Journal of Scientific & Industrial Research
Vol. 65, May 2006, pp. 426-431

CNG: An alternative fuel for public transport

Santosh A Jalihal* and T S Reddy
Central Road Research Institute, New Delhi 110 020

Received 16 June 2005; accepted 06 February 2006

Paper presents a case study of Delhi on the impact of using compressed natural gas (CNG) in reducing exhaust emissions. The total emissions of air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x) and particulates (PM) and hydrocarbons (HC) are estimated using vehicle-kilometers traveled, traffic and travel characteristics and emission factors of different fuel types used. Further, the impact of different fueling scenarios and interventions on air quality is assessed. The use of CNG fuel as an alternative to the conventional fuel in public transport and intermediate public transport vehicles benefits by reducing CO and PM emissions whilst increases HC and NO_x emissions. The reduction of PM emissions will go a long way in reducing the impacts on public health in general and respiratory and cardio-vascular system related health problems in particular.

Keywords: Air pollution, Compressed natural gas (CNG), Fuel, Transport

IPC Code: C01L3/06, F01N3/00

Introduction

The urban population[1] of India (around 28% of the total population) is a matter of concern to the planners and administrators of urban infrastructure. Nearly 38 percent of the total urban population is located in metropolitan cities (population of 1 million and above). On the impact of automobile exhausts in the cities, a number of actions have been taken to improve the technology of vehicles and quality of fuel. In Delhi, the Supreme Court has directed the operation of city buses on exclusively compressed natural gas (CNG) fuel mode. This paper presents the impact of using CNG in reducing traffic emissions by taking the case study of Delhi. The total emissions of air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), particulates (PM) and hydrocarbons (HC) are estimated using vehicle-kilometers traveled, traffic and travel characteristics and emission factors of different fuel type used.

Road transport has become the dominant mode of travel in urban as well as rural India, accounting for 80 percent of the passenger kilometers traveled and 60 percent of ton-kilometers of freight moved at national level and almost entirely in urban areas[2]. In Delhi, it is estimated that 72 percent of air pollution is caused by vehicular traffic[3]. The overall emissions will be lower if the vehicles travel at a steady speed particularly within the speed[4] of 40-88 km/h. Further, congested conditions result in higher emissions not only due to lower speeds but also due to frequent speed changes and idling at traffic controls and traffic jams. Clagget *et al*[5] and Matzoros & Van Vliet[6] demonstrated that the CO emissions are likely to be four times higher in a queuing zone compared to that in a cruising zone. Emissions are observed to increase further where a cold start is immediately followed by heavy congestion, since the efficiency of the catalytic converter will be lower under cold start condition.

Emissions from road vehicles with gasoline or diesel-powered engines can be identified into three main types: the crankcase, the fuel system and the exhaust emissions[7]. Crankcase emissions account for roughly 20 percent of HC emissions of uncontrolled vehicles[8]. In the new vehicles, this is avoided by closing the crankcase vent and preventing its exposure to the ambient air. The locked up gases of the crankcase are re-circulated to the intake manifold (PVC). Crankcase emissions from diesel vehicles are minimal. Exhaust emissions from road traffic consist mainly of water vapor and CO_2 emitted by the complete combustion of fossil fuel. In addition, nitrogen in the air combines with oxygen in the combustion chamber and result in the oxides of nitrogen. Primary emission is nitric oxide, but this is

*Author for correspondence
Tel: 00 91 11 2631 0339
E-mail: sjalihal@crridom.org

Table 1— Emission factors of different technologies and fuel types

Technology/Fuel type	Emission factor (g/km) Bharat Stage-II norms		
	CO	HC+NO_x	PM
Car - Petrol engine	2.2	0.5	-
Car - Diesel engine	1.0	0.7	0.08
Car/Taxi - CNG	0.786	1.55+0.92	0.02
Auto rickshaw - CNG	0.1	2.07+0.25	0.02
LCV – Diesel engine			
a) rw <1250 kg	1.0	0.7	0.08
b) 1250 < rw <1700 kg	1.25	1.0	0.12
c) 1700 kg < rw	1.5	1.2	0.17
HCV - Diesel engine*	4.0	1.1+7.0	0.15
Bus - Diesel*	0.8	0.24+6.62	0.115
Bus – CNG*	1.77	0.88+2.81	0.032
Bus – CNG converted*	3.47	3.03+8.95	0.032

*g/kWh, rw= reference weight

largely oxidized further to nitrogen dioxide when in contact with the atmosphere. Other exhaust pollutants are PM, CO and HC.

