# MATHEMATICAL MODEL FOR EVALUATION OF BACKPRESSURE EFFECT OF DPF ON PERFORMANCE PARAMETERS OF VCR 4S CI ENGINE

[1]Dr. Maish S. Deshmukh, [2]Dr. Mangesh R. Phate, [3]Dr. Dheeraj S. Deshmukh
[1]Associate Professor, [2]Associate Professor, [3]Associate Professor
[1&2]Mechanical Engineering, AISSMS College of Engineering, Pune-01, Maharashtra State, India
[3]Mechanical Engineering, G H R College of Engineering, Nagpur-16, Maharashtra State, India

*Abstract:* Since last 3 to 4 decades aftertreatment techniques are being increasingly utilized and research work is well under progress. Effective after treatment system, specifically for C.I. engines, requires critical analysis of the overall effect of backpressure on each particular C.I. engine performance. More efforts are required for the analysis of the after-treatment System, by further study of the theory of operation of each device related to C.I. engines. Search on Diesel Particulate Filters as a modern technology is very active because particulate matter is designated as a major cancer material.

Regeneration phenomenon in after treatment devices is a subject of special interest for design and development of Particulate Matter emissions control activities. The Backpressure acting on engine is most important factor which basically deteriorates the engine and emission control performance. In the present work, Dimensional analysis technique is used for determining the relationship between operating variables of Internal Combustion engines, then validation of the effect of back pressure generated on a C.I. engine, with and without the use of a specially designed Diesel Particulate Filter is done.

***IndexTerms* - VCR 4S CI Engine, DPF, Pressure drop, back pressure, Exhaust Emissions**

## I-INTRODUCTION

Particulate emissions from C.I. engines are an immediate health concern furthermore as a significant supply of overall environmental degradation. Development of a much feasible particulate emission management technology is thought-about as one of the foremost difficult tasks associated with the after-exhaust treatment technologies. The exaggerated use of C.I. engine for all classes of applications is that the major trend discovered worldwide since starting nearly in each field. Whereas the energy benefits of the C.I. engines are unchallenged, lower price of diesel oil is additionally answerable for its increasing popularity, significantly with reference to the less developed countries. Although, inherently cleaner than S.I. engines from the point of view of monoxide (CO) and hydrocarbons (HCs), C.I. engines emits a lot of aldehydes, sulfur oxides (because of the upper sulfur content in diesel fuel) and N oxides. Offensive smoke and odor emissions also are a problem of nice concern, most importantly; but uncontrolled diesel engines emit vital amounts of particulate. Despite the technical and industrial advantages of C.I. engines over the traditional S.I. engine power-plants, considerations became to grow as early as in 1980's over the environmental consequences of enhanced dieselization[1].

The exhaust system route exhaust gas from the engine and exhausts it into the atmosphere, whereas providing noise attenuation and after treatment of the exhaust gas to cut back emissions. one amongst the foremost necessary sources of car noise, the noise related to exhausting combustion gases from the engine, is controlled using mufflers. Exhaust gas properties that are vital for the design of exhaust system its physical properties, exhaust gas temperature, that depends on the vehicle duty and/or test cycle, and therefore the exhaust gas rate of flow. exhaust system materials are exposed to a range of harsh conditions, and should be resistant to such degradation mechanisms as hot temperature oxidization, condensation and salt corrosion, elevated temperature mechanical failure, stress corrosion cracking, and intergranular corrosion.

Exhaust emission from vehicles are often controlled in 3 alternative ways. One is to push additional oxygen for complete combustion, in order that there's less byproduct. The second is to supply excessive hydrocarbons into the engine for combustion, and also the third one is to arrange an extra space for oxidization or combustion to occur. Thus, the aftertreatment techniques appear to be more possible as compared to different diverse techniques for reducing exhaust emissions rather than going for engine and fuel modifications[2].

## II-AFTERTREATMENT TECHNOLOGIES

Engine after treatment requirement changes in response to dynamic Pollution management norms or legislation, that sometimes needs new technologies to be introduced. New technologies place specific challenges on after treatment systems. A quick summary relating to the most trends in after treatment system development and issues associated are discussed here. A demand for reduced back pressure altogether forms of C.I. engines in old, present and future engines using diesel or any alternate renewable fuel, since back pressure rise causes increase in fuel consumption. A requirement for economical exhaust energy recovery system and new improved noble & non-noble metal based mostly economical catalyst technologies, to get most attainable conversion efficiency for pollution management with sturdiness problems.

