A Comparison of Engine Emissions from Heavy, Medium, and Light Vehicles for CNG, Diesel, and Gasoline Fuels

Abdullah Yasar*, Rizwan Haider, Amtul Bari Tabinda, Fidous Kausar, Maryam Khan

Sustainable Development Study Center, GC University,
Lahore, Pakistan

Abstract

Like other developing countries (Brazil, Argentina, and India) compressed natural gas (CNG) is becoming a popular vehicular fuel in Pakistan. Rapid shifting of diesel and gasoline vehicles to CNG has brought Pakistan the highest number of CNG vehicles in the world. To quantify a possible decrease in vehicular emissions for different types of vehicles, engine and fuel types were monitored for five parameters: SO_2, CO, NO, hydrocarbons, and smoke opacity. Emissions from heavy vehicle engines shifting from diesel to CNG showed a decrease in HC (14 times), NO (2.8 times), and smoke opacity (3.2 times), while shifting diesel car engines to CNG resulted in reduced emissions of HC (24.6 times), NO (2.8 times), and smoke opacity (6 times). However, switching of light vehicles such as gasoline car engines to CNG released low emissions of HC (4.6 times), smoke opacity (1.2 times), SO_2 (1.2 times), and CO (1.1 times), but an increase in NO (1.2 times) was observed. Similarly, a 4-stroke CNG rickshaw engine increased NO emissions by 1.4 times over a 4-stroke gasoline rickshaw engine.

Introduction

Vehicles are an important source of air pollution and contribute high ambient pollutant concentrations in urban areas [1]. The use of different types of fuels adds different concentrations of toxic pollutants to the environment. Based on the significant emissions of the fuel components, several vehicle fuels such as diesel, gasoline, compressed natural gas (CNG), gas to liquid (GTL), rapeseed oil methyl ester (RME), and dimethyl ether (DME) are the subject of new focus studies [2]. Airborne particulate matter (PM), due to the increasing fuel demand for rapidly growing global population growth, also is of main concern [3]. Moreover, particulates generated through combustion of diesel are more potent than the particulates generated

through non combustion sources [4]. Some of the gaseous emissions like SO_2 simply depend on the fuel and not the engine. On the other hand, auto-rickshaws, 2-strokes and un-maintained vehicles are great contributors of CO, volatile organic compounds (VOCs), HCs, non-methane HC, and carbonyl compounds [5], and emit high concentrations of HC and PM/smoke opacity as compared to 4-stroke engines. Diesel engines are extensively used in heavy-duty vehicles for better fuel efficiency and power yield than gasoline and other engines. The emissions of gas as CO, HC, NOx, and particulate matter (PM) cause serious air pollution, which is of great concern due to chronic respiratory diseases, cardiovascular diseases, cancer, and toxicological explorations [2, 6]. Pakistan, being the most urbanized country in South Asia, has a high rate of air pollution. The mega city Lahore followed by Karachi is highly urbanized and the numbers of vehicles have reached

*e-mail: yasar.abdullah@gmail.com

nearly 5 million. With the use of unclean engines and fuels such as diesel and gasoline, air pollution has increased at alarming rates. In recent years a trend of fuel shifting to CNG has been observed for many vehicles to overcome the vehicular emissions [7]. It is apparent that vehicular emission levels are directly associated with fuel as well as the type of engine, so it is important to compare pollution contributions of different vehicles such as 2-stroke and 4-stroke on the basis of fuels, CNG, gasoline, and diesel for the emissions of HC, NO, CO, SO_2, and smoke opacity.

Experimental Design and Apparatus

Depending on fuel and type of vehicle engine, 15 different types of vehicles were monitored. Ten samples of each category of vehicle such as bus (CNG, diesel), rickshaw (2-stroke LPG, 4-stroke CNG, 4-stroke gasoline), van (CNG, diesel, and gasoline), motorcycle (2-stroke gasoline, 4-stroke gasoline), and car (CNG, diesel, and petrol) were tested. Smoke opacity was measured in accelerating conditions, while CO, SO_2, NO, and hydrocarbon were measured in idle mode [8]. Vehicular exhaust emissions such as SO_2, HC (ppm), NO (ppm), and CO (%) were tested through Testo 350 XL [8]. A smoke pump (Brigon) was used to monitor smoke opacity (%) of vehicular exhaust emissions (acceleration mode was used for the Ringlemann chart method). Data regarding the number of vehicles on CNG, gasoline, diesel, and LPG was collected from the transport department [9].

