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Estimation of Blow-by in Diesel Engine: Case Study of a Heavy Duty Diesel Engine

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Abstract: *In modern day vehicles, according to European Union's guidelines designers are not allowed to directly vent out the blow-by gases to atmosphere as it contains uncombusted hydro-carbons which reacts with oxygen and produces gases like carbon mono-oxide, carbon dioxide causing air pollution. Also these gases carry fuel vapors with it which have not been burned in combustion chamber resulting in decrease in volume of burnt mixture. This ultimately hampers the power produced and efficiency of engine. The leaking fumes of fuel not only hampers power produced and efficiency of engine but also gets mixed with the oil stored in oil sunk in lower part of crankcase. Due to the mixture with fuel fumes oil loses its important properties such as density, viscosity. There is no such equation available to estimate the amount of Blow-by. Therefore in this paper we have tried to formulate an equation to calculate amount of Blow-by generated in heavy duty diesel engine.*

Keywords: *Blow-by, Crankcase ventilation system, Engine Emissions, Empirical formula for Blow-by.*

Symbol	Nomenclature
Q	Amount of Blow-by
bmep	Break mean effective pressure
T	Torque
t	Temperature
n	Rotational speed of engine crankshaft
S	Stroke length of piston
D	Bore diameter of piston

Table No	Description
1	Ranges of parameters selected for engine 1
2	Ranges of parameters selected for engine 2
3	Ranges of parameters selected for engine 3

1. Introduction

Diesel engines are internal combustion engines with very high compression ratio hence they generate large amount of power with higher thermal efficiency than spark ignition (S.I.) engines. Due to this these engines are preferred for off road duties. These are also called as "Heavy duty diesel engine". Heavy duty diesel engines are used particularly where large power output is necessary. For eg. Earthmovers, Diesel locomotives, Trucks.

The unit which consist piston cylinder assembly with piston rings mounted on the piston is the sliding closure of the engine workspace. Despite accurate construction there is always some amount of leakage to the crankcase. The mathematical description of the blow-by phenomenon to a crankcase is hardly available, since every engine has different blow-by intensity. [1]

When combustion occurs in the combustion chamber some fuel vapors gets leaked past the sealing rings, no matter how much sealing rings we use, there is always a small amount of clearance left between the piston, rings and wall. The fuel vapors consists unburned hydrocarbons and other harmful gases like Sulphur dioxide, Carbon mono-oxide. Also Swhen leaked gases enter the crankcase they get mixed with oil. Due to the high temperature of escaping gases on mixing with these gases oil loses its vital properties. Oil viscosity gets reduced due to the increased temp of oil. Due to this oil can't perform its expected functions with reduced viscosity lubrication gets affected which leads to more friction and frictional wear of engine components. [2] Due to new emission control regulations as per BS IV, these gases cannot be directly vented out to atmosphere, instead they should be re-circulated for further use through a positive crankcase ventilation system.

Positive crankcase ventilation (P.C.V) involves recycling of the blow-by (Mixture of Gasoline + Air, which slips back through the piston rings to the crankcase) gases through a valve called, the PCV valve to the intake manifold, where they are pumped back into the cylinders for another shot at combustion [3,4]. As the engine speeds up, the air pressure in the intake manifold increases and the suction slows down, reducing the amount of blow-by gas recycled to the cylinders. With ventilation system mounted on engine internal pressure in crankcase never gets built up and is maintained to level slightly less than atmospheric pressure. This helps to increase life of all piston sealing rings, cylinder liners and oil seals which ultimately helps to decrease the amount of blow-by generated.

2. PARAMETERS AFFECTING BLOW-BY

Amount of Blow-by gases generated in an engine is dependent upon following different parameters. Engine load, engine speed, break mean effective pressure are the parameters which are measurable and have major effect on the amount of Blow-by. But there are few more small parameters which are important and affect amount of Blow-by gasses leaking through the piston sealing rings yet they are difficult to measure. For example wear of components is extremely difficult to measure as we have to take reading for no. of days or no of hours like 1000 hrs, 2000 hrs of engine running condition to have rough idea about wear happening in different components. Amount of Blow-by directly depends on the wear of parameters i.e. as wear of piston or piston sealing rings increases the volume flue gases leaking through which ultimately increases the Blow-by occurring in engine.

Distributions of re-circulated gases between cylinders are slightly influenced by the injection Velocity and its Orientation. Injection location also affects re-circulating gases in intake manifold.