The most outstanding diesel particulate matter emission management technique uses Diesel Particulate Filter system. Collected particulates are removed from the filter, endlessly or sporadically, through thermal regeneration. The device captures ash, however the buildup of ash within the device is spare to cause an increase in back pressure. The failure of exhaust devices could also be because of System element meltdown, Catalyst fracture or Catalyst Poisoning. The broken items will move around and acquire in position to plug up the flow of exhaust through the device.

After productive design additionally back pressure on a selected engine will increase attributable to following reasons -1) Engine design and operative condition decides the fuel combustion and ultimately back pressure for a selected engine system. In most of the C.I. engine applications lack of space availability wants compactness of after treatment devices, it creates restriction in exhaust flow. correct timely maintenance and calibration of all the elements is incredibly vital issue for hassle free efficient helpful life span of the engine system. every variety of fuel or lubrication oil variations for a selected engine system additionally decides the engine operation and ultimately back pressure for a selected engine system. 2) Installation of further device like trap, convertor, EGR system, Turbocharger etc., if after new inventions that are to be enforced. Improper regeneration could cause to plug up the flow of exhaust through the after-treatment devices attributable to accumulation of particulate matter, since particulate matters contains noncombustible compounds, thus 100 percent regeneration isn't possible. Thus, every alternation in after treatment system or exhaust system with time causes variations in back pressure on every variety of C.I. engine [3,4].

## III-DIMENSIONAL ANALYSIS TECHNIQUE

Following table gives the list & brief details of important operating variables of any particular type of C.I. engine.

| Sr. No | Parameters | Type of variable | Causes of variations |
|---|---|---|---|
| 1. | Fuel consumption rate | Basic dependent variable | It is an important parameter of an engine, varies because of any possible variable variations such as engine design (type of engine) & fuel (type of fuel) and After treatment system (type of devices used and flow resistance offered by exhaust system) |
| 2. | Load on engine | Independent variable | As per the output power requirements such as vehicle weight, number of persons seating, road resistance or slope condition, drag force variations, electrical load etc. |
| 3. | Speed | Independent variable | As per the availability of time or time requirements. Speed can be kept constant as in case of electric generator applications with the help of a governor. |
| 4. | back pressure on the engine | Independent variable | As per the complete exhaust system designs and their maintenance aspects because of aging effects. Particulate Matter accumulation causes variations of pressure drop across each component of exhaust system. |

As per the above data, the fuel consumption ($F_c$) of four stroke, single cylinder C.I. engine during a test run can be considered as dependent upon load($l_d$), speed(N) and back pressure ($P_b$) on the engine. Using the dimensional analysis, the functional relationship between these variables and the fuel consumptions is determined here -.

$$F_c = D_d\left[\frac{\sqrt{P_b}.l_d}{N}\right]$$

Where $D_d$ = Non- dimensional constant.

Verification of the equation using Buckingham`s $\Pi$ –theorem
Total no of variables, n = 4, No of fundamentals dimensions, m = 3
Therefore, the number of dimensionless л – term = n – m = 4 – 3 = 1
Thus, one л – term is formed.
Hence equation mentioned above is dimensionally homogeneous.

$$D_d = \frac{F_c.N}{\sqrt{P_b.l_d}} \quad \text{---------------------(i)}$$

## IV-EXPERIMENTATION

In the present work, perforated circular copper plate arrangement in Diesel Particulate Filter is used as a test piece for back pressure variations. Throughout the complete trials conducted, the speed of the engine is kept constant, at 1500 rpm and also engine jacket cooling water is kept constant at 0.1666 liters/sec, so as to provide ease in comparison of different parameters, in some cases by varying the load on the engine also. Further during the trials on DPF, each times the fresh perforated plates and rings were used. To reduce the backpressure on the engine, maximum no. of plates (i.e. 20 plates) provided with extra 8 no. of holes, of 5 mm diameter were used for determining the effect i.e. back pressure reduction mainly. The different parameters are compared with the values of same parameters without using DPF, for the same engine output conditions.