Results and Discussion

Shifting of Vehicles to CNG

Data collected from the transport department [9] depicted that the total number of vehicles is more than 2.48 million (Fig. 1). The number of motorcycles was 1.5 million (61% of the total vehicles), whereas 0.67 million (28%) are cars, jeeps, and vans, out of which 21% of cars and vans were on CNG, 2.6% on gasoline, and the remaining 4.4%
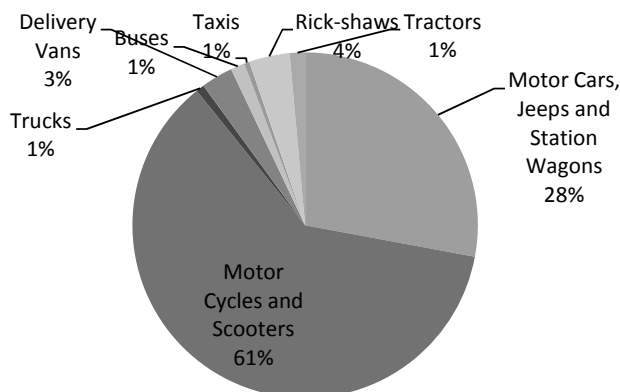
Table 1. Number of vehicles (millions) on the basis of fuel type.

Category	No. of vehicles	Diesel	Gasoline	CNG	LPG
Motor cars, jeeps, and station vans	6.9	1.03	0.6	5.2	-
Motorcycles and scooters	15.1	-	15.1	-	-
Trucks	0.1	0.1	-	-	-
Delivery vans	0.7	0.1	0.05	0.4	-
Buses	0.3	0.3		0.01	-
Taxis	0.1	-	0.002	0.1	-
Auto rickshaws	0.9	-	0.05	0.4	0.4
Tractors	0.3	0.3	-	-	-

were on diesel (Table 1). The third big category was rickshaws, and almost 3% of total vehicles out of 0.4 million each were on LPG and CNG, and 0.05 million were gasoline.

Gaseous Emissions

Average concentration emissions of CO, NO, SO_2, HC, and smoke opacity for different categories of vehicles using different types of fuels are given in Table 2. CNG engines produced 9-20 times higher CO emissions as compared to diesel engines. The CNG van engine added 8.7 times CO emissions with respect to the diesel van engine while reducing emissions by 1.9 times as compared to the gasoline van engine. For 2-stroke engines high CO emission levels were observed. For diesel car engines, CO emissions were 0.1% only but for CNG and gasoline car engines; these were 1.6% and 1.8%, respectively, so the CNG car engine was responsible for 16 times more CO emissions than the diesel car, and 1.1 times less than that of gasoline car. For the CNG rickshaw engine, CO emissions were 1.4 times lower than that of LPG rickshaw. CO emission concentrations were found to be dependent both on engine and fuel type. Diesel as fuel irrespective of engine type appears to have less contribution of CO emissions; on the other hand, low carbon fuel (CNG) was found to release high CO pollution owing to less mixing of air into the gaseous fuel [10].

Diesel vehicle engines produced high NO emissions, for the diesel bus engine NO emissions were 1.8 times higher than the CNG bus engine (Table 2). CNG car engine emitted 2.8 times less NO (16 ppm) than that of diesel car engine (45 ppm), and 1.2 times higher than that of gasoline car engine (13 ppm). CNG rickshaw engine released 1.4 times higher NO emissions (21 ppm) than the gasoline rickshaw engine (15 ppm), while the LPG rickshaw engine released negligible NO emission. The variation in NO emissions appeared to be irrespective of the fuel types depending on the engine of the vehicle. In fact, generation of NO depends on the temperature in the engine, which converts the atmospheric N_2 to NO [11].

Fig. 1. Percentages of different vehicles.

Table 2. Comparison of different mean emissions by different vehicles.

Vehicle Type	Fuel Type	CO (%)	NO (ppm)	SO_2 (ppm)	Smoke Opacity %	HC (ppm)
Bus	CNG	2	45	22	16	1500
	Diesel	0.1	82	120	51	21000
Rickshaw	2-stroke LPG	3.5	2	55	47	13000
	4-stroke CNG	2.5	21	25	10	700
	4-stroke Gasoline	2.6	15	30	16	3100
Van	CNG	1.3	60	23	24	1350
	Diesel	0.15	78	115	40	19000
	Gasoline	2.4	75	28	22	4200
Motorcycle	2-stroke gasoline	4.7	21	45	21	6200
	4-stroke gasoline	1.6	16	21	12	1500
Tractor	Diesel	0.4	110	120	38	20000
Truck	Diesel	0.2	120	123	54	22000
Car	CNG	1.6	16	25	5	610
	Diesel	0.1	45	125	30	15000
	Gasoline	1.8	13	31	6	2800

