Environmental effects of conversion of petroleum fuel-based motor cars to natural gas vehicles (NGVs)

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Abstract

In order for saving constrained resources and preservation of environment, natural gas has been found as a proven low cost and low emission alternative fuel to petroleum fuels for all types of motor vehicles. It is being widely used throughout the globe. In Malaysia, still millions of vehicles are plying on use of petroleum fuels. These fuels release huge anti-body and anti-environment gases to the environment. Definitely, this adversely affects the natural ecosystem. In this backdrop, a study is felt important to predict the trend of emissions of these gases released by cars in Malaysia for use of liquid fuels and natural gas between 2006 and 2020. The growth of the demand of vehicles has been considered alongside. The study reveals that the current emission levels of different anti-body gases are huge and these can be significantly reduced by converting liquid fuel based engine into the natural gas based engine.

Keywords: Liquid fuels, Natural Gas (NG), Emission, Passenger Cars, Alternate Fuel

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1. Introduction

High efficient and effective use of constrained energy, materials, time, and space through the development of resource-saving products that would preserve human-and-living friendly environment is felt important to maximize contributions of science and technology to the human-society. This is now a global responsibility to the present and future generations. The impact of emissions of petrol and diesel engines to the air or environment is simply enormous. Pollutants of different types cause diverse nature of impacts and their gravity to the human health and environment is varied. Critical pollutants emanate from motor vehicles due to the use of these fuels are particles, toxic compounds and other substances that increase global warming, cause acid rain, and impair visibility.

Increasing concentration of greenhouse gases, such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxide (NO_x), carbon monoxide (CO) and hydrocarbons (HC) in the atmosphere has already warned the concerned engineers, scientists and environmentalists to stand on it. Nevertheless, a huge amount of these gases are generated by vehicles using the foretold liquid fuels. In 1990s, the transportation sector was found as the fastest growing source of carbon dioxide emission in the USA. It has been projected that by 2025 this sector would be responsible to generate nearly half of the 40 percent rise in carbon dioxide in the USA [Joseph, 2006].

The Executive Director of the International Energy Agency (IEA) Claude Mandil has said, ‘‘in the absence of strong government policies, we project that the worldwide use of oil in transport will nearly be double between 2000 and 2030, leading to a similar increase in greenhouse gas emissions'' [IEA, 2004]. In Malaysia, emissions from motor vehicles were the main source of air pollution, burdening to at least 70–75 percent of the total pollutants during last 5 years [Afroz, *et al*., 2003]. Reported by the Department of Environment Malaysia, only in 1996, the percentage of the emission loads from different sources to its air were motor vehicles, 82 percent; power stations, 9 percent; industrial fuel burning, 5 percent; industrial production processes, 3 percent; domestic and commercial furnaces, 0.2 percent; and open burning at solid waste disposal sites, 0.8 percent [Department of the Environment, Malaysia, 1996]. Obviously, huge number of passenger cars in use was the main source of atmospheric pollution in Malaysia. These vehicles also discharge about 75 percent of the total CO and 76–79 percent of the oxides of sulfur and nitrogen [Department of the Environment, Malaysia. 2001].

In recent years, the environmental legislations exerted a notable influence to hold the pollutant gas emissions by motor vehicles. In January 2000, the European regulation EURO-III came into force and promulgated severe limits to the allowable exhaust pipe emissions from vehicles. Widely known as the Kyoto protocol, signed by EU in December 1997, it states that greenhouse gases should be reduced by 8 percent within 2012 from the level recorded in 1990. Malaysia is one of the 160 countries that have accepted this protocol. However, the amount of greenhouse gases emission by transportation sector has not yet been analyzed in here. On the other hand, due to rapid economic growth and infrastructure development, the usage of petrol and diesel fuels in transportation sector has rather increased tremendously. As a result, Malaysia's oil reserve fallen rapidly in the past decade. From the prevailing circumstances, it could be reasonably assumed that huge amount of greenhouse gases have been released to the environment in recent years. The necessity has gain the ground to apply a suitable energy policy for transportation sector in order to balance the demand and supply of energy and to contain the overall release of greenhouse gases. This effort would lead to conservation of limited nonrenewable energy resources and preservation of environment. It is the responsibility, and most likely be the remarkable contribution of the present people to future generations.

