Emission Measurement and Testing of Multi Cylinder C.I. Engine Operated by Intercooled Turbocharger

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Abstract— We know Turbocharger as boosting device which increases volumetric efficiency. Here is this work turbocharger is modified with Wastegate valve. Wastegate operated and Intercooler equipped turbocharger are used to enhance the performance and reduce emission. This study is mainly concerned on the effect of bypassing the exhaust which is going to turbine. Three types of Wastegate opening are selected that is 20, 50, and 80% opening. Now emissions at both outlets that is Wastegate and turbine outlet are measured. It is found that waste gate outlet has lesser emission of CO2 and HC.The use of a Wastegate operated turbocharger on this test engine has clearly increased its performance compared to its stock naturally aspirated form. As exhaust is bypassed from main exhaust line with different Wastegate opening selected. Intercooler is mainly functioned for increase in volumetric efficiency by cooling the intake charge so that more air to engine and which results finally at higher engine output. As a result we found increase in volumetric efficiency up to 7%.

Key words: WG, DI, PPM

I. INTRODUCTION

A turbocharger is device as important part of all multicylinder diesel engines. Turbocharger is an exhaust gas driven induction device used in I.C. Engine to improve engine performance. This is done by forcing compressed air into the combustion chamber allowing more fuel to be burned resulting in a large air fuel ratio, large power & the method is called turbo charging. These devices use the energy of exhaust gases out from engine to run the turbine that in turns the air-compressor that provides. Now a day's Wastegate operated turbocharger are also becoming popular now a days. Waste gate valve bypasses the flow that is coming from exhaust so that we can vary speed of turbine. It has certain effect of emissions that is being studied here in paper. We know that due to compressor pressure and temperature of air is increases. If it is possible to cool this air then density of air increase and thus volumetric efficiency. Intercooler are also used after the compressor to enhance performance of engine.

II. LITERATURE SURVEY

How turbocharger design has effect on engine performance and exhaust emissions was studied [1]. The test engine was a DI turbocharged, intercooled diesel engine. Attention was paid to the exhaust emissions particulate matter (PPM) emissions of the engine that is CO, HC and CO2. The engine was first equipped with a standard (Standard), which was then replaced by a waste-gate (WG) turbocharger. The engine was operated at three speeds within the entire load range. Basic performance, gaseous exhaust emissions and exhaust particle quantities were recorded. The results shows that the Wastegate TC is advantageous at high loads at low and medium speeds, where reductions of PPM emissions observed when running the engine with this TC. At rated speed, however, the Standard TC proved better than the WG one.

The effect of inter cooled turbocharged condition is tested.[2] Boost pressure is one the main parameter in comparing the performance indifferent conditions as it influences the engine torque, power, and efficiency and exhaust emissions. The use of a given turbocharger on this test engine has clearly increased its performance compared to its stock naturally aspirated form. The incorporation of intercooler to the turbocharger system increases the performance even further. With the worldwide effort towards eco-friendly engines and fossil fuel shortage, the turbocharger can help to have engines with enhanced engine performance, less exhaust emissions and maximum fuel economy. At conclusion it is mentioned that addition of the turbocharger increased the maximum output of the engine and reduction in emission at the speeds above 2000rpm and Below 2000rpm, the turbocharger is not supplied with enough exhaust energy to spin fast enough to produce above-atmospheric pressures in the intake manifold. Also HC and CO emissions are reduced considerably when the engine is turbocharged compared to its stock naturally aspirated condition.

The effects of turbocharger on the performance of a diesel engine using diesel fuel and biodiesel in terms of BP, torque, BSFC and thermal efficiency, as well as CO and NO emissions. [3] For this aim, a naturally aspirated four-stroke DI diesel engine with diesel fuel and biodiesel, which is rapeseed oil methyl ester, at full load condition at the speeds between 1200 and 2400 RPM? Then, a turbocharger system was installed on the given engine and the tests were conducted for both fuel cases. It was observed that emissions of CO in the operations with biodiesel were less than those in the operations with diesel fuel, whereas NO emission in biodiesel operation was higher. This study concludes that1 the use of biodiesel improves the performance parameters and decreases CO emissions of the turbocharged engine compared to normal diesel fuel.