Fuels and Their Impact on Emissions

Seshadri & Harrison[9] illustrated that the emissions vary significantly for different pollutants according to the operating conditions. For example, the CO and HC emissions are higher during idling and deceleration modes when compared to cruising mode. CNG is cleaner than the conventional fuels (petrol and diesel) as far as PM is concerned (Table 1). Further, CO, HC and NO_x emissions for CNG based cars are lower because of the catalytic converters fitted with them whilst CO, HC and NO_x are higher for CNG converted buses. This is because the converted/retrofitted buses do not have catalytic converters fitted with them. CNG converted buses means retrofitting of new engines in old in-use vehicles. Retrofitting is done mainly for cost-effectiveness when the overall condition of the vehicle is good enough.

Materials and Methods

Study Area

Population of Delhi, the capital city of India with a total population of 12.7 million in 2001, has been growing fast (average annual growth, 4.5%) as compared to the national average rate (2.1%). Per capita vehicular trip rates for all vehicles in Delhi are observed to have gone up from 0.45 trip/day in 1969 to 0.72 in 1981 to more than 1.0 trip/day in 2001[10,11]. The increasing travel demand is mainly met by road. Basic modes of transportation are buses, taxis, auto rickshaws and private vehicles like cars, two wheelers (motor cycles and scooters) and bicycles. As per the available records, buses cater to about 55 percent of passenger trips, followed by cars, two wheelers, auto rickshaws (3-wheelers) and taxis. The slow moving vehicles (cycle and cycle rickshaws) cater to about 5 percent of the total trips. The lack of efficient public transport (PT) system has resulted in the growth of personal vehicles. Delhi is having total registered vehicles of more than 3.5 millions with the predominance of two wheelers and cars, used as private passenger vehicles. The road network of Delhi comprises of ring and radial pattern, which serve as major arterials to carry the major traffic in Delhi. A total road network of about 25,000 km is available in Delhi, of which 1100 km are provided with right-of-way 30 m and above (master plan roads) while another 1000 km form the major links carrying the traffic in Delhi. Amongst all the metropolitan cities in India, Delhi has the highest percentage of land (about 15 %) of the total area allocated to road network, which is equipped with about 600 signalized junctions located all over Delhi to control the traffic operations and encourage smooth flow of traffic.

Traffic Studies

Mid-block Traffic Counts

This survey was carried out to obtain the volume of traffic during different hours of the day at all the count points and the data has been analyzed to understand the composition of traffic by vehicle type and the fuel type.

Outer Cordon Traffic Surveys

Classified traffic volume counts and roadside interviews were conducted at 10 locations on outer cordon line of Delhi in February 2002 for 24 h to assess pattern of external traffic.

Fuel Station Survey

A total of 33 fuel stations, out of about 500 stations located in Delhi, were selected to conduct interviews of the owners/drivers of vehicles visiting the fuel stations for refueling. Care was taken to spread the survey stations across the space of Delhi to obtain representative sample of Delhi's vehicle population.

Results and Discussion

Traffic Load on Road Network

Classified traffic counts, conducted at 42 mid block stations, 10 outer cordon stations and 14 intersections, provided extensive data of traffic flows on the road