Energy policy and planning with that orientation has become a very important public agendum of most developed and developing countries today. As a result, the governments are encouraging the use of alternative fuels in motor vehicle engines as well. Compressed natural gas (CNG) has appeared as a proven alternative fuel. The advantages of CNG as an automotive fuel over conventional fuels are quite many, and these are broadly stated by Nylund *et al*., [2002] and Aslam *et al*., [2003]. Emissions of CNG using vehicles are generally lower than that of petrol and diesel operating vehicles, and consequently after conversion, the expected emission levels would be lower [Aslam *et al*. 2006].

In the said backdrop, this study on natural gas vehicle (NGV) has been undertaken to identify the deficiencies of and scope of improvement to the previous policies. Another matter that has been considered to reduce pollutant emissions from motor vehicles is the conversion of motor vehicles being operated on petrol and diesel fuels to CNG vehicles. In conversion, the main factors that should be taken into account are the costs that must incur and the expected gains in terms of reduction of the emissions of the major pollutants that pose environmental hazards or health risks. Appreciably, Malaysia has planned to reduce the production of CO_2, SO_2, NO_x, CO and HC but the data on their emission levels are not readily available. Therefore, this study attempts to estimate potential production of these gases from transportation sector, particularly from the use of passenger cars in this country. Having known the accurate figures on their emissions, the relevant agencies can take the appropriate measures in order for prudent use of limited energy resources and conservation of environment.

2. Methodology

This study used the scenario approach of data analysis and presentation. Schwartz [1996] states that scenarios are tools for projecting views about alternative future environments despite the end-result might not present an accurate picture. This can, however, provide a good ground for better decision. No matter how things might actually turn out, both the analysts and the policy makers can have a scenario that resembles a given future and that can help them think about the opportunities and the consequences of the future.

The analysis in this study is generally based on modeling methodologies to figure out the potential emissions from passenger cars using liquid fuels (petrol and diesel) and CNG fuel in Malaysia between 2006 and 2020. For this purpose the types of fuel used for passenger cars have been identified. Literature survey and relevant information has been gathered from books, journals and Internet sources. The data has been collected from the relevant Malaysian government bodies like Department of Statistic, Department of Road and Transportation and other government agencies. Some of the data has been found available but others have been calculated with respect to the trend of fuel consumption by passenger cars. Polynomial curve fitting method has been employed to analyze and predict unavailable data. The best fit from these methods is used for this study.

The polynomial method has been used as an attempt to describe the relationship between a variable *X* as the function of available data and a response variable *Y*. Mathematically, a polynomial of order *k* in *X* is expressed in the following form [Klienbaum, D.G., 1998].

$$Y = C_0 + C_1 X + C_2 X^2 + \ldots\ldots\ldots\ldots + C_k X^k \quad \ldots (1)$$

Where *C*'s are constants in the polynomial equation.

To develop the model, historical data on the number of passenger cars and fuel consumption from year 1990 to 2004 has been analyzed and shown in Table 1. Using Equation (1) and the data in Table 1, a regression Equation (2) has been generated to predict the total number of passenger cars in Malaysia between 2006 and 2020.

$$Y_1 = -4.28 \times 10^8 + 243309X, R^2 = 0.95.6 \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The fuel consumption for the same period has been estimated by Equation (3):

$$Y_2 = -12.366 + 0.0132X - 3 \times 10^{-6} X^2, R^2 = 0.80 \quad \ldots\ldots\ldots\ldots (3)$$

The results of the estimated number of passenger cars and fuel use are shown in Table 2.

