UNIT 2
THEORY OF LUBRICATION.

Engine friction: introduction, total engine friction, effect of engine variables on friction, hydrodynamic lubrication, elastic hydrodynamic lubrication, boundary lubrication, bearing lubrication, functions of the lubrication system, introduction to design of a lubricating system.

THEORY OF LUBRICATION

INTRODUCTION OF FRICTION

Friction generally refers to forces acting between surfaces in relative motion. In engines,frictional losses are mainly due to sliding as well as rotating parts. Normally, engine friction, in its broader sense, is taken as the difference between the indicated power (power at piston top as produced by the combustion gases) and the brake power (useful power). Usually engine friction is expressed in terms of frictional power f_p. Frictional loss is mainly attributed to the following mechanical losses.

Friction power = Indicated power – Brake power

TOTAL ENGINE FRICTION

Total engine friction, defined as the difference between indicated horse power and brake horse power, includes the power required to drive the compressor or a scavenging pump and the power required to drive engine auxiliaries such as oil pump, coolant pump and fan, etc.
Total engine friction can be divided into five main components. There are

1. Crankcase mechanical friction.
2. Blowby losses (compression-expansion pumping loss).
3. Exhaust and inlet system throttling losses.
4. Combustion chamber pumping loop losses.
5. Piston mechanical friction.

Crankcase Mechanical Friction

Crankcase mechanical friction can further be sub-divided into three types

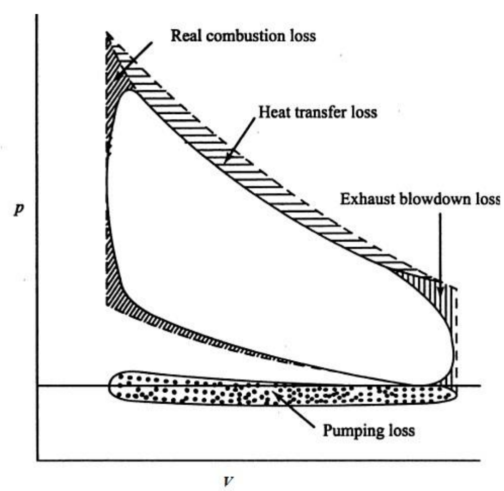
- ✓ Bearing friction

- ✓ Valve gear friction
- ✓ Pump and miscellaneous friction.

The bearing friction includes the friction due to main bearing, connecting rod bearing and otherbearings. Bearing friction is viscous in nature and depends upon the oil viscosity, the speed, sizeand geometry of the journal. All crankcase friction losses other than bearing and valve gearlosses vary roughly in proportion to engine displacement and speed. The bearing losses areaffected very little by the loading of the bearing but they rise rapidly with increase in speedbecause these losses are primarily the result of continuous shear of the oil film in the bearingclearance. Crankcase mechanical friction is about 15 to 20 percent of total engine friction. Since,there are a number of moving parts, the frictional losses are comparatively higher inreciprocating engines.

Blowby Losses.

Blowby is the phenomenon of leakage of combustion products past the piston and piston ringsfrom the cylinder to the crankcase.These losses depend upon the inlet pressure and compressionratio. These losses vary as the square root of inlet pressure, and increase as the compression ratiois increased. Blowby losses are reduced as the engine speed is increased.



Blowby losses

Exhaust and Inlet Throttling Loss.

The standard practice for sizing the exhaust valve is to make them a certain percentage smaller than inlet valves. This usually results in an insufficiently sized exhaust valve and hence, results in exhaust pumping loss.

Combustion Chamber Pumping Loop Losses.

In the case of pre-combustion chamber engines an additional loss occurs. This is the lossoccurring due to the pumping work required to pump gases into and out of the precombustion chamber. The exact value of this would depend upon the orifice size connecting the precombustion chamber and the main chamber, and the speed. Higher the speed greater is the loss and smaller the orifice size greater is the loss

Piston Mechanical Friction.

Piston Mechanical Friction sub-divided into two types.

1. Viscous friction

2. Non-viscous friction

Non-viscous friction further divided into

(a) Friction due to ring tension, (b) Friction due to gas pressure forces behind the ring.

The viscous friction depends upon the viscosity of the oil and the temperature of the variousparts of the piston. The degree to which the upper part of the piston can be lubricated also affects the viscous friction. The oil film thickness between piston and the cylinder is also affected by the piston side thrust and the resulting vibrations.

