THE AUTOMOTIVE RESEARCH ASSOCIATION OF INDIA

Air Quality Monitoring Project-Indian Clean Air Programme (ICAP)

Draft report on

"Emission Factor development for Indian Vehicles"

as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies

Project Sponsored by

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Indian Oil Corporation Ltd. Faridabad
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Project Executed by

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Executive Summary

This project is an outcome of the efforts put in by the stake holders (Oil Industry, research Organizations, academic institutions, under the aegis of MoEF (Ministry of environment and Forests), CPCB and State Pollution Control Boards) realizing the need for an integrated air quality management in India. The input for undertaking such a project was recommendations of Dr. Mashelkar Committee report published in 2003, which clearly outlined the alarming levels of pollutions in many Indian cities and the absence/lack of appropriate scientific data on air quality monitoring, source apportionment and emission factors. In the absence of such a data, it would be very difficult to conceive and implement holistic policy decisions to curb air pollution.

The project undertaken by the stakeholders consists of three major sub-components as below.

1. Development of emission factors for Indian vehicles
2. Vehicle source profiling
3. Ambient air quality monitoring, emission inventory and source apportionment

The best available data (Dr. Mashelkar Committee Report) for some of the metro cities suggests that automobiles could be major contributor to the overall pollution problem in that city. As it is commonly perceived, a properly compiled emission inventory is the fundamental building block of any air quality management system in a country and two essential building blocks required for compiling emission inventory are the emission factors and the activity data. As no data is available on emission factors for vehicles plying in Indian cities, the need was felt to develop the emission factors and estimate contribution of mobile sources (especially vehicles) in urban environment. This project aimed at development of emission factors for Indian vehicles.

The project was sponsored to ARAI by the oil industry by entering into a MoC (Memorandum of Collaboration) in Aug 2003 and subsequently the ownership of the project was taken up by MoEF and co-ordinated by CPCB in Oct 2005. To steer-head the project and monitor the progress of the project, a steering committee was constituted comprising of Ministry of environment and Forests, Oil Industry, CPCB, R&D and Academic institutions. It was also decided that a technical committee should be constituted to look into the technical issues, monitoring of progress of the project comprising of representatives from oil industry, research organizations which formulated the test matrix, test methodology, etc. Accordingly the technical committee was constituted and given the responsibility to evolve the common methodology, resolve the field issues, take up periodic review of the project so that the project could be completed in a time bound manner and all the stake holders could adopt a common methodology for the execution of the project.

The details of the emission factor project were also discussed in the technical committee meetings and a number of meetings were held with experts in the field for deciding the procedure, methodology, test matrix, fuel matrix, and the reporting methodology. The highlights of the project are given below.

- In-use vehicles of different vintages (Viz, 1991-96, 1996-2000, Post 2000 and Post 2005 [Tech Matrix] were included in the test matrix to understand the effect of technology on emission factors and give appropriate representation to all kinds of vehicles plying on Indian roads
- The project involved Exhaust Emission testing of in-use 2 Wheelers, 3 Wheelers, Passenger Cars, LCVs and HCVs on Chassis dynamometer.
- After the tests with commercial fuel, maintenance was carried out at authorized service stations.
- After the maintenance, the tests with commercial fuel was repeated followed by fuels with different fuel specifications to understand the effect of fuels on emissions.
- The committee decided to adopt the Indian Driving cycle for 2-W, 3-W and Pre-2000 4W.
- Modified Indian Driving cycle was used for testing for post-2000 4W. For comparative purpose, post -2000 4W were also tested on IDC.
- As there is no standard test procedure and driving cycle for HCV category for chassis dynamometer tests as the HCV engines are tested on the engine dynamometer for regulatory tests. Also since there is no correlation between engine test and field emission performance of the vehicle, a special cycle was formulated by ARAI. Hence the principal decision was taken to use the ARAI developed overall Bus Driving cycle for HCV category as it was the best available driving cycle for that category which is based on the average driving pattern of HCV vehicles in the four metro cities (Mumbai, Delhi, Kolkata and Chennai).
- Different inertia settings were used depending on the vehicle category as follows:
    - 2-wheelers: ULW (Unladen Weight) + 75 kg
    - 3-wheelers gasoline: 225 kg (3 passengersX75)
    - 3-wheeler diesel: GVW
    - Passenger cars: ULW+225 kg(3 passengersX75 kg)
    - Multi Utility Vehicles: ULW+450 kg (6 passengersX75kg)

- LCV
  - Bus: ULW + 1500 kg (equivalent to 20 passengers of 75 kg weight each)
  - Trucks: GVW (As specified by the vehicle manufacturer)
- HCV:
  - Bus – ULW + 4500 kg (Equivalent to 60 passengers of 75 kg each)
  - Trucks – GVW (To be limited to 20 ton max. for GVW > 20tons. If GVW is less than 20 tons, Inertia will be set to the maximum specified GVW)

- Apart from measuring conventional emissions like CO, HC, NOx, CO2 and PM, emissions of PAH, Benzene, 1,3-Butadiene, Aldehydes and Ketones were also measured and expressed in mg/km.
- The particulate matter was chemically characterized into SOF (Oil and fuel fraction) and IOF (Sulphate, Nitrate, H_2O, Carbon Soot, Metal Oxides).
- The particulate size distribution in terms of number, size and mass was also measured by ELPI and MOUDI instruments.
- The idle and constant speed mass emissions were also measured and expressed in g/min.