Injection velocity of re-circulated gases determines the back pressure created at the non return valve used as positive crankcase ventilation valve. [5]

$$Q = f(n,\epsilon,pi,T,t,D,dz,z,i,l_i,s,k,\rho,\tau,bmep) \qquad (1)$$

Where

n -rotational speed of engine crankshaft

ϵ - the compression ratio

pi -the mean indicated pressure

T – Torque

t – Temperature inside cylinder

D - Cylinder diameter

z - Wear within the PRC group

i- Quantity of cylinder

dz - shape and clearance of piston ring joint

l_i - Quantity of piston sealing rings

s - Stroke

k - Type and shape of piston ring sealing's

ρ – Viscosity of lubricating oil

τ - Type of cycle (two stroke/ four stroke)

bmep – break mean effective pressure [6]

Analysis and evaluation of all the above mentioned parameters is not possible due to the complexity of problem. Hence to simplify the problem statement we decided to consider parameters majorly affecting the amount of blow-by. Therefore we have decided to consider following important parameters in our equation. And other small parameters are considered as some percent of power losses occurring due to blow-by gases.

1. Engine Torque:

The amount of Blow-by varies with torque. Blow-by increasers directly with increase in torque.

2. Speed:

With increase in speed there is decrease in amount of blow-by.

3. Break mean effective pressure(bmep):

With increase in bmep blow-by increases. Although at some instant of time due to variation in wear factor and other such small parameters the amount of blow-by decreases even with increase in bmep.

Table 1. *Engine 1 Parameters*

No.	Parameter	Range
1	Engine Torque(Nm)	1.2 – 290.6
2	Speed (rpm)	1000 - 2200
3	BMEP (bar)	0.0 – 10.5

Table 2. *Engine 2 Parameters*

No.	Parameter	Range
1	Engine Torque(Nm)	1.6 – 241.4
2	Speed (rpm)	1000 - 2200
3	BMEP (bar)	0.1 – 13.6

Table 3. *Engine 3 Parameters*

No.	Parameter	Range
1	Engine Torque(Nm)	0.9 - 198.7
2	Speed (rpm)	1000 - 2200
3	BMEP (bar)	0.1 – 13.3

3. GOVERNING EQUATION

All the parameters mentioned in above section affects the amount of Blow-by occurring in an engine. To get perfect idea we need to consider all the above parameters in our mathematical equation representing total volume of Blow-by gases leaked through piston cylinder assembly.

In this study we have considered following variables which directly or indirectly affects amount of Blow-by occurring in an engine.

Monte Carlo (Simulation) technique could have been used to derive the equation of Blow-by. As there are several random variables which are related through non linear equation. Using appropriate set of random numbers (which can be possibly obtained by taking practical readings) we could have drafted a mathematical relation to express the amount of Blow-by.

But to assign a proper and valid random number to parameters like wear of different engine components, shape factor of piston, cylinder and liners is extremely difficult to express in mathematical terms. Hence we are adopting following method to calculate amount of Blow-by occurring in the heavy duty diesel engine.

To formulate the equation of amount of Blow-by we are distributing the above mentioned factors in three different categories for the simplicity of calculations. The group 1 consists of geometrical parameters like stroke, cylinder diameter. The second group consists of parameters like shape and clearance of piston rings joints, shape of piston sealing ring edge, piston accuracy and manufacturing defects (if any) present piston and cylinder. And the third group considers all the wear occurring in components of an engine. Like wear of piston, cylinder, piston sealing rings and cylinder liners [6]. Also we have to consider the wear of components occurring in engine due to excessive load, over usage. As the engine gets older wear of components increases accordingly so we have to consider some power lost out of total power generated by the combustion to get more accurate estimate of value of Blow-by taking place in engine.

Following equation gives us the value of Blow-by happening in a heavy duty cylinder engine.

In the equation **α** and **γ** represent the constant in equation considered for the various losses caused due to the wear and shape factors of engine components.

$$Q = \alpha * n + \beta + \gamma\,(bmep)^2 \qquad (2)$$

Where,

α - the factor that takes into consideration the pressure of wear and the engine crankshaft rotational speed

β- the factor that takes into consideration the geometrical and shape parameters

n - Engine crankshaft per min rotational speed

γ - BMEP dependent factor

BMEP - break mean effective pressure

Where the **β** factor is calculated by the following formula:

$$\beta = \frac{(s \times \ln(i + \sqrt{(i+1)}) \times \sqrt{D^3})}{30 \times \sqrt[3]{l_i}} \quad \ldots\ldots\ldots. \qquad (3)$$