III. EXPERIMENTAL SETUP & PROCEDURE

The multi cylinder, four strokes 27.6 KW Mahindra, water-cooled DI diesel engine with a bore of 88 mm and stroke of 101 mm and a compression ratio of 18.1:1 is used for the experiment. The engine load is applied with help of eddy current dynamometer.

Fig. 1: Multi cylinder CI Engine setup

Engine specification of current set up is as tabulated below.

Make	Mahindra
Model	MDI 3200 TCI
Rated power	27.6 KW@5000 rpm
Bore	88.9
Stroke	101.6
Compression ratio	18.1:1
Type	4 stroke 4 cylinder water cooled turbocharged Diesel engine

Table 1: Engine Specifications

As per above mentioned title engine is tested for modified turbocharger which is provided with waste gate at turbine end And intercooler at compressor end. Wastegate is for controlling emissions purpose and intercooler is obviously for improving volumetric efficiency and reduction of NOx emissions.

Intercooler: - It is fitted after the compressor as shown in figure.it consists of coiled structure of copper pipe. We are not interested in design consideration of intercooler, so information about no of turns of coil, insulating material, outer material of intercooler is omitted from study. After the compressor air gets heated and thus temperature of this hot air is to be cooled with intercooler so that air density is increases. Increases in air density causes increase in volumetric efficiency.

The Wastegate:-The Wastegate is a valve that bypasses the turbine flow. When the Wastegate is opened the gases do not flow through turbine. This results in lesser power to the turbine and the turbine speed decreases, which in its turn results in a lowered intake manifold pressure, In the long run this influences the torque, but the effect is delayed and there is no direct connection between the Wastegate and the torque produced. One way the Wastegate is used is to avoid that the turbine spins to fast. Another purpose of the Wastegate is to avoid a phenomenon called knocking. Knocking occurs when the air/fuel mixture auto ignites and burns before the flame front, which can cause damages to the engine. There is a larger risk for knocking when a turbocharger is used because of the boost pressure. Today the Wastegate is a mechanical valve opened by the difference in compressor pressure and ambient pressure. If an electrical valve would be used instead this would not be an issue.

Wastegate fitted at current work is provided with three various positions. Firstly it is at 20 % closed position, it means 20% of valve position is open that is bypasses 80 % exhaust through Wastegate valve and remaining 20% is allowed towards the turbine. After rotating the turbine it is directed towards the atmosphere. Secondly it is at 50 % closed position, it means 50% of the valve position is open that is bypasses 50 % exhaust through Wastegate valve and remaining 50% is allowed towards the turbine. Lastly it is at 80 % closed position, it means 80% of the valve position is open that is bypasses 20 % exhaust through Wastegate valve and remaining 80% is allowed towards the turbine. After rotating the turbine it is directed towards the atmosphere. After rotating the turbine it is directed towards the atmosphere Emissions are measured at both the ends using Gas Analyser. Gas analyser gives in details about emissions of CO, HC and CO2.

Setup with Wastegate operated turbocharger and installed intercooler at compressor end is as shown in pictures below. All modified setup is installed at exhaust line coming from the turbine end.

Fig. 2: Turbocharger with Wastegate Valve And Intercooler Installed At Exhaust Line

The engine is tasted as per above three mentioned conditions of Wastegate positions, at various engine speed and at various engine load. The engine is kept firstly at 50 % load. Then it is set at speed of1000 RPM and this condition three Wastegate valve positions are tested for emissions. Then keeping same 50 % load, engine speed is changed to 1500 RPM and same procedure is repeated of Wastegate position. Lastly again at same load speed is increased up to 2000 RPM and same procedure for Wastegate.

Now load is changed from 50 % to 100% and again engine speed is varied from 1000 RPM to 2000 RPM at this condition Wastegate position is varied from 20% closed, 50% closed and 80% closed. At above these all conditions emissions are measured at both ends that is Wastegate outlet and turbine outlet. Wastegate outlet is treated as unused exhaust and turbine outlet is treated as used exhaust.

