Development of Opacity Meter to Monitor Diesel Engine Performance and Environmental Pollution

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ABSTRACT

The role of internal combustion engines is very vital in the development of modern world. Engine ignites hydrocarbon fuel and emits CO, CO_2, SO_2, NOx, HC, smoke, etc into the air. The composition of these gases depicts the health of the engine i.e. poorly maintained or properly maintained. Excessive smoke from diesel engines is a sign of poorly maintained and inefficient engine. Excessive smoke indicates excessive fuel consumption, higher operating costs, low fuel economy, higher maintenance costs, and shorter engine life. Engine emissions are responsible for about 60% of air pollution. The exhaust emissions carry gases which are toxic to human, animal and plant lives when exceed safe limits. To diagnose the smoke of a diesel engine, an Opacity Meter has been fabricated using local material and workmanship. The meter was calibrated with the help of a commercially available DX 210 diesel tune smoke meter. The opacity meter measures the opaqueness of engine exhausts by passing a beam of light through the smoke. The darker and thicker is the smoke the greater is the opacity. The results of the meter are comparable with the commercially available smoke meter after applying proper corrections for effective optical path length and wavelength of blue photodiode.

Key Words: Diesel engine; Opacity meter; Carbon particulates; Hydrocarbons; Smoke meter; Photodiode

INTRODUCTION

The internal combustion engines convert heat energy into more useful mechanical energy by igniting fossil fuels in a controlled combustion chamber. The efficiency of an engine to convert heat energy of fuel into mechanical energy is largely dependent upon valve, fuel injection and ignition timing and fuel quality. The exhaust of diesel engine contains water and carbon dioxide as the major components i.e. from 80-90% and the remaining 10% as un-burnt carbon particles, nitrogen oxides, oxides of sulfur, carbon mono oxide and hydrocarbons, etc. A well-maintained engine will admit a predetermined amount of air and fuel into its combustion chamber and ignite at a right time. It emits fewer amounts of un-burnt carbon particles and hydrocarbons (HC) in its exhaust gases. Its exhaust smoke will almost be white or less dark. On the other hand, a poorly maintained engine has disturbed valve and injection timing that results into incomplete combustion. Therefore, it emits more amounts of un-burnt carbon particles and HC in its exhaust. Its exhaust emission will be very dark (black). A scientific method to investigate the quantity of carbon particulates in the exhaust is by passing a collimated beam of light directly across the smoke. Lesser the light transmits through the smoke more are the carbon particles in the exhaust, which do not permit light to pass through them. Thus by measuring opaqueness of smoke with the help of an Opacity meter, one can estimate the quantity of un-burnt fuel in the exhaust of diesel engines.

Opacity meter is one of the basic tools to diagnose a diesel engine. A regular gas analyzer used for petrol engines cannot be used to diagnose a diesel engine, as the carbon monoxide levels are much lower. Further more, the HC content cannot be measured by the normal infrared technique and for reliable results a chassis dynamometer is desirable (OTC, 1995). For diesel, carbon forms at least half of the particulate content, the remainder being made up of HC (un-burnt fuel and lubrication oil), sulfates (from sulfur in diesel) and water.

Estimation of carbon particulates is also very important from air pollution point of view. The carbon particles present in the air when inhaled do not get absorbed by mucous lining in the upper respiratory tract and get drawn deep into the lungs where they can damage the ciliar lining of the bronchial tube. This damages the lungs defense and clearance mechanism (Gundel *et al.*, 1994). Many other components of diesel exhaust such as benzene, sulfur dioxide and formaldehyde are carcinogens. They cause respiratory, pulmonary, Pneumonia and heart diseases, etc. (Barrett *et al.*, 1989; Carl, 1995). Epidemiological studies further suggest that un-burnt particulate of diesel increase the risk of lung cancer. The overall objective of this study was to develop a low cost engine emission analyzer and thereby transfer this technology to local industry.

MATERIALS AND METHODS

To diagnose the exhaust of diesel engines an opacity meter was fabricated in the Department of Farm Machinery and Power, University of Agriculture, Faisalabad. The Opacity meter works on the principle of traveling of light in a straight line. When some opaque material falls in the way of light it reflects back. Since carbon particles present in the exhaust of vehicles are also opaque therefore, the visible light can be used to detect them. The opacity meter is also called as smoke meter in the auto-industry. The opacity

meter mainly consists of a light source, light receiver, smoke sampling tube and a display unit. A 125 mm long copper tube of 1cm diameter was used to hold the smoke sample through which light is to pass. In this tube exhaust of motor vehicle is partially introduced. At one end of the tube a light source called transmitter was installed. At the other end of the tube a photo-diode (sensor) was installed. This is commonly calle

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The green LED was not available from local market so a blue LED with 470 nm wavelength was used as an emitter.