The cylinder gas pressure behind the top rings. Because of the ring tension the ring pressesagainst the cylinder wall and results in frictional losses. In addition to the ring tension, the gaspressure behind the ring also causes friction losses. The pressure behind the top piston ring is ashigh as the pressure of the combustion chamber. For other piston rings it is much lower.

EFFECT OF ENGINE VARIABLES ON ENGINE FRICTION

Effect of stroke to bore ratio

The effect of stroke to bore ratio on engine friction and economy is very small. High stroke to bore ratio engines have equally good friction mep values as that for low stroke to bore ratio engine. At high speeds the higher stroke to bore ratio engine may have some disadvantages.

Effect of cylinder size and number of cylinders

The friction and economy improves as a smaller number of larger cylinders are used. This is because the proportion between the working piston area and its friction producing area, i.e. circumference, is reduced. Thus,there seems to be some justification for the layman's notion that four and six-cylinder engines are more efficient than eight cylinders.

Effect of number of piston rings

The effect of number of piston ring is not very critical and this number is usually chosen on the basis of cost, size and other requirements rather than on the basis of their effect on friction.

Effect of compression ratio

Friction mean effective pressure increases as the compression ratio is increased. But the mechanical efficiency either remains constant or improves as the compression ratio is increased. If the displacement is varied to keep the maximum engine torque constant, this results in better part load friction characteristics.

Effect of engine speed

Engine friction increases rapidly as the speed increases. The best way to improve mechanical efficiency at high speed is to increase the number of cylinders.

Effect of oil viscosity

Higher the oil viscosity greater is the friction loss. The temperature of the oil in the crankcase significantly affects the friction losses, wear and service life of an engine. As the oil temperature increases, the viscosity decreases and friction losses are reduced during a certain temperature range. If the temperature goes higher than at a certain value the local oil film is destroyed resulting in metal to metal contact.

Effect of cooling water temperature

A rise in cooling water temperature reduces engine friction through its effect on oil viscosity. During starting operation the temperature of both the oil and the water is low.Hence, the viscosity is high. This results in high starting friction losses and rapid engine wear.

Effect of engine load

As the load increases the maximum pressure in the cylinder has a tendency to increase slightly.This results in slightly higher friction values. However, this increase in friction loss is more than compensated by the decrease in oil viscosity due to higher temperatures resulting from increasedload. Further in case of petrol engines the throttling losses reduce as the throttle is opened moreand more to supply more fuel for allowing an increase in engine load. Both these effects combineto reduce frictional losses of a petrol engine as engine load is increased.However, for diesel engines the frictional losses are more or less independent of engine load.

LUBRICATION

Lubrication is the admittance of oil between two surfaces having relative motion. The purpose oflubrication may be one or more of the following:

1. Reduce friction and wear between the parts having relative motion.

2. Cool the surfaces by carrying away heat generated due to friction.

3. Seal a space adjoining the surfaces such as piston rings and cylinder liner.

4. Clean the surface by carrying away the carbon and metal particles caused by wear.

5. Absorb shock between bearings and other parts and consequently reduce noise.

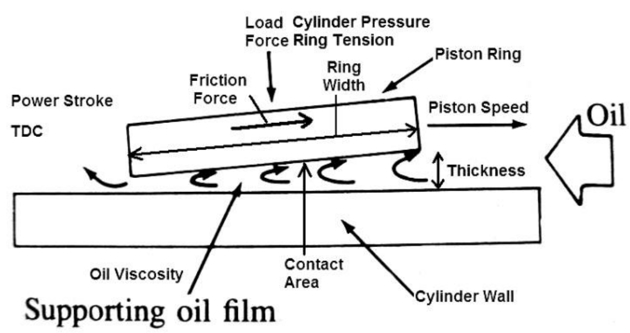
MECHANISM OF LUBRICATION

There are mainly three types of mechanism by which lubrication is done.

(a) Fluid-film or thick-film or hydrodynamic lubrication

In this, the moving or sliding Surfaces are separated from each other by a thick-film of fluid, so that direct surface-to surface contact and welding of junctions rarely occurs. The lubricant film covers or fills the irregularities of the sliding or moving surfaces and forms a thick layer in between them, so that there is no direct contact between the material surfaces. This consequently reduces wear. The resistance to movement of sliding or moving parts is only due to the internal resistance between the particles of the lubricant moving over each other. Therefore, the lubricant chosen should have the minimum viscosity.