Also at compressor end we have intercooler as modification. The temperature of air entering at compressor end, temperature behind the intercooler and temperature after the intercooler is measured at all these various condition so as to calculate intercooling effect and its effect on volumetric efficiency and reduction of NOx emissions Another purpose of this setup to evaluate quality of air entering the engine.

IV. OBSERVATION AND DISCUSSIONS

As per project title here effect of various Wastegate opening of turbocharger on engine emissions is identified. Multi cylinder four stroke CI engine is available for testing. Engine is already turbocharged one. Exhaust coming from

engine is passed through turbine which makes it to rotate. Turbine rotates common shaft which is connected to compressor. Now exhaust coming out from the turbine which is going to atmosphere is used for the further work which is modified setup with new turbocharger and Wastegate setup. Also after compressor the intercooler is fitted for medication purpose. Use of intercooler improves the volumetric efficiency and reduces NO emissions. Now Wastegate fitted is modified setup for turbocharger. This Wastegate provided with facility of bypassing the exhaust through turbine.

Wastegate fitted provides facility of bypassing the exhaust at various positions. For further mentioned work we have selected three types of opening as stated below,

1) 20 % closed position of Wastegate
   At this position 20 % of total exhaust is bypassed, it means 80 % of Wastegate valve is open and 80 % of total exhaust is bypassed to atmosphere.
2) 50 % closed position of Wastegate
   At this position 50 % of total exhaust is bypassed, it means 50 % of Wastegate valve is open and 50 % of total exhaust is bypassed to atmosphere.
3) 80% closed position of Wastegate
   At this position 80 % of total exhaust is bypassed, it means 20 % of Wastegate valve is open and 20 % of total exhaust is bypassed to atmosphere.

Engine is maintained at fix RPM and above three conditioned are tested and emissions at both ends that is passing through Wastegate and which is not passing through Wastegate valve. For mentioned work engine speed is maintained at 1000 RPM, 1500 RPM, 2000RPM.Also engine is maintained at 50 %and 100 % load. This is done with dynamometer provided. The observations taken at this all conditions which is tabulated below.

For intercooler we passed the water through the coiled structure and compressor air allowed to pass over the coiled pipe structure which contains cold water.so thus air got cooled by convection. To study exact intercooling effect mass flow rate of water is varied. Three conditions of mass flow rate are taken into consideration first one is without water, second one with 180 ml/20 sec and third one 390ml/20 sec. how can this different mass flow rate can affect intercooling phenomenon is studied.

At Constant Speed of 1000 RPM		Used exhaust emission			Unused exhaust emission		
Load	Wastegate position	CO	HC	CO2	CO	HC	CO2
50	X1=20% closed	0.04	8	3.9	0.04	7	3.8
	X2=50% closed	0.03	7	3.8	0.03	6	3.7
	X3=80% closed	0.02	5	3.7	0.02	3	3.6
100	X1=20% closed	0.02	8	7.1	0.02	4	7
	X2=50% closed	0.03	5	7	0.03	3	6.9
	X3=80% closed	0.03	5	7	0.0	2	6.8
	closed				3		
At Constant Speed of 1500 RPM							
50	X1=20% closed	0.02	6	3.7	0.02	6	3.6
	X2=50% closed	0.02	7	3.6	0.02	4	3.5
	X3=80% closed	0.02	4	3.5	0.02	3	3.4
100	X1=20% closed	0.01	5	6.2	0.01	3	6.1
	X2=50% closed	0.01	3	6.1	0.01	2	6
	X3=80% closed	0.01	2	6.0	0.01	1	6.1
At Constant Speed of 2000 RPM							
50	X1=20% closed	0.01	6	3.2	0.01	4	3.1
	X2=50% closed	0.01	5	3.1	0.01	3	3
	X3=80% closed	0.01	3	3	0.01	2.8	2.8

