons, catch cans are not used in OEM applications, but due to them not requiring an oil drain back the crankcase (and therefore no mechanical changes alterations to it), they are popular as aftermarket self-fit items. They are also very useful in engine development because they offer a way of measuring exactly how much oil is being carried over into the breather system. Indeed, catch-can tests are a required part of new engine development and test programmes to demonstrate the effectiveness of the breather and oil separation systems.

In a test environment, oil catch cans are inserted into the WOT and part-throttle breather pipes, and the engine is run at specific speeds and loads for extended periods of time to determine an average rate of oil carry over (measured in grams per hour).

Despite some of the elaborate aftermarket offerings, it is possible to make a very effective catch can very simply.

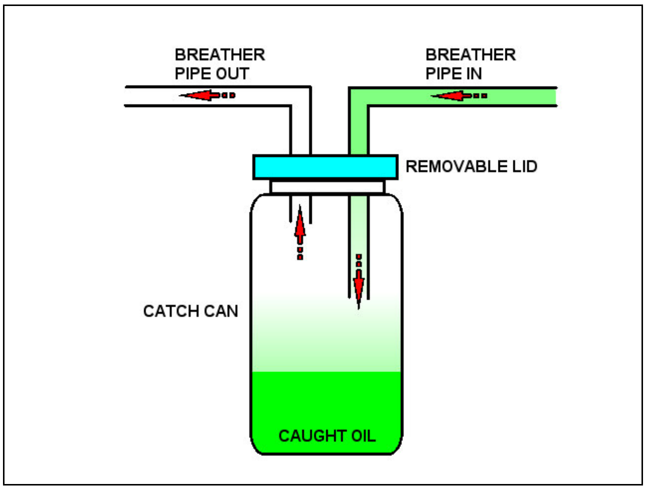

Figure 13: A simple oil catch can.

Design targets for carry-over oil:
A "world class" engine will carry over 1g or less of oil per hour of running when measured using a catch can type arrangement.

Design considerations for oil separators and catch cans:
The most important feature of a non-driven centrifugal or volume type oil separator must be its cross-sectional area. This should be sufficient to allow the speed of the blow-by gas to drop below 1m/s as it transits the separator volume. It is worth including at least a tangential entry pipe to promote some circular motion as an additional effect even though, as stated earlier, it is not very effective at oil separation unless blow-by volumes are very high. The same is true for a catch can, since it is a purely volumetric separator, lacking an oil drain. The proper cross section area can be calculated using the blow-by volume figures derived in the manner described at the beginning of this article, and equation 7:

Vb = blow-by volume (in litres per minute)
Vc = Critical speed for oil drop-out (in meters per second).
A = cross-sectional area or oil separator or catch can (in m^2)

$$A = \frac{Vb \times 0.0000167^*}{Vc}$$

*0.0000167 is a constant to allow the mixing of units of measure away from standard S.I. units.

Equation 7: Cross-sectional area for an oil separator or catch can.

For a simple circular separator, this area can be easily converted into a suitable diameter (equation 8).

A = cross-sectional area or oil separator or catch can (in m^2)
D = diameter of circular volume (in mm).

$$D = 1000 \times \sqrt{\ }(4 \times A) / \pi$$

Equation 8: Diameter for a circular oil-separator or catch-can.

The next most important feature is the positioning of the entry and exit pipes, and it is this detail that can get lost in the design of some aftermarket catch cans.

In an oil separator, the aim is for it to be difficult for the blow-by gases to simply pass straight through the chamber. For this reason, in vertically oriented oil separators the entry should always be at the bottom and the exit at the top. However, this is not the case for the catch can. Since the catch can retains a quantity of oil, it is not possible to put the entry right at the bottom, as it would be fouled. Catch cans have their entry and exit together at the top, but not facing each other. In this way, blow-by gases are forced to enter the can and slow down enough to drop their oil before reversing direction and exiting again. To prevent caught oil being sucked back out again, it is worth making the can long enough so that the surface of the caught oil level never gets close to the exit pipe. The exit pipe could also be made shorter than the entry pipe, but note that when used in the WOT breather pipe, the gas flow though the catch can could reverse direction during part-throttle operation.

In a horizontally oriented separator volume as shown in figure 9 (i.e. in a cam cover), the gas by default will pass straight through, so the critical cross section must be maintained for as long a distance as possible (or a greater than critical cross section for a shorter distance) so as to ensure that the gas has time to drop its oil on the way through.

Summary:

- Breather systems equalise the crank case pressure created by blow-by, and maintain the crankcase at slightly below atmospheric pressure to ensure that blow-by gases and oil cannot enter the atmosphere.
- Blow-by gases contain oil mist, which in excess, can get carried over into the intake system.
- Oil separation is required in the breather system to remove carry over oil and prevent it from re-entering the engine.
- There are three main types of oil separator: Volumes, labyrinths and centrifuges.
- Critical oil separator dimensions can be calculated if the blow-by volume is known.
- Separated oil can be either returned to the oil pan or held in a catch can.
- The designs of oil separators and oil catch cans are necessarily different, principally in the location of the entry and exit pipes.

Written by “Digsy” for Vortex-Power.co.uk and MKIVSupra.net
22nd August 2005

References:

1. SAE paper – The Importance of Blow-by Measurements, Measuring Equipment and Implementation. Heinz W. Ebner and Dr. Alfred O. Jaschek.
2. Personal reference material – source unknown (Ford / Ricardo?).
3. Development and Testing of Automotive Oil Separators in the PCV System – Brandish Technologies.