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Research on The Ultra-Low Emission Technology in Internal Combustion Engine

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Abstract: Increasing the efficiency of internal combustion engines is a technologically proven and cost effective approach to dramatically improving the fuel economy of the nation's fleet of vehicles in the near- to midterm, with the corresponding benefits of reducing our dependence on foreign oil and reducing carbon emissions. This review paper discusses on the research of ultra-low emission technology in internal combustion engine. Efficiency can be increased by improving combustion processes, minimizing engine losses such as friction, reducing the energy penalty of the emission control system and using recovered waste energy in propulsion. Compliance with exhaust emission regulations will be mandated and requires after-treatment technologies integrated with the engine combustion approaches. Fuels under consideration include hydrocarbon-based. Because of their relatively low cost, high performance, and ability to utilize renewable fuels, internal combustion engines, including those in hybrid vehicles, will continue to be critical to our transportation infrastructure for decades.

Keywords: Internal combustion, light duty vehicle, efficiency

1. Introduction

Air pollution's health risks are extremely serious. Bad air quality improves respiratory problems and raises the risk of life-threatening diseases [1-5]. A major contributor to emissions is passenger vehicles, which produce significant quantities of nitrogen oxides, carbon monoxide and other pollutants. Ultra-low emissions technologies provide us fuel-efficient vehicles that use less oil, cleaner fuels that produce fewer emissions. Ultra-low emission vehicles (ULEV) emits 75g/km of CO_2 or less. Improving ICEs is also a cost-effective CO_2 mitigation strategy. Additional CO_2 emissions reductions could also be gained through the use of bio-derived or other low-carbon fuels along with ICE design optimization. Low-emission systems use a number of key advanced technologies to dramatically reduce greenhouse gas emissions [6-7]. These technologies focus on a suite of innovative engineering association with CO_2 capture and storage. An emission performance standard is a limit setting thresholds that might require a different type of vehicle emission control technology.

1.1 Emissions

Emissions known as pollution discharged into the atmosphere by residential, commercial, and industrial facilities. Vehicle emissions are the gasses released through a vehicle's exhaust system. Carbon monoxide, hydrocarbons and

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*Corresponding author: amirk@uthm.edu.my sulfur-oxide along with nitrogen-oxides and particulates are all harmful vehicle emission that spew out of the exhaust gasses of an internal combustion engine [7-8].

1.2 Unburned Hydrocarbons (HC)

Volatile hydrocarbons also called volatile organic compounds (VOCs) can encompass a wide range of compounds, some of which are hazardous air pollutants. These compounds are discharged into the atmosphere when some portion of the fuel remains unburned or just partially burned. Some organics are carried over as unreacted trace constituents of the fuel, while others may be pyrolysis products of the heavier hydrocarbons in the gas. Volatile hydrocarbon emissions from reciprocating engines are normally reported as non-methane hydrocarbons (NMHCs).

1.3 Nitrogen Oxide (NO_x)

These pollutants cause lung irritation and weaken the body’s defense against respiratory infections such pneumonia and influenza. In addition, the assist in the formation of ground level ozone and particulate matter.

1.4 Carbon Monoxide (CO)

This odourless, colourless, and poisonous gas is formed by the combustion of fossil fuels such as gasoline and is emitted primarily from cars and trucks. When inhaled, CO blocks oxygen from the brain, heart and the other vital organs. Fetuses, newborn children, and people with chronic illnesses are especially susceptible to the effects of CO.