Table 2: Turbine Reading

Sr.	Volumetric Efficiency before Intercooler	Volumetric Efficiency after Intercooler	% increase in efficiency	Sr.	Volumetric Efficiency before Intercooler	Volumetric Efficiency after Intercooler	% increase in efficiency
1	0.3336	0.3745	4.099	10	0.3480	0.4001	5.207
2	0.3336	0.3835	4.992	11	0.3335	0.3835	5.004
3	0.3360	0.3869	5.082	12	0.3217	0.3703	4.864
4	0.3383	0.3869	4.852	13	0.3283	0.3802	5.194
5	0.3437	0.3935	4.98	14	0.3277	0.3769	4.929
6	0.3464	0.3968	5.034	15	0.3300	0.3769	4.693
7	0.3411	0.3935	5.237	16	0.3164	0.3637	4.734
8	0.3388	0.3902	5.137	17	0.3157	0.3670	5.131
9	0.3353	0.3869	5.16	18	0.3216	0.3736	5.201

Table 3: Intercooling Reading (1000RPM)

Sr. No.	Volumetric Efficiency before Intercooler	Volumetric Efficiency after Intercooler	% increase in efficiency	Sr. No	Volumetric Efficiency before Intercooler	Volumetric Efficiency after Intercooler	% increase in efficiency

1	0.4569	0.5218	6.490	10	0.4844	0.5510	6.653
2	0.4726	0.5378	6.510	11	0.4427	0.5063	6.369
3	0.4606	0.5249	6.431	12	0.4403	0.5031	6.281
4	0.4454	0.5064	6.100	13	0.4359	0.4954	5.951
5	0.4356	0.4962	6.067	14	0.4381	0.5008	6.270
6	0.4669	0.5318	6.486	15	0.4514	0.5128	6.143
7	0.4642	0.5290	6.480	16	0.4532	0.5149	6.170
8	0.4531	0.5188	6.562	17	0.4318	0.4926	6.084
9	0.4557	0.5222	6.649	18	0.4234	0.4824	5.903

Table 4: Intercooling Reading (1500RPM)

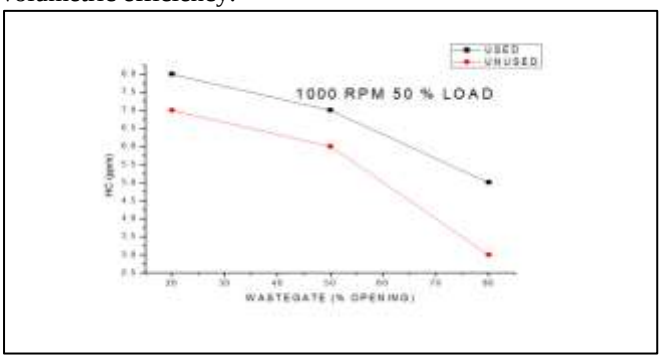
Graphical presentation of above observations is presented below

All above graphs explains the effect on emissions for current Wastegate modification. Graph 1 and 4to explains about HC and CO2 emission at 1000 rpm and 50 %, 100% load. It shows continuous reduction in emission when opening is increased gradually from 20% to 80%.also it can be seen that emissions are less at unused (Wastegate outlet) comparatively than used (turbine outlet).

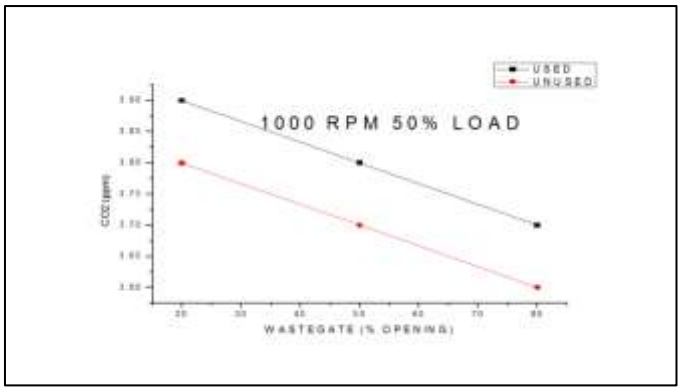
Graph 5 and 8 to explains about HC and CO2 emission at 1500 rpm and 50 %, 100% load. It shows continuous reduction in emission when opening is increased gradually from 20% to 80%.also it can be seen that emissions are less at unused (Wastegate outlet) comparatively than used (turbine outlet).