The study generated huge amount of data by testing of 89 nos. of vehicles for approximately 450 tests. However one of limitations of the project is that sample size in most of the categories of vehicles is less even to the extent of only one vehicle for some categories.

An expert group on emission factors was constituted by CPCB to critically analyze the data collected under the project and identify and take corrective action for anomalies in the data and suggest emission factors for different categories. The expert group has conducted the 5 nos. of meetings to analyze the data with regard to vintage effect, fuel effect, maintenance effect and suggest emission factors for Indian vehicles. After numerous deliberations the emission factors were evolved on the following basis as agreed upon by all the members of the expert group.

- While reporting the emission factors, it has been attempted to optimize the number of emission factors subject to vehicle category, vintage and cc. Wherever there are 2- 3 nos. of vehicle models in the same vintage and category, emission data of such vehicles has been averaged for before maintenance tests and after maintenance tests. Also tests results with different fuels as per the fuel matrix after maintenance are provided for reference only.
- The Average of Emission results of before and after maintenance are reported as emission factors. Wherever it is seen that the results are not as per the expected trend, such vehicles would be tested again under Source Profiling of Vehicular Emissions

project to ascertain the trend and arrive at the emission factors. It is also seen in some of the cases that although the vehicle is fitted with cat. con., the results are higher than previous vintages. In such cases it is seen that the vehicles are practically 5-6 years old at the time of testing and efficacy of cat. Con. is difficult to ascertain. Although the results were higher than the previous vintages, the mass emission results show less variability. In such cases also Source Profiling of Vehicular Emissions project data will be considered for arriving at emission factors.

- In case of technology matrix, mass emission results of Euro-III fuel were considered as emission factors. These vehicles being brand new vehicles, maintenance was not necessary and hence before maintenance effect does not reflect in the emission factors.
- CNG/LPG vehicles of various vintages are difficult to source at the test location viz., Pune. So principal decision was taken to take those vehicles available at ARAI, Pune for certification Testing. These vehicles were tested for after maintenance tests and after maintenance results are considered as Emission Factors.
- MIDC results were considered as emission factors for Post 2000 passenger cars and MUV's.

Thus a total of 62 emission factors have been worked out depending on vehicle categories, vintages and engine cubic capacities out of the total 89 nos. of vehicles tested under the project for 450 nos. of emission tests.

The emission factors reported in this study are based on prevailing driving cycles. However, the need was felt to establish Emission Factors on city specific Driving Cycles as there is continuous change in the road traffic pattern such as synchronization of traffic signals, construction of flyovers, one way traffic, restriction of entries of HCV in city areas and continuous increase in density of vehicles. The driving pattern of one city may not be same as the other cities due to the reasons mentioned above. Use of city specific Driving Cycle will lead us to closer EF to real world scenario. However it is intended to take up future work on formulation of city specific driving cycles and evolve emission factors on the same. Though the study has generated huge amount of data, the sample size is limited and the technical committee has also felt the need to test more number of vehicles as the automotive industry in Indian is expanding at a very rapid rate and more and more nos. of vehicle models are introduced. The technical committee has felt the need to evolve the emission factors on a continuous basis and on city specific driving cycles so that the information on emission factors is continuously upgraded to reflect the dynamic nature of the emissions scenario on account of continuous change in transport sector and traffic patterns of the city.

The following Emission Factors have been worked out based on the numerous deliberations of the expert group.

