A Simple and Accurate Experimental Method for Measurement of Engine Oil Consumption

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Abstract— **Oil consumption in today's internal combustion engines has become a major concern. There are various methods available today in industry to measure engine oil consumption. However, the slow process of oil consumption during engine operation presents a big challenge in a quick and accurate measurement. This acts as a big hindrance for oil consumption studies. Existing measurement methods are very expensive, require huge resources for setup, time consuming, not portable and involve various sources of errors. In this paper, first a review of the various techniques available for petrol and diesel engines along with their advantages and disadvantages are presented. Then a simple and a reliable method which bridges the gap between cost, time and accuracy between existing measurement techniques is proposed. Results obtained from the present method are compared with existing method and the error is quantified. It was found the drain and measure method consistently over predicts the oil consumption by about 20%.**

Keywords—**Engine, Oil consumption, Experimental method, Drain and weigh, Pressure**

I. Introduction

The effect of emissions of the engines due to the combustion of oil is a major factor to be concerned about, in the scenario of rapidly changing strict emission norms. As the oil prices are skyrocketing and the availability of this natural resource is getting scarce, there is a definite need for controlling the amount of oil consumed in engines. Better performance of the lubricant in the engine results in less frictional losses and improved engine performance. So there is an explicit need to study the process of oil consumption and its dependence on the various parameters of the engine. However, the oil consumption measurement itself is a big hindrance as it requires sophisticated measuring instruments and the accuracy of the measurement is always doubtful. The problem of oil consumption is a complex phenomenon to study [1, 2]. Oil is consumed though various sources and each of these sources depend on many other factors such as geometry of the piston assembly and engine operating conditions.

Various sources of consumption are [3]:

- Throw off from top land due to inertia forces
- Oil entrainment in blow-by gases, and consumption through positive crankcase ventilation
- Oil transport to the combustion chamber due to entrainment in reverse blow-by
- Evaporation from the cylinder liner
- Oil transport from the cylinder head through the valve guide into the intake port

TABLE I. COMPARISON OF VARIOUS OIL CONSUMPTION MEASUREMENT TECHNIQUES

Method	Advantages	Disadvantages
Drain & measure	- Simple and economical - No complicated equipment required - No skilled labor required	- Error in measurement - Approx 25 hrs to run - Impossible to drain all oil practically - Increase in viscosity due to degradation increases time of drain
Tracer Radioactive Sulfur [5,6,7,8]	- Measurement time – order of minutes - Transient effects can be measured	- Very costly equipment and special handling procedures for radioactive material - Secondary measurements and calibration of air and fuel flow - Oil deposited on piston, valves, and exhaust after treatment devices not accounted for in final measurement
Smart Oil Consumption Meter [11]	- Level sensor to gauge level of oil in crankcase - Measurement time of the order of hours	- Accuracy of level sensor is of concern - Requires addition of new oil - Suitable for diesel engines - Transient effects cannot be measured
New Method	- Cheap to build and use - Portable - Run time of the order of hours - Pump flow characteristics can be studied - Addition of new oil not required	- Accuracy of the scale - Vibrations need to be handled better - Leakages have to be monitored

Due to complexity in the process of oil transport and consumption, modeling and simulation is difficult [4]. Measurement of oil consumption is a crucial part of testing and development of engines. In the next section a brief review of the

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existing methods is provided and discussed their advantages and disadvantages. In section III a new method of oil consumption measurement is discussed. In section IV the results and analysis of the new method is provided along with the recommendations for the future followed by conclusion in section V. A short review of the existing methods is presented in Table 1. These methods are discussed briefly in the following sections.