Based on the model from 'Highway Network Development Plan (HNDP)' study (1993), a trip generation model has been developed for this study. Using this model it has been estimated that more than 25.8 million person-trips per day would be used in year 2020 and around 80 percent of that would come from passenger cars [Masjuki *et al*, 2005]. Figure 1 reveals that of the total number of vehicles, 41.60 percent are passenger cars and 48.60 percent are motorcycles. Together these constitute the majority proportion of vehicles in Malaysia. Nevertheless, fuel consumption of motorcycles is much lower than that of passenger cars. CNG is not yet been used in motorcycle engine. Therefore, this study emphasized on passenger cars only.

From the historical records available with the Road Transport Department, it is observed that about 99.6 percent of the total passenger cars in Malaysia use petrol fuel and the rest use diesel and CNG [Masjuki *et al*, 2005]. Based on this observation the estimated patterns of passenger cars for the aforesaid period have been shown in Table 2.

3. Data Analysis, Results and Discussions

3.1 Emission Calculation

The estimated amount of CO_2, SO_2, NO_x, CO and HCs produced from liquid fuels (petrol & diesel) and the natural gas by passenger cars per day have been calculated. Emission factors for different types of fuel in production (in refinery) and distribution of NG have been collected from earlier works [Masjuki *et al*, 2005, Hampden *et al,* 2004 & Lewis, 1997], and are shown in Tables 3 and 4. The demands of petrol and diesel fuels have been calculated for period 2006 to 2020 for the predicted number of passenger cars. Fuel use per vehicle kilo-meter and mean-trip-length of a vehicle per day in km has also been estimated. According to HNDP study, the mean-trip-length for the total vehicle population is 17.2 km per day [Masjuki *et al*, 2005], which has been assumed constant for 2006 to 2020 in this study.

Natural gas (NG) equivalent to liquid fuel consumption has also been estimated based on lower heating value of the respective fuels. The lower heating values of petrol and diesel have considered 44.5 MJ/kg and 42.0 MJ/kg respectively and that of NG is 43.6 MJ/kg [Aslam *et al*. 2006]. Calculations of emission for using 100 percent liquid fuel and then gradually substituting the liquid fuels by 20, 40, 60, and 80 percent NG have also been made. Emission patterns of full substitution by NG for passenger cars have been revealed. For finding the total emissions per day, the estimated emissions from petrol, diesel and NG have been done separately and then added. Total emissions calculated for year 2010 with an assumption of 60 percent replacement of the liquid fuels (petrol, diesel) by NG are shown in Table 5.

The same procedure has been followed to predict the emission for non-conversion, full conversion and partial replacement of liquid fuels driven passenger cars by NGVs for period 2006 to 2020. The results are shown in Figures 2-6.

3.1.1 CO_2 Emission

Out of all the gases being produced by human activities, the largest supplier to the greenhouse effect is CO_2. Because of the growing number of motor vehicles using liquid fuels, the amount of CO_2 in the atmosphere continues to grow. Control of the emission of CO_2 is thus an important issue. The most effective way to reducing the amount of CO_2 is to burn less liquid fuels and replace it by NG fuel. From the related works done earlier, it is obvious that NG produces much less amount of CO_2 (20%) compared to the liquid fuels. NG gas principally contains CH_4 and liquid fuels contain hydrocarbon. From the concept of chemical equilibrium, it is confirmed that for higher hydrogen to carbon ratio (H/C) of a fuel, the amount of CO_2 release is lower. CNG fuel has much higher H/C ratio than a liquid fuel.

The predicted amount of CO_2 emission from passenger cars per day using liquid fuel is shown in Figure 2. For year 2020, estimated CO_2 emission per day will be around 41.79 kton for using liquid fuels, which is simply huge for a fast developing country like Malaysia. Figure 2 evidently shows that this amount of CO_2 can gradually be reduced with the increasing use of NG fuel instead of petrol and diesel. About 23 percent of CO_2 emission can be reduced from operating passenger cars plying in Malaysia if all of them are converted to NGVs.

