INLET AIR HUMIDIFICATION TECHNIQUE IN CI ENGINES- FOR REDUCTION OF NOx

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Abstract - *Diesel engine is the most efficient among all types of IC engines due to its better thermal efficiency and high fuel economy. Hence, it is widely used in automobiles, industrial units and power plants. The main problem regarding diesel engine is emission of NOx in larger quantity. The control of oxides of nitrogen from diesel engines has become major crisis, because of its hazardous effect on human life. In order to meet progressively stringent regulation on NOx from diesel engines, an inlet air humidification unit has been developed. A single cylinder direct injection SAMSON diesel engine has been retrofitted and assembled with an air humidification system. Installed in the air inlet tract, air humidification system achieves adiabatic cooling by injecting water through special atomizing nozzles producing a fog of very fine droplets, which evaporate almost instantaneously. Cooling the inlet air increases its density, improving mass flow and thus allowing the engine to operate at a higher capacity. The end result is better efficiency, with higher performance and reduced emissions.*

Key Words: CI Engines, Humidification Technique, Reduction of NOx, Reduced emissions, Diesel Engine.

1.INTRODUCTION

The primary aim of this project is to reduce NOx emissions coming out of a diesel engine. A novel way to decrease the amount of NOx from the diesel engine is to cool the inlet air by introducing water in form of fog of very fine droplets into the air inlet tract. This would decrease the combustion temperature to the extent which is not enough to form NOx. Cooling the inlet air also increases its density thus increasing the mass flow rate, hence increasing the output power by not more but noticeable amount. Currently such a technique is in use for heavy duty diesel engines used in large power plants, ships etc. wherein the space constraint is not applicable for installation of the humidification unit. An attempt is made in this project, to miniaturize the humidification unit in order to fit it in the automobiles like trucks, buses, cars, etc.

Thus, some experiments were carried out on a single cylinder diesel engine retrofitted with the humidification unit to note the reduction in amount of NOx emitted by the diesel engine.

1. Literature Survey

1.1 Three phases of combustion in Diesel Engines:

Combustion in diesel engines can be divided into 3 different phases. The first phase involves evaporation and mixing of the early injected fuel with the air in the cylinder. During this phase, certain pre-reactions occur prior to actual combustion. During this delay period, fuel air mixture is forming continuously. As soon as the actual combustion starts, the fuel air mixture formed during the delay period ignites and burns rapidly, as it is already mixed and ready to burn. This is the second phase of combustion or premixed phase, which typically produces the highest pressure rise rates.

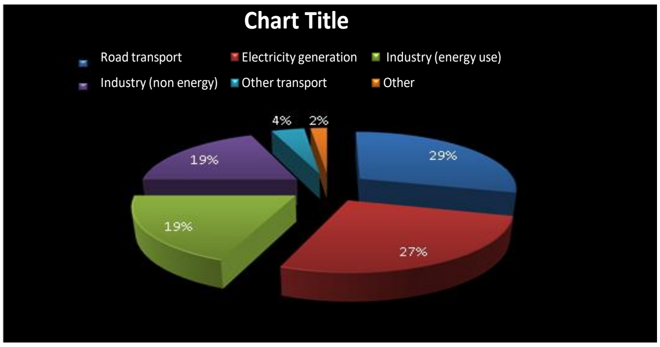
After this pre-mix of fuel and air formed during the delay period is consumed, the combustion rate becomes controlled by the rate of evaporation and mixing of the fuel and air. This is the third phase or diffusion controlled phase. The length of the delay period is a function of the fuel ignition characteristics and the temperature in the combustion chamber. Reducing the length of the delay period reduces the amount of fuel consumed in the second phase. The second phase of combustion involves high temperatures and pressures because the combustion rate is high.

Also, because it happens early in the combustion process the burnt gas from this phase will remain at high temperatures for a relatively long time due to further compression by the rising cylinder pressure. This phase is likely to produce high NOx concentrations and is more important in medium speed engines.

1.2 Mechanism of NOx formation in Diesel Engines:

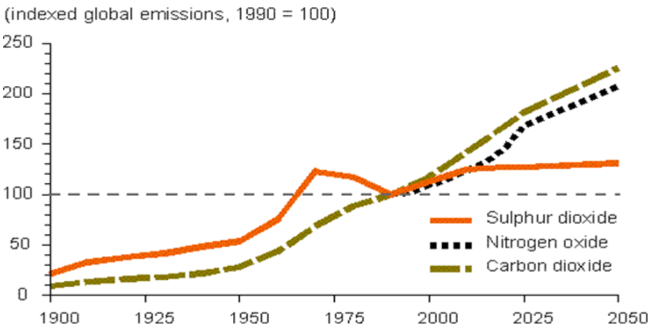
Nitrogen is normally an inert gas. At the temperatures of the burning fuel spray, (about 2000K to 2500K) the nitrogen in the air is no longer inactive and some will combine with oxygen to form oxides of nitrogen. Initially mostly nitric oxide (NO) is formed. Later, during the expansion process and in the exhaust, some of this NO will convert to nitrogen dioxide (NO_2) and nitrous oxide (N_2O), typically 5% and 1%, respectively, of the original NO. The mix of oxides of nitrogen is called NOx.