II. LITERATURE REVIEW & RELATED WORK

A. Drain & Measure

One of the simplest methods employed is the "Drain & Measure" method. As the name suggests a known amount of oil is filled up in the engine. The engine is run for a known period of time. After the engine is stopped the remaining oil is drained and the volume/weight is measured. The difference in volume/weight divided by the total time gives the amount of oil consumed in ml/h or g/h. The only advantage in favor of this method is that it can be implemented cheaply without the requirement of any skilled labor. Even though the approach is quite simple, it leads to erroneous results as it involves the subtraction of two very similar large values [9]. In order to overcome this flaw in the method, the engine has to be run for quite a long period of time, i.e. of the order of 20-30 hours. A measurable amount of oil is consumed in this time. It is also practically impossible to drain all the oil present in the crankcase. Using any sort of device such as a pump in order to accelerate the draining process would invoke more errors due to the oil getting entrained in the pump itself. Furthermore, when oil becomes more degraded with time, it takes even more time to drain due to increase in viscosity [17]. Due to the large time required for the engine to consume a measurable volume of oil, this approach eliminates any opportunity to investigate the impact of transient effects on instantaneous rates of oil consumption. Presently however, new and advanced methods exist for the monitoring of oil consumption. This competes against the older method of weighing the amount of oil present before and after running, requiring hours of operation to obtain a measurable quantity.

b. Tracer Technique

Real time oil consumption measuring methods involve using a tracer or mass spectrometry to analyze the exhaust gases during operation. Two tracer systems are currently employed: radioactive and sulfur [2, 9]. The basic concept of this method is to add a tracer in the lubricating oil and analyze the exhaust for the tracer. The amount of tracer in the exhaust can be directly correlated to the amount of oil consumed.

1) *Radioactive Tracer*: The radioactive tracer systems measures oil consumption by adding radioactive tracers (especially tritium) into the oil and measuring the concentration of the tracer in the exhaust gases.

Tritiation is the process of replacing some of the hydrogen atoms in the oil with radioactive tritium (^{3}H) atoms through catalytic exchange [5, 6]. This is done in a sample of base stock, which is then mixed with the fully formulated oil prior to testing. If all hydrocarbons in the consumed lube oil are burned to completion, all hydrogen, including the tritium will be converted to water. Consequently, activity of the water collected in the exhaust sample will be directly proportional to the mass of oil consumed in the engine during the sampling period. During testing, a continuous exhaust sample is taken at each engine operating condition. The sample is processed to obtain the total amount of water available. The radioactivity of this water is directly related to the mass of lubricant consumed during the sampling period. This amount is calculated mathematically from the data. The measurement time of this method is of the order of several minutes. But this method requires special equipment and safety procedures for handling the radioactive material, which also tend to be very costly [9].

2) *Sulfur Tracer:* The older tracer technique is sulfur trace method, where sulfur acts as the tracer rather than the radioactive material [9]. Use of high sulfur oil and low sulfur fuel in this type of tests facilitates measurement of concentration of sulfur in the exhaust gases, which will be the contribution from the oil being consumed. Since oil transport into the combustion chamber is in both liquid and vapor form, a consistent sulfur concentration in the oil is required in order to assume that consumed oil in the exhaust has the same concentration of sulfur as in the original oil [7, 8]. To properly measure the amount of oil consumed, the other sources of sulfur should be minimized or better still eliminated. There are two other sources that can alter the amount of sulfur present in the exhaust gases: air and fuel. Air contributes very little sulfur to the combustion products. However the common gasoline that is purchased at the pump has a relatively higher amount of sulfur. So for this method low sulfur research gasoline has to be used which has a sulfur percentage of less than 2 ppm. The oil consumption rate is calculated from mass flow rate of fuel and air, and total sulfur concentration in oil, fuel, air and exhaust gas [11]. In general, the oil consumption is calculated as shown in the equation.

$$M_{oil} = \frac{M_{fuel}\,(S_{exh} - S_{fuel}) + M_{air}\,(S_{exh} - S_{air})}{S_{oil} - S_{exh}} \quad (1)$$

M_{oil} = Mass flow rate of oil (rate of oil consumption)
M_{fuel} = Mass flow rate of fuel
M_{air} = Mass flow rate of fuel
S_{oil} = Sulfur mass concentration in oil (%)
S_{fuel} = Sulfur mass concentration in fuel (%)
S_{air} = Sulfur concentration in intake air (%)
S_{exh} = Sulfur mass concentration in exhaust (%)

