EMISSION CHARACTERISTICS OF IN-USE CNG VEHICLES IN DELHI

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ABSTRACT

Road transportation has most adversely affected the air quality in Delhi. The existing fleet of 3.5 million motor vehicles in Delhi contributes nearly 70% of the total air pollution load. To improve the air quality status in Delhi various measures viz. improvement in fuel quality and engine technology, use of exhaust treatment devices, use of cleaner alternative fuels (CNG) etc. have been adopted in the recent past.

The Supreme Court of India has promulgated the mandatory use of CNG as automotive fuel in Delhi for public transport vehicles, which include diesel-driven buses, taxis (diesel and petrol) and petrol-driven three wheelers (autorickshaw: intermediate public transport). These vehicles present a combination of new, converted and retrofitted vehicles operating on CNG. In addition, a small number of private vehicles also operate on CNG (duel-fuel: petrol and CNG). In Delhi, more than 8-year old buses and pre-1990 taxis and autrickshaws have already been scrapped since March 2000. Hence, nearly 25,000 autos, 9,000 buses and 8000 taxis are required to run on CNG. The existing 87 dispensing stations are unable to meet the demand due to various factors. This has resulted in long queues (at dispensing stations) along the roads, thus seriously hampering the flow of traffic and has induced congestion and unwarranted pollution loading along the corridors.

The CNG vehicles have been assumed as non-polluting vehicles, hence no certification (PUC: pollution under control certificate) was required until recently for tail-pipe emissions, which otherwise is mandatory for all other vehicles. To understand how these in-use CNG-powered vehicles compared against their petrol-driven counterparts, the present study was undertaken in Delhi. The tailpipe CO and HC emission characteristics of CNG vehicles were analysed and compared against the emission characteristics of similar vehicle categories earlier using petrol as fuel. The emission levels were compared against the legislated tailpipe CO emission standards of 4.5% and 3% (by volume) for three and four wheelers respectively. All CNG-powered three wheelers are four-stroke engine vehicles, whereas petrol-driven conventional three wheelers are powered by two-stroke engines. This difference appears to have influenced the emission characteristics from CNG-powered three wheelers. The comparison has revealed notable reduction in CO and HC emissions from CNG-driven vehicles, especially from three wheelers. We have also tried to ascertain whether the lower emissions from three wheelers were due to the combination of CNG and four-stroke technology or because of the use of CNG alone. In addition, the present scenario has also been analysed, in limited scope, with respect to CNG-induced chaos, congestion and pollution. Nevertheless, there is a pressing need to initiate the process of certification and generation of database for CNG-powered vehicles, when the true picture would emerge as to how effective the CNG conversion is?

1.0 INTRODUCTION

Motor vehicles have been closely identified with increasing air pollution levels in urban centres of the world. Substantial CO_2 emission besides, significant quantities of CO, HC, NO_x, SPM and air toxins are emitted, causing serious environmental and health impacts. Like many other parts of the world, air pollution from motor vehicles is one of the most serious and rapidly growing problems in urban centres of India. In India, the number of motor vehicles has grown from 0.3 million in 1951 to approximately 50 million in 2000 of which two wheelers account for more than 70 percent of the total vehicular population. Moreover nearly 25% of the total energy in the country is consumed by the road transport sector of which 98% comes from oil *(1)*. The higher consumption of fuel has lead to increase in vehicular pollution loads and deterioration in air quality especially in metropolitan cities**.** Air pollution levels in these large urban centres invariably exceed the NAAQS (National Ambient Air Quality Standards). Vehicular emissions have been identified as one of the major contributors in deteriorating air quality. The problem has further been compounded by the concentration of large number of vehicles and comparatively high motor vehicle/population ratios resulting in higher pollution levels in these cities. Approximately 35% of the total vehicles are registered in 23 metropolitan cities of India *(2)*.