Where,

S - Piston stroke,

i - Number of cylinders

D - Cylinder diameter

l_i - Number of piston sealing rings

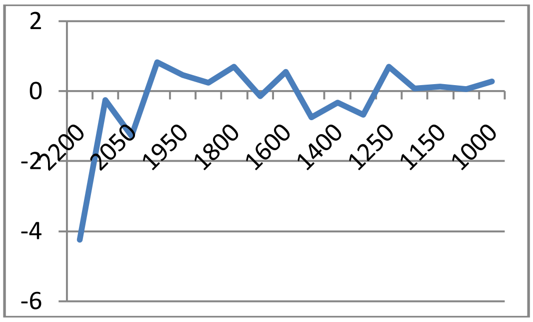

Fig. 1. *Validation of Model for Engine 1*

Fig 1. Shows the difference between experimental and calculated values of Blow-by for engine 1 at various engine speeds

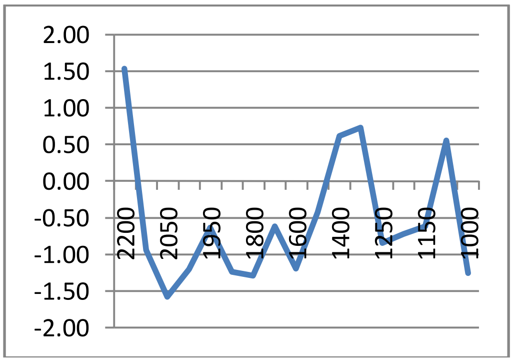

Fig. 2. *Validation of Model for Engine 2*

Fig 2: shows the difference between experimental and calculated values of Blow-by for engine 2 at various engine speeds

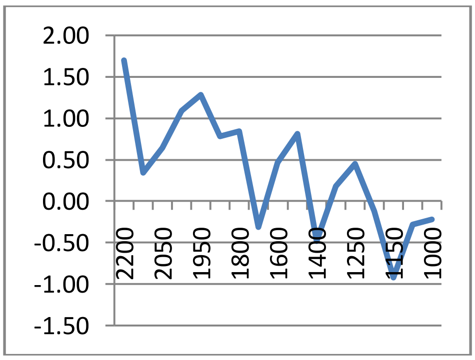

Fig. 3. *Validation of Model for Engine 3*

Fig 3: shows the difference between experimental and calculated values of Blow-by for engine 3 at various engine speeds

All the graphs show us the difference between experimental values of Blow-by and values calculated by using our equation. On Y axis difference in values of Blow-by and on X axis various speeds are plotted.

4. Conclusion

Considering the complexity of different parameters affecting the amount of Blow-by they were distributed in following three different groups i.e. geometrical parameters, Shape and Clearances of engine components and Wear considerations of engine components and considering them as a factors or percentage of power required in equation. This method was found much easier than other conventional mathematical methods or simulation techniques. Equation 2 is used to calculate the amount of Blow-by gases leaking passed the piston sealing rings. With practical test performed on 3 different heavy duty diesel engines we can state that the experimental amount of Blow-by and calculated values of amount of Blow-by using above equation matches with high accuracy.

Graphs of difference between experimental and calculated values of Blow-by support above statement showing the accuracy between experimental and calculated values of amount of blow-by.

5. Future Scope

In this project work we have considered only few of the many parameters which actually affect the amount of Blow-by gases generated in an engine. Due to the complexity of the subject and time constraint we had to neglect some parameters. These parameters have minor but very important effect on Blow-by gases.

For example we conducted the test on an engine which got air at constant pressure 1 bar but in daily world engine gets air which may have different and varying pressure. A vehicle running on roads of city like Mumbai, Chennai or any other located at sea level will get high pressure air as inlet air than vehicle running on the roads of city located at high altitude. Atmospheric condition of air may increase or decrease pressure difference in crankcase and combustion chamber causing changes in amount of Blow-by gases generated.

For this project work we have chosen only green engines i.e. new engines. Due to time constraint we were unable to perform test on engine which have been used for some time. Test performed after 1000 hrs, 2000 hrs of running amount of Blow-by will increase due to the wear of engine components. To get more accurate estimation of Blow-by one may consider wear of engine components.

Recirculation of Blow-by gases and back pressure generated at crankcase ventilation valve also affect the amount of Blow-by gases a separate study can be done to evaluate effect of this parameters.

Considering all the above factors which we had to neglect or compensate in our model will result in more accurate estimation of Blow-by gases generated in an engine.

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