The engine used for experimentation has following specifications:
1. Make: Kirloskar make, single cylinder, 4-stroke VCR CI Engine
2. Rated power out put: 5 H.P
3. Speed: 1500 R.P.M.
4. Stroke length: 110 mm
5. Bore diameter: 80mm

6. Loading type: Water resistance type load, with copper element and load changing arrangement
7. Moment arm: 0.2 meter
8. Orifice diameter (for air box): 25mm
9. Co-efficient of discharge of orifice: 0.64

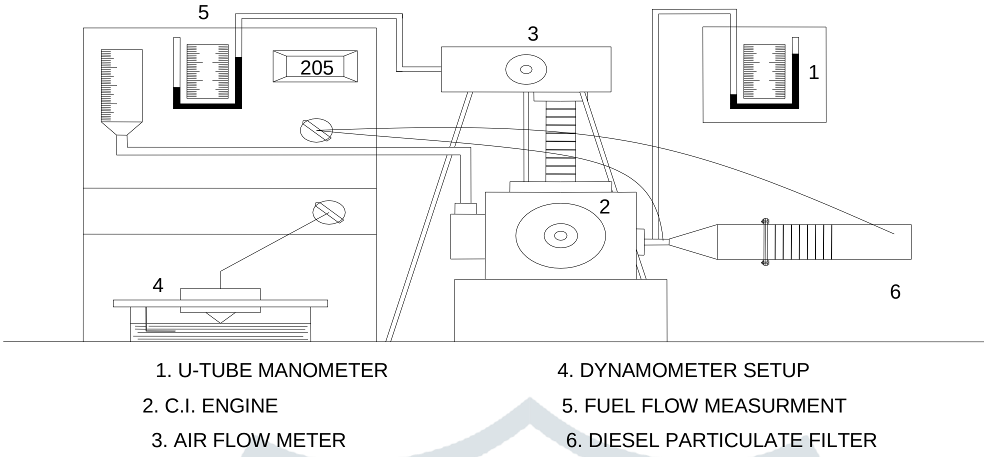


**FIGURE: 1** Schematic view of experimental set up

Diesel Particulate Filter**:**
1) Space velocity: 50,000 hr$^{-1}$
2) Catalyst used: Copper-based catalyst system
3) Circular perforated copper plates with 256 no. of holes per square cm and copper rings made up of 5 mm diameter rod.
4) Flange arrangement for dismantling and varying no. of perforated plates and no. of rings, more details are given in figures.