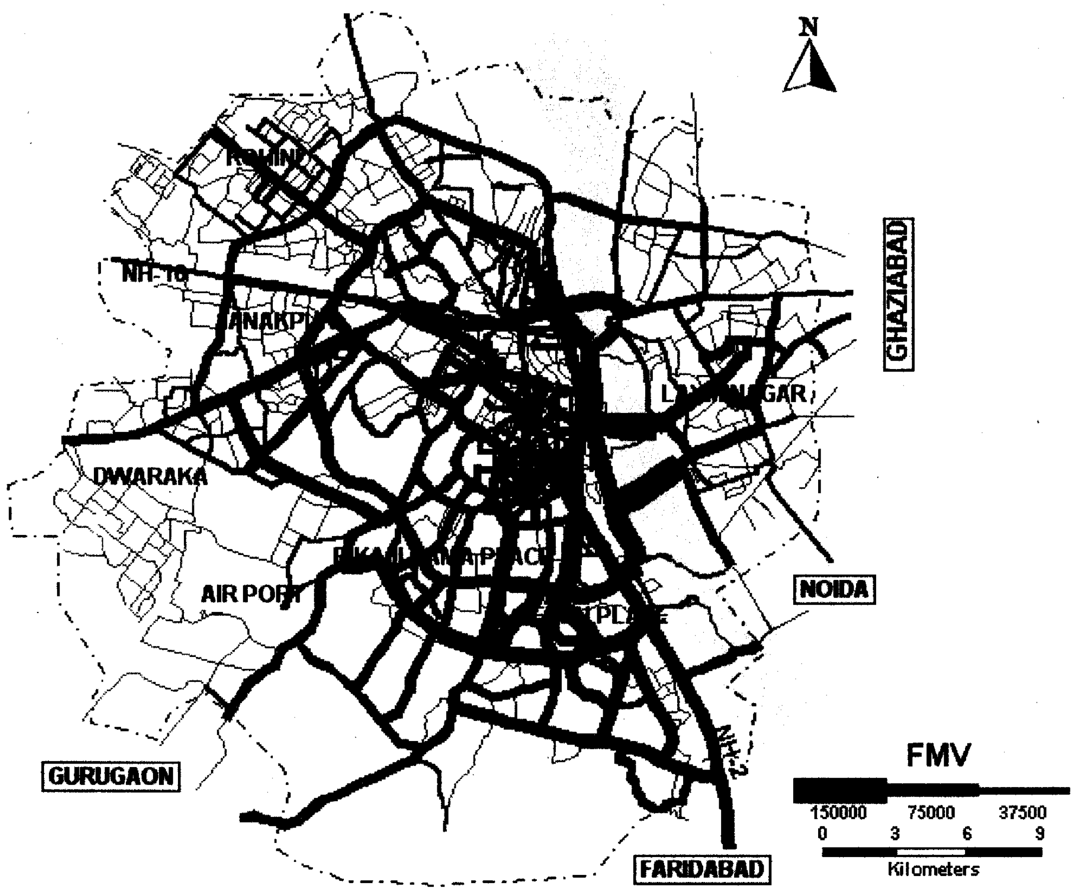

Fig. 1— Traffic flow pattern in Delhi

Table 2— Daily traffic load on Delhi road network

Vehicle type	Vehicle - km/d, millions	
	Roadside counts	Fuel stations
Cars + taxis	30.689 (38.7)	26.799 (34.9)
Two wheelers	33.823 (42.7)	38.700 (50.5)
Auto rickshaws	9.357 (11.8)	5.779 (7.5)
Goods vehicles	2.514 (3.2)	2.990 (3.9)
Buses	2.851 (3.6)	2.428 (3.2)
Total	79.234 (100.0)	76.696 (100.0)

Note: Numbers in parenthesis are percentages

network of Delhi. The estimated traffic load along each of the links is translated into pictorial form using digitized map of Delhi and GIS Software, TRANSCAD (Fig. 1). The radials and ring roads carry major portion of traffic movements in Delhi. Using the link traffic loads and composition of traffic by vehicle type, vehicle-kilometers traveled on each of the links have been estimated and in turn the total vehicle-kilometers traveled by each category of vehicles on the road network of Delhi have been estimated (Table 2). To validate the vehicle-kilometers traveled, comparison has been made by estimating the vehicle-kilometers traveled on the basis of data obtained from the surveys at the fuel stations and vehicles in use. It can be seen that the estimated vehicle-kilometers of travel from roadside and the fuel station interviews do not exactly match because most of the external traffic may not get accounted for at the fuel stations. The maximum proportion of travel (80 %) is made by two wheelers and cars, followed by 3-wheelers (12 %), while buses and goods vehicles have almost equal share (3% each).