3.1.2 SO_2 Emission

A colorless gas SO_2 belongs to the family of oxides of sulfur (SO_x). It is the main pollutant that causes acid rain. Fossil fuel combustion is the main source of SO_2 emission. Many countries have enacted laws restricting the amount of sulfur to be allowed in a fuel, and the laws are continuously and more stringent updated. Petrol and diesel contain large amount of sulfur, which gets oxidized and produces SO_2. SO_2 combines with water that forms a sulfuric acid aerosol. The amount of sulfur contains in natural gas is almost nil. Therefore, use of natural gas as a viable alternate fuel is the most effective way of minimization of acid rain and other problems to the environment caused by sulfur. For uses of liquid fuels, passenger cars in Malaysia are producing a large volume of SO_2 everyday, which is rather increasing day by day. The predicted SO_2 emissions per day by passenger cars from 2006 to 2020 in Malaysia have shown in Figure 3. If the current rate of SO_2 emission continues, it will create a serious environmental problem in the near future. One of the best ways to save environment from this problem is to increase the uses of natural gas in transportation sector. Figure 3 also shows that significant amount of SO_2 emission can be reduced by fractional conversion of liquid fuel driven passenger cars to NGVs.

3.1.3 NO_x Emission

NO_x is a collective term used to describe oxides of nitrogen, namely nitric oxide (NO) with a small amount of nitrogen dioxide (NO_2) and traces of other nitrogen-oxygen combinations. NO_x is mostly created from nitrogen constituent in air. Presence of NO_x is one of the primary causes of photochemical smog, which has become a major problem in many large cities of the world. NO_2 plays a major role in the atmospheric reactions that produces ozone. Ground-level ozone is harmful to lungs and other biological tissues. It is also harmful to trees and plants, and causes billions of dollars of crop loss each year throughout the world [Willard W, 2004]. Tables 3 and 4 show that the use of petrol in passenger cars produces large amount of NO_x compared to diesel fuel and natural gas. NG as a low emission fuels can play an important role to keep NO_x emission in lowest level. NO_x emissions per day produced by passenger cars have predicted for the period 2006 to 2020 and are shown in Figure 4. It is clear that NO_x emission is increasing with the increasing use of liquid fuels in transportation sector in Malaysia. This can be controlled by changing liquid fuel vehicles to NG vehicles. Figure 4 also shows the change of future NO_x emission scenario with the changing fuel mood. It is possible to reduce as high as 65 percent NO_x emission produces from passenger cars in Malaysia by converting conventional liquid fuel vehicles to natural gas vehicles.

3.1.4 CO Emission

Carbon monoxide is a colorless and odorless poisonous gas. It is produced inside the engine when there is not enough oxygen to convert all carbon to CO_2. Unburnt fuel produces CO. This CO emission has terrible impact on environment and human health. CO damages coronary arteries in the heart and cerebral arteries in the brain. Recent studies have proved that even a low concentration of CO can decrease the pregnancy rate. Table 4 also shows that emission factor of CO for production and distribution of petrol fuel is high (0.2403 g/kg) compared to diesel (0.21 g/kg) and NG (0.061 g/kg). Table 5 also show that emission factor of CO for combustion of petrol fuel is very high (152.20 g/kg) compared to NG (10.14 g/kg) and diesel (4.34 g/kg). Reported earlier that as many as 99.6 percent of the total passenger cars in Malaysia use petrol as fuel. So, huge amount of CO is released to air every day. The emission of CO is increasing day by day because of the increasing number of passenger cars in use. Figure 5 exhibits that if the present state of use of liquid fuels continues; CO emission will reach to 1,761.41 ton per day in the year 2020. This figure is definitely frightening for environment and human life. The best solution to this problem is to reduce the use of petrol in motor vehicles. CO emissions from passenger cars for the use of natural gas have also been estimated and are shown in Figure 5. The result shows that using natural gas as an alternate fuel can reduce CO emissions to an enormous extent (about 93%).