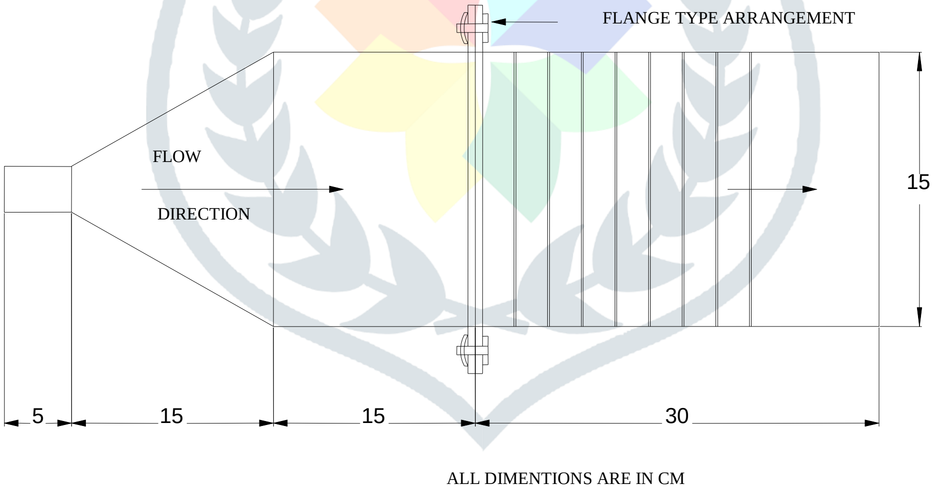


**FIGURE: 2** View of Diesel Particulate Filter with copper plates

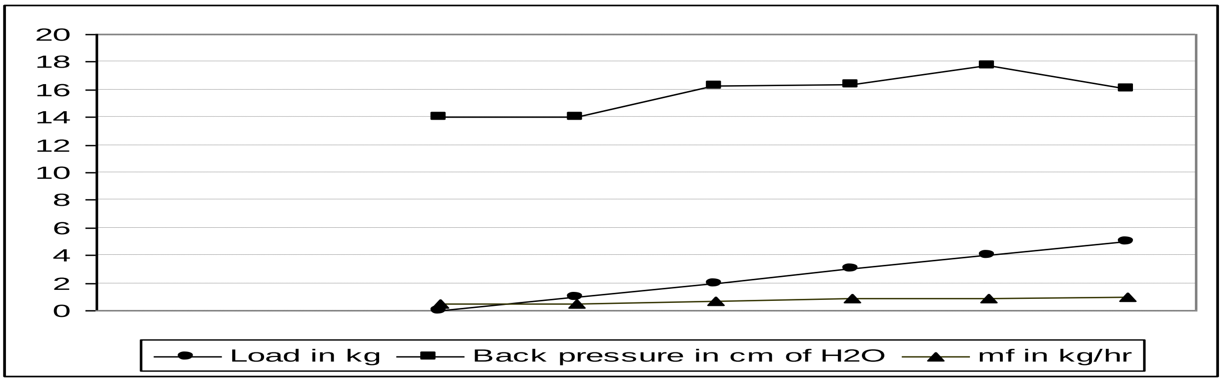
The 22 runs are made and the basic dependent result, which is fuel consumption in kg of fuel per sec, is determined. The calculation table shows important details: -

| Sr.No | Fuel consumption rate ($F_c$) in Kg/sec | Load on Engine ($L_d$) in N | Speed (N) in rps | Back pressure on the engine in Pascal | Value of $D_d$ |
|---|---|---|---|---|---|
| 1. | 0.0003315 | 49.05 | 25 | 1863.9 | 0.00002741 |
| 2. | 0.000355472 | 49.05 | 25 | 1942.38 | 0.00002879 |
| 3. | 0.000356222 | 49.05 | 25 | 2668.32 | 0.00002462 |
| 4. | 0.000322389 | 49.05 | 25 | 2001.24 | 0.00002572 |
| 5. | 0.000338556 | 49.05 | 25 | 1736.37 | 0.00002900 |
| 6. | 0.000267611 | 49.05 | 25 | 1579.41 | 0.00002404 |
| 7. | 0.000370972 | 49.05 | 25 | 2933.19 | 0.00002445 |
| 8. | 0.000412028 | 49.05 | 25 | 3198.06 | 0.00002601 |
| 9. | 0.000341167 | 49.05 | 25 | 1726.56 | 0.00002931 |
| 10. | 0.000318111 | 49.05 | 25 | 1667.7 | 0.00002781 |
| 11 | 0.000128639 | 9.81 | 25 | 1373.4 | 0.00002771 |
| 12. | 0.000182528 | 19.62 | 25 | 1599.03 | 0.00002576 |
| 13. | 0.000247 | 29.43 | 25 | 1608.84 | 0.00002838 |
| 14. | 0.000258972 | 39.24 | 25 | 1736.37 | 0.00002480 |
| 15. | 0.000164056 | 9.81 | 25 | 2158.2 | 0.00002819 |
| 16. | 0.000224389 | 19.62 | 25 | 2011.05 | 0.00002824 |
| 17. | 0.000248417 | 29.43 | 25 | 1962 | 0.00002584 |
| 18. | 0.000274583 | 39.24 | 25 | 1981.62 | 0.00002462 |
| 19. | 0.00014625 | 9.81 | 25 | 1814.85 | 0.00002740 |
| 20. | 0.000205167 | 19.62 | 25 | 1775.61 | 0.00002748 |
| 21 | 0.000236417 | 29.43 | 25 | 1775.61 | 0.00002586 |
| 22 | 0.000275306 | 39.24 | 25 | 1726.56 | 0.00002644 |