1.5 Carbon Dioxide (CO_2)

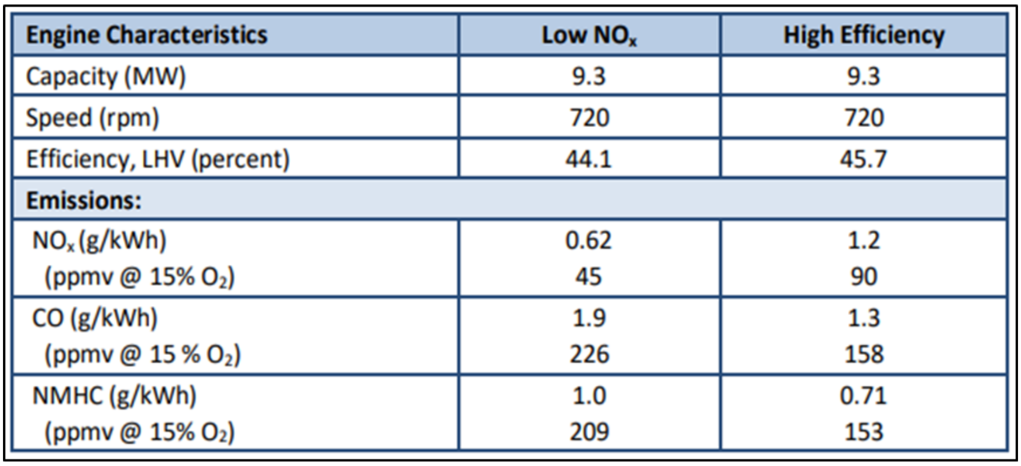
While not considered a pollutant in the ordinary sense of directly affecting health, emissions of carbon dioxide (CO_2) are of concern due to its contribution to climate change. The amount of CO_2 emitted is a function of both fuel carbon content and system efficiency. The fuel carbon content of natural gas is 34 lbs carbon/MMBtu; oil is 48 lbs carbon/MMBtu; and (ash-free) coal is 66 lbs carbon/MMBtu. As converted to CO_2 in the exhaust, these values are 117 lb/MMBtu for natural gas, 160 lb/MMBtu for diesel oil, and 205-226 lb/MMBtu for coal.

2. Combustion Process Emission Control

Control of combustion temperature has been the principal focus of combustion process control in gas engines. Combustion control requires tradeoffs - high temperatures favor complete burn up of the fuel and low residual hydrocarbons and CO, but promote NO_x formation. Lean combustion dilutes the combustion process and reduces combustion temperatures and NO_x formation, and allows a higher compression ratio or peak firing pressures resulting in higher efficiency. However, if the mixture is too lean, misfiring and incomplete combustion occur, increasing CO and VOC emissions [9-11].

Lean burn technology was developed during the 1980 as a direct response to the cleaner burning gas engine. The focus lean burn to lower the combustion temperature in the cylinder using lean fuel/air mixture. Most lean burn engines use turbocharging to supply excess air to the engine and produce the homogeneous lean fuel-air mixtures. Optimized lean burn operation requires sophisticated engine controls to ensure that combustion remains stable and NO_x reduction is maximized while minimizing emissions of CO and VOCs [5]. Table 1 shows uncontrolled NO_x emission against efficiency tradeoffs.

Table 1 - Uncontrolled NO_x emissions versus efficiency trade-offs



Engine Characteristics	Low NO_x	High Efficiency
Capacity (MW)	9.3	9.3
Speed (rpm)	720	720
Efficiency, LHV (percent)	44.1	45.7
Emissions:		
NO_x (g/kWh)	0.62	1.2
(ppmv @ 15% O_2)	45	90
CO (g/kWh)	1.9	1.3
(ppmv @ 15 % O_2)	226	158
NMHC (g/kWh)	1.0	0.71
(ppmv @ 15% O_2)	209	153

3. Emissions Control Options

Emissions from natural gas SI engines have improved significantly in the last decade through better design and control of the combustion process and through the use of exhaust catalysts. Advanced lean burn natural gas engines are available that produce NO_x levels as low 1.8 lb/MWh and CO emissions of 8.1lb/MWh before any exhaust gas treatment. Adding selective catalytic reduction (SCR) and a CO oxidation catalyst can allow lean burn reciprocating engines to meet the very stringent California South Coast emissions standards of 0.07 lb/MWh for NO_x and 1.0 lb/MWh for CO. NO_x control has been the primary focus of emission control research and development in natural gas engines. The following provides a description of the most prominent emission control approaches [12-15].

3.1 Post-Combustion Emissions Control

There are several types of catalytic exhaust gas treatment processes that are applicable to various types of reciprocating engines. Table 2 shows the methods in use today, the applicable engine types, and the pollutant reduction achievable. The table referred to Jay Warner and Gary Bremigan, System Solutions for Optimizing Exhaust Emission Control Systems,Universal Acoustic & Emissions Control Technologies USA, 2010.