3.1.5 HC Emission

Hydrocarbons (HC), more appropriately organic emissions, are also the consequence of incomplete combustion of the hydrocarbon fuel. Table 3 shows that maximum HC emission caused by diesel-fuel vehicles (6.5 g/kg) followed by petrol (4g/kg) and natural gas (2 g/kg) vehicles through combustion process. The rate of HC release is caused by the molecular weight of the respective fuel. The molecular weight of diesel (170-200) or petrol (110) is much higher than NG (16.04) [Heywood, 1988]. Being lightweight fuel, NG can form much better homogeneous air-fuel mixture and NG engine runs with high combustion efficiency. On the other hand, Table 4 shows production and distribution emission of HC (9.7533 g/kg) from NG is much higher than petrol (0.7743 g/kg) and diesel (0.6594). HC emissions are mainly occurred due to gas (CH_4) losses during production and distribution process [Lewis, 1997]. As a result the total HC emission will increase with the use of NG in passenger cars. The future aspect of HC emission formed by passenger cars in Malaysia has been predicted and is shown in Figure 6. Study shows that HC emission will be about 2.5 times higher through 100 percent conversion of passenger cars from liquid fuels to natural gas. All HC components, except CH_4 reacts with atmospheric gases and form photochemical smog but the HC emissions from NGVs (mainly CH_4), which is not harmful to the extent that is caused by HC emitted from liquid fuels.

4 Conclusion:

Air pollution is a global concern. Malaysia, being one of the largest automobile manufacturers and users in Asia, the consumption of conventional fuels by motor vehicles such as diesel and petrol would significantly donate to air pollution in this country. The use of natural gas would provide a way to reduce the emission of air pollutants. Natural gas is a very environment-friendly alternative car fuel. Besides, the use of natural gas as the future motor fuel will help the country's economy significantly, since Malaysia ranks twelfth in the world as per as natural gas reserve is concerned. Both the government and private sectors can increase their investments in improving infrastructures, and also to conduct more awareness campaigns regarding NGV benefits.

The results obtained in this study show that NG has much lower emission levels than gasoline or diesel fuels. The study revealed that from the use of NG as motor fuel, the air pollution reduction could be as high as 90 percent from passenger cars in Malaysia. This reduction would create a tremendous direct impact on the cleanliness of Malaysian air. This indication should be a good piece of information for its policymakers to consider the use of NGVs.

However, more research should go on board in this area before it can be fully exploited. Typically, when a new idea is put forward, it takes a long time to disseminate the information to the public.

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FIGURES

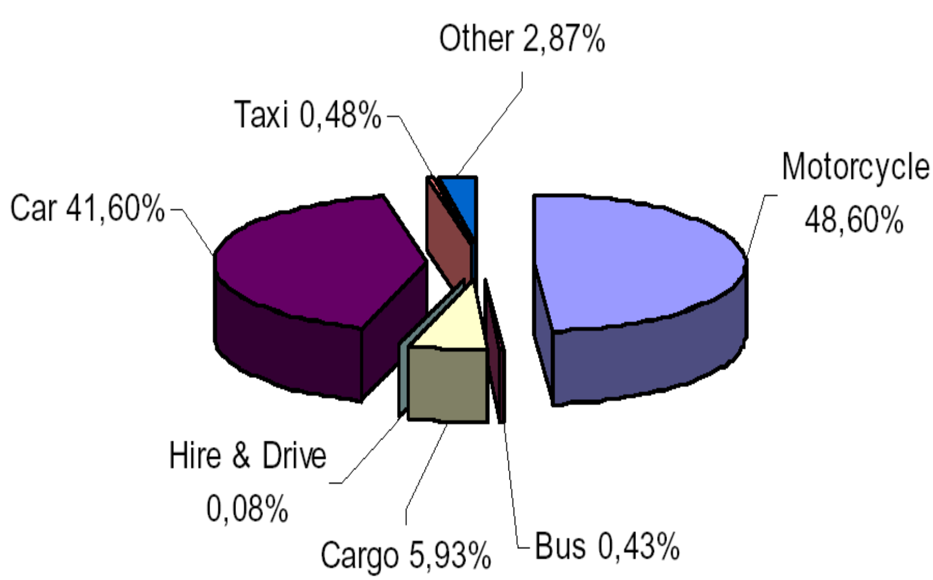

Figure 1 Percentage use of different types of vehicles in transportation sector of Malaysia [Masjuki *et al*, 2005]