Diesel engines produced SO_2 emissions in the range of 115 to 125 ppm as compared to gasoline engines' 21 to 45 ppm, and CNG engines 22 to 25 ppm (Table 2). The diesel bus engine released 5.5 times higher SO_2 (120 ppm) than the CNG bus engine (22 ppm). There were five times higher SO_2 emissions produced by the diesel van engine (115 ppm) than that of the CNG (23 ppm) and gasoline van engines (28 ppm). Similarly, the CNG car engine reduced five times and 1.4 times SO_2 emissions as compared to diesel and gasoline car engines, respectively. The CNG rickshaw engine emitted 2.2 times lower SO_2 than the 2-stroke LPG rickshaw engine. Sulfur content in the fuel appeared to be responsible for SO_2 emissions, as SO_2 emission were highest for diesel, followed by LPG, gasoline, and CNG.

Diesel and 2-stroke LPG engines were responsible for most of the smoke opacity (Table 2). There was 51% smoke opacity recorded for the diesel bus engine, followed by the 2-stroke LPG rickshaw engine with 47% smoke opacity. In contrast, CNG and gasoline car engines, CNG and gasoline rickshaw engines, and the CNG bus engine showed very low smoke opacity. The CNG bus engine produced 3.19 times less smoke opacity (16%) than the diesel bus engine (51%). Smoke opacity of the CNG van engine was 1.7 times lower than the diesel van engine, but 1.1 times higher than the gasoline van engine. The smoke opacity of the CNG car engine was 6 and 1.2 times lower than diesel and gasoline car engines, respectively. The CNG rickshaw engine released 4.7 and 1.6 times lower smoke opacity than the LPG (47%) and gasoline rickshaw (16%) engines, respectively.

HC emissions for the engines of diesel bus, van, car, and 2-stroke LPG rickshaw were 22,000, 21,000, 19,000, 15,000, and 13,000 ppm, respectively (Table 1). CNG vehicle engines (bus, van, car, and rickshaw) produced low HC emissions and proved to be the most environmentally friendly vehicles. The CNG bus engine released 14 times lower HC (1,500 ppm) as compared to the diesel bus engine (21,000 ppm), whereas HC emissions of CNG van engine were 14 and 3.1 times lower than of diesel and gasoline van engines, respectively. In contrast, HC emissions of CNG car engines (610 ppm) were 24.6 and 4.6 times lower than that of diesel (15,000 ppm) and gasoline car engines (2,800 ppm), respectively. CNG rickshaw engines released 18.6 and 4.4 times lower HC emissions as compared to LPG and gasoline rickshaw engines, respectively.

Comparison on the Basis of Engines and Fuels

A comparison of vehicular emissions on the basis of fuel and engine type is shown in Figs. 2-4. The diesel bus engine emitted 14, 5.5, 3.2, and 1.8 times higher HC, SO_2, smoke opacity and NO emissions, respectively, as compared to the CNG bus. In contrast, the CNG bus engine released 20 times higher CO emissions. By considering all the pollutant concentrations, a diesel bus engine produced 13.4 times higher vehicular emissions than that of the CNG bus engine (except CO).

Comparative analysis revealed that the CNG van engine (medium vehicles) emitted 14 and 3 times lower HC emissions as compared to diesel and gasoline van engines, respectively. The CNG van engine produced 5 times lower SO_2 as compared to diesel van engine. CO emissions of the

CNG van engine were almost two times less than gasoline van engine, but 8 times higher than the diesel van engine.

The CNG car (light vehicles) engine reduced 23 and 4.3 times vehicular emissions as compared to diesel and gasoline car engines, respectively. From comparative analysis, it was derived that the conversion of gasoline car engine to CNG decreased emissions of HC (4.6 times), smoke opacity (1.2 times), SO_2 (1.2 times), and CO (1.1 times), but enhanced emissions of NO (1.2 times). In contrast, conversion of the diesel car engine to CNG reduced HC (24.6 times), NO (2.8 times), smoke opacity (6 times), and SO_2 (5 times), but increased CO (16 times) emissions. CO is of main concern because it can cause death. The concentration of CO also can increase many fold due to unfavorable traffic handling and low wind speeds [12].