For example consider a block resting on a flat surface covered with a layer of lubricating oil. If the weight of the block is very high or the oil is thin, the oil will squeeze out. In other words, thick oil can support a higher load than that supported by a thin oil. When this block is moved over the surface, a wedge shaped oil film is built up between the moving block and the surface. This wedge shaped film is thicker at the leading edge than at the rear.



Hydrodynamic lubrication

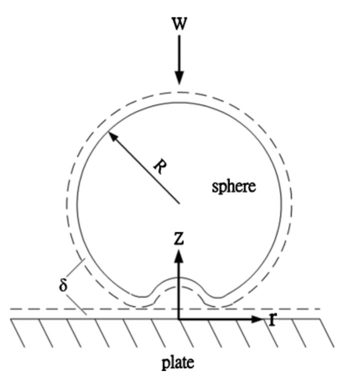
In other words the moving block acts as a pump to force oil into clearance that narrows down progressively as the block moves. This generates appreciable oil film pressure which carries the load. This type of lubrication where a wedge-shaped oil film is formed between two movingsurfaces is called hydrodynamic lubrication. The main advantage of this type of lubrication isthat the load carrying capacity of the bearing increases with increase in relative speed of themoving surfaces.

The force required to move the block over the surface depends upon the weight of the block, the speed of movement, and the thickness or viscosity of the oil. This force divided by the pressurecaused by the weight of the block is called the coefficient of friction. A higher coefficient offriction signifies a greater force to move the block.

The flat surface lubrication of the kind referred above exists at places such as thrust bearings,valve tips and cam lifters. Many other surfaces which use hydrodynamic lubrication are cylinderwall, valve guide, connecting rod bearings and camshaft bearings.

(b) Elastohydrodynamic lubrication

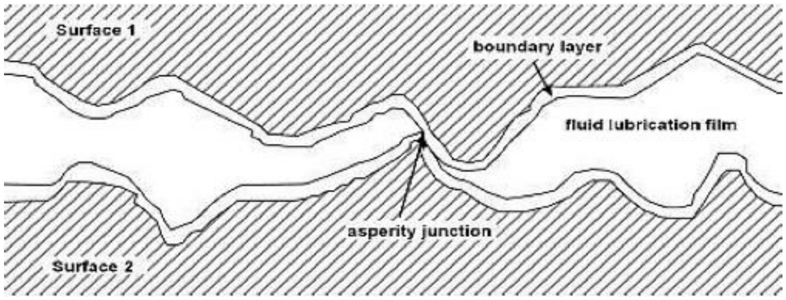
When the load acting on the bearings is very high, the material itself deforms elastically against the pressure built up of the oil film. This type of lubrication is called elastohydrodynatnic lubrication, occurs between cams and followers, gear teeth, and rolling bearings where the contact pressures are extremely high.



Elasto hydrodynamic lubrication

(c) Boundary lubrication

If the film thickness between the two surfaces in relative motion becomes so thin that formation of hydrodynamic oil film is not possible and the surface high spots or asperities penetrate this thin film to make metal tometal contact then such lubrication is called boundary lubrication. This happens when (i) A shaft starts moving from rest, or (ii) The speed is very low, or (iii) The load is very high, and (iv) Viscosity of the oil is too low.

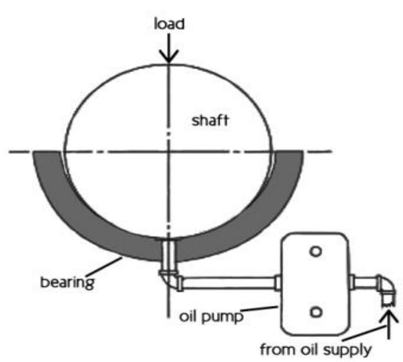


Boundary lubrication

A condition of boundary lubrication always exists when the engine is first started. The shaft is in contact with the bottom of the bearing with only a thin surface film of oil formed on them. The bearing surfaces are not perfectly smooth. They have uneven surfaces which tear this thin filmwhich is constantly formed. While the crankshaft is turning slowly. As the speed increases itswitches on to hydrodynamic lubrication. Boundary lubrication may also occur when the engine is under very high loads or when the oil supply to the bearing is insufficient.