Graph 9 and 10 to explains about HC and CO2 emission at 2000 rpm and 50 %, 100% load. It shows continuous reduction in emission when opening is increased gradually from 20% to 80%.also it can be seen that emissions are less at unused (Wastegate outlet) comparatively than used (turbine outlet).

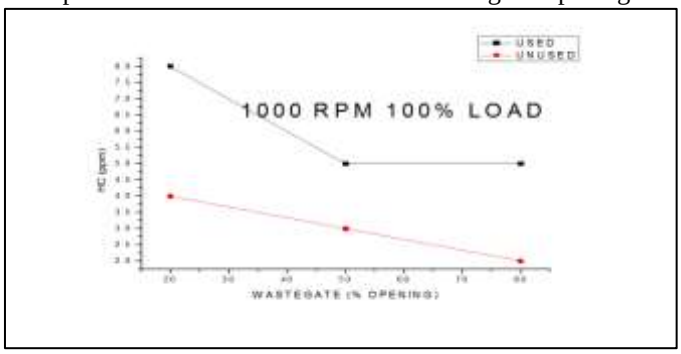
Table 3 and table 4 explains about how volumetric efficiency increases at 1000 RPM and 1500 RPM. It shows that there is considerable increase in volumetric efficiency. Experiments shows maximum of 5 to 6 % increase in volumetric efficiency.



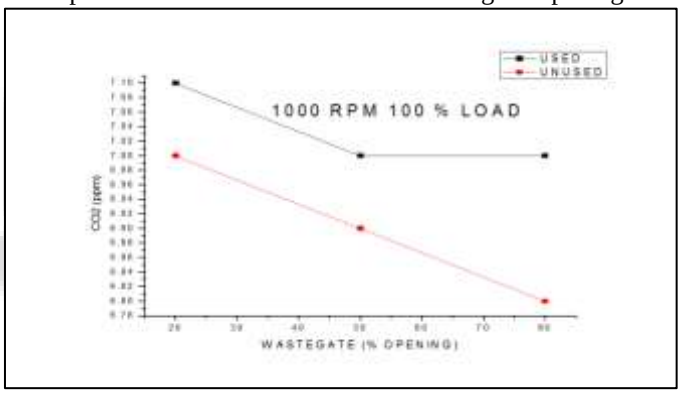
Graph 1: HC Emissions At Various Wastegate Opening



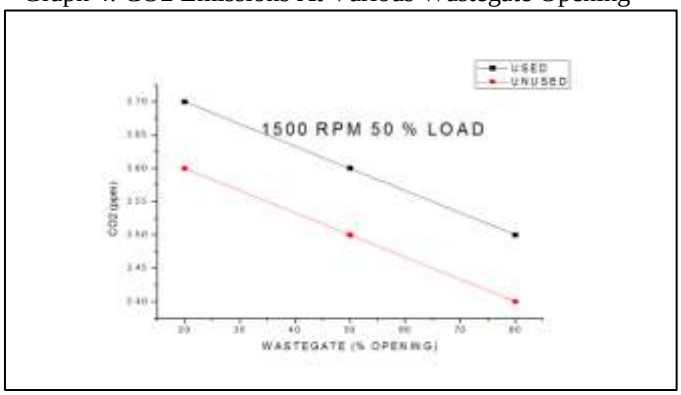
Graph 2: CO2 Emissions At Various Wastegate Opening



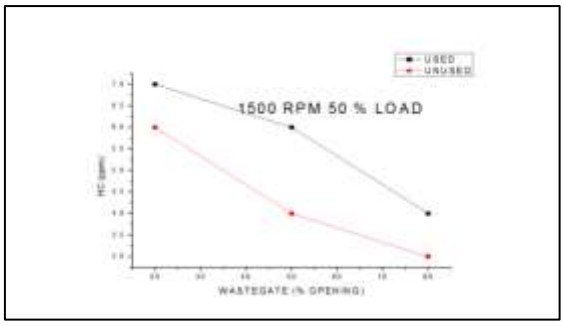
Graph 3: HC Emissions At Various Wastegate Opening