Table I: Summary of Finalized Emission Factors for Indian Vehicles

Sr. No. (With ref. to report)	Type of veh.	Sub-Category	Vintage	Fuel	Emission Factors											Applicable Vehicle Models
					g/km					mg/km						
					CO	HC	Nox	Co2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH	
1	Moped (2 Stroke)	< 80cc	1991-96	BS-II	11.41	7.70	0.02	15.37	-	0.0035	0.0016	0.0004	0.0000	0.0036	0.0014	HERO PUCH 3G/Automatic 65cc, Tvs Xls Super 70, Avanti 3 Gear , Tvs Euro Champ 50cc , LUNA TFR PLUS /Super/Magnum Kinetic Safari (V2) , Hero Puch 50 Cc, etc
2	Moped (2 Stroke)	< 80cc	1996-2000	BS-II	2.97	2.77	0.03	21.13	0.060	0.0020	0.0039	0.0059	0.0231	0.0395	0.2249	Hero Puch 65 Cc 2g/Super Shakti 3g , Tvs Xl Super 70 , Tvs Champ 60 , Tvs 50 Xl Electronic , LUNA SUPER ELECTRONIC/TFR Plus , Kinetic Safari V2 Hero Puch Automatic 65 Cc, etc
3	Moped (2 Stroke)	< 80cc	Post 2000	BS-II	0.45	3.10	0.04	29.69	-	0.0008	0.0032	0.0024	0.0010	0.0053	0.0017	Bajaj Sunny Spice , Super 70, Luna Elec Kinetic Style , Kinetic Safari V2 Hero Gizmo 60, Hero Panther 60, Shakti 2g 50 Cc , TVS Champ/50xl (49cc), etc
4	Moped (2 Stroke)	< 80cc	Post 2005	BS-II	0.46	0.60	0.02	36.81	0.018	0.0008	0.0004	0.0371	0.0071	0.0441	1.7500	All TVS 2S Mopeds, All Bajaj 2S Mopeds , All Kinetic 2S Mopeds, etc
5	Moped (4 Stroke)	< 100cc	Post 2000	BS-II	0.81	0.50	0.29	20.09	0.010	0.0032	0.0061	0.0000	0.0037	0.0089	0.3373	Hero Panther 4S , etc
6	Scooter (2 Stroke)	< 80cc	1996-2000	BS-II	5.20	2.51	0.04	24.24	NA	0.0013	0.0016	0.0037	0.0046	0.0140	0.0121	Kinetic Style , Kinetic Spark , Kinetic Pride KINETIC SAFARI V2, etc
7	Scooter (2 Stroke)	< 80cc	Post 2000	BS-II	2.37	2.05	0.03	27.08	0.049	0.3582	0.0009	0.0640	0.0168	0.8650	0.1916	Kinetic Style , KINETIC SAFARI, etc
8	Scooter (2 Stroke)	> 80cc	1991-96	BS-II	6.00	3.68	0.02	24.75	0.073	0.0062	0.0042	0.0003	0.0165	0.0309	2.2482	Bajaj Chetak , Chetak Classic (145.45cc) LML Vespa(150cc) , Bajaj Cub (100cc) Bajaj Stride , Bajaj Rave , Kinetic Marvel, etc
9	Scooter (2 Stroke)	> 80cc	1996-2000	BS-II	5.10	2.46	0.01	25.05	NA	0.0013	0.0073	0.0029	0.0001	0.0044	0.0012	Bajaj Chetak , Chetak Classic (145.45cc), LML Vespa(150cc) , Bajaj Super (3

Sr. No. (With ref. to report)	Type of veh.	Sub-Cate gory	Vintage	Fuel	Emission Factors											Applicable Vehicle Models
					g/km					mg/km						
					CO	HC	Nox	Co2	PM	Benze ne	1-3 Butadie ne	Formald ehyde	Acetald ehyde	Total Aldehy de	Total PAH	
																port) Bajaj Cub (100cc) , Bajaj Stride , Bajaj Rave , Kinetic Marvel, etc
10	Scooter (2 Stroke)	> 80cc	Post 2000	BS-II	3.02	2.02	0.03	29.62	0.046	0.0500	0.0021	0.0847	0.0189	1.0516	0.3795	Kinetic ZX Zoom , Bajaj Chetak, Bajaj Super, etc
11	Scooter (2 Stroke)	> 80cc	Post 2005	BS-II	0.16	0.86	0.02	38.54	0.057	0.0106	0.0123	0.0403	0.0573	0.1209	1.0075	All Bajaj 2S Scooters, All Kinetic Scooters, All TVS 2S Scooters, etc
12	Scooter (4 Stroke)	>100 cc	Post 2000	BS-II	0.93	0.65	0.35	33.83	NA	0.0051	0.0168	0.0062	0.0009	0.0087	0.0062	HHML Street(100cc), Kinetic K4(100cc), Honda Activa(102cc), Bajaj Legend(116cc), Honda Dio(102cc), BAL Chetak 4s, BAL Bravvo 4S, etc
13	Scooter (4 Stroke)	>100 cc	Post 2005	BS-II	0.40	0.15	0.25	42.06	0.015	0.0015	0.0128	0.1048	0.0576	0.1716	1.5200	All Honda 4S Scooters, All Bajaj 4S Scooters, All Kinetic 4S Scooters, All TVS 4S Scooters, etc
14	Motorcy cle (2 Stroke)	< 80cc	1991-96	BS-II	5.64	2.89	0.04	23.48	NA	0.0088	0.0082	0.0023	0.0003	0.0081	0.0035	Hero Puch, TVS Max, Yamaha Rajdoot, Yamaha RX 100, TVS Shogun, Bajaj KB 100 , etc
15	Motorcy cle (2 Stroke)	> 80cc	1996-2000	BS-II	2.96	2.44	0.05	24.17	NA	0.0003	0.0078	0.0002	0.0007	0.0010	0.0008	Bajaj M80, Yamaha Rajoot, Yamaha RX series, TVS Shogun, KB125, Escort Ace TVS Samurai, TVS Shaolin , etc
16	Motorcy cle (2 Stroke)	> 80cc	Post 2000	BS-II	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Bajaj M-80, Yamaha Rajdoot 154, Yamaha RX series, etc
17	Motorcy cle (4 s)	<100 cc	1991-96	BS-II	3.12	0.78	0.23	22.42	0.010	0.0043	0.0021	0.0010	0.0015	0.0053	0.9233	Bajaj 4S Champ, HHML Sleek,HHML Splendor, etc
18	Motorcy cle (4 s)	<100 cc	1996-2000	BS-II	1.58	0.74	0.30	23.25	0.015	0.0012	0.0030	0.0103	0.0016	0.0173	0.5124	Bajaj 4S Champ, HHML Splendor,Bajaj Caliber, Yamaha YBX, etc
19	Motorcy cle (4 s)	<100 cc	Post 2000	BS-II	1.65	0.61	0.27	24.97	0.035	0.0016	0.0101	0.0030	0.0000	0.0100	1.5752	CD 100, Passion, Dawn, KEL Challenger Yamaha Crux, Bajaj Byk,Yamaha Libero, TVS Centra, Star, etc