Table 2 - Post-combustion exhaust cleanup option [6]

Emission Control Technology	Applicable Engine Type	Typical Performance Reductions, %			
		CO	NMHC	NO_x	PM
Diesel Oxidation Catalyst (DOC)	Diesel	90	80	0	20
Catalyzed Diesel Particulate Filter (DPF)	Diesel	90	90	0	90+
Non-selective Catalytic Reduction (NSCR)	Rich Burn Natural Gas	90	80	95	0
NG Oxidation Catalyst	Lean Burn Natural Gas	95	95	0	0
Selective Catalytic Reduction (SCR)	Lean Burn Diesel or Natural Gas	0	0	95	0

3.2 Oxidation Catalysts

Oxidation catalysts generally are precious metal compounds that promote oxidation of CO and hydrocarbons to CO_2 and H_2O in the presence of excess O_2. CO and non-methane hydrocarbon analyzer (NMHC) conversion levels of 95 percent are achievable. Methane conversion may approach 60 to 70 percent. Oxidation catalysts are now widely used with all types of engines, including diesel engines. They are being used increasingly with lean burn gas engines to reduce their relatively high CO and hydrocarbon emissions [15-16].

3.3 Diesel Particulate Filter

While not an issue for spark ignition engines firing gaseous fuels, compression ignition engines fuelled by diesel or heavy oil produce particulates that must be controlled. Diesel particulate filters can reduce over 90 percent of particulate (soot) emissions from diesel engines. There are a variety of filter materials and regeneration strategies used. Currently, there are no commercially available particulate control devices available for large, medium speed diesel engines [7]. Figure 1 shows assembly of diesel particulate filter.

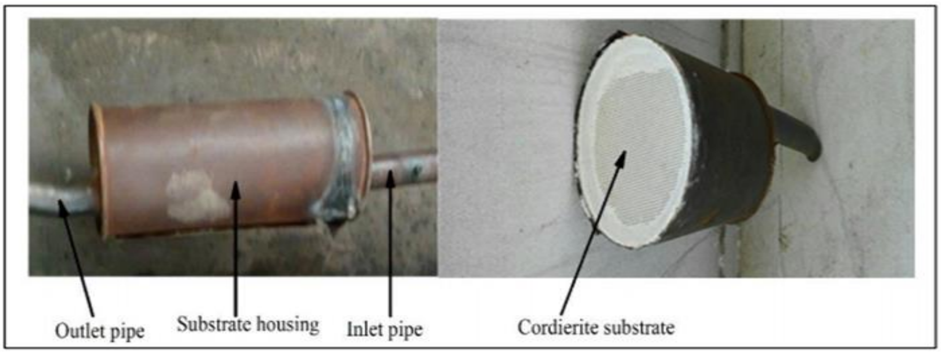


Fig. 1 - Assembly of diesel particulate filter

3.4 Three-Way Catalyst (Non Specific Catalytic Reduction)

The catalytic three-way conversion process (TWC) is the basic automotive catalytic converter process that reduces concentrations of all three major criteria pollutants - NO_x, CO, and VOCs. The TWC is also called non-selective catalytic reduction (NSCR). NO_x and CO reductions are generally greater than 90 percent, and VOCs [5-8] are reduced approximately 80 percent in a properly controlled TWC system. Because the conversions of NO_x to N_2, the conversion of CO and hydrocarbons to CO_2 and H_2O will not take place in an atmosphere with excess oxygen (exhaust gas must contain less than 0.5 percent O_2), TWCs are only effective with stoichiometric or rich-burning engines. Typical “engine out” NO_x emission rates for a rich burn engine are 10 to 15 gm/bhp-hr. NO_x emissions with TWC control are as low as 0.15 g/bhp-hr.