This method eliminates the special handling equipment, which was required in the radioactive method. But this method requires equipment for analyzing the concentration of sulfur in the exhaust gases. The use of high sulfur oil and low sulfur fuel in this method is of concern, as this limits the variation in oil and fuel properties that can be used in the engine. Measurement of near instantaneous oil consumption rates requires a sophisticated experimental arrangement, careful calibration and a series of secondary measurements like air and fuel flow rates on the engine [9]. In cases where radioactive tracer materials are employed, special precautions

for handling and disposing of radioactive materials are also needed. The basic principle on which these methods work is on the assumption that the total oil consumed is reflected in the exhaust emissions. Some of the oil that enters the combustion chamber is combusted along with the fuel, and the oil is oxidized. The products of this oxidation reaction sometimes get deposited on the piston and valves. Furthermore some of the oil additives poisons the exhaust gas after-treatment devices and does not show up in the final exhaust gases [17]. All this oil is not accounted for when the exhaust gas is finally sampled out of the engine in the tracer techniques.

C. Smart Oil Consumption Meter

Cummins had developed a new method called as "Smart Oil Consumption Measurement System". This method uses a PID controller, which maintains the same level of oil in the crankcase by adding oil from an external reservoir. The level of oil in the crankcase is monitored with the help of an extremely sensitive level sensor. The amount of oil consumed is measured by monitoring the weight of the external reservoir [12]. The drawback in this method is the addition of oil from the external reservoir. Oil, which is returned to the sump from the ring pack, is degraded. The oil is oxidized and it transports back undesirable materials like abrasive particles, corrosive combustion products and small amounts of fuel. All these results in the change in properties of the oil present in the crankcase. Oxidation results in change in properties of the lubricant, resulting in the formation of a thick fluid. This results in change in density. So for fixed mass of oil to be added, the volumes will be different (due to difference in densities) for both oils. These different volumes result in different change in levels of the oil. In this situation addition of newer, lighter oil to older, degraded and heavier oil will result in inaccurate measurements of the oil consumption. To get correct readings, oil with similar characteristics as the oil present in the sump should be added, which is practically not possible. The accuracy of the level sensors used in this method is also of concern. Petrol engines vibrate more compared to diesel engines. This is due to the fact that petrol engines are typically lighter and run at a higher rpm. As a result the operation of the high precision level sensor becomes difficult. Diesel engines provide a more stable environment for the reliable operation of the level sensors, making this method not applicable for petrol engines.

D. AVL Oil Consumption Meter

This system uses an external pump to completely drain the oil and measure the weight or volume. It is an automated "Drain & Measure" method. A measurement cycle consists of the following steps: pumping (out), weighing and pumping (back). The difference between two subsequent measurement cycles indicates the oil consumption [14]. As discussed in the "Drain & Measure" method the oil that is entrained in the pump while pumping in and out is a source of error.

E. Techniques for Diesel Engines

There are techniques, which can be used for diesel engines but not for petrol engines. Particulate matter is one of the major contributors of diesel emissions [19]. The total engine-out particulate emission is the sum of fuel-contribution and oil-contribution to particulate. So by understanding the impact of lubricant contribution on particulate matter, oil consumption can be measured from exhaust analysis of particulate matter [15]. In modern diesel engines along with organic soot particles, NO_x and HC, incombustible metallic compounds and sulfur-derived compounds are found. This component of emissions is called "Ash". It is a product of combustion of fuel and oil. Lubricant oil measurement can also be done through trace-metals balance, that is a mass balance between the trace metals (Ca, Zn, Mg) in the lubricating oil and particulate mass, but these methods are not yet completely verified [18]. All these techniques face the same problem as that discussed above in the tracer techniques, where the oil that is deposited on the piston and valves is not accounted as oil consumption.

III. PROBLEM STATEMENT

The present experimental techniques used for measuring oil consumption are either very costly or time consuming. Also the various sources of error present in each method are of concern. So there is a need for a cheap but a reasonably accurate measurement method of oil consumption. In this paper, a simple and reliable method of measuring oil consumption has been presented which works on simple scientific principles. The components used in this setup are completely off the shelf and it tries to bridge the various gaps present in the existing techniques.