Delhi has the dubious distinction of one of the most polluted cities of the world. The city is facing serious environmental problems due to increasing vehicular emissions and high concentrations of pollutants in its urban atmosphere. It can further be substantiated by the fact that approximately 8% of the total vehicles in India are registered in Delhi alone. The air pollution levels generally exceed the NAAQS and the WHO guidelines. It has been reported that contribution of motor vehicle emissions to total air pollution has increased from 42% in 1981 to 64% in 1991 and projected to increase to 72% in 2001. It has also been estimated that motor vehicles account for approximately 97% of total HC, 48% of NO_x, 76% of CO, 10% of SPM and 6% of SO_2 emissions in Delhi. *(3)*. At present there are more than 3.5 million motor vehicles are registered in Delhi. It is noteworthy that despite the phenomenal growth of vehicles in Delhi (over the years), the proportion of different categories of vehicles has remained more or less unchanged (Table 1). Private vehicles (two wheelers and cars) constitute about 90% of the total vehicles. Hence, for any air pollution control strategy to be effective in Delhi, efforts should be directed towards controlling emissions from these vehicles.

2.0 RECENT INITIATIVES TO CONTROL VEHICULAR POLLUTION IN DELHI

For effective and efficient control of air pollution in Delhi, predominantly from motor vehicles, the government has taken several initiatives. In this direction 'White Paper on Pollution in Delhi With An Action Plan' was brought out by Ministry of Environment and Forests *(4)*. A few of the recent initiatives taken by the government includes introduction of unleaded petrol, phasing out of older commercial vehicles, introduction of Euro I and Euro II emission norms (enforced in the Delhi since April, 2000), check on adulteration of fuel, improvement in fuel quality, reduction of sulfur content in petrol and diesel and lowering of benzene content in petrol etc. In these efforts the Government has modified or made several amendments in the existing MVA (Motor Vehicle Act, 1988) and CMVR (Central Motor Vehicle Rules, 1989) to make them more effective in view of the advances in vehicle and pollution control technologies *(5)*.

Recently, the government has also taken steps to encourage the use of alternate fuels like CNG and LPG in the motor vehicles. The Supreme Court of India has also played a key role in directing the government and regulatory agencies to take stringent measures. As per the directions of the Supreme Court of India, the Delhi Government has banned the use of conventional fuels in commercial vehicles (taxis, three wheelers and city buses) and mandated the use of CNG in these vehicles. In addition, efforts have also been directed to strengthen the emission norms for various categories of in-use vehicles. These measures have influenced the improvement in air quality. A significant reduction in various air pollutant levels in various residential, industrial and commercial areas and also at intersections has been reported *(6)*. On the contrary, a TERI study has reported increase in the levels of air pollutants in Delhi *(7)*. Despite all the controversies, the air in Delhi appears to be cleaner now.

3.0 INTRODUCTION OF CNG IN DELHI

Ministry of Environment and Forests (MoEF) vide its gazette notification dated 29th January 1998 had constituted Environmental Pollution (Prevention and Control) Authority (EPCA) for the National Capital Region (NCR) of Delhi. The EPCA was given wide-ranging powers to control and tackle various environmental pollution related problems. Among other responsibilities the committee was also empowered to take all necessary steps to control vehicular pollution in the NCR. This committee was formed as a follow up action on "White Paper on Pollution in Delhi With An Action Plan" *(4)*. Based on various public interest litigation (PIL) and on the recommendation of EPCA, the Supreme Court on July 28, 1998 directed that all public transport vehicles comprising of taxis, three wheelers, and buses in Delhi are to run only on Compressed Natural Gas (CNG) after April 2001.

Initially, various concerned authorities and agencies were not serious about the Supreme Court order, obviously pinning their hopes on getting extension from time to time. But when it became clear that Supreme Court is quite serious about implementation of its orders regarding CNG conversion, the concerned agencies had started taking action in a knee jerk reaction. However, all concerned with CNG issue had requested the Supreme Court to extend the deadline beyond 1st April 2001 on one or the other pretext. Consequently, the CNG deadline was extended initially to October 1st, 2001 and then finally up to January 2002. There are 42,756 vehicles including 1,100 DTC buses, 1,070 private buses, 12,000 taxis and 24836 three wheelers have been converted to CNG mode. The actual number of buses to be converted is approximately 17,500 (10,000 in the NCT, 3500 tourist buses, 1000 school buses and 3000 coming from other states). As it stand now, only a very small fraction (1.5%) of 3.5 million vehicles presently registered in Delhi are to be converted into CNG mode. But how much influence these CNG vehicles will have on improvement in air quality in Delhi is not known.