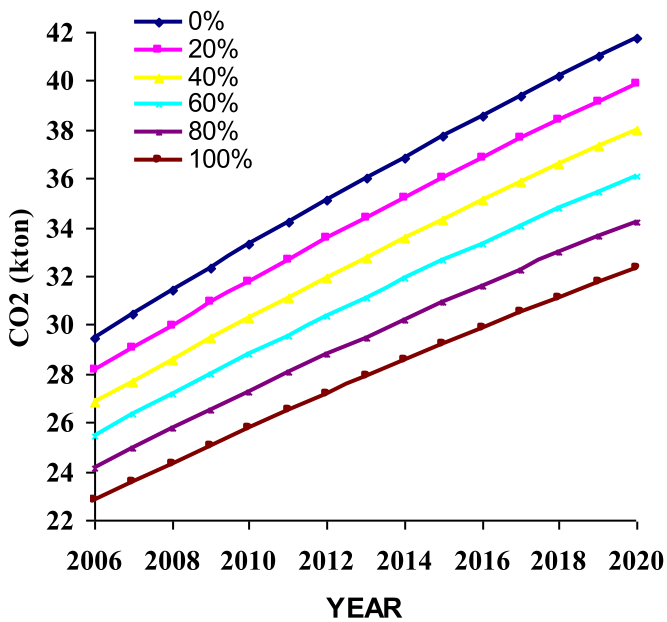

Figure 2 CO_2 emission pattern at different percentage of NG substitution.