A photo-diode was used as an opacity sensor. The electrical signals from the photo-diode were amplified by using an operational amplifier LM308 as shown in Figure 1. LM308 is a low noise operational amplifier and is used here as an inverting amplifier also. When there was no smoke in
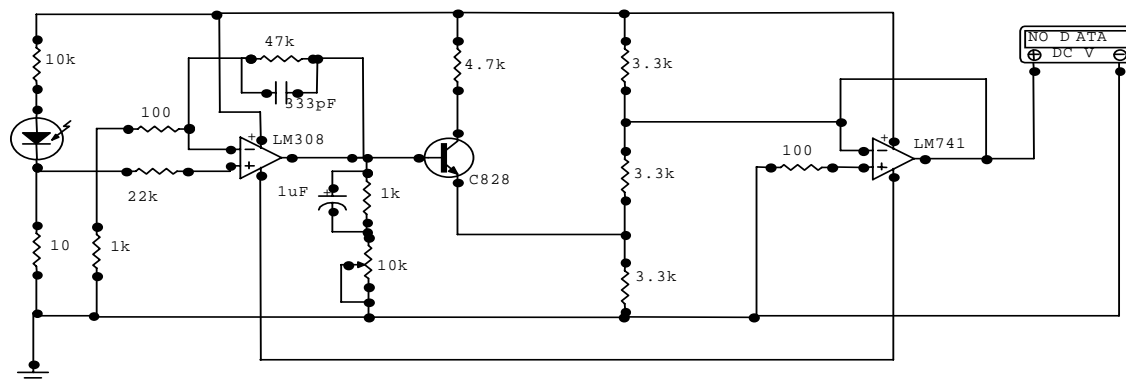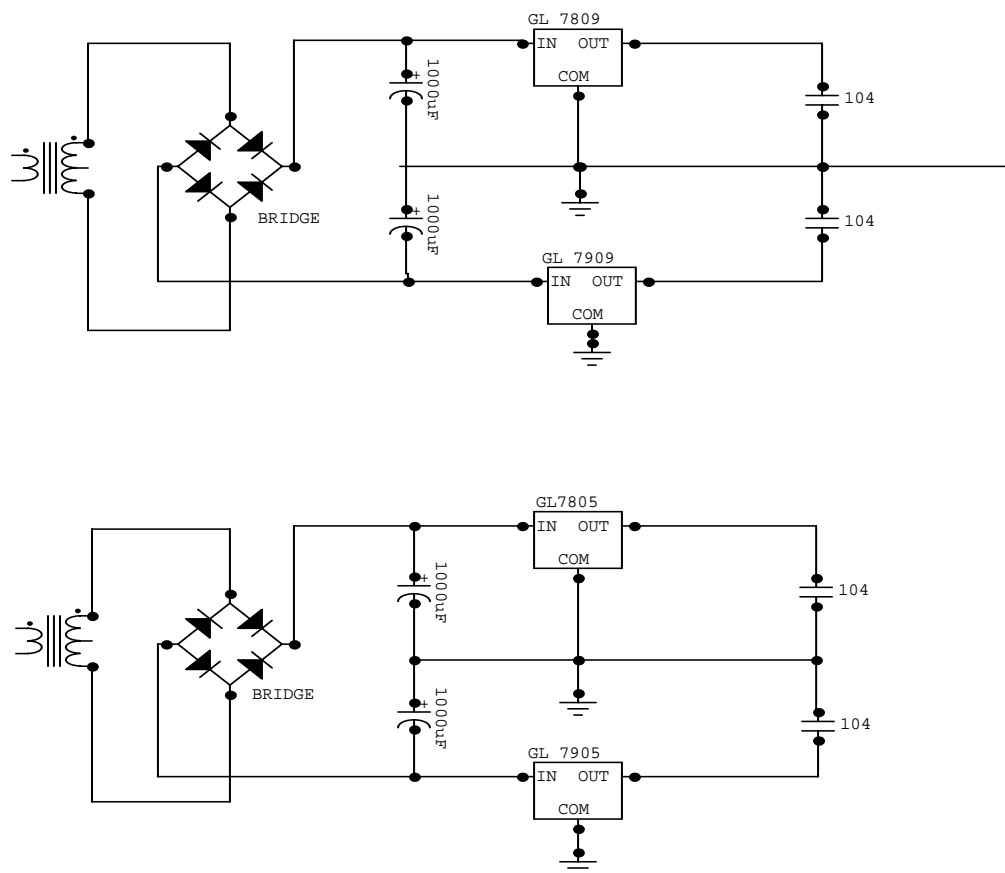
Fig 1. Simple circuit diagram of opacity meter