The CNG in Delhi is being supplied by IGL (Indraprastha Gas Limited) *(8)* through a network of 87 dispensing outlets (inclusive of 15 mother stations, a few daughter booster stations and daughter stations) which are likely to go up by March 2002. The existing demand of CNG stands at 3.4 lakhs kg per day with a supply gap of 2.1 lakhs kg per day (with a supply deficit of about 32%). The CNG supply is expected to be increased to 4.4 lakhs kg per day by March 2002. Time delays, affidavits and counter affidavits, claims, denials and confusion followed by chaos, marked the whole controversy of CNG in Delhi.

4.0 CNG RELATED VEHICULAR EMISSION LEGISLATIONS

There are several laws in India, which directly or indirectly deal with vehicular emissions *(9)*. Important amongst them are the Air (prevention and control of pollution) Act (1981), the Environment Protection Act (1986) including the Environment (Protection) Rules (1987), The Motor Vehicles Act (1988) including the Central Motor Vehicle Rules (CMVR, 1989). Apart from these, Ministry of Environment and Forests (MoEF) and the Ministry of Petroleum and Natural Gas (MoPNG) have also issued notifications, which have direct bearing on vehicular emission in India. However, most of the vehicle emission related legislations are issued by MoRTH (Ministry of Road Transport and Highways).

Earlier CNG related specifications were completely missing from MVA and CMVR, but after the introduction of CNG in Delhi for public transport vehicles, as per the orders of the Supreme Court, the need was felt to incorporate various emission and safety related norms for CNG vehicles. At the same time efforts have also been made to prescribe emission and safety norms for other alternate fuels such as LPG.

The Section 115 of CMVR had prescribed emission norms for in-use petrol and diesel driven vehicles but did not prescribed norms for CNG vehicles. MoRTH vide notification dated 13 July 2001 have specified the emission norms for in-use as well as mass emission standards for CNG vehicles *(10)*. According to this notification, idling CO emission limits for in-use two and three wheelers operating on CNG/LPG/petrol has been fixed at 4.5% by volume; whereas emission norms for vehicles other than two and three wheelers have been fixed at 3%. However, for CNG vehicles separate tailpipe idle emission norms needs to be notified since it is a cleaner burning fuel than petrol.

5.0 SIGNIFICANCE OF THE PRESENT STUDY

A few of the studies have been carried out to evaluate the emission characteristics of in-use petrol driven vehicles in India *(11)* however, no study pertaining to in-use CNG vehicles in India has been reported so far. In Delhi, after the Supreme Court directive, approximately 45,000 commercial vehicles (OE (factory fitted) \ converted \ retrofitted) have already been converted to CNG mode out of the existing fleet of 3.5 million vehicles in Delhi.

Many studies from developed countries have reported emission characteristics of in-use CNG vehicles but direct applicability of their results to Indian conditions raises doubts in view of the current vehicle technology, efficacy of the conversion kits, driving characteristics, road surface and climatic conditions. Moreover, the experience of retrofitting and conversion technology to CNG mode is in nascent stage. Secondly, the gazette notification (MoRTH second notification) has put the CNG vehicles at par with other petrol driven vehicles as far as emission characteristics of in-use vehicles are concerned thereby ignoring the environment friendly potential of CNG vis-à-vis other conventional fuels. An attempt has been made in the present study to evaluate the emission characteristics of in-use CNG vehicles in Delhi so as to evaluate the relative advantage of CNG over conventional fuelled vehicles.

6.0 EXPERIMENTAL

In-use CNG vehicles (OE; factory fitted / retrofitted / converted) consisting of three wheelers (auto), cars and buses were tested for their exhaust emission characteristics between November 2000 to December 2000 and again in September 2001, using AVL 4000 light Digas exhaust gas analyser. The tailpipe emissions of CO, HC (n-hexane equivalent), CO_2, O_2 and lambda (λ; air fuel ratio) were measured under idle conditions. The instrument was calibrated as per the operating manual of the instrument. Precaution was taken to replace the filter at regular intervals. The other information such as category of vehicles, registration number, year of registration etc. were also recorded. The emission data so collected were analysed and compared with other in-use petrol driven vehicles as reported in the earlier CRRI study *(11)*.

