Exhaust Gas Recirculation as a Nobel Technique for NOx Emission Control

Abdul Hannan, S. M. Khaled Khan, Md. Mashrur Islam

***Abstract*— The world civilization is growing very fast and for this reason the utilization of internal combustion engines is increasing day by day. Environmental pollution concern and energy crisis all over the world recently forced the attention to control engines exhaust emissions and energy savings. But this internal combustion engine increases both regulated and unregulated emissions. This study shows the effect of hot EGR (Exhaust Gas Recirculation) and cold on diesel combustion and exhaust emission with neat diesel fuel in a diesel engine. EGR is a well-known process to reduce NOx. For the EGR system more NOx emission is reduced and for the use of EGR. Comparatively better overall engine emission is found with the EGR system.**

***Index Terms*— Pollutant, NOx, Nitrogen, EGR.**

I. Introduction

DIESEL engine is an internal combustion engine because the combustion of fuel takes place inside the engine cylinder. The running cost of diesel engine is low because lower cost of fuel is needed in diesel engine. The thermal efficiency of diesel engine is about 40% which is higher than SI engine. DI diesel engine is preferable than IDI diesel engine because in DI diesel engine the fuel consumption is 15-20% lowers than IDI diesel engine [1]. Besides the combustion phenomenon of DI diesel engine is easier than IDI diesel engine because in DI diesel engine there is a single combustion chamber. As for the fuels in diesel engines, research has been conducted to clarify the effects of fuel properties on diesel combustion and exhaust emissions. Over recent past years, stringent emission legislations have been imposed on NOx, smoke and particulate emissions emitted from automotive diesel engines worldwide. Diesel engines are typically characterized by low fuel consumption and very low CO emissions. However, the NOx emissions from diesel engines still remain high. Hence, in order to meet the environmental legislations, it is highly desirable to reduce the amount of NOx [2]. Diesel engines are predominantly used to drive tractors, heavy lorries and in the pollution aspect. For reducing vehicular emissions, baseline technologies are being used which include direct injection, turbo-charging, air-to-air inter-cooling, combustion optimization with and without swirl support, multi-valve cylinder head, advanced high-pressure injection system i.e. split injection or rate shaping, electronic management system, lube oil consumption control etc.

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II. Literature Review

The development of the compression-ignition (CI) engine, also known as Diesel engine, was mainly due to the work of Dr. Rudolf Diesel, who got a patent of his engine in 1892 [3]. Today the CI engine is a very important prime mover, being used in buses, trucks, locomotives, tractors, pumping sets, and other stationary industrial applications, small and medium electric power generation and marine propulsion. The first CI engine was started in August 10, 1893. The principle that compressed air was capable of igniting a fuel, in this particular case gasoline, was thus demonstrated. However, the combustion was sporadic, due to the defective fuel injection system. The injection system and the engine construction were improved only four years later, the efficiency of the engine was 30.2% [4]. After another four years, 1901, and with the contribution from Jonas Hesselman working with the design of the combustion space, the efficiency for the CI engine was raised to 36%.Because of the utilization of higher compression ratio 12:1 to 22:1 the forces coming on the various parts of the engine are greater and therefore heavier parts are necessary [5]. Also because of heterogeneous mixture, lean mixture (large air-fuel ratio) is used. Both the factors result in a heavier engine. The smoke and odor are the result of the nature of diesel combustion phenomenon, i.e. incomplete combustion of a heterogeneous mixture, and droplet combustion, compression-ignition engines, because of their varied applications, are manufactured in a large range of sizes, speeds, and power output. The emission researches of diesel engines are going on mostly for the regulated emissions such as NOx, PM and others due to severe regulation standards of that components. Emission standard specify the maximum amount of pollutants allowed in the exhaust gases discharged from a diesel engine. Choongsik Bae and Junemo Koo from Korea Advanced Institute of Science and Technology [6] reported that EGR is widely used to reduce NOx, pumping loss, and to increase thermal efficiency in automobile engines. However, it does have some disadvantages such as its detrimental effects on combustion stability. Baert et al. [7] showed that 50% reduction NOx reduction and high reduction of thermal loading can be achieved with 10% EGR rate at full load condition in the maximum torque and rated speed range.