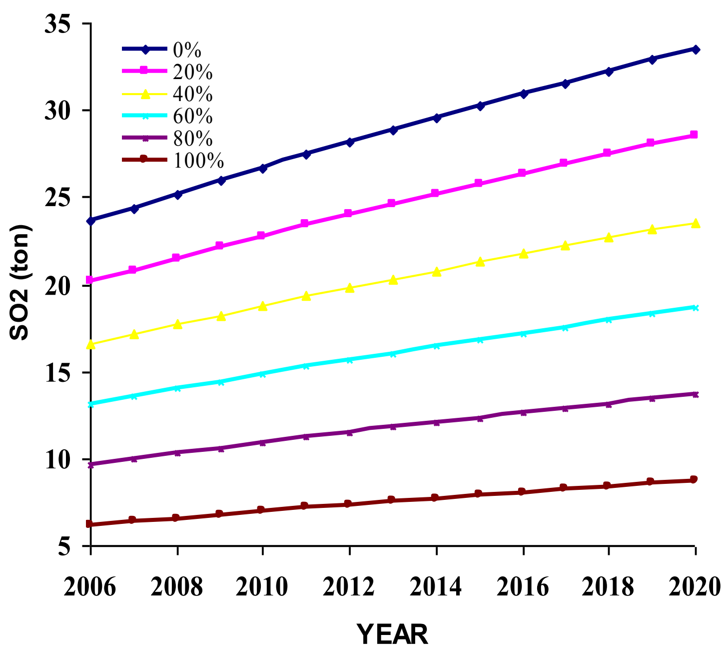

Figure 3 SO_2 emission pattern at different percentage of NG substitution

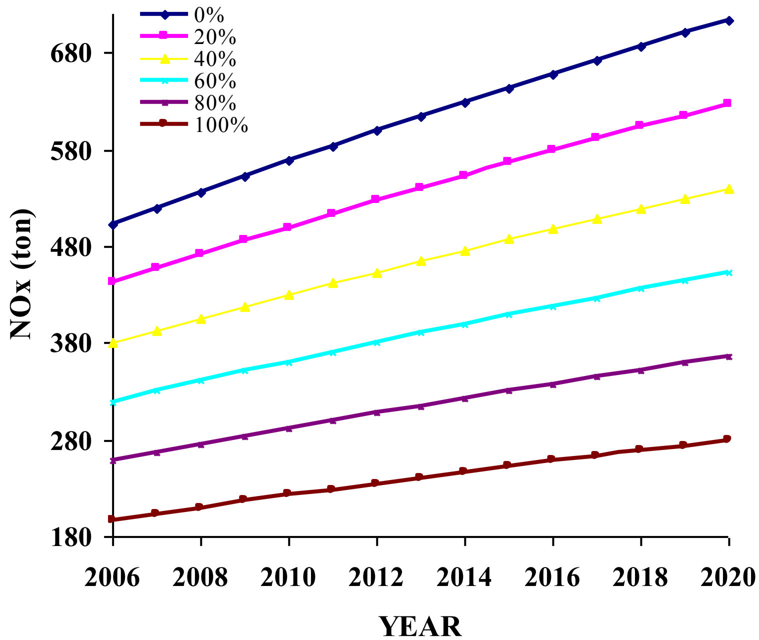

Figure 4 NO_x emission pattern at different percentage of NG substitution

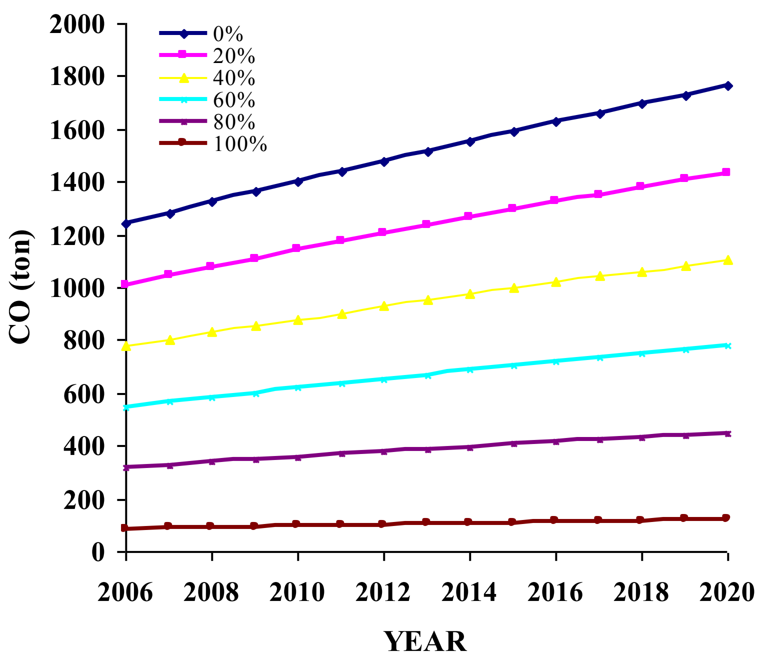

Figure 5 CO emission pattern at different percentage of NG substitution

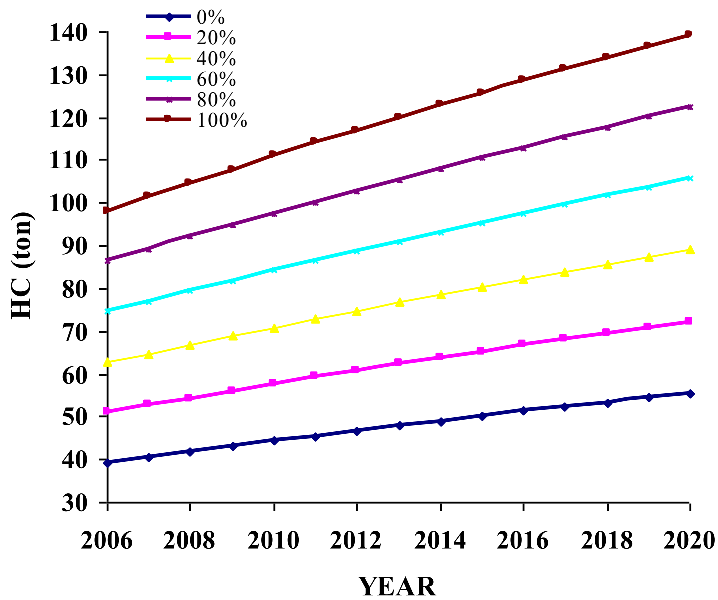

Figure 6 HC emission pattern at different percentage of NG substitution

TABLES

Table 1 Number of passenger cars and fuel used per vehicle-km for the year between 1990 and 2004 [Masjuki *et al*, 2005].