7.0 RESULT AND DISCUSSION

A total of 846 CNG vehicles (OE, converted/retrofitted), consisting of three wheelers (400), cars (346) and buses (100) were checked for evaluation of their emission characteristics. The compliance levels of these CNG vehicles were evaluated as per the MoRTH draft notification (dated 13^{th} July 2001) and has been shown in Table 2*(10)*. Three wheelers (auto), cars and buses have constituted approximately 41%, 47% and 12% respectively. Almost, all the three wheelers (duel fuel; four-stroke) and buses (mono fuel) checked were OE vehicles, whereas the cars were duel fuel CNG vehicles (retrofitted / converted). Because of the limited data and in absence of other pertinent information regarding performance of CNG engines, it was not possible to evaluate in detail the relative emission characteristics of in-use CNG vehicles.

Amongst the three wheelers category the percentage compliance was observed to be 100% whereas, the percentage compliance for cars and buses was found to be approximately 85% and 81% respectively. The overall compliance level for in-use CNG vehicles was found to be approximately 91%. An effort has also been made to compare the emission characteristics of in-use CNG vehicles with in-use petrol driven counterparts, except for buses. The vehicle emission analysis data for petrol driven vehicles were taken from earlier study for comparison purposes *(12)*. Additional information regarding CO_2, O_2 and λ (A/F ratio) has also been collected while evaluating the emission characteristics of in-use CNG vehicles. However, the comparison has been made only for CO and HC parameters.

7.1 Emission Distribution Analysis of In-use CNG Vehicles

Three Wheelers: Figures 1 and 2 details the observed frequency distribution and cumulative frequency pattern of CO and HC for three wheelers (autos). It is evident from the figures that for most of the three wheelers (~ 70%) CO levels were lower than 0.1% (by volume). None of the three wheelers was found to emit CO more than 3% (compliance limit value of 4.5% of CO by volume) hence have shown a compliance level of 100%. With regard to HC emissions, approximately 75% of the vehicles had HC emission values lower than 200 ppm (by volume), approximately 90% vehicles had HC emission values lower than 400 ppm.

Cars: Figures 3 and 4 show the frequency and cumulative frequency distribution of CO and HC for cars. Most of the cars (~ 60%) were observed to have CO emission levels of less than 0.5% (by volume) in the exhaust. Approximately, 75% of cars had CO levels less than 2% (compliance limit value of 3% of CO by volume). However, emission values of as high as 8% of CO was also recorded. As regards to HC emission distribution analysis, most of the cars (65%) were found to be in the range of 0 to 200 ppm range. Approximately 20% of the vehicles had HC emission values between 200 to 400 ppm range. However, HC levels as high as 2400 ppm was found for a few of the cars also.

Buses: Figures 5 and 6 show the frequency and cumulative frequency distribution of CO and HC emissions. The CO levels of less than 0.5% was recorded for approximately 50% of the buses. Whereas, emission values of less than 3% of CO was obtained for 75% of the buses (compliance limit value of 3% of CO by volume). However the maximum CO value of 6% was recorded. Similarly, HC emission values of less than 400 ppm were recorded for approximately 60% of the vehicles. Nevertheless nearly 80% of the vehicles have registered HC values lower than 800 ppm. The maximum HC value of 2,800 ppm was observed for a few of the buses.

7.2 Effect of air/fuel ratio on the emission parameters

An effort has also been made to find out the effect of air fuel ratio on various exhaust emission parameters of in-use CNG vehicles viz. CO, HC, CO_2, and O_2. The influence of λ on emission characteristics of CO, HC CO_2 and O_2 has been presented in Figures 7 (a-d) to Figures 9 (a-d) for three wheelers, cars and buses respectively. The λ has been defined as the follows

$$\lambda = \frac{\text{(Air/Fuel Ratio) actual}}{\text{(Air/Fuel) Stoichiometric}}$$

For CNG vehicles, the stoichiometric A/F ratio has been reported as equal to 16.2 *(13)*. Any value of λ lower than 1 and greater than 1 indicates the rich and lean mixture combustion respectively.