Tabata et al. [8] reported that a large quantity of recycled gas could be introduced into combustion chamber under the stoichiometric air/fuel ratio condition, and it resulted in much lowered NOx emissions and reduced fuel consumption. They also made it possible to charge combustible mixture independently from combustion air and recirculated exhaust gas introduced from intake port in order to stratify the mixture. This work examined the effect of EGR on the combustion characteristics in a 4-cylinder LPG SI engine. This experimental study investigated various effects of both hot- and cooled-EGR on combustion stability so as to pursue the improved thermal efficiency and fuel economy. Hountalaous et al. [9] examine the effect of EGR temperature on a turbocharged DI diesel engine with different engine speeds, and they reported that high EGR temperature affects the engine brake thermal efficiency, peak combustion pressure, air fuel ratio and also soot emissions, and the combined effect of increased temperature and decreased O_2 concentration resulted low NOx emissions. Also, they suggested that EGR cooling is necessary to retain the low NOx emissions and prevent rising of soot emissions without affecting the engine efficiency at high EGR rates. Ken Satoh et al. [10] investigated on a naturally aspirated single cylinder DI diesel engine with various combinations of EGR, fuel injection pressures, injection timing and intake gas temperatures affect exhaust emissions and they found that NOx reduction ratio has a strong correlation with oxygen concentration regardless of injection pressure or timing. NOx reduction ratio is in direct proportion to intake gas temperatures. EGR may adversely affect the smoke emission because it lowers the average combustion temperatures and reduces the oxygen intake gases, which in turn keeps soot from oxidizing. Also, they suggested that for a given level of oxygen concentration the cooled EGR reduces more NOx with less EGR rates than does at hot EGR. Istituto Motori - C.N.R., Napoli – ITALY [11] reported that, the effect of the clean and cold EGR flow on the performance of a diesel engine running under Low Temperature Combustion conditions is investigated by means of experimental tests on a single-cylinder research engine. The engine layout was “ad hoc” designed to isolate the effect of the clean and cold recirculated gas flow on the combustion quality. The results have shown the possibility to increase the EGR rate by EGR flow temperature reduction, with a decrement of both NOx and PM emissions, at the same fuel consumption, highlighting that the intake manifold temperature is the main factor affecting the engine performances. Saravanan et al. [12] performed a series of test on a single cylinder water cooled DI diesel engine with hydrogen was used as dual fuel mode with EGR technique and their results showed increase in brake thermal efficiency and lowered smoke level, particulate and NOx emissions due to absence of carbon in hydrogen fuel. Das and Mathur [13] reported that Many theoretical and experimental investigations have well established the fact that the concentration of NOx in exhaust is related and anything is done to reduce this temperature will reduce the oxides of nitrogen EGR is one of this method to oxides of nitrogen.

III. Main Harmful Pollutants In Diesel Exhaust

Oxides of nitrogen are a combination of nitric oxide (NO) and nitrogen dioxide (NO_2) the air supplied for combustion contains about 77% of nitrogen at lower temperature. The nitrogen is inert but at temperature higher than 1100c nitrogen reacts with oxygen. Therefore, higher temperature and availability of oxygen are two main reasons for the formation of NOx. When the proper amount of oxygen is available with highest local peak combustion temperature highest amount of NO_2 is formed in diesel exhaust. Organic and inorganic compounds of higher molecular weights are exhausted in the form of small size particles of odor of 0.02 to 0.06 micro bul.100 of separate organic compounds can be formed when the combustion reaction is not complete [14]. It is the product of incomplete combustion due to insufficient amount of air in the air fuel mixture. It is not formed in large quantities due to excess amount of oxygen available during combustion and generally not in concern. The two main reasons for the formation of NOx are high temperature and availability of oxygen. Engine design and the model of vehicle operation affect the NOx concentration in exhaust. A pre combustion chamber engine produces less NOx than a direct injection engine due to lower peak temperature. The maximum NOx formed at ratios between 14:1 and 16:1. At lean and rich air fuel mixtures the NOx concentration is comparatively low. At high fuel air ratio, the additional fuel tends to cool the charge, so the localized peak temperature is lowered resulting in drop in NOx concentration. Injected system and time also significantly affect the NOx formation. Also, the variations in fuel characteristics such as Cetane number, viscosity, modules of elasticity and rate of burning etc. all contributes to differences in NOx obtained from different levels.

IV. Materials And Methods

The engine used in the experiment is single cylinder water cooled, NA, DI diesel engine. The experiment was conducted with conventional diesel fuel. The rpm was measured directly from the speed meter attached with the engine output shaft. The outlet temperature and exhaust gas temperature were measured directly from the thermometer attached with the engine. The fuel consumption was measured directly from the burette attached with the engine. The injection timing was set in 13 degree after TDC (top dead center). The stopwatch was started when the fuel level passes the top space and stops it when it passes second. The any test of a diesel engine was increased if the air flow to the engine was measured. Air consumption was measured using the air flow meter which consists of sharp edge- machined brass orifice carried in the side of steel air box which supported on a stand and connected by flexible hose pipe in the air inlet of the engine. The engine was first run for allowing it to reach in the steady state condition. Then the reading for 900, 1100, 1200, 1400 rpm was taken in no EGR condition. The load was varied with 0, 4, 7, 10, 14 lbs by changing the flow of water that passes through the pump. The exhaust gas including NOx and CO was measured by a portable digital gas analyzer (IMR 1400). By the same process the reading for hot EGR and cold EGR was taken. The percentage of EGR was taken 10%, 15% and 20%.