Two-stroke vehicles and auto rickshaws are considered a major source of CO, CO_2, NOx, and non-methane volatile organic compounds in the air [13]. Results showed that the 2-stroke LPG rickshaw engine released 18.5 and 4.5 times more HC emissions than the 4-stroke CNG and gasoline rickshaw engines, respectively. Smoke opacity of the 2-stroke rickshaw engine was 4.7 and 1.6 times more than the 4-stroke CNG and gasoline rickshaw engines, respectively. For 2-stroke rickshaw engines, SO_2 emissions were 2.2 and
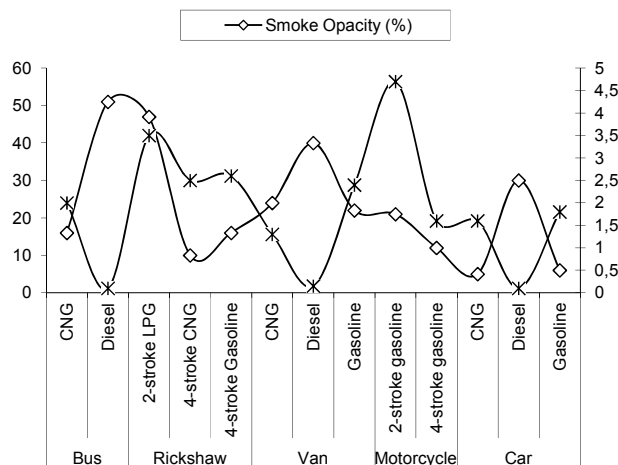

Fig. 4. Comparison of mean emissions of CO and smoke opacity (%) on the basis of fuel type.

1.8 times higher than engines of 4-stroke CNG and gasoline rickshaw, respectively. High emissions from 2-stroke rickshaws (especially SO_2) can cause serious health effects. It is important to calculate the emission distribution with air quality models to determine the concentrations and distributions in advance [14].
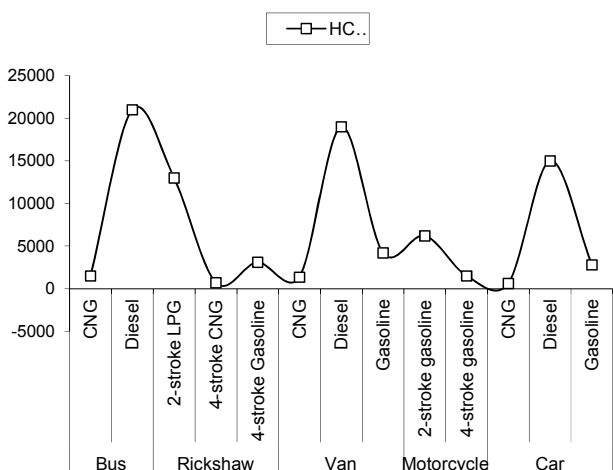
Conclusions

- The highest trend (> 95%) of shifting to CNG from gasoline and LPG was observed for rickshaws, while shifting of cars to CNG also was at the highest rate (> 90%).
- Emissions like CO, HC, and smoke opacity seem to depend on both fuel and engine type. Gasoline and CNG engines had 15 to 20 times higher CO emissions as compared to diesel engines.
- Smoke opacity and HC were very high for diesel vehicle engines. Reduction of HC and smoke opacity for conversion of heavy (bus) and medium (van) vehicles from diesel to CNG was almost the same, 14 and 3 times, respectively. However, this decreasing trend was almost doubled for light vehicles (cars).
- Under most test conditions, low NO levels were observed for gasoline engines as compared to diesel engines, and for two-stroke gasoline rickshaw NO level was almost zero.
- It is evident that the concentration of most of the pollutants showed a significant decrease after switching of heavy, medium, and light diesel and gasoline vehicle engines to CNG fuel, which would be helpful in reducing vehicular emissions.

Fig. 2. Comparison of mean emissions of hydrocarbons on the basis of fuel type.

Acknowledgements
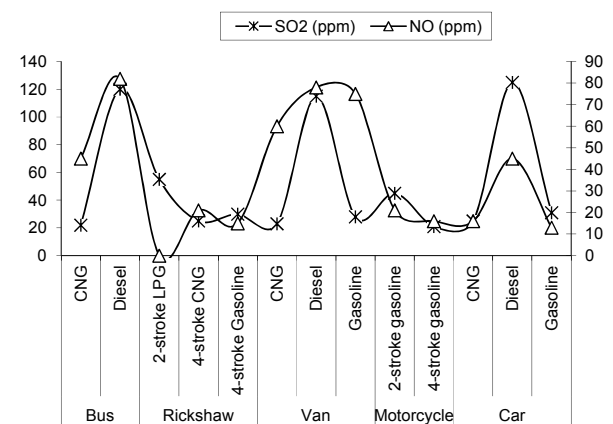
Fig. 3. Comparison of mean emissions of SO_2 and NO on the basis of fuel type.

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