Automobile Pollution Load

For determining the quantity of pollution, the emission factors[12] (Table 1) are employed along with the appropriate deterioration factors to account for the age of the vehicle. Employing emission factors, the pollution loads in terms of CO, NO_x, HC and PM have been estimated for the year 2002. The vintage of

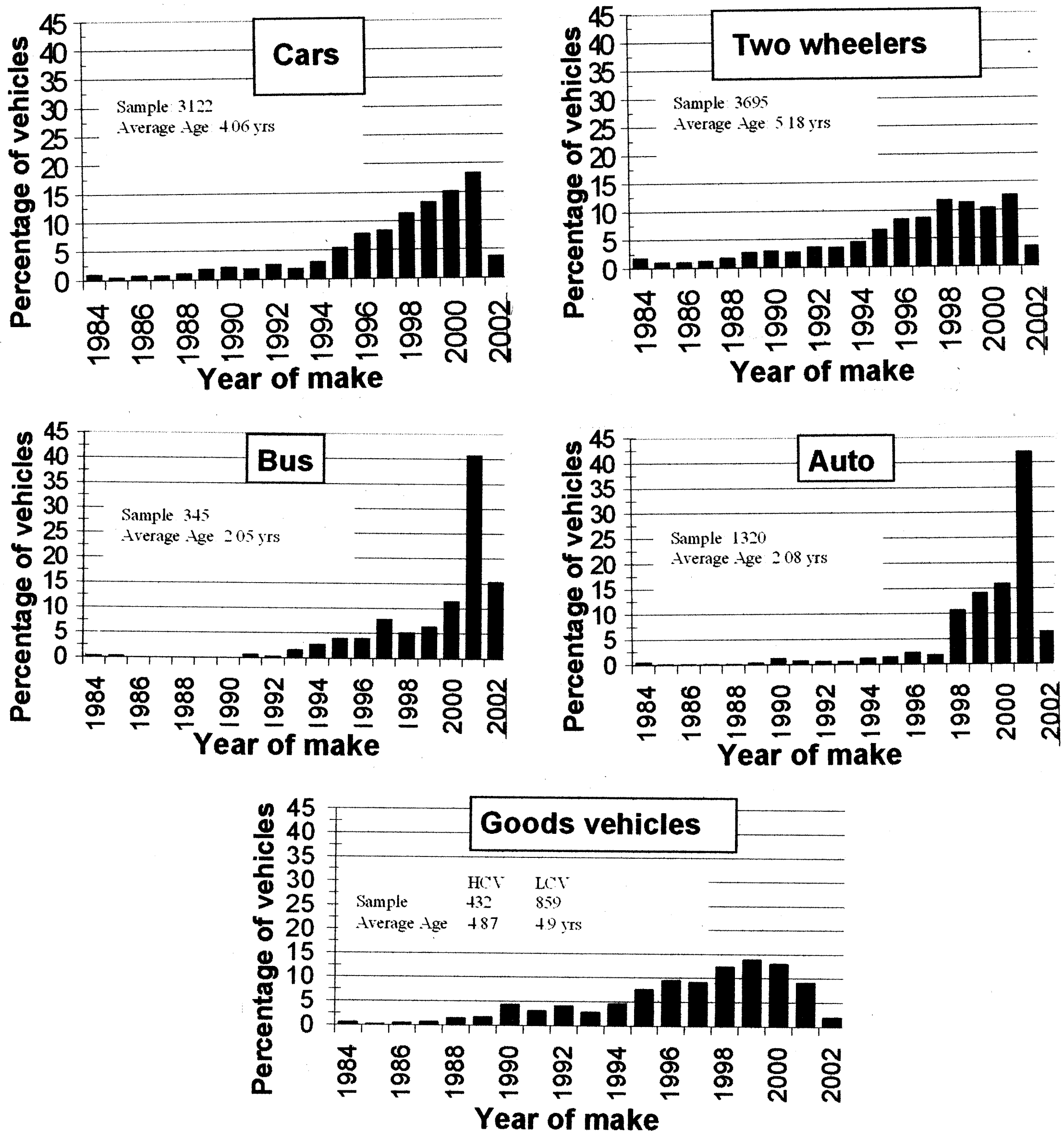

Fig. 2— Distribution of vehicles as per age in Delhi

vehicles as observed at the fuel station (Fig. 2) has been adopted to arrive at the emission factors and the corresponding pollution loads.