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					g/km					mg/km						
					CO	HC	Nox	Co2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH	
20	Motorcycle (4 s)	100-200cc	Post 2000	BS-II	1.48	0.50	0.54	24.82	NA	0.0174	0.0019	0.0014	0.0000	0.0022	0.0004	Pulsar, BAL Wind/ Avenger, Bajaj Discover, Eliminator, Yamaha Enticer Unicorn, HHML Ambition/ CBZ, etc
21	Motorcycle (4 s)	>200 cc	Post 2005	BS-II	0.72	0.52	0.15	45.60	0.013	0.0019	0.0016	0.0057	0.0053	0.0109	0.4600	Karisma, Bullet, etc
22	Three Wheelers (2Stroke)	<200 cc	1996-2000	BS-II	3.15	6.04	0.30	54.50	0.110	0.0062	0.0048	0.0426	0.0110	0.0623	2.9760	All Bajaj 3-W 2S Models , etc
23	Three Wheelers (2Stroke)	<200 cc	Post 2000	BS-II	1.37	2.53	0.20	62.41	0.045	0.0026	0.0038	0.0162	0.0175	0.0362	1.9610	All Bajaj 3-W 2S Models , etc
24	Three Wheelers (2Stroke)	<200 cc	Post 2005	BS-II	1.15	1.63	0.16	71.50	0.043	0.0053	0.0080	0.1054	0.1979	0.3954	2.0500	All 2S Bajaj A/R BS-II , etc
25	Three Wheelers (4Stroke)	<200 cc	Post 2000	BS-II	4.47	1.57	0.61	57.44	0.011	0.0925	0.0071	0.0253	0.0081	5.9738	0.2706	All Bajaj 3-W 4S Models , etc
26	Three Wheelers (4Stroke)	<200 cc	Post 2005	BS-II	2.29	0.77	0.53	73.80	0.015	0.0006	0.0004	0.0132	0.0125	0.0609	0.4954	All Bajaj 4S petrol 3-W , etc
27	Three Wheeler Diesel	<500 cc	1996-2000	BS-II	9.16	0.63	0.93	140.87	0.782	0.5669	0.0008	0.0281	0.0701	0.3594	0.1312	BAL 3W Diesel A/R, Greaves 360 KAL Diesel A/R, SIL Vikram Diesel A/R , etc

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					g/km					mg/km						
					CO	HC	Nox	Co2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH	
28	Three Wheeler Diesel	<500 cc	Post 2000	BS-II	2.09	0.16	0.69	173.85	0.347	0.0175	0.0014	0.0155	0.0048	0.0233	0.7989	BAL 3W Diesel A/R, Greaves 360 KAL Diesel A/R, SIL Vikram Diesel A/R M&M Champion A/R APE Cargo and Pass. A/R , etc
29	Three Wheeler Diesel	<500 cc	Post 2005	BS-II	0.41	0.14	0.51	131.61	0.091	0.0123	0.0112	0.0072	0.0057	0.0169	1.1847	Ape D3S (395, Ape Goods Carrier(422) Bajaj GC (416), Mahindra Champion (510cc) , etc
30	Three Wheeler CNG OEM 4S	<200 cc	Post 2000	BS-II	1.00	0.26	0.50	77.70	0.015	0.0359	0.0042	0.0072	0.0012	0.0085	0.4035	All Bajaj OEM CNG 4S 3W (Post 2000) , etc
31	Three Wheeler CNG Retro 2S	<200 cc	Post 2000	BS-II	0.69	2.06	0.19	57.71	0.118	0.0049	0.0061	0.0051	0.0071	0.0149	0.3237	All Bajaj Retrofit CNG 4S 3W (Post 2000) , etc
32	Three Wheeler LPG (Retrofit 2S)	<200 cc	1996-2000	BS-II	7.20 (VSP data)	5.08 (VSP data)	0.05 (VSP data)	44.87 (VSP data)	0.171 (VSP data)	NA	NA	NA	NA	NA	NA	Bajaj 3-W LPG Retrofit Models (1996-2000) , etc
33	Three Wheeler LPG (Retrofit 2S)	<200 cc	Post 2000	BS-II	1.70	1.03	0.04	68.15	0.130	0.0057	0.0169	0.0075	0.0040	0.0142	0.3358	Bajaj 3-W LPG Retrofit Models (Post 2000) , etc
34	Passenger Cars (Petrol)	<1000cc	1991-96	BS-II	4.75	0.84	0.95	95.65	0.008	0.2126	0.1322	0.0181	0.0109	0.0453	0.1577	Maruti Omni, Maruti Gypsy, Premier Padmini, Premier 118NE, Ambassador, etc
35	Passenger Cars (Petrol)	<1000cc	1996-2000	BS-II	4.53	0.66	0.75	106.96	0.008	0.0291	0.0073	0.0142	0.0057	0.6195	0.1428	Maruti Omni, Fiat Uno, Maruti Gypsy Premier Padmini, Premier 118NE Daewoo Matiz, Maruti 1000, Ambassador, etc
36	Passenger Cars	<1000cc	Post 2000	BS-II	1.30	0.24	0.20	126.37	0.004	0.0002	0.0031	0.0034	0.0012	0.0088	0.0955	Zen, Alto, Santro, Matiz, etc