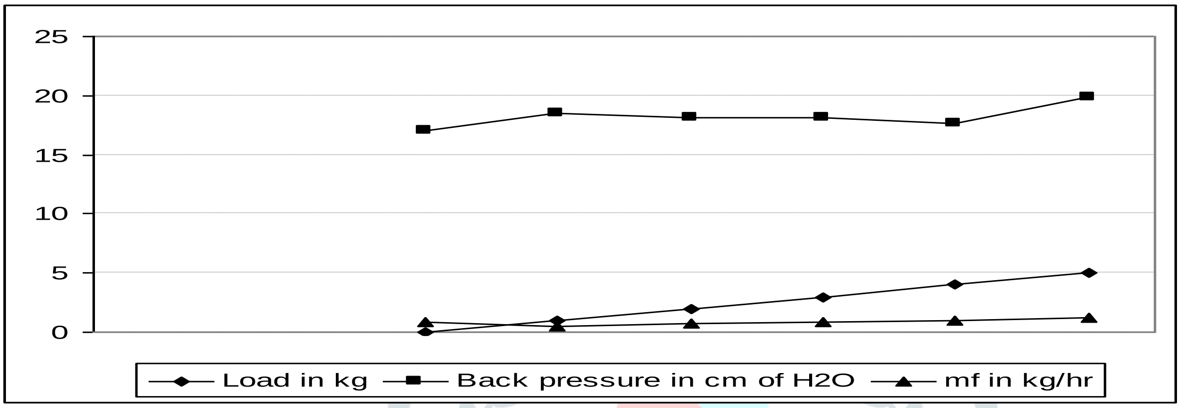
The differences in the various $D_d$'s are indications of how badly the data deviates from the ideal of Eq. (i). These deviations may be a result of the lack of control in holding the variables at their planned levels, or simple lack of precision in the measurements. The average $D_d$ for these 22 runs is 0.00002672, and the maximum deviation from this is-0.00000268 or 10 per cent. In this test, most of this deviation is probably due to the difficulty in control of speed and back pressure, while fuel consumption readings are being taken. Using this average $D_d$, we could now answer a number of questions about the engine system performance. The conditions that were not actually run can be analyzed with ease. The uncertainty is about plus or minus 10 per cent, with this uncertainty figure including perhaps 90 to 95 per cent of all the data.

Further analysis is possible using different engines. Experience with engines world lend us to expect somewhat greater fuel consumption with increased back pressure, which is predicted in basic thermodynamic theory. In this test, the back pressure was recorded as gauge pressure.