Impact of Alternative Fuels

The following possible scenarios of fuel use and technological changes of vehicle engines are employed in this analysis:

Scenario	Description	Remarks
1	Business As Usual (BAU): Emissions due to the PT and intermediate public transport (IPT) modes are estimated using the conventional fuel used (diesel for buses and taxis and gasoline for auto rickshaws).	No change in fuel policy
2	In this scenario, it is assumed that 50% of PT and IPT modes are using the conventional fuel (diesel for buses and taxis and gasoline for auto rickshaws), and 50% run on CNG fuel.	Gradual change in fuel policy.
3	Under this scenario, it is assumed that 100% of the PT and IPT modes are using the CNG fuel.	Complete conversion of city public transport and IPT modes to CNG fuel.

Table 3—Estimated annual pollution load due to different vehicles in Delhi

Mode and fuel type	CO pollution load, ton/annum		
	Scenario-1 (BAU)	Scenario-2	Scenario-3
Petrol car	72948	72948	72948
Diesel car	2666	2666	2666
Diesel/cNGtaxi	533	435	336
Petrol scooters	50359	50359	50359
Petrol motor cycle-2 stroke	3396	3396	3396
Petrol motor cycle-4 stroke	7493	7493	7493
Petrol autorickshaw	15167	7583	0
CNG autorickshaw	0	180	360
Diesel light commercial vehicle	4818	4818	4818
Diesel heavy commercial vehicle	1742	1742	1742
CNG bus	0	4831	9662
Diesel bus	4316	2158	0
Total	163438	158609	153780
Mode and fuel type	Nox pollution load, ton/annum		
Petrol car	14887	14887	14887
Diesel car	1145	1145	1145
Diesel/cNGtaxi	229	211	194
Petrol scooters	539	539	539
Petrol motor cycle-2 stroke	36	36	36
Petrol motor cycle-4 stroke	845	845	845
Petrol autorickshaw	2039	1019	0
CNG autorickshaw	0	450	901
Diesel light commercial vehicle	1598	1598	1598
Diesel heavy commercial vehicle	2720	2720	2720
CNG bus	0	10931	21862
Diesel bus	15075	7538	0
Total	39114	41920	44727
Mode and fuel type	HC pollution load, ton/annum		
Petrol car	13088	13088	13088
Diesel car	344	344	344
Diesel/cNGtaxi	69	197	326
Petrol scooters	36166	36166	36166
Petrol motor cycle-2 stroke	2439	2439	2439
Petrol motor cycle-4 stroke	2052	2052	2052
Petrol autorickshaw	4787	2394	0
CNG autorickshaw	0	3729	7458
Diesel light commercial vehicle	176	176	176
Diesel heavy commercial vehicle	430	430	430
CNG bus	0	2933	5865
Diesel bus	1118	559	0
Total	60670	64507	68345
Mode and fuel type	PM pollution load, ton/annum		
Petrol car	582	582	582
Diesel car	429	429	429
Diesel/cNGtaxi	86	45	4
Petrol scooters	1522	1522	1522
Petrol motor cycle-2 stroke	103	103	103
Petrol motor cycle-4 stroke	173	173	173
Petrol autorickshaw	352	176	0
CNG autorickshaw	0	36	72
Diesel light commercial vehicle	355	355	355
Diesel heavy commercial vehicle	353	353	353
CNG bus	0	45	90
Diesel bus	1148	574	0
Total	5103	4394	3684