(d) Hydrostatic lubrication

In hydrostatic lubrication a thin oil film resists its instantaneous squeezing out under reversal of loads with relatively slow motions. The oil film acts as a cushion. If oil supply is sufficient the oil film thickness is restored before next reversal of load.



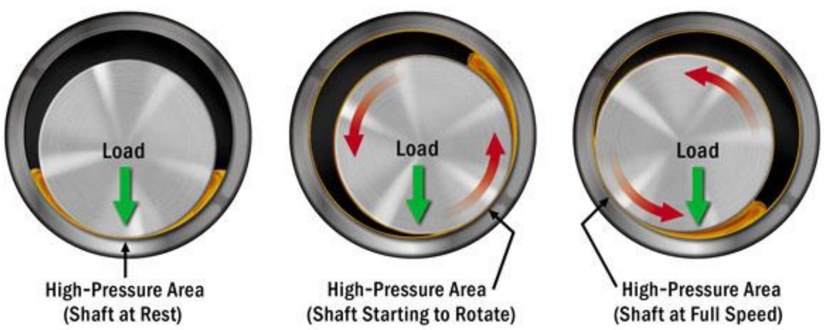
Hydrostatic lubrication

BEARING LUBRICATION

When the shaft is not rotating, there is metal-to-metal contact between the shaft and bearing due to squeezing out of oil from under the journal because of shaft weight. As the shaft starts to rotate, due to high starting friction, the journal momentarily rolls slightly up the side wall. If some surface oil remains on the bearing the shaft will slide back to the bearing bottom when it hits the oil.

This climbing and sliding back continuous till sufficient oil is supplied by the pump so that the climbing shaft grabs the oil instead of the bearing wall and a curved wedge shaped oil film is formed. This film now supports the shaft in the bearing. The only friction encountered is the small fluid friction caused by the rapid shear of the oil particles as they slip over one another.

The operation of bearing in this zone is unstable because under boundary lubrication the coefficient of friction is high which results in more heat generation. This further decreases the viscosity of the oil which, in turn, leads to higher value coefficient of friction. This ultimately leads to seizure of metallic surfaces. An increase in bearing temperature reduces the oil viscosity and hence, results in a lower friction coefficient which gives rise to lower bearing temperature due to reduced heat generation,thereby, stabilizing the bearing temperature.



Bearing lubrication

It should be noted that a continuous new oil supply is essential for maintaining the wedgeshaped oil film because of leakage of oil from the side of the bearing. This leakage removes wear particles as well as the heat generated in the bearings. The pressure generated due to the wedge type film may be over 65 bar compared to the relatively low pressure of 2 to 4 bar developed by the oil pump. It is the film pressure which carries the engine load, not the oil pump pressure. The pump pressure ensures a continuous oil supply.

LUBRICATION SYSTEM

The function of a lubrication system is to provide sufficient quantity to cool filtered oil to give positive and adequate lubrication to all the moving part of an engine. The various lubricationsystems used for internal combustion engines may be classified as

- mist lubrication system
- wet sump lubrication system
- dry sump lubrication system

Mist Lubrication System

This system is used where crankcase lubrication is not suitable. In two-stroke engine as thecharge is compressed in the crankcase, it is not possible to have the lubricating oil in the sump.Hence, mist lubrication is adopted in practice. In such engines, the lubricating oil is mixed with the fuel, the usual ratio being 3% to 6%. The oil and the fuel mixture are inducted through the carburettor. The fuel is vaporized and the oil in the form of mist goes via the crankcase into the cylinder. The oil which strikes the crankcase walls lubricates the main and connecting rod bearings, and the rest of the oil lubricates the piston, piston rings and the cylinder.

Advantages:

- Simplicity
- Low cost

Disadvantages:

- It causes heavy exhaust smoke due to burning of lubricating oil partially or fully and also forms deposits on piston crown and exhaust ports which affect engine efficiency.
- Since the oil comes in close contact with acidic vapours produced during the combustion process gets contaminated and may result in the corrosion of bearing surface.

- For thorough mixing this system requires either separate mixing prior to use or use of some additive to give the oil good mixing characteristics.
- During closed throttle operation as in the case of the vehicle moving down the hill, the engine will suffer from insufficient lubrication as the supply of fuel is less.

In some of the modern engines, the lubricating oil is directly injected into the carburettor and the quantity of oil is regulated. Thus the problem of oil deficiency is eliminated to a very great extent. In this system the main bearings also receive oil from a separate pump. For this purpose, they will be located outside the crankcase. With this system, formation of deposits and corrosion of bearings are also eliminated.