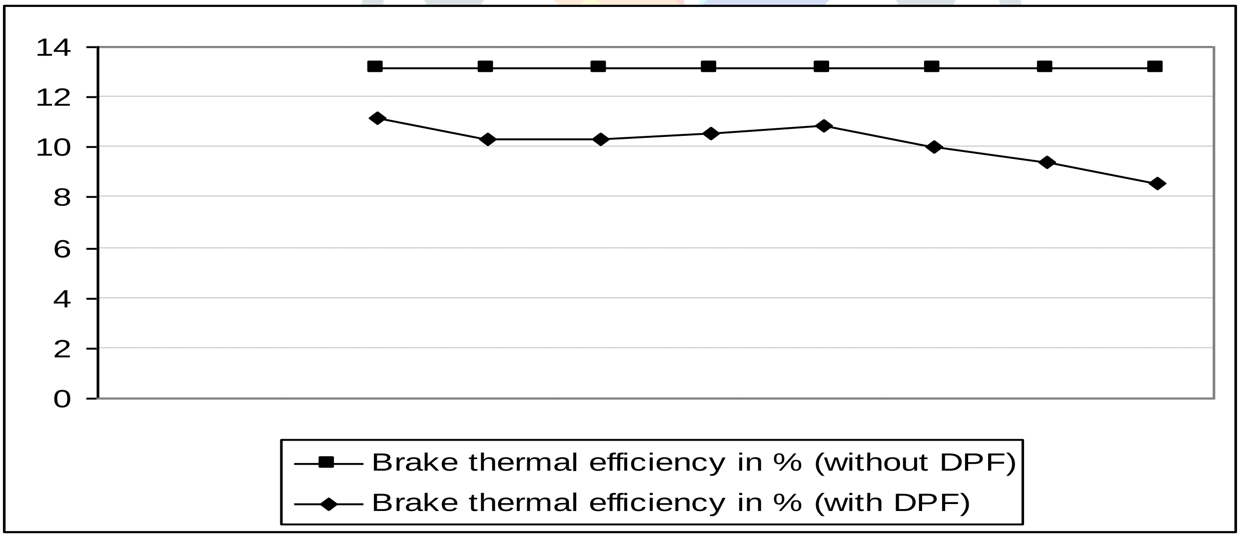
**4.1- PERFORMANCE CHARACTERISTICS**



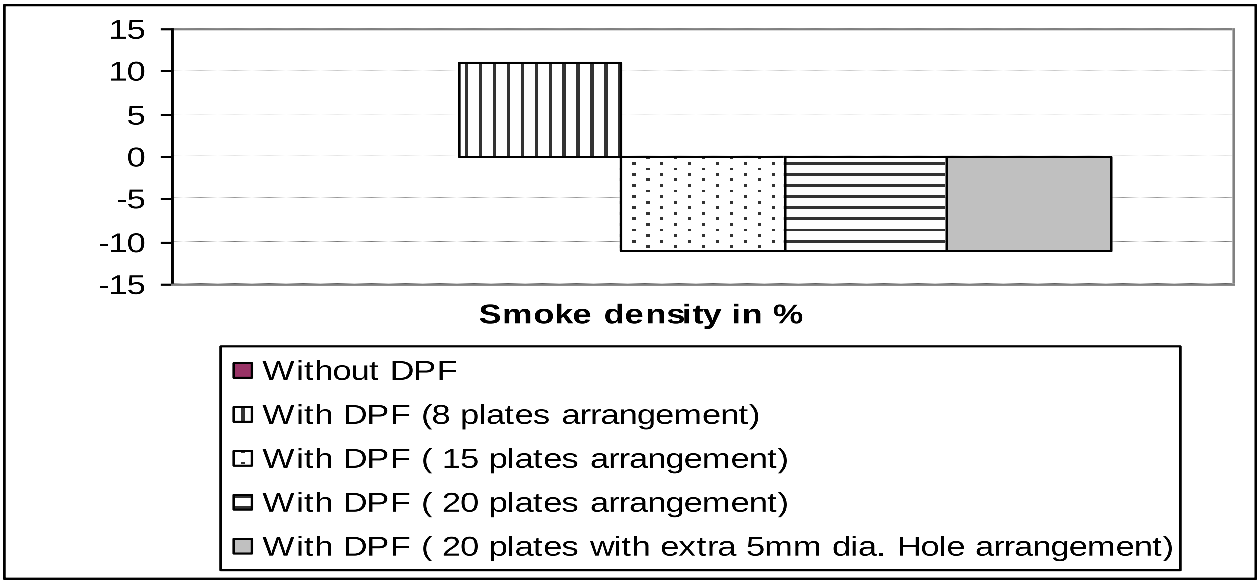
GRAPH-1 Variation in fuel consumption ($M_f$) and load (Kg) Vs back pressure (in cm of $H_2O$), without using DPF.



GRAPH-2 Variation in fuel consumption ($M_f$) and load (Kg) Vs back pressure (in cm of $H_2O$), using DPF



GRAPH-3 Variations in brake thermal efficiency without using DPF & with DPF (different no. of plates arrangement), at 5 kg load condition.



GRAPH-4 Comparison of filtration efficiency at different exhaust conditions

## V-CONCLUSIONS:

The main problem associated with development and effective utilization of after treatment techniques is exhaust back pressure. It is necessary not only just to adequately implement after treatment techniques in new technology, but also the older technology engines which are still on the road.

Since backpressure is only one operating parameter of a particular engine, which must be minimized for overall engine performance improvement. For this reason, the ability for after treatment which meet new specifications must also be backward compatible with older specifications is extremely important factor, and it will be a challenge to continue to do this with future emission limits.

In this paper an important correlation for C.I. engine operating variables, for limited test run region, is investigated & experimentally validated for a C.I. engine.

Further scope is, to check that the applicability of equation and feasible operating regime, by the determination of the value of ‘$D_d$’ for any particular internal combustion engine and its utility for performance analysis & optimization. Regeneration phenomenon requires special care particularly in C.I. engine after treatment devices.

## VI-ACKNOWLEDGEMENTS:

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