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					g/km					mg/km						
					CO	HC	Nox	Co2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH	
	(Petrol) BS-II		(MIDC)													
37	Passenger Cars (Petrol) BS-I	1000 - 1400 cc	Post 2000 (MIDC)	BS-II	3.01	0.19	0.12	126.50	0.006	0.0007	0.0034	0.0034	0.0012	0.0079	0.1324	Fiat Palio, Wagon R, Getz, Tata Indica Esteem, etc
38	Passenger Cars (Petrol) BS-I	>1400cc	Post 00 MIDC	BS-II	2.74	0.19	0.21	142.86	0.006	0.0009	0.0001	0.0086	0.0012	0.0101	0.4636	Skoda Octavia, sonata, accent, beleno Corolla, Camry, etc
39	Passenger Cars (Petrol)	>1400cc	Post 05 MIDC	BS-II	0.84	0.12	0.09	172.95	0.002	0.0003	0.0003	0.0003	0.0000	0.0096	0.0500	Indica, Ford Ikon, Maruti Swift, Hyundai Getz, Fiat Palio, Esteem, Hyundai Ascent honda city, , etc
40	Passenger Cars (Diesel)	<1600cc	1996-2000	BS-II	0.87	0.22	0.45	129.09	0.145	1.5962	0.3132	0.0261	0.0003	0.0813	0.1013	Fiat 137D(1366cc), Ambassador (1500cc) Maruti Zen (1527cc) , etc
41	Passenger Cars (Diesel) **BS-I**	<1600cc	Post 2000(MIDC)	BS-II	0.72	0.14	0.84	156.76	0.19	0.0386	0.0528	0.0206	0.0021	0.0422	0.1490	Zen Diesel(1527cc), Esteem Diesel(1527cc), Indigo (1405cc), Accent(1493cc), Ambassador(1489cc) Zen Diesel(1527cc), Esteem Diesel(1527cc), Indigo (1405cc) Accent(1493cc), Ambassador(1489cc) , etc
41	Passenger Cars (Diesel) **BS-II**	<1600cc	Post 2000(MIDC)	BS-II	0.30	0.26	0.49	154.56	0.06	0.0010	0.0025	0.0108	0.0015	0.0131	0.1112	Zen Diesel(1527cc), Esteem Diesel(1527cc), Indigo (1405cc), Accent(1493cc), Ambassador(1489cc) Zen Diesel(1527cc), Esteem Diesel(1527cc), Indigo (1405cc) Accent(1493cc), Ambassador(1489cc) , etc
42	Passenger Cars (Diesel)	<1600cc	Post 2005 (MIDC)	BS-II	0.06	0.08	0.28	148.76	0.015	0.0018	0.0007	0.0889	0.0033	0.0922	0.2109	Indica, Palio, Skoda Superb, Hyundai Ascent, Ambassador, Mercedes C Class Hyundai Elantra, Ford Ikon, etc