(a) Three Wheelers: Figures 7 (a-d) show the variation of CO, HC, CO_2 and O_2 with respect to λ. The λ values were found to be greater than 2 in most of the cases, indicating lean mixture combustion. In a few of the vehicles had λ values as high 10. It has been observed that as the value of λ increased the CO and HC emission values have registered a decreasing trend. However, the influence of λ on CO_2 and O_2 emissions was found to be just opposite to each other.

(b) Cars: It is evident from Figures 8 (a-d) that λ value in most of the cars was greater than 1, indicating that most of the cars were operating on lean combustion mixture. The λ values were found to vary between 0.9 to 1.8. It has also been observed that lower CO and HC emission values were obtained when λ values were high. The distinct sharp peak near λ = 1 was noted for CO_2 (Fig. 8c) whereas, a cluster pattern (fig. 8d) was observed in the case of O_2 values (λ = 1).

(c) Buses: Figures 9 (a-d) show the influence of λ on CO, HC, CO_2 and O_2 emission patterns. The λ values were observed to be between l and 2. A typical pattern was observed for CO and HC emissions exhibiting as if λ has no definite influence on CO and HC in dedicated CNG buses. No plausible reason could be ascertained. For CO_2 and O_2 opposite distribution pattern to each other was observed.

8.0 EMISSION GAINS THROUGH ADOPTION OF CNG TECHNOLOGY

8.1 Performance of CNG cars versus cars fitted with catalytic converters

In the present study approximately 346 CNG cars (retrofitted, dual fuel; petrol and CNG) were tested for evaluation of emission characteristics. These cars belong to two distinct categories of vehicles. The first category of vehicles (251 cars) consists of pre-1995 CNG cars (conventional with no exhaust treatment device) retrofitted with CNG kits. The second category of CNG vehicles (95 cars) consisted of post-1995 retrofitted CNG cars equipped with emission control devices (oxidation catalytic converters). The emission characteristics of these CNG cars were compared against the petrol driven cars fitted with catalytic converters (CC). For the comparative analysis emission data pertaining to CC fitted cars (284 cars) obtained during earlier study were used *(12)*. The emission distribution analysis for CO and HC for the above three categories and total CNG cars has been given in Tables 3 and 4 and also shown in Figure 10. It is evident that although the frequency distribution pattern of CO and HC for different categories of CNG and petrol (CC) cars are more or less similar, a significant deviation in CO frequencies occurs for CO ranges below 1% (Fig. 10). Similarly, for HC frequency distribution analysis significant change in frequency distribution was obtained for HC values less than 600 ppm. The observed mean values and their standard deviations for different categories of CNG vehicles are shown in Table 5.

The above exercise clearly indicates that with adoption of CNG technology offered a gain of approximately 10% in CO emissions and 23% in HC emissions in case of cars. As there is no mechanism existing in India which can determine the efficiency of catalytic converters fitted in the vehicles, it may be assumed that alongwith CC the age of the vehicles had also contributed towards the emission gains.

8.2 Performance CNG fitted three wheelers versus conventional petrol driven three wheelers

In the present study the emission characteristics of 400 three wheelers fitted with CNG engines (OE; four-stroke) were compared against their petrol driven counterparts fitted with two-stroke engines whose emission characteristic were evaluated in our earlier study (CRRI, 1998). Table 6 and Figure 11 show the emission gains by adoption of CNG technology in three wheelers. The phenomenal emission gains of nearly 350% for CO and approximately 3000% for HC were observed. Since, three wheelers (autos) constitute only 3% of the total vehicular population of Delhi the reduction in CO and HC emissions through the introduction of CNG technology may contribute only marginally in improving the vehicular air pollution load in Delhi.