IV. PROPOSED EXPERIMENTAL SETUP

A. Working Principle

The arrangement of the setup is shown in Fig. 1. As oil is added into the crankcase, through the dipstick it is distributed evenly in both the glass tube (i.e. pipette) and the crankcase. At any point of time, the level in pipette indicates level of oil in the crankcase.
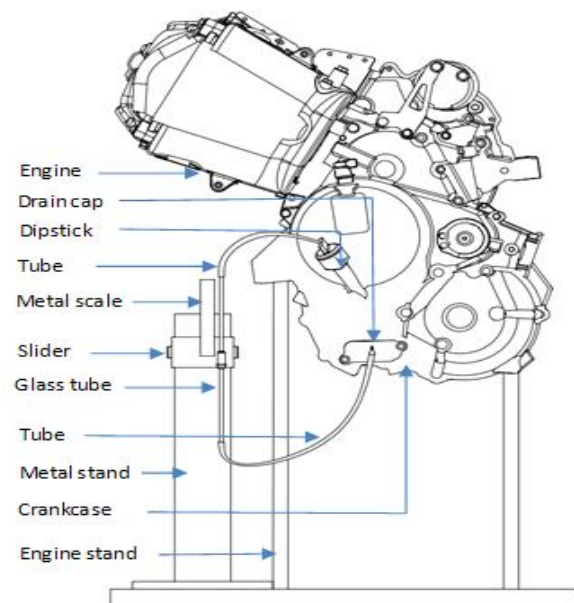

Figure 1. The new experimental setup.

The differential pressure of gas and oil in the crankcase is sensed by the two fiber tube connected at the dipstick and drain cap. A glass tube is mounted on the stand and connects these two fiber tubes. The glass tube has a bulge at the center. This bulge is necessary for stabilizing the flow of oil during engine running condition. A tube and metal scale is mounted on the slider which is used to adjust the height of the oil level in the glass tube. For a given measurement the position of slider remains fixed. The volume of oil consumed is calibrated with the drop in oil height in the tube. The calibration method is discussed in the next section.

Pressure of a liquid column of a height 'h' is

$$P = \rho g h \qquad (2)$$

So the pressure at the bottom of the crankcase P_b for any amount of oil is

$$P_b = P_g + \rho g h \qquad (3)$$

where P_g is the gas pressure in the crankcase. The difference in height of two connected liquid columns depends on the differential pressure on top of the liquid levels. The top end of pipette is connected to the dipstick so that the variation in pressure in the crankcase is experienced by oil in the glass tube too. So the level in the pipette shows the level of oil in the crankcase. During operation, due to oil consumption there is a drop in the level of oil in both crankcase and pipette. This drop in level directly gives the amount of oil consumed as explained below.

B. Calibration

Calibrating the setup helps in calculating the oil consumption without disturbing the oil in the crankcase.
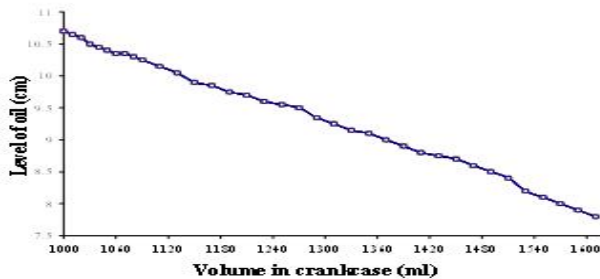

Figure 2. Calibration of level of oil against the volume of oil added in the crankcase

Calibration simply means recording the known amount of oil present in the crankcase against the height of oil in the glass tube. In order to calibrate an engine with oil capacity of 1500 ml, initially 1000ml can be added and the level of oil in the glass tube is noted. Then oil is added in steps of 10 ml and the corresponding increase in level of oil is recorded. After calibration, the amount of oil present in the engine for different levels is known. Hence decrease in height of oil level directly indicates the volume of oil consumed. A three-wheeler engine of sump capacity of 1600 ml was calibrated from 1000ml. The calibration data is shown in the Fig. 2. The oil level in the pipette is plotted against the volume of oil present in crankcase.