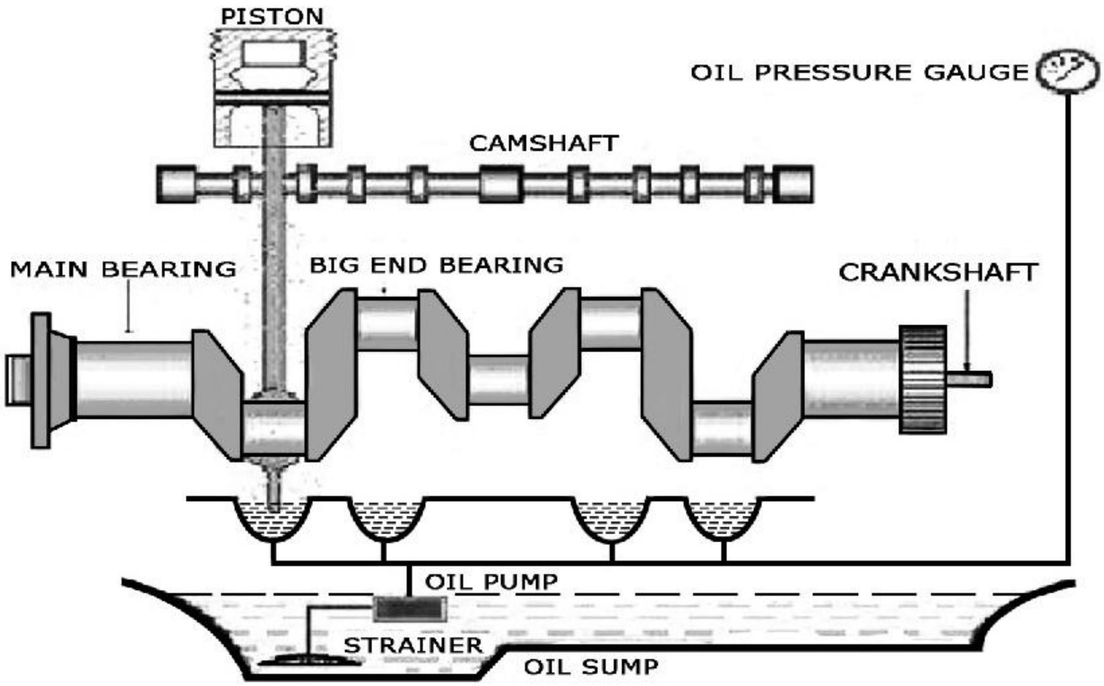
Wet Sump Lubrication System

In the wet sump system, the bottom of the crankcase contains an oil pan or sump from which the lubricating oil is pumped to various engine components by a pump. After lubricating these parts, the oil flows back to the sump by gravity. Again it is picked up by a pump and recirculates through the engine lubricating system. There are three varieties in the wet sump lubrication system. They are

(i) The splash system
(ii) The splash and pressure system
(iii) The pressure feed system

Splash system:

This type of lubrication system is used in light duty engines. The lubricating oil is charged into the bottom of the crankcase and maintained at a predetermine level. The oil is drawn by a pump and delivered through a distributing pipe extending the length of the crankcaseinto splashtroughs located under the big end of all the connecting rods. These troughs were provided withoverflows and the oil in the troughs is therefore kept at a constant level.



A splasher or dipper isprovided under each connecting rod cap which dips into the oil in the trough at every revolutionof the crankshaft and the oil is splashed all over the interior of the crankcase, into the pistons andonto the exposed portions of the cylinder walls. A hole is drilled through the connecting rod capthrough which oil will pass to the bearing surface.

Oil pockets are also provided to catch thesplashing oil over all the main bearings and also over the camshaft bearings. From the pocketsthe oil will reach the bearings surface through a drilled hole. The oil dripping from the cylinders is collected in the sump where it is cooled by the air flowing around. The cooled oil is then recirculated.

The Splash and Pressure Lubrication System:

In this system the lubricating oil is supplied under pressure to main and camshaft bearings. Oil is also supplied under pressure to pipes which direct a stream of oil against the dippers on the bigend of connecting rod bearing cup and thus the crankpin bearings are lubricated by the splash or spray of oil thrown up by the dipper.