3.5 Selective Catalytic Reduction (SCR)

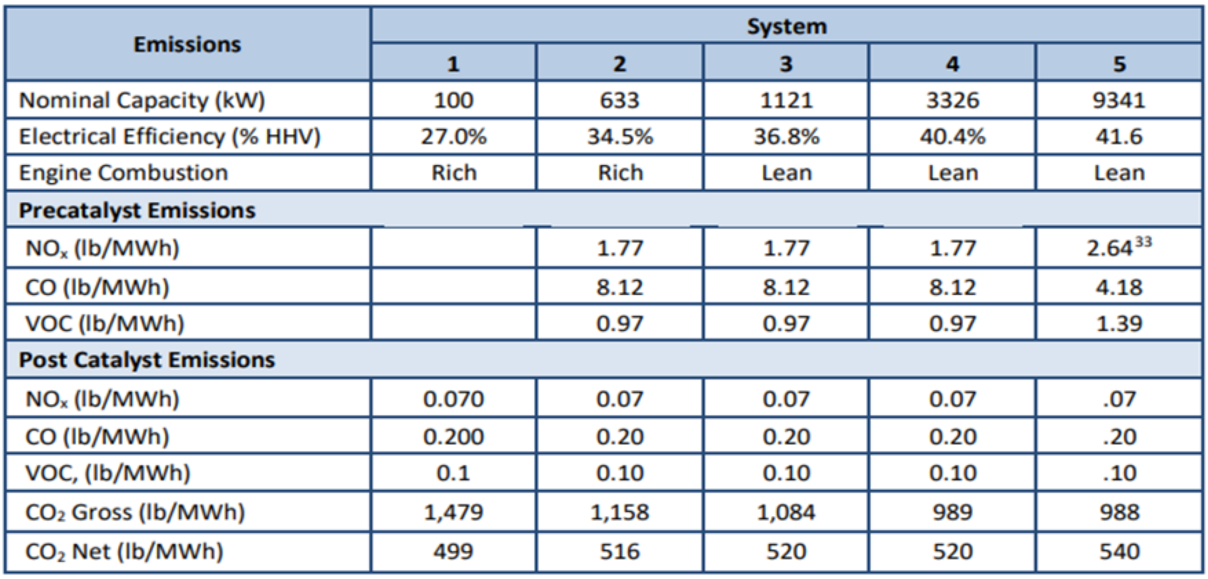
This technology selectively reduces NO_x to N_2 in the presence of a reducing agent. NO_x reductions of 80 to 90 percent are achievable with SCR. Higher reductions are possible with the use of more catalyst or more reducing agent, or both. The two agents used commercially are ammonia (NH_3 in anhydrous liquid form or aqueous solution) and aqueous urea. Urea decomposes in the hot exhaust gas and SCR reactor, releasing ammonia. Approximately 0.9 to 1.0 mole of ammonia is required per mole of NO_x at the SCR reactor inlet in order to achieve an 80 to 90 percent NO_x reduction. SCR systems are considered commercial today and represent the only technology that will reduce NO_x emissions to the levels required in Southern California and the Northeast U.S. Still, SCR adds significantly to the capital and operating cost of a reciprocating engine CHP system [12-15].

4. Discussion and Result

Table 3 shows achievable emissions for each of the five representative gas engine systems. The emissions presented assume available exhaust treatment. System 1, the 100 kW engine, is a high speed, rich burn engine. Use of a TWC [8] system with EGR provides NO_x emissions of just under 0.07 lb NO_x per MWh after credit is taken for the thermal energy provided.32 The Lean burn engine systems use an SCR/CO system providing emissions reduction that meets the CARB 2007 emissions limits without consideration of the thermal energy credit. With current commercial technology, highest efficiency and lowest NO_x are not achieved simultaneously.

Therefore, many manufacturers of lean burn gas engines offer different versions of an engine - a low NO_x version and a high efficiency version based on different tuning of the engine controls and ignition timing. With the addition of SCR after-treatment, described below, some manufacturers tune engines for higher efficiency and allow the SCR system to remove the additional NO_x. Achieving highest efficiency operation results in conditions that generally produce twice the NO_x as low NO_x versions (e.g., 3 lb/MWh versus 1.5 lb/MWh). Achieving the lowest NO_x typically entails sacrifice of 1 to 2 points in efficiency (e.g., 38 percent versus 36 percent). In addition, CO and VOC emissions are higher in engines optimized for minimum NO_x.