C. Description of the setup

The instruments existing today for measurement are very bulky and are not very portable. So the main aim was to make the setup portable and versatile. The setup consists of two movable parts.

* Base
* Attachment

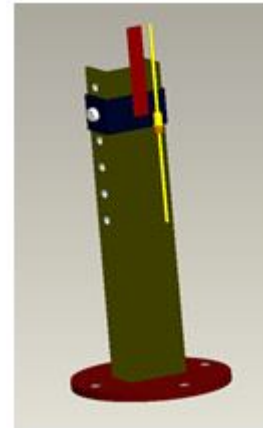A CAD model of the setup is shown in Fig 3.

Figure 3. CAD model of the experimental setup.

1) Base: It is a circular steel plate onto which a U-shaped channel is welded. The four holes on the circular plate help to mount the base onto any test bed. The channel has holes drilled on the side. This helps to adjust the height of
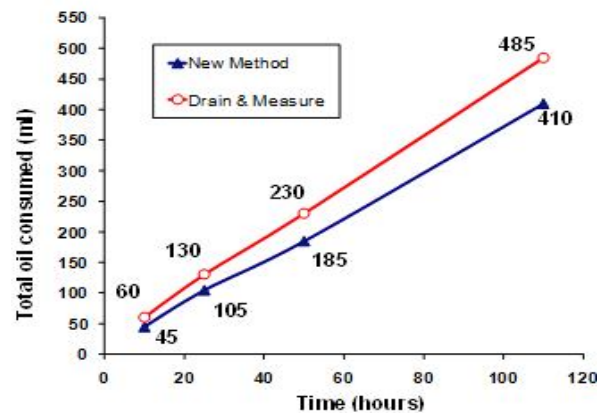

Figure 4: Experimental measurement total oil consumed against time.

the attachment using a nut and bolt. This helps the setup usable on any type of test bed regardless of the height at which the engine is mounted. The base is made of steel. This provides it a sturdy character, which helps in reducing the vibrations of the setup when mounted on to the test bed.

2) Attachment: It is a U-shaped steel bracket, which can be clamped on to the base using nut and bolt. Two holes are drilled on the sides of the bracket, which will help mount the attachment onto the base. A metal scale is welded on the front face of the bracket and a pipette of capacity 5-10 ml is mounted on to it as shown in the Fig. 3. The pipette has a bulge at the center. This bulge helps in stabilizing the flow during engine run and remove any air bubbles while adding oil into the crankcase. Connecting the setup to the engine without incurring any damage to the engine was a challenge. Modifications were done on two parts, which were easily detachable from the engine. A dipstick assists the customer in measuring the approximate level of oil in the crankcase. A

hole is drilled into the dipstick, through which the oil is poured. The top end of the glass tube is connected to the dipstick using a pipe. A drain cap is provided on every engine to drain the oil. A hole is drilled into the drain cap and a metal tube is press fitted into the cap. Sealing is provided with the help of metal paste around the tube so that there are no oil leakages. The lower end of the glass tube is connected to the metal tube by means of a pipe.

V. EXPERIMENTS & RESULTS

A. Observations

When the engine is started, there is a steady drop in the oil level of the pipette. This is due to the sucking of the oil by the pump, which it sends to various engine parts. After a period of time, the amount of oil that is being sucked in by the pump will be equal to the amount of oil being returned to the crankcase. At this point there will be no further drop in the level of oil. Once the engine is stopped, level of oil rises again. This is because the pump is not lubricating the engine anymore and oil from all
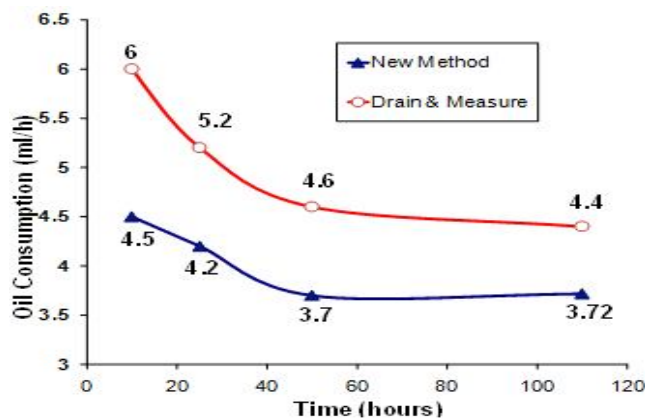

Figure 5. Rate of oil consumption against time.

parts return to the crankcase. This feature can be used to study the pump flow characteristic also. The amount of oil that is being used by the pump for lubrication can be measured based upon the volume of oil present in the crankcase.