1.3 NOx formation by various sectors:



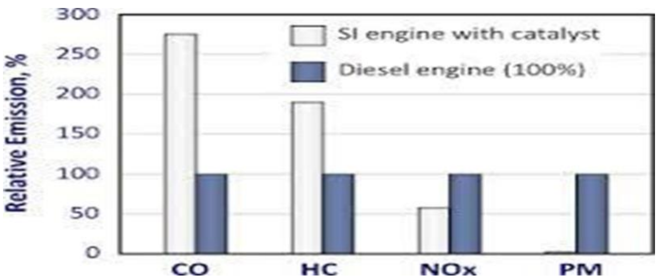
It can be noticed from the above pie chart that, the major contribution of NOx is by Road transport sector (29%) and Electricity generation sector (27%). Hence measures should be taken to control the amount of NOx exhaust by these two sectors.

1.4 Change in NOx emissions along the years:



It can be observed from the above graph that, the amount of emissions along the years is increasing. And the NOx emissions are predicted to increase furthermore along the years. Thus a control action must be taken to reduce the amount of NOx in the emissions.

1.5 NOx emissions from Diesel and Petrol engines:



It can be observed from the above graph that, the NOx produced by diesel engines are way too higher than those produced by petrol engines, reason being NOx are formed at very high temperatures of order more than 1100^0C. Whereas in a diesel engine the combustion temperature is around 1100^0C, hence the amount of NOx formed by diesel engines is greater. Thus controlling NOx emissions from diesel engines is of greater concern.

1.6 NOx control technologies:

There are different methods to control NOx coming out from the exhaust of a diesel engine. The control methods discussed here are applicable to diesel engines in general, regardless of the engine's application. The NOx control measures that were evaluated are:

- Injection Timing Retard.
- Exhaust Gas Recirculation.
- Ceramic Coating.
- Alternative Fuels.
- Engine Electronic Controls.
- Fuel Injection Treatment.
- Variable Geometry Turbocharging.
- Atomic Oxygen Aftertreatment.
- Ceramic Coating of Engines.
- Water Injection i.e. humidification.

1.7 Limitations of other methods of reducing NOx compared with humidification technique:

1. Since EGR reduces the available oxygen in the cylinder, the production of particulates is increased when EGR is applied. The deliberate reduction of the oxygen available in the cylinder will reduce the peak power available from the engine.
2. Drawbacks in catalytic conversion are, platinum has low activity for the conversion of NOx and is costly relative to palladium.
3. Ceramic coating is a costly process and usually is not budgeted into many modification projects for this very reason.
4. VGTs are very complex and require complicated control systems. The small moving parts, sensors, and controllers make them more expensive. All the parts are exposed to extreme temperatures of over 1000^0F making them wear quickly.
5. As it can be observed that, other methods to reduce NOx have many drawbacks which cannot be neglected in order to solely reduce the NOx emissions. Hence we choose the simplest method for reduction of NOx emissions i.e. inlet air humidification, which eliminates all the above drawbacks.

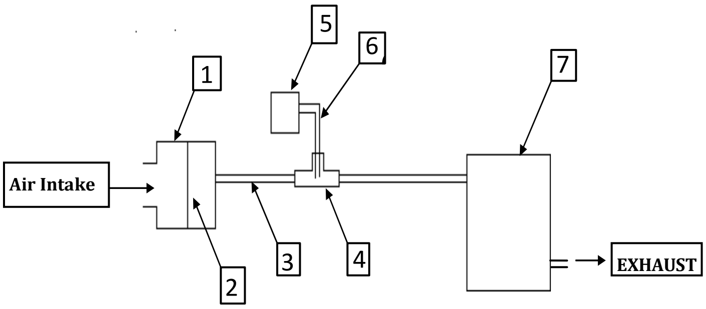
2. DESIGN AND EXPERIMENTATION

2.1 Selection of the method:

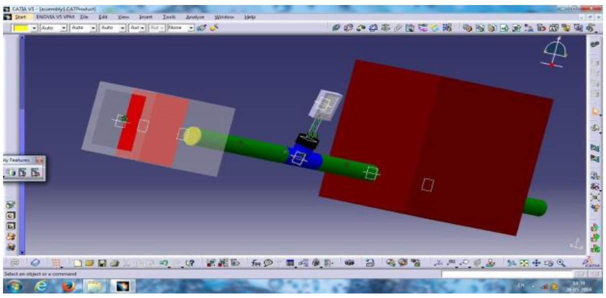
In our project we have used HUMIDIFICATION technique as a NOx control measure. Water in the combustion gases reduces the flame temperature which results in a decrease in the NOx production. A small amount of NOx reduction also occurs through the scavenging of atomic oxygen by water molecules, however, this mechanism is a minor source of NOx reduction.