Pressure Feed System:

In this system the oil is drawn in from the sump and forced to all the main bearings of thecrankshaft through distributing channels. A pressure relief valve will also, be fitted near thedelivery point of the pump which opens when the pressure in the system attains a predetermined value. An oil hole is drilled in the crankshaft from the centre of each crankpin to the centre of an adjacent main journal, through which oil can pass from the main bearings to the crankpinbearing. From the crankpin it reaches piston pin bearing through a hole drilled in the connecting rod. The cylinder walls, tappet rollers, piston and piston rings are lubricated by oil spray from around the piston pins and the main and connecting rod bearings. The basic components of the wet sump lubrication systems are (i) Pump (ii) Strainer (iii) Pressure regulator (iv) Filter (v) Breather.

Oil is drawn from the sump by a gear or rotor type of oil pump through an oil strainer. Thestrainer is a fine mesh screen which prevents foreign particles from entering the oil circulatingsystems. A pressure relief valve is provided which automatically keeps the delivery pressure constant and can be set to any value. When the oil pressure exceeds that for which the valve is set, the valve opens and allows some of the oil to return to the sump thereby relieving the oil pressure in the systems.

Most of the oil from the pump goes directly to the engine bearings and a portion of the oil passes through a cartridge filter which removes the solid particles from the oil. This reduces the amount of contamination from carbon dust and other impurities present in the oil. Since all the oil coming from the pump does not pass directly through the filter, this filtering system is called by pass filtering system. All the oil will pass through the filter over a period of operation.

FUNCTIONS OF THE LUBRICATING SYSTEM:

The following are the important functions of a lubricating system

1. Lubrication:

The main function of the lubricating System is to keep the moving parts sliding freely past each other and, thus, reduce the engine friction and wear.

2. Cooling:

To keep the surfaces cool by taking away a part of their heat through the oil passing over them. This cooling action usually takes place simultaneous to the lubricating function. However,under certain conditions lubrication system is used to keep certain engine parts cool which due to their typical location do not come in direct contact with the cooling water. One typical example is the oil cooling of pistons of high specific output engines.

3.Cleaning:

To keep the bearings and piston rings clean of the products of wear and the products ofcombustion especially the carbon, by washing them away and then, not allowing them to agglomerate to form sludge.

4.Sealing:

The lubricating oil must form a good seal between piston rings and cylinder walls. The oilshould be physically capable of filling the minute leakage paths and surface irregularities of the mechanical sealing elements, i.e., cylinders, pistons and piston rings. The oil as a sealant is subjected to high temperatures and hence must possess adequate viscosity stability.

5.Reduction of noise:

Lubrication reduces the noise of the engine.

DESIGN OF A LUBRICATING SYSTEM

The primary purpose of the lubrication system is to lubricate sliding surfaces and reduce friction losses in the engine. Basic lubrication systems use a positive displacement oil pump feeding all bearings with full flow oil filtration, whilst more complex systems can include pressure relief valves, by-pass filtration, piston cooling, hydraulic lash adjusters and hydraulically activated cam phasing mechanisms. The main factors to be considered in the lubrication system design process are flow balancing and pump sizing (volumetric flow rate of oil) required for satisfactory operation.

GENERAL CONSIDERATIONS FOR THE LUBRICATION CIRCUIT

Typically oil velocities in excess of 3m/s in the pick-up pipe can result in cavitation reducing engine and oil pump life. However, at low temperatures the pressure in the lubrication system is high due to high oil viscosity and a majority of the oil is then re-circulated or directed back to sump via the pressure relief valve.

Aeration is another of concern, which is caused by crankshaft churning (exacerbated by too high sump levels), oil break up (typically by a chain), high oil return velocities (from the cylinder head) and long suction lengths.

If the oil level is too low the pick-up pipe is not fully flooded under all conditions, again causing air bubbles to be mixed with the oil by the oil pump and circulated around the lubrication system. For drainage, if the oil velocity is in excess of 0.5m/s, air is mixed into the oil, which is the main reason for re-circulating oil from the pump relief valve rather than directing it straight back to sump at high speed.

Another important criterion to consider is the engine running temperature (or the average oil temperature in the sump). Which ranges from 120°(-150°(for light duty automotive applications. If localized temperatures are too high, i.e. above 220°(for mineral hydrocarbon oils and above 300°(for synthetic oils, the oil is likely to carbonize into solid matter, which can accumulate in critical areas of the engine.