Fig. 2. Circuit diagram of positive and negative voltage regulators

were used as negative voltages regulators. These IC are available in fixed output voltages. The integrated circuit LM 317 is adjustable voltage regulator. Here it is used to give adjusted potential to transmitter. The above-mentioned five integrated circuits were best suited for the present opacity meter.

Opacity meter corrections. Fundamentally, all smoke opacity meters measure the transmittance of light through a smoke plume or a sample of a gas, which contains smoke particles. Typically, however, it is desired to quantify and report the exhaust smoke emissions in units of either smoke opacity (N) or smoke density (k). Furthermore, if the level of smoke is reported as smoke opacity, then it is also necessary to report the associated effective optical path length to fully specify the smoke level of the vehicle. This is because measured smoke opacity is a function of the effective optical path length (EOPL). For example, an engine that yielded 20% opacity when tested with EOPL of 76 mm would have been measured as 26, 31 and 36% opacity when tested with an instrument having EOPL of 102, 127, and 152 mm, respectively. Therefore, to facilitate comparisons of smoke opacity data from different sources and with smoke standards, opacity values must be reported at standard effective optical lengths set be Society of Automotive Engineers (SAE, 1996).

When smoke is measured using an effective optical path length, which is different than the standard, then measured smoke values must be converted to opacity at standard path length by using appropriate Beer-Lambert relationship. Similarly, if it is desired to report test results in units of smoke density, Beer-Lambert relationship can be used to do this conversion. Finally, if smoke measurements are made using a smoke meter with LED other than green, a wave length correction is to be made to account for the fact that the ability of diesel smoke to absorb light depends on the wavelength of the light.

Opacity meter calibration. The Opacity Meter was calibrated by comparing its opacity results with that of DX.210 Diesel tune smoke meter for MF 260 tractor lying in the Department of Farm Machinery and Power. The smoke meter was borrowed from Environment Protection Deaprtment, Faisalabad. Unfortunately, both the meters had different transmitting LEDS and EOPL which made it difficult to compare the results directly with each other. Moreover, the opacity meter measures opacity whereas DX210 smoke meter gives out smoke density. The opacity meter has EOPL of 125 mm and uses blue LED with 470 nm wavelengths. Whereas, the DX.210 had 250 mm EOPL and a green LED with 560 nm wavelength. Therefore, EOPL and wavelength corrections were applied to DX210 smoke meter using Beer-Lambert relationship to get standard (Ns) opacity. The results of Calibration are presented in Table I after necessary corrections

From the calibration results it was noted that a close match between two opacity values may be found when Nm

Table I. Calibration results of opacity meter (fabricated) and smoke density meter (DX.210).

N_m	Ks	Ns (25 cm)	Ns (12.5 cm)	Nm/4	Nm/3.5
10	0.2	4.8	2.46	2.5	2.85
12	0.22	5.3	2.71	3	3.42
22	0.28	5.9	3.43	5.5	6.28
25	0.36	8.6	4.4	5.5	6.28
28	0.42	9.96	5.11	7	8
30	0.42	9.96	5.11	7.5	8.57
35	0.86	19.34	10.19	8.75	10
40	1.00	22	11.7	10	11.42
45	1.06	23.27	12.4	11.25	12.85

Table II. Smoke opacity values of university buses and massey ferguson tractor

Throttle Position	MF 265 Tractor	Bus No. 5	Bus No.4
¼	3	13	10
½	10	25	28
¾	15	43	47
Full	22	49	Out of range

values were divided by a factor of 4. Further, during calibration it was noted that the smoke meter some times was giving different errors beyond our control which could have affected the calibration results. To verify the

functioning of opacity meter, it was tested for two different University Buses and a tractor without using pre-air cleaner. The results of these tests are given in Table II.

CONCLUSIONS

The results of opacity meter were comparable with the commercially available DX.210 smoke meter after necessary corrections. The opacity meter is about 15 times cheaper than commercially available smoke density meters. Opacity meter is very simple in construction and easy to use with digital readout. Further studies and work on the opacity meter may make the present attempt fully successful.

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