For working out the quantity of pollutants (CO, NOx, HC and PM) under the above scenarios, an interactive computer program was written in C++ language and input files regarding the quantum of travel and its distribution amongst different vehicle types and their age wise distribution along with respective emission factors were separately created and used in the computation. The change in fuel type in PT and IPT vehicles from conventional fuel (petrol and diesel) to CNG, has resulted in general (Table 3), reduction in pollution load of CO (5.9%) and PM (27.8%), whilst at the same time increase in the emission of NOx (14.4%) and HC (12.7%). Further, within the same mode, it is observed that the benefits due to reduction of one pollutant is offset by the increase of another/other pollutant(s). The use of CNG fuel compared to diesel in buses increases CO, NOx and HC pollutants by 5346, 6787 and 4747 tons per annum respectively whilst reducing PM pollutants by 1058 tons per annum. In the case of auto rickshaws, generally run on petrol, pollutants emitted due to CNG indicated reduction in CO (97%), NOx (56%) and PM (79%), whilst HC emissions increased (56%). Similarly, in the case of taxis, generally run on diesel, the use of CNG resulted in reductions of CO (37%), NOx (16%) and PM (95%). However, HC emissions in this case increased by almost 4 times for the same vehicle-kilometers traveled. This indicates that the use of CNG instead of diesel in buses/taxis gives benefits in reducing PM emission loads, which are more harmful to human health. However, this also results in the increase of other pollutants (NOx and HC).

Conclusions

The emissions from vehicles depend on type of fuel used, engine size, driving conditions, emission control devices and meteorological conditions. CNG fuel in buses leads to 1½ times increase in NO_x, more than double increase in CO and 5 times increase in HC emissions. However, PM emissions are reduced by as much as 12 times. The use of CNG in auto rickshaws and taxis resulted in the decrease of CO, NO_x and PM emissions (15-94%) whilst the increase in HC emissions (1½-5 times). Thus, the use of CNG fuel in the PT and IPT modes in the national capital of Delhi has resulted in halving the CO emissions and reducing the PM emissions by 9 times while HC emissions are estimated to increase by more than twice and NO_x emissions by 1½ time. In a recent study by COMEAP[13] (committee on the Medical Effects of Air Pollutants, UK) about 2 percent of deaths and hospital admissions for respiratory diseases are brought forward per year by PM_{10} in urban areas of Great Britain. The COMEAP study further states that many of the deaths associated with days of higher air pollution are in the elderly and the sick. Therefore, it is concluded that the significant reductions in PM emissions would help in improving the respiratory and cardio-vascular system related problems thus improving the public health in the city of Delhi.

References

1 *General Population Tables 2001*, *Part IIA (i), Census of India* (Registrar General and Census Commissioner, Govt of India, New Delhi).
2 *Motor Transport Statistics of India* (Ministry of Road Transport & Highways, Govt of India, New Delhi) 2000.
3 *Air Quality in Delhi*, *Report No. NAAQMS/17/2000-2001* (Central Pollution Control Board, New Delhi) 2001.
4 *Air quality and traffic management*, LAQM, G3 (97) (The Stationary Office, Department of the Environment, Transport and the Regions, London) 1997.
5 Claggett M, Shrock J, & Noll K E, Carbon monoxide near an urban intersection, *Atmos Environ*, **15** (1981) 1633-1642.
6 Matzoros A & Van Vliet D, A Model of air pollution from road traffic based on the characteristics of interrupted flow and junction control: Part II- model results, *Transportation Res- Part A*, **26** (1992) 331-355.
7 Horowitz J. L, *Air Quality Analysis for Urban Transportation Planning* (MIT Press, London) 1982.
8 Sherwood P T & Bowers P H, *Air Pollution From Road Traffic- A Review of The Present Position*, LR 352 (Transport Road Research Laboratory, Crowthorne) 1970.
9 Seshadri P & Harrison R, Work-zone mobile source emission prediction, in *Research Report, SWUTC/92/60021-3* (Centre for Transportation Research, University of Texas, Texas, USA) 1993.
10 *Comprehensive Traffic and Transportation Planning Studies of Greater Delhi* (Central Road Research Institute, New Delhi) 1969.
11 *Road Development Plan Priorities for Delhi Urban Area-2001* (Central Road Research Institute, New Delhi) 1992.
12 *Transport Fuel Quality for the Year 2005* (Central Pollution Control Board, New Delhi) 2000.
13 *Quantification of the effects of air pollution on health in the United Kingdom,* (HMSO, Norwich) [Committee on the Medical Effects of Air Pollutants (COMEAP), UK] 1998.