Table 3 - Gas engine emission characteristic with available exhaust control option



Emissions	System				
	1	2	3	4	5
Nominal Capacity (kW)	100	633	1121	3326	9341
Electrical Efficiency (% HHV)	27.0%	34.5%	36.8%	40.4%	41.6
Engine Combustion	Rich	Rich	Lean	Lean	Lean
Precatalyst Emissions					
NO_x (lb/MWh)		1.77	1.77	1.77	2.64[33]
CO (lb/MWh)		8.12	8.12	8.12	4.18
VOC (lb/MWh)		0.97	0.97	0.97	1.39
Post Catalyst Emissions					
NO_x (lb/MWh)	0.070	0.07	0.07	0.07	.07
CO (lb/MWh)	0.200	0.20	0.20	0.20	.20
VOC, (lb/MWh)	0.1	0.10	0.10	0.10	.10
CO_2 Gross (lb/MWh)	1,479	1,158	1,084	989	988
CO_2 Net (lb/MWh)	499	516	520	520	540

4.1 Emission Result with Oxidation Catalysts

The oxidation of hydrocarbons and CO in diesel emissions can be described by the following chemical reactions:

$$[\text{Hydrocarbons}] + O_2 = CO_2 + H_2O \tag{1}$$

$$CnH_2m + (n + m/2)\, O_2 = nCO_2 + mH_2O \tag{1a}$$

$$2CO + O_2 = 2CO_2 \tag{2}$$

Hydrocarbons are oxidized to form carbon dioxide and water vapor, as described by reaction (1) or in a more stoichiometric rigorous way by reaction (1a). In fact, reactions (1) and (1a) represent two processes: the oxidation of gas phase HC, as well as the oxidation of compounds. Reaction (2) describes the oxidation of carbon monoxide to carbon dioxide. Since carbon dioxide and water vapor are considered harmless, the above reactions bring an obvious emission benefit. The oxidation of HCs also results in a reduction of the diesel odour. Figure 2 shows the use of oxidation catalyst on hydrocarbon and carbon monoxide

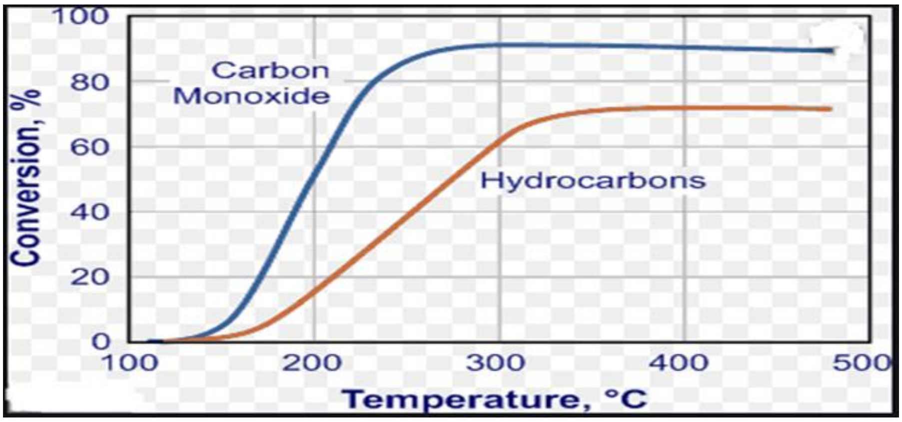


Fig. 2 - Use of oxidation catalyst on Hydrocarbon and Carbon Monoxide [6]

4.2 Emission Result with Diesel Particulate Filter

Figure 3 shows the smoke opacity which is increasing with load at a constant speed (1400rpm). The smoke emission level from engine exhaust without fitment of DPF is increasing with increase in load because of incomplete combustion in the engine cylinder. Incomplete combustion leads to increase the level of soot in the engine exhaust. But, when DPF is installed to the exhaust stream the level of smoke was decreased drastically. The decrease in the smoke emission after the installation of DPF shows the filtration effect of this device. The soot gets trap in the honeycomb structure of the filter by allowing gases to flow through its porous wall material. The efficient working of DPF filtration can be seen in Figure 3.