9.0 CONCLUSION

The analysis of exhaust emission characteristics of in-use CNG vehicles has revealed a high percentage of compliance to the existing norms of exhaust emissions for motor vehicles. The present study stresses the need for notification of separate and more stringent norms for pollution under control certification (PUC) for different category of CNG vehicles. The comparison of emission characteristics of three wheelers and catalytic converter fitted CNG cars against their respective petrol driven counterparts have shown emission gain in CO and HC emissions. Emission gains were observed to be much higher for HC as compared to the CO emissions. The emission gains for CNG cars with CC over petrol cars with CC were observed to be marginal, however the CO and HC gains were observed to be 4-fold for CO and 30-fold for CNG driven three wheelers against their conventional (two-stroke) petrol driven counterparts.

The emission analysis of CNG vehicles has also revealed that the most of these vehicles operate under lean burn mixture conditions (A/F ratio > 16.2 and $\lambda > 1$). It was further observed that increase in λ values decreased CO and HC emissions. However, increase in λ has also influenced decrease in CO_2 emissions, but increased the O_2 emissions, indicating that most of the CNG vehicles are able to burn CNG efficiently leaving very little of fuel as unburnt portion.

At present, only a small fraction (1.5% or 45,000 vehicles approximately) of the total vehicles (3.5 million) are operating on CNG. There is no doubt that CNG is a cleaner and comparatively environment friendly fuel as far as CO, HC and CO_2 emissions are concerned. But with the present number of CNG vehicles significant improvement in air quality is not envisaged unless suitable measures are taken to target the private vehicles in Delhi. Also at this juncture it is not clear what strategy will be best suited in addressing the core issue of vehicular pollution and what price would be paid for reducing the vehicular air pollution load in Delhi? However there appears to be no clear road to attain air quality improvement under present circumstances.

10.0 POINTS TO PONDER

1. There is a need for exhaustive quantitative evaluation of emission of critical pollutants of concern from CNG and technologically advanced conventionally fuelled vehicles to promote the advantage of using CNG or other gaseous fuels as auto fuel. This might help in overcoming most of the prevailing misgivings and establish CNG as environment friendly and economic fuel.
2. It is still too early to comment on emission characteristics of CNG vehicles. It is important to understand the emission characteristics under accelerated testing conditions to capture the effect of aging of vehicles on emissions. Would the CNG vehicles then match their technologically advanced counterparts in future?
3. The existing CNG chaos in Delhi is a big deterrent for promoting the use of CNG as alternative auto fuel. An improvement in infrastructure, easy availability of CNG, lower cost against conventional fuel, technical problems and safety issues etc. will then provide a much needed boost to the CNG campaign.

4. No air quality management and control strategy in Delhi can be successful unless private vehicles (two wheelers and cars) are targeted, which constitute more than four-fifth of total vehicular population of Delhi. Moreover, CNG should be encouraged to be used in conjunction with cleaner conventional fuels. Otherwise hasty decision of conversion of different categories of vehicles to CNG mode without considering other associated factors may prove to be a disaster.
5. There is an urgent need to create the public awareness towards the need of improving air quality in Delhi and also the crucial role CNG could play in this campaign.

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LIST OF TABLES

TABLE 1 Motor Vehicle Population in Delhi (Lakhs)

Sl. No.	Year	2W	Private Car	Taxis	TSR	Goods Vehicles	Buses	Total
1.	1991	12.94	4.27	0.10	0.65	1.06	0.19	19.23
2.	1992	13.81	4.68	0.11	0.69	1.10	0.22	20.64
3.	1993	14.67	5.10	0.11	0.71	1.14	0.23	21.98
4.	1994	15.08	5.57	0.12	0.74	1.22	0.25	23.49
5.	1995	17.07	6.17	0.13	0.77	1.31	0.27	25.75
6.	1996	18.44	6.85	0.14	0.80	1.39	0.29	27.93
7.	1997	19.91	7.65	0.16	0.82	1.46	0.32	30.35
8.	1998	20.76	8.04	0.16	0.85	1.48	0.34	31.67
9.	1999	21.69	8.57	0.17	0.87	1.54	0.36	33.23
10.	2000	22.61	9.09	0.18	0.99	1.60	0.39	34.79