Sr. No. (With ref. to report)	Type of veh.	Sub-Category	Vintage	Fuel	Emission Factors											Applicable Vehicle Models
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					CO	HC	Nox	Co2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH	
43	Passenger Cars (Diesel)	1600 - 2400 cc	1996-2000	BS-II	0.66	0.25	0.61	166.14	0.180	0.0032	0.0118	0.0400	0.0005	0.1244	0.1301	Ford Escort Diesel (1800cc), Fiat Uno (1700cc) , etc
44	Passenger Cars (CNG) BS-I	1000 - 1400 cc	Post 2000 (MIDC)	BS-II	0.60	0.36	0.01	131.19	0.002	0.0009	0.0002	0.0007	0.0011	0.0018	0.0154	Maruti Esteem retrofit CNG, Lancer Retrofit CNG, Maruti 800 CNG, Maruti OMNI CNG, etc
45	Passenger Cars (CNG)	<1000cc	1996-2000	BS-II	0.85	0.79	0.53	149.36	0.001	NA	NA	NA	NA	NA	NA	Ambassador retrofit CNG Ford Escort Retrofit CNG, etc
46	Passenger Cars (CNG) BS-I	<1000cc	Post 2000 (MIDC)	BS-II	0.06	0.46	0.74	143.54	0.006	0.0001	0.0003	0.0108	0.0022	0.0130	0.0164	Maruti baleno retrofit CNG , etc
47	Passenger Cars (LPG)	1000 - 1400 cc	1996-2000	BS-II	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Maruti Esteem retrofit LPG, Maruti 800 LPG, Maruti OMNI LPG, etc
48	Passenger Cars (LPG) BS-I	>1400cc	Post 2000 (MIDC)	BS-II	2.72	0.23	0.20	140.05	0.002	0.0006	0.0016	0.0005	0.0011	0.0021	0.0247	Maruti Esteem retrofit LPG , Lancer Retrofit LPG, Indigo LPG Retrofit, Ambassador Retrofit LPG, etc
49	MUV Diesel	<3000cc	1991-96	BS-II	2.49	1.39	1.70	163.56	0.570	0.0131	0.0057	0.0135	0.0003	0.0153	1.7892	Trax (2399cc), Sumo(1948cc), Matador, etc
50	MUV Diesel	<3000cc	1996-2000	BS-II	1.38	1.39	0.65	189.48	0.560	0.0059	0.0593	0.0003	0.0028	0.0300	5.0397	Sumo(1948cc), Tata Sierra(1948cc), M&M Commander(2523cc), Marshal(2523cc), Qualis(2446) , etc
51	MUV Diesel **BS-I**	<3000cc	Post 2000 (MIDC)	BS-II	1.94	0.89	2.46	242.01	0.48	0.008	0.006	0.000	0.003	0.006	2.604	M&M CL 550 MDI(2523cc) ,Scorpio(1998cc), Ford Endeavour(2500cc), Sumo(1948cc) Safari(1948cc), Trax(2399cc), Pajero(3200cc), Terra can (2902cc) Innova(2494cc) , etc
51	MUV Diesel	<3000cc	Post 2000	BS-II	0.39	0.10	0.62	216.75	0.10	0.0104	0.0010	0.0039	0.0015	0.0109	0.3153	M&M CL 550 MDI(2523cc) ,Scorpio(1998cc), Ford Endeavour(2500cc), Sumo(1948cc)

Sr. No. (With ref. to report)	Type of veh.	Sub-Cate gory	Vintage	Fuel	Emission Factors											Applicable Vehicle Models
					g/km					mg/km						
					CO	HC	Nox	Co2	PM	Benze ne	1-3 Butadie ne	Formald ehyde	Acetald ehyde	Total Aldehy de	Total PAH	
	BS-II		(MIDC)													Safari(1948cc), Trax(2399cc), Pajero(3200cc), Terra can (2902cc) Innova(2494cc) , etc
52	MUV Diesel	<300 0cc	Post 2005 (MIDC)	BS-II	0.25	0.19	0.67	255.98	0.096	0.2675	0.0403	0.0142	0.0083	0.0370	0.1252	Scorpio CRDI (2.6 ltr), Safari (2.95ltr) Innova (2.5 ltr), Tata 207 (2.95ltr), Spacio (2.95ltr) Endeavor (2.5) Tavera (2.5 ltr) Tourister (2.6 ltr) , etc
53	LCV Diesel	<300 0cc	1991-96	BS-II	3.07	2.28	3.03	327.29	0.998	0.5427	0.0094	0.1975	0.0117	0.2957	8.1284	Eicher 10.70 (3298cc), BTL Excel (2650cc), M&M DI Load Carrier(2523cc) M&M Loadking(2609cc), Telco SFC410 (2956cc), Telco LPT712(3783cc), Eicher Skyline(3298cc), M&M DI Express(2523cc), M&M Tourister(2609cc) AL PSV3 LYNX(3839cc), Tata SFC 407 minibus(2956cc), Telco LP709minibus(3783cc), HM RTV(3.3 and 2ltr) , etc
54	LCV Diesel	<300 0cc	1996-2000	BS-II	3.00	1.28	2.48	333.31	0.655	0.2015	0.2147	0.1176	0.0059	0.2169	3.7742	Eicher 10.70 (3298cc), BTL Excel (2650cc), M&M DI Load Carrier(2523cc) M&M Loadking(2609cc), Telco SFC410 (2956cc), Telco LPT712(3783cc) Eicher Skyline(3298cc), M&M DI Express(2523cc), M&M Tourister(2609cc) AL PSV3 LYNX(3839cc), Tata SFC 407 minibus(2956cc), Telco LP709minibus(3783cc), HM RTV(3.3 and 2ltr) , etc
55	LCV Diesel	>300 0cc	Post 2000	BS-II	3.66	1.35	2.12	401.25	0.475	0.1959	0.4154	0.0028	0.0083	0.0222	8.2679	BTL Traveller (2650cc), M&M DI Express(2523cc), M&M Tourister(2609cc) AL PSV3 LYNX(3839cc), Tata SFC 407 minibus(2956cc), Telco LP709minibus(3783cc), HM RTV(3.3 and 2ltr) , etc