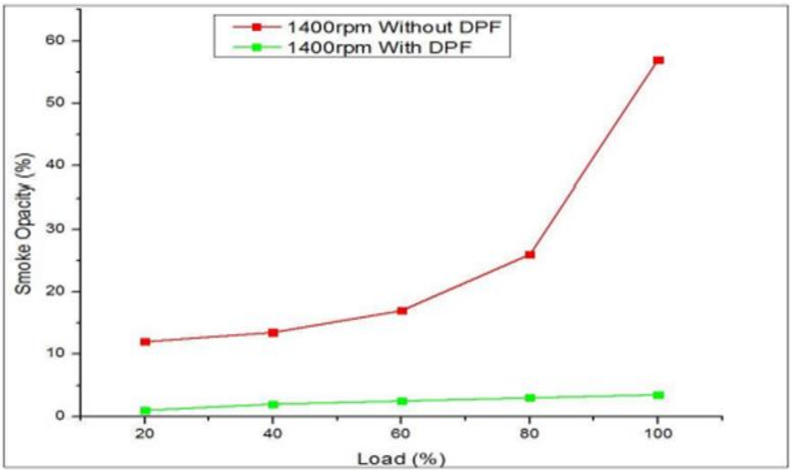


Fig. 3 - Smoke opacity with respect to load [7]

4.3 Emission Result with Three-Ways Catalyst (Non-Specific Catalyst Reduction)

The regulated gaseous emissions measured in the engine exhaust before and after the TWC in the first 280 seconds are presented in Figure 4. No apparent changes in the gas composition pre and post-catalyst can be observed in the first

150 seconds. A peak of CO of 10,000 ppm is produced just after the engine start, corresponding to overall rich lambda conditions and this is rapidly decreased to around 1300 ppm. At 235 seconds, engine acceleration leads to an increase in CO. On the other hand, HC emissions remained stable at 4000 ppm during this cold-start period, therefore HC emissions are not influenced by the engine conditions. No oxidation of CO and THC [8] was observed during the first 120 seconds of the engine operation. At this point the exhaust pre-TWC reached temperatures higher than 300°C and the oxidation of HC and CO started. NO reduction did not start until the TWC temperature exceeded 300°C.