TABLE 2. COMPARISON OF TIME TAKEN BY VARIOUS MEASUREMENT METHODS

Method	Measurement Time
Tracer	10 –15 minutes
New Method	5 hours
Drain & Measure	30 hours

B. Comparative result analysis

Measurements were made using calibration data and the "Drain & Measure" method. Both values are compared in Fig. 4. It can be seen that "Drain & Measure" method over predicts the oil consumption. As time increases the difference in values also increases. Oil becomes more degraded and viscous with time. This increase in viscosity results in slow and partial draining of the oil. So the oil that is leftover in the engine is considered as oil consumed. Furthermore errors creep in while draining and measuring the drained volume.

Draining gives a consistent error of around 20% in the amount of oil consumed. The rate of oil consumption is also compared in Fig 5. The measurement times of each method are shown in Table. 2. Tracer techniques give measurements in 10-15 minutes. "Drain & Measure" technique has a run time of about 30 hours. It can be noticed that new method stands between both these methods, without compromising on cost, time and accuracy.

VI. CONCLUSIONS

In this paper, a review of the existing measurement techniques for engine oil consumption is presented and discussed a simple and accurate method that bridges the gap between the cost, time and accuracy. The proposed method works on the pressure differential due to the oil pressure at the bottom of the crankcase and gas pressure in the crankcase. It requires a metal stand with metal scale mounted on it, a glass and fiber tube connected to both the ends of the glass tube. The setup is cheap and at the same time it is accurate and portable. The setup can be used either on engine or vehicle dynamometer. The volume of oil consumed is directly calibrated with the change in height of the oil in glass tube. Hence, addition of oil after engine run-up is not required in this method unlike the existing techniques. Some existing methods require addition of oil, which is a source of error as new oil and oil in the crankcase does not have same the properties. Furthermore, addition of tracers and its special handling is also eliminated in the present method. In the era of fierce competition and tight R&D budget, this new technique would provide automotive industries a cheap and reliable method for engine testing and development.

VI. FUTURE WORKS

Environmental protection is a major concern in today's market. Industries try to make their products as eco-friendly as possible. This is only possible through extensive testing of various design iterations in the least possible time and cost. The proposed setup could be easily built and is very portable unlike other equipments. The accuracy of the whole setup depends on the accuracy of the scale. Improvement in the accuracy of level measurement can improve the accuracy of the setup by a great extent. Measurements can be done on both engine and vehicle dynamometers. Furthermore it can be operated on both petrol and diesel engines. Effort should be put into the development of efficient measurement systems. This will indirectly improve the efficiency of the final product produced. Apart from measuring the amount of oil consumed the other parameters that effects engine performance should also be investigated. E.g. oil degradation also plays a major role in engine performance. So research should be directed on the factors that depend on amount of oil consumed, lubricant properties, engine-operating conditions etc. An Engine Performance Factor (EPF), which is related to the lubricant, should be evaluated as

$$\text{EPF} \, \alpha \, LOC^a \, m^b \, \rho^c \qquad (4)$$

LOC represents lubricant oil consumption, *m* for viscosity of oil, *r* the oil density, and *a, b,* and *c* are constant that can be

determined experimentally. However, getting the correlation as indicated above is challenging and requires substantial effort by the scientific community. Due to the difficulties involved in measuring oil consumption accurately, it does not provide us all the information relating to engine performance. Degradation, which in turn affects viscosity, affects engine performance by a major extent. Hence, this kind of factor can provide us a better and a clear understanding of the engine performance.

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