Sr. No. (With ref. to report)	Type of veh.	Sub-Category	Vintage	Fuel	Emission Factors											Applicable Vehicle Models
					g/km					mg/km						
					CO	HC	Nox	Co2	PM	Benzene	1-3 Butadiene	Formaldehyde	Acetaldehyde	Total Aldehyde	Total PAH	
56	HCV Diesel Bus	>6000cc	1991-96	BS-II	13.06	2.40	11.24	817.52	2.013	0.1529	0.0313	0.1007	0.0148	0.1259	1.0123	Eicher 20/16RHD(4.9lt), TELCO LF936CE(5.9ltr), TELCO LP1510(5.9lt) Eicher 20/16RHD(4.9lt), TELCO LF936CE(5.9ltr), TELCO LP1510(5.9lt), AL 3/1 COMET (6.54Lit) , etc
57	HCV Diesel Bus	>6000cc	1996-2000	BS-II	4.48	1.46	15.25	920.77	1.213	0.1008	0.0093	0.1015	0.0029	0.1191	3.6515	Eicher 30.25RHD(4.9lt), TELCO LPT2515(5.9lt), TELCO LP/LPO /LPS/SE/SK(5.9lt), Eicher 30.25RHD(4.9lt) TELCO LPT2515(5.9lt), TECO LPT 2518(5.9lt) , etc
58	HCV Diesel Bus	>6000cc	Post 2000	BS-II	3.97	0.26	6.77	735.51	1.075	1.1782	0.0041	0.0562	0.0859	2.6629	0.1749	Volvo FM9, B7R (9.4lt) , Volvo FM12 (12.3lt), TECO LPT 2518(5.9lt), TELCO LPT2515(5.9lt), Volvo FM9, B7R (9.4lt) Volvo FM12 (12.3lt), TECO LPT 2518(5.9lt) TELCO LPT2515(5.9lt) , etc
59	HCV Diesel Bus	>6000cc	Post 2005	BS-II	3.92	0.16	6.53	602.01	0.300	0.0101	0.0096	0.0523	0.0082	0.1458	1.3715	Volvo FM9, B7R (9.4lt), Volvo FM12 (12.3lt), TATA NOVUS, TATA LPT2515, etc
60	HCV CNG Bus	>6000cc	Post 2000	BS-II	3.72	3.75	6.21	806.50	0.044	N A	N A	N A	N A	N A	N A	All TATA and AL CNG Buses , etc
61	HCV Diesel Truck	>6000cc	1991-2000	BS-II	19.30	2.63	13.84	837.50	1.965	0.0199	0.0175	0.0925	0.0197	0.1374	4.5975	Eicher 20/16RHD(4.9lt) TELCO LF936CE(5.9ltr) TELCO LP1510(5.9lt) ALCO 3/1 COMET (6.54Lit) Eicher 20/16RHD(4.9lt) TELCO LF936CE(5.9ltr) TELCO LP1510(5.9lt) ALCO 3/1 COMET (6.54Lit), etc
62	HCV Diesel Truck	>6000cc	Post 2000	BS-II	6.00	0.37	9.30	762.39	1.240	0.0049	0.0074	0.0610	0.0000	0.0837	3.9707	TECO LPT 2518(5.9lt) , TELCO LPT2515(5.9lt) , Volvo FM9, B7R (9.4lt) , Volvo FM12 (12.3lt) , TECO LPT 2518(5.9lt) , TELCO LPT2515(5.9lt) , etc

@ Since 2W 2s Motorcycle>80cc are very few in no. actually plying on road, the expert group has decided to neglect this category

The report, that follows, contains the details based on the expert group recommendations comprising of introduction, Objectives and scope of the project, project execution methodology, test matrix, driving cycles, methodology for evolving emission factors, logical explanations, analysis of data and discussions.

The detailed report containing the actual test data with different fuels, details of the vehicles tested and suggested emission factors are given as annexure IV (as a separate excel file). This report gives the summary emission factor along with detailed data for

- Emission Factors for Indian Vehicles With BS-II Fuel,
- Emission Factors for Indian Vehicles With BS-II and BS-III Fuels,
- Emission Factors for Indian Vehicles With BS-III Fuel

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1. Introduction

The emissions inventory is the foundation upon which the regulatory strategy can be formulated. Prior to the consideration of any new vehicle standard or in use emissions control program, an inventory assessment is made of that source's contribution to the overall inventory, and what properties and process lead to excess emissions. The inventory can be used as one gauge by which progress toward attainment is measured, and by which each estimate of the cost effectiveness of control measures can be assessed. Over the years, the increasing stringency of emissions standards is met with technological solutions of greater complexity. In response, the emissions estimation models have grown in size and complexity world over.

There are many emission sources that contribute to the urban air pollution such as point sources, non-point or area sources, motor vehicles, non-road mobile and natural. Magnitude of contribution from each of the sources depends upon the individual emission rates and the activity level.