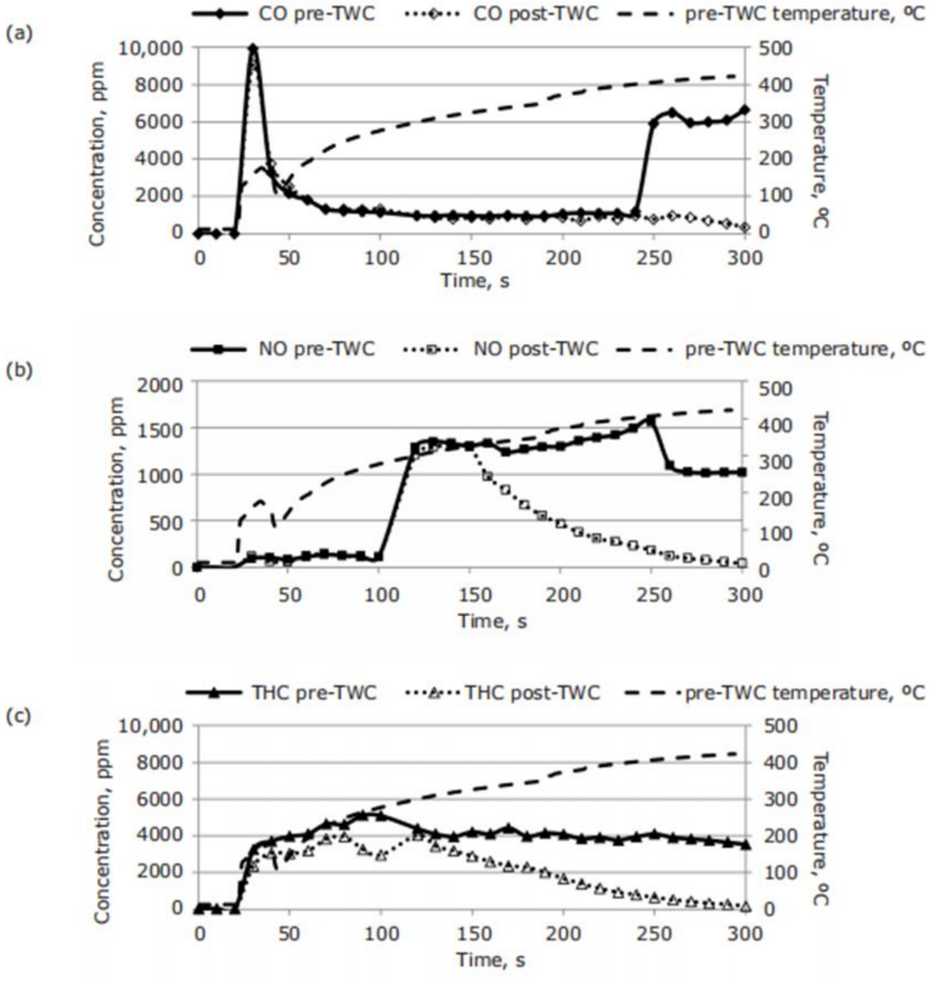


Fig. 4 - Emission during cold-start (a) CO; (b) NO_x; (c) TWC

4.4 Emission Result with Selective Catalytic Reduction (SCR)

A number of chemical reactions occur in the ammonia SCR system. These processes represent desirable reactions which reduce NO_x to elemental nitrogen. This reaction is responsible for the promotion of low temperature SCR by NO_2. Normally, NO_2 concentrations in most flue gases, including diesel exhaust, are low. In diesel SCR systems, NO_2 levels are often purposely increased to enhance NO_x conversion at low temperatures. Undesirable processes occurring in SCR systems include several competitive, non-selective reactions with oxygen, which is abundant in the system. These reactions can either produce secondary emissions or, at best, unproductively consume ammonia.

The SCR process requires precise control of the ammonia injection rate. An insufficient injection may result in unacceptably low NO_x conversions. An injection rate which is too high results in release of undesirable ammonia to the atmosphere. These ammonia emissions from SCR systems are known as ammonia slip. The ammonia slip increases at higher NH_3/NO_x ratios. According to the dominant SCR reaction, the stoichiometric NH_3/NO_x ratio in the SCR system is about 1. Ratios higher than 1 significantly increase the ammonia slip. Figure 5 presents an example relationship between the NH_3/NO_x ratio, NO_x conversion, temperature, and ammonia slip. The ammonia slip decreases with increasing temperature, while the NO_x conversion in an SCR catalyst may either increase or decrease with temperature, depending on the particular temperature range and catalyst system.

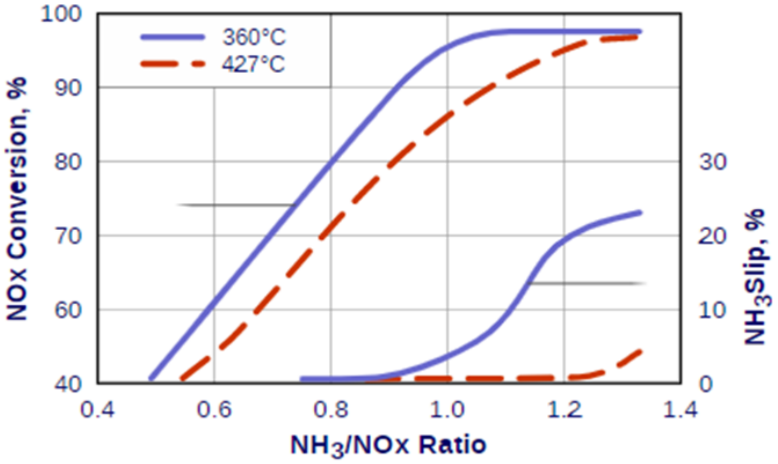


Fig. 5 - NO$_x$ conversion and ammonia slip or different NH$_3$/NO$_x$ ratios [9]

5. Conclusion

In this paper review, the usage of EGR towards heavy duty is to be familiar to be installed in each vehicle as heavy duty tend to leave such a big quantity of emission. The temperature effects in forming the NO$_x$ emission, as temperature gets to be higher, the possibility for NO$_x$ formation can occur. Through these post-emission control, it helps in controlling and reduce the excess of emission through the exhaust. Most of the post-emission control treatment use catalyst and only can be activated when it reaches the specific point of temperature. Most of the NO$_x$ emission are produces from high temperatures. Medium loads and high loads are to be differentiate between both factors. The viscosity in fuel can be a factor of the performance in the engine. Injection of hydrogen into a diesel engine’s air-fuel mixture can dramatically improve fuel mileage and reduce emissions. By injecting hydrogen into the mixture, 20-30% percent of fuel consumption reduction, 85% less particulate matter and 50%-90% NO$_x$ reduction.

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