Year	Passenger Car	Fuel use per veh-km (Liter)
1990	1,709,754	0.116
1991	1,858,123	0.111
1992	1,977,612	0.112
1993	2,126,578	0.114
1994	2,344,751	0.114
1995	2,600,381	0.111
1996	2,936,021	0.111

1997	3,322,597	0.109
1998	3,507,442	0.109
1999	3,842,673	0.111
2000	4,202,134	0.107
2001	4,614,571	0.107
2002	5,059,339	0.107
2003	5,347,927	0.106
2004	5,591,236	0.106

Table 2 Forecasted number of passenger cars and fuels used per vehicle-km for the year between 2006 and 2020

Year	Passenger Cars	Petrol Car	Diesel Car	Fuel Use per Veh-km (Liter)
2006	6,077,854	6,053,543	24,311	0.104
2007	6,321,163	6,295,878	25,285	0.104
2008	6,564,472	6,538,214	26,258	0.103
2009	6,807,781	6,780,550	27,231	0.102
2010	7,051,090	7,022,886	28,204	0.102
2011	7,294,399	7,265,221	29,178	0.101
2012	7,537,708	7,507,557	30,151	0.100
2013	7,781,017	7,749,893	31,124	0.099
2014	8,024,326	7,992,229	32,097	0.099
2015	8,267,635	8,234,564	33,071	0.098

2016	8,510,944	8,476,900	34,044	0.098
2017	8,754,253	8,719,236	35,017	0.097
2018	8,997,562	8,961,572	35,990	0.096
2019	9,240,871	9,203,908	36,963	0.095
2020	9,484,180	9,446,243	37,937	0.095

Table 3 Emission factors for different types of fuels in production and distribution.

Fuels	Emission factor				
	CO_2 (g/kg)	SO_2 (g/kg)	HC (g/kg)	CO (g/kg)	NO_x (g/kg)
Petrol	418.30	2.79	0.77	0.24	2.03
Diesel	294.00	1.89	0.66	0.21	1.64
NG	178.80	0.73	9.75	0.06	0.46

Table 4 Exhaust emission factors for different types of fuel

Fuels	Emission factor				
	CO_2 (g/kg)	SO_2 (g/kg)	HC (g/kg)	CO (g/kg)	NO_x (g/kg)
Petrol	3,183	0.0994	4.00	152.20	59.68
Diesel	3,145	0.0995	6.50	4.34	12.09
NG	2,553	0.0000	2.00	10.14	23.12

Table 5 A sample calculation for the year 2010

	Estimated Total	Petrol (99.6%)	Diesel (0.4%)	Equivalent NGV & NG fuel consumption
No of cars	7,051,090	7,022,886	28,204	7,051,090

Fuel consumption		$N_P \times V_{km} \times F_{km} \times S_P$ = 9203569.35 kg	$N_D \times V_{km} \times F_{km} \times S_D$ = 42382.7 kg	$\frac{(W_P \times H_P)}{H_{NG}} + \frac{(W_D \times H_D)}{H_{NG}}$ = 9434378.66 kg
Fuel used after 60% replacement	-	3681427.74 kg	16953 kg	5660626.8 kg
Where, H_p, H_D and H_{NG} are the lower heating value of petrol, diesel and NG respectively. Vehicle-km per day (V_{km}) = 17.2 km. Fuel use per vehicle-km (F_{km}) = 0.102 liter. [Table. 2] Specific Gravity of petrol (S_P) = 0.75. Specific Gravity of petrol (S_D) = 0.86				
Using emission factors from Tables 3 and 4: CO_2 Emission = 28.78 kton; SO_2 Emission = 14.84 kg; HC Emission = 84.23 ton; CO Emission = 619.02 ton; NO_X Emission = 360.92 ton				