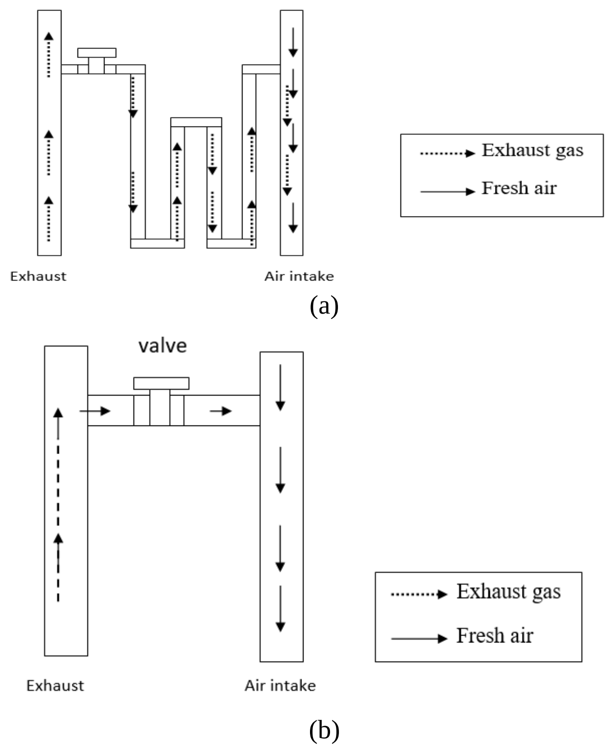

Fig.1: Experimental setup schematic (a) Cold EGR, (b) Hot EGR.

V. Results And Discussions

The Figure-2 shows the efficiency at different rpm and at different EGR system. Here it is shown that the efficiency is increased with increasing rpm and after a certain speed it falls with increasing rpm. The maximum efficiency is obtained at 1200 rpm the efficiency is slightly reduced in hot EGR and reduced in cold EGR with increasing rpm because EGR reduces peak combustion temperature which occur more incomplete combustion. When EGR is applied, fresh air flow decreases, and engine requires the same amount of fuel thus F/A ratio increase. Hence fuel consumption increases with EGR and efficiency is reduced in hot EGR and cold EGR system.

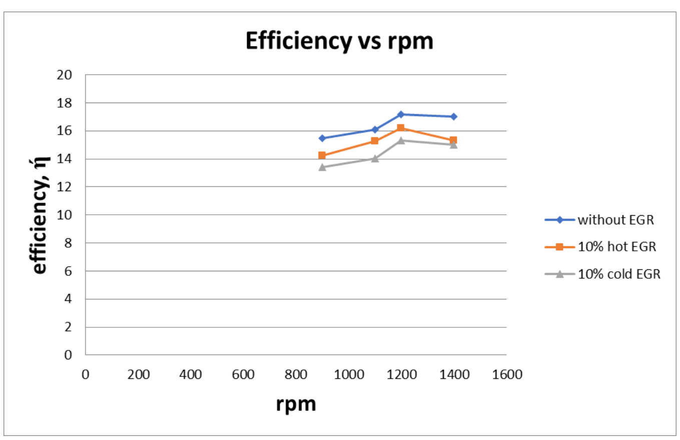

Fig.2: Efficiency at different rpm and at different EGR rate in 6.35 kg load.

Whereas, Figure-3 demonstrates the effect of variation of load on brake thermal efficiency of engine. Brake thermal efficiency increases with increase in load. When load is increased, torque is also increased. As torque increases, according to the formula, rake thermal efficiency also increases. Thus, when engine load is increased, brake thermal efficiency is also increased. At the same time with the increase in percentage of EGR, brake thermal efficiency decreases. When EGR is applied and increased, availability of air decreases. So, combustion does not occur as well as required. As a result, brake thermal efficiency decreases.