Some studies have shown that water injection has the added benefit of improving the specific fuel consumption. In general, water injection may be classified into direct injection methods (fuel side) and fumigation (air side) methods. Both these methods are known to reduce NOx emissions and both have their advantages and disadvantages.

2.2 SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP:



2.3 3-D MODEL OF HUMIDIFICATION UNIT:



2.4 COMPONENTS:

- AIR BOX
- 1" PIPE
- CLOTH DIAPHRAGM
- T-FITTING
- DIGITAL DISPLAY WITH RH MEASUREMENT SENSOR
- DIESEL ENGINE

2.5 TESTING MACHINE: TESTO 350 GAS ANALYSER

Testo 350 is a portable emission analyser, wherein we get the digital readings of amount of each gas coming out from the exhaust.

Specifications of Testo 350 gas analyser

Feature	Values
Battery charge time	<6hr
Battery operation time	2.5hr (with gas cooler and IR module) / 4.5hr (without gas cooler and IR module)
Dimensions	12.99 x 5.03 x 17.24 in.
Housing	ABS URL 94V0
Weight	10.58 lbs. (completely assembled)
Memory	250000 readings
Flue gas overpressure	20.07 "H_2O
Underpressure	max. 120.43 "H_2O
Pump volumetric flow rate	1 l/min (controlled), standard litre ±0.1l/min
Hose length	max. 53 ft. (corresponds to five probe hose extensions)
Diluting gas	Fresh air or nitrogen
Flue gas dust load	max. 20g/m³
Humidity load	max. 158 °F td at measuring input
USB interface	USB 2.0
Trigger input	Voltage: 5...12V (falling or rising flank) Pulse width: >1 s Load: 5V/max. 5mA, 12V/max. 40mA
Bluetooth option	Class1 module (reach <100m in open field)

2.6. PROCEDURE OF TESTING

1. We transported the engine and all other components required for the testing at NCL. We arranged the experimental setup prior to the testing.
2. Before starting of actual testing, we started the engine and allowed it to run for around 40 minutes so that it could warm-up and give appropriate results while testing.
3. First reading was noted without installing the humidification unit. The engine was kept near a condenser present at the testing area for allowing dry air to enter the engine. The temperature at this point of time was noted to be 43.50C and RH of the air was 25%.
4. The probe of exhaust gas analyser was then kept in the flow of flue gases coming out from the exhaust of engine, and the corresponding readings of composition of exhaust gas was noted.
5. Later the humidification unit was installed, and we sprayed water on the cloth diaphragm from the opening in the air box, and the corresponding temperature and RH was noted after 9 minutes (i.e. the RH remained constant for 9 minutes). We also noted the result displayed by exhaust gas analyser.
6. Later we increased the amount of water sprayed into air box, and thus noted the corresponding temperature and RH of the inlet air till the point it remained constant, and followed this procedure till we finally got RH as 70%. The exhaust gas readings were noted for each value of RH.
7. Finally a result table was drawn from the readings of the test.

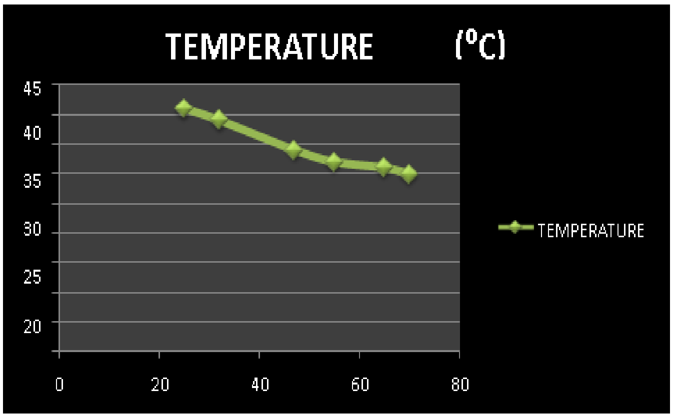
3. RESULT AND ANALYSIS

3.1. EXPERIMENTAL READINGS:

RH (%)	TEMPERATURE (°C)	NOx (ppm)	NO (ppm)	CO_2 (%)	CO (ppm)
25	41	7.8	7.8	0.31	70
32	39	5	5	0.29	68
47	34	3	3	0.25	65
55	32	2	2	0.23	63
65	31	1.5	1.5	0.2	76
70	30	1	1	0.31	78