Note: Values in parenthesis are the percentage share of the vehicles
1 lakh = 0.1 million

TABLE 2 Summary of the Exhaust Emission Analysis of In-Use CNG Vehicles

Type of Vehicle	No. of Vehicles	Prescribed Limit of CO (%) *	Numbers of Vehicles within limits	% Compliance
Cars	346 (40.8%)	3.0	293	85
3 Wheelers	400 (47.3%)	4.5	400	100
Buses	100 (11.8%)	3.0	81	81
Total	846 (100%)	-	774	91

* *As per the draft notification of Ministry of Road Transport and Highways (MoRTH) dated 13th July 2001*

TABLE 3 Emission Distribution Analysis of CO for Different Categories of Cars

CO Range*	Conventional with CNG (%)	CC with CNG (%)	Total with CNG (%)	CC with Petrol (%)
0-.5	49.40	58.56	56.06	55.60
.5-1	5.26	8.36	7.50	9.05
1-1.5	8.42	5.50	6.35	8.62
1.5-2	6.31	5.10	5.49	6.46
2-2.5	7.30	2.70	3.75	4.31
2.5-3	7.30	4.30	5.49	4.74
3-3.5	3.15	5.50	4.90	1.72
3.5-4	3.15	1.90	3.25	0.86
4-4.5	3.15	2.70	2.80	0.86
4.5-5	2.10	2.70	2.30	0.86
5-5.5	0.00	1.20	0.86	0.43
5.5-6	2.10	0.39	1.15	0.86
6-6.5	1.00	0.00	0.28	0.86
6.5-7	0.00	0.39	0.28	1.72
7-7.5	0.00	-	0.00	0.86
7.5-8	1.00	-	0.28	0.43
8-8.5	-	-	-	1.29

** Observed in % unit as per convention*

TABLE 4 Emission Distribution Analysis of HC for Different Categories of Cars

HC Range*	Conventional with CNG (%)	CC with CNG (%)	Total with CNG (%)	CC with Petrol (%)
0-200	56.80	67.70	64.73	49.45
200-400	18.90	15.53	16.18	28.36
400-600	9.40	7.20	8.09	15.27
600-800	5.20	3.50	4.04	4.00
800-1000	3.20	1.60	2.03	0.72
1000-1200	0.00	1.20	0.86	0.36
1200-1400	0.00	0.39	0.28	0.36
1400-1600	3.10	0.79	1.44	0.00
1600-1800	0.00	0.39	0.28	0.00
1800-2000	1.00	1.60	0.28	0.36
2000-2200	1.00	-	-	0.00
2200-2400	1.00	-	-	0.00
2400-2600	-	-	-	0.00
2600-2800	-	-	-	0.00
2800-3000	-	-	-	0.00
3000-3200	-	-	-	0.00
3200-3400	-	-	-	0.36
3400-3600	-	-	-	0.00
3600-3800	-	-	-	0.00
3800-4000	-	-	-	0.72

** Observed in ppm as per convention*

TABLE 5 Emission Gains Through Application of CNG Technology in Cars

Type of Vehicle	CO% Mean ± SD	HC (ppm) Mean ± SD	Emission Gain (%) with respect to Petrol cars with CC	
			CO	HC
(i) CNG car Pre 1st April, 1995 (CNG without CC)	1.39 ±1.74	279 ±434	2.79	6.37
(ii) Post 1st April, 1995 (CNG +CC)	1.22±1.51	210 ±335	14.68	29.53
Total (i + ii)	1.28±1.58	229 ±366	10.48	23.15
Petrol Cars fitted with CC	1.43±2,08	298 ±681	-	-

TABLE 6 Emission Gains Through Application of CNG Technology in Three Wheelers

Type of Vehicle	CO% Mean ± S.D.	HC (ppm) Mean ± S.D.	Emission Gain (%) with respect to petrol driven three wheelers	
			CO	HC
Three Wheelers (CNG)	0.45 ±0.68	166 ±262	346	2880
Three Wheelers (Petrol Driven)	2.01±1.89	4947± 3012	-	-

LIST OF FIGURES