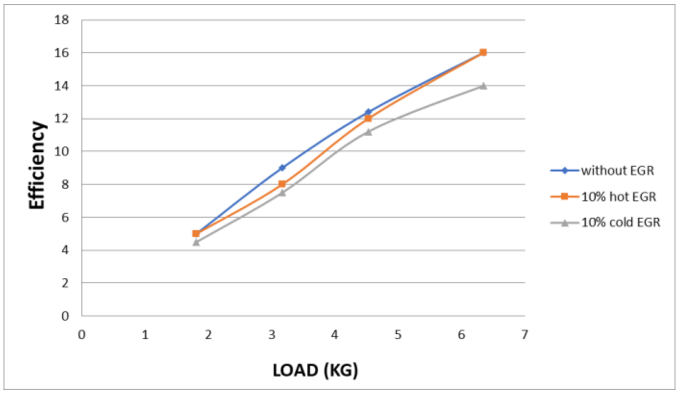

Fig.3: Effect on engine load on brake thermal efficiency at 1200 rpm.

The below two figure shows the effect of 15% and 20% hot EGR and cold EGR on NOx using diesel fuel in 1200 rpm. Those graphs can be described as same as 10% EGR rate. From figures, NOx is more reduced in 15% EGR rate and in 20% EGR rate than 10% EGR rate. It is because 15% hot EGR rate decreases the amount of air that enter in the combustion chamber more than 10% EGR rate. And in case of 15% cold EGR both the availability of oxygen and lower peak temperature is reduced than 10% EGR rate. So that NOx is reduced more in 15% EGR rate. 20% EGR rate can be explain by the same way. At 15% hot EGR rate NOx is reduced about 30% and in cold EGR rate NOx is reduced about 46%. At 20% hot EGR rate NOx is reduced about 43% and10% cold EGR rate NOx is reduced about 53%.

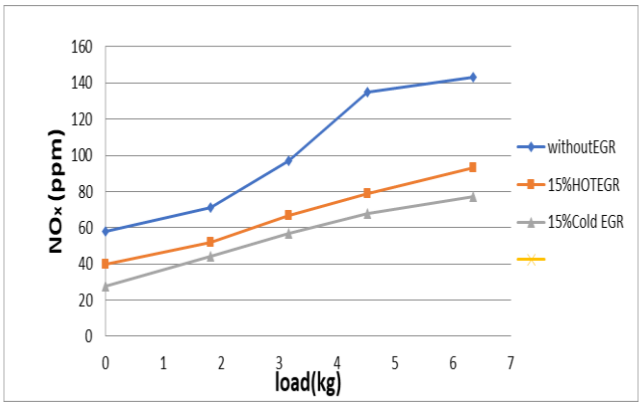

Fig.4: Effect of 15% hot EGR and cold EGR on NOx using diesel fuel in 1200 rpm.

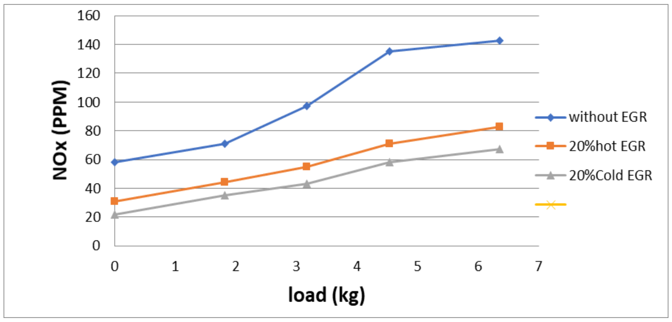

Fig.5: Effect of 20% hot EGR and cold EGR on NOx using diesel fuel in 1200 rpm.

The Figure-5 shows the effect of different % of EGR on NOx emission. From figure it is shown that NOx emission is reduced with increasing EGR rate because EGR reduces the availability of oxygen for combustion and reduces peak combustion temperature. So that NOx is reduced with increasing EGR rate. This effect is shown in Figure-6.

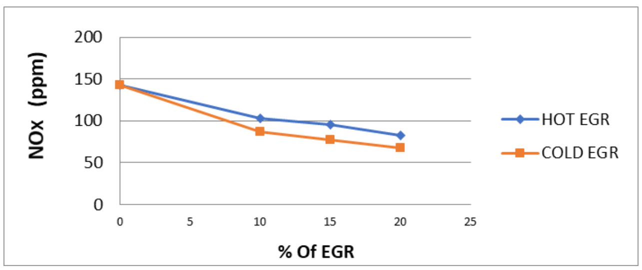

Fig.6: Effect of EGR rate on NOx emission at 1200 rpm.

VI. CONCLUSION

NO_X is increased with increasing load. With EGR NOx is reduced significantly. At 10% hot EGR rate NOX is reduced about 22% and10% cold EGR rate NOX is reduced about 39% but CO increases by 16%. At 15% hot EGR rate NOx is reduced about and 30% cold EGR rate NOx is reduced about 46% but CO increases by 34%. At 20% hot EGR rate NOx is reduced about 43% and10% cold EGR rate NOx is reduced about 53%. Brake thermal efficiency decreases more in cold EGR than hot EGR.

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