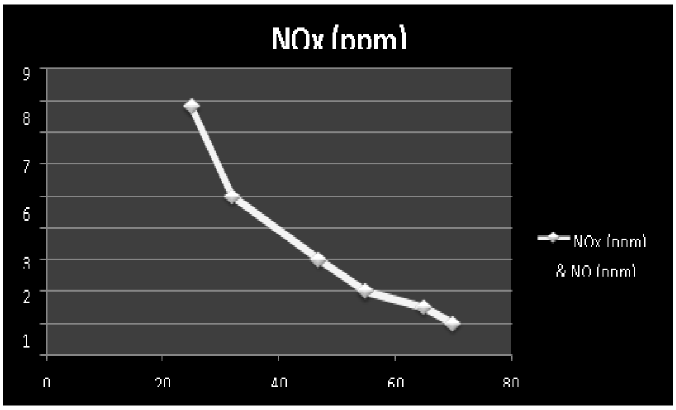
3.2. GRAPHS FOR THE RESULTS:

1. **Graph of Temperature (°C) Vs RH (%)**



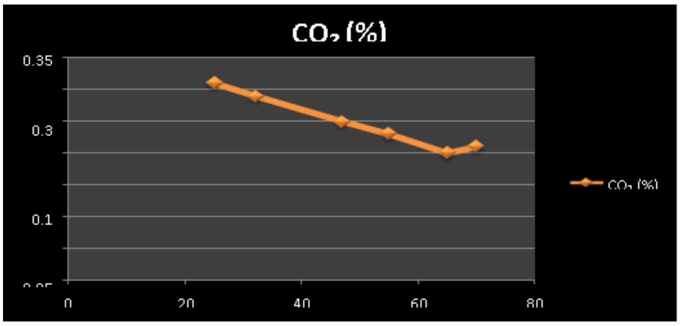
As we can observe in the graph, with increasing RH the temperature goes on decreasing which is in resemblance with the expected results.

2. **Graph of NOx (ppm) and NO (ppm) Vs RH (%)**



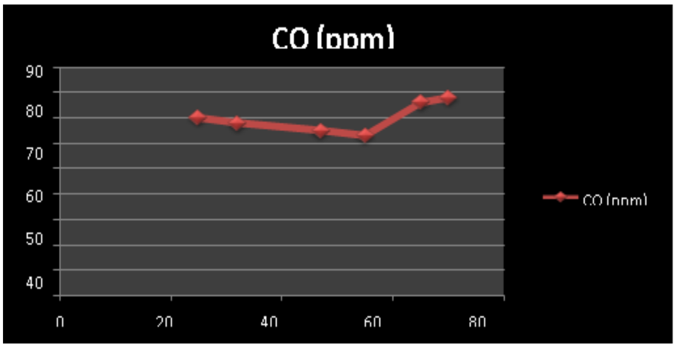
It can be observed from the graph that, with increase in the RH the amount of NOx and NO from the exhaust decreases by considerable amount.

3. **Graph of CO_2 (%) Vs RH (%)**



It can be observed from the above graph that, for RH value of 25% the amount of CO_2 in the exhaust is 0.31% and for higher values of RH the amount of CO_2 goes on decreasing, i.e. for 65% RH the amount of CO_2 is 0.2%.

4. **Graph of CO (ppm) Vs RH (%)**



As observed from the graph the amount of CO in the exhaust increases at higher values of RH. This can be counted as a disadvantage of humidification technique, but as we can see that the increase is not too large and can be considered to be within the permissible limits.

4. RESULT AND CONCLUSION

4.1 Advantages and Disadvantages:

Advantages:

- Reduction in NOx and CO_2.
- Water resource easily available.
- Comparably cheaper than other methods.
- Simple design and working.
- Increase in volumetric efficiency.
- Increase in power
- Complete combustion due to excess availability of oxygen.
- Decrease in fuel combustion.

Disadvantages:

- Increase in CO in small quantity.
- Water needs to be in pure form.
- Durability of engine yet not tested.

CONCLUSION:

1. ***Reduction of NOx from the exhaust gas:***
   With increase in the RH the amount of NOx and NO from the exhaust decreases by considerable amount.

2. ***Reduction of CO_2 from the exhaust gas:***
   For RH value of 25% the amount of CO_2 in the exhaust is 0.31% and for higher values of RH the amount of CO_2 goes on decreasing,

3. ***Effect on CO:***
   The amount of CO in the exhaust decreases upto particular RH but it increases at higher values of RH. The increase is not too large and can be considered to be within the permissible limits

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