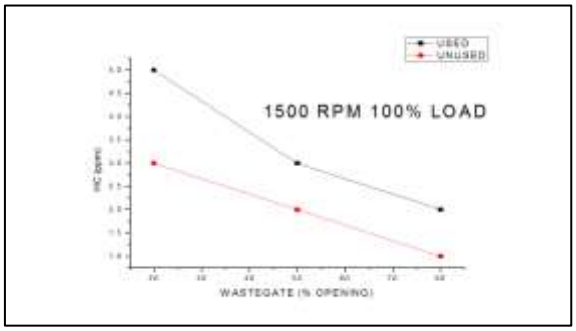
Graph 4: CO2 Emissions At Various Wastegate Opening



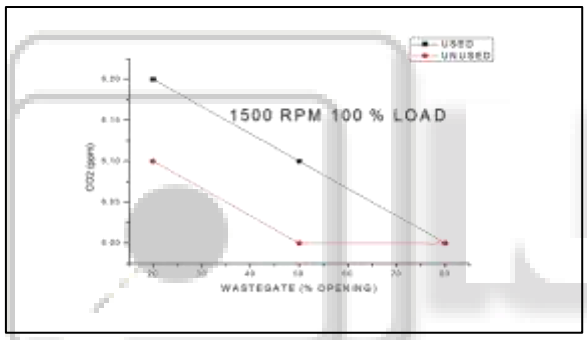
Graph 5: CO2 Emissions At Various Wastegate Opening



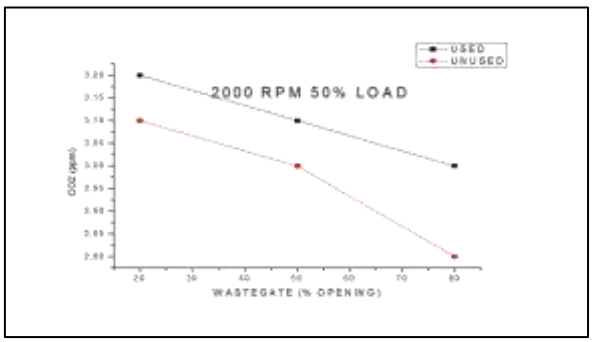
Graph 6: HC Emissions At Various Wastegate Opening



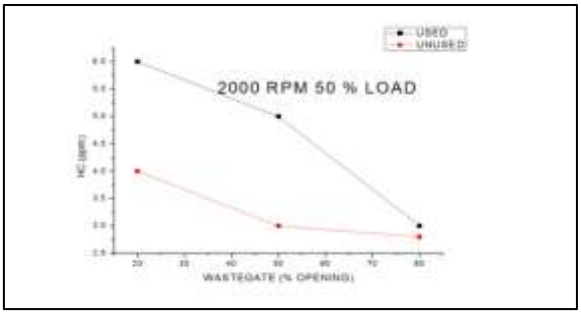
Graph 7: HC Emissions At Various Wastegate Opening



Graph 8: CO2 Emissions At Various Wastegate Opening



Graph 9: CO2 Emissions At Various Wastegate Opening



Graph 10: HC Emissions At Various Wastegate Opening

V. CONCLUSION

Current work represents effect of Wastegate operated turbocharger on engine emissions at various speed and load conditions and effect of intercooler on engine performance which is mentioned below.

1) When engine speed and load kept constant and Wastegate opening changed from 20% to 80%, it is found that both HC and CO2 emissions are decreasing continuously.
2) It is also concluded that Wastegate outlet (Unused) has less emissions than turbine outlet (Used).
3) When engine load is kept constant and speed is increased gradually it is found in reduction in emissions of CO, HC and CO2.
4) When load is increased and speed condition kept same again there is reductions of CO, HC and CO2
5) Also it is found that when load kept constant and speed increases and Wastegate position being 20 % closed, then Wastegate outlet has fewer emissions than turbine outlet.
6) Due to intercooler volumetric efficiency is increased by up to 5-6 %. As RPM increases the volumetric efficiency also increase up to certain extent.so it is concludes intercooler is more effective at higher speeds.

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