The on-road motor vehicle emission inventory can be summarized as the product of an emission rate (e.g., gram/km) and an associated vehicle activity (e.g., km/day). Emission rate data are collected on individual vehicles in a laboratory setting.

ARAI had entered into a Memorandum of Collaboration (MoC) with oil companies on 13th August 2003. Under this MoC, the oil companies Hindustan Petroleum Corporation Limited (HPCL), Bharat Petroleum Corporation Limited (BPCL), Reliance Industries Limited (RIL) and Indian Oil Corporation Limited had sponsored the project titled, 'Development of Emission Factors for Indian Vehicles'. The MoC defines Scope of the project, Objectives, Methodology, Deliverables of ARAI, duration of the project, cost of the project, payment terms and confidentiality agreement between ARAI and Oil companies.

2. Literature Review:

Available Literature in India:

Working group on fuel quality under chairmanship of Dr. Mukhopadhyaya, was formulated by ministry of Environment and Forests and CPCB to identify and reduce vehicular emissions and improve fuel quality and to achieve desired ambient air quality. The deliberated on transport fuel quality for year 2005, comprising of

- Pollutants from transport fuel, air quality requirements, analysis of available Indian air quality data. Effects of different transport fuel parameters are summarized. After reviewing emerging fuel quality standards in different advanced countries, recommendations are made for India in 2005.
- Effects of fuel quality and engine design on pollutant inventory from auto exhaust in different years in 2000 and 2010 are presented.

- Presently available refining technology in Indian refineries are briefly discussed. The required technology up gradation for meeting proposed 2005 transport fuel quality and the approximate cost for Indian petroleum industry are provided.
- Number of logical activities are recommended to be taken up in future to provide the rational basis for ensuring air quality targets with appropriate indigenous infrastructure.

The study mentions about the pollutants discharged from the transport sector evaluated for the years 2000, 2005 and 2010. The calculation of annual emission quantity is based on summation of emission factors for a particular pollutant for a particular category multiplied by the mileage traveled and vehicle population while taking into account a suitable deterioration factor based on the vehicle age.

The emission factors used in the study are as per the following table.

Table: Emission factors used for the Delhi Study

Type	Year	CO	HC	NOX	PM	BENZENE	BUTDAN
2W, 2T (a,b)	1986-1990	6.5	3.9	0.03	0.23	.226/.074	.010/.008
	1991-1995	6.5	3.9	0.03	0.23	.226/.075	.010/.008
	1996 -2000	4	3.3	0.06	0.1	.191/.062	.008/.007
	2001-2005	2.2	2.13	0.07	0.05	.123/.040	.005/.004
	2006-2010	1.4	1.32	0.08	0.05	.076/.025	.003/.003
2 W , 4T (a,c)	1986-1990	3	0.8	0.31	0.07	.061/.036	.008/.007
	1991-1995	3	0.8	0.31	0.07	.061/.036	.008/.007
	1996 -2000	2.6	0.7	0.3	0.06	.053/.031	.007/.006
	2001-2005	2.2	0.7	0.3	0.05	.053/.031	.007/.006
	2006-2010	1.4	0.7	0.3	0.05	.053/.031	.007/.006
3 W, 2T (a,c)	1986-1990	14	8.3	0.05	0.35	.481/.157	.021/.019
	1991-1995	14	8.3	0.05	0.35	.481/.157	.021/.019
	1996 -2000	8.6	7	0.09	0.15	.406/.133	.018/.016
	2001-2005	4.3	2.05	0.11	0.08	.118/.038	.005/.004
	2006-2010	2.45	0.75	0.12	0.08	.043/.014	.002/.001
P C G (f,g)	1986-1990	9.8	1.7	1.8	0.06	.130/.076	.019/.014
	1991-1995	9.8	1.7	1.8	0.06	.130/.076	.019/.014
	1996 -2000	3.9	0.8	1.1	0.05	.061/.036	.009/.007
	2001-2005	1.98	0.25	0.2	0.03	.019/.011	.003/.002
	2006-2010	1.39	0.15	0.12	0.02	.011/.006	.001/.001
P C D (h)	1986-1990	7.3	0.37	2.77	0.84	0.022	0.007
	1991-1995	7.3	0.37	2.77	0.84	0.022	0.007
	1996 -2000	1.2	0.37	0.69	0.42	0.022	0.007
	2001-2005	0.9	0.13	0.5	0.07	0.007	0.002
	2006-2010	0.58	0.05	0.45	0.05	0.003	0.001
L C V (i)	1986-1990	8.7	0.34	3.15	0.8	0.017	0.005
	1991-1995	8.7	0.34	3.15	0.8	0.017	0.005
	1996 -2000	6.9	0.28	2.49	0.5	0.014	0.004
	2001-2005	5.1	0.14	1.28	0.2	0.007	0.002
	2006-2010	0.72	0.063	0.59	0.07	0.003	0.001
Trucks (j)	1986-1990	5.5	1.78	9.5	1.5	0.01	0.002

	1991-1995	5.5	1.78	9.5	1.5	0.01	0.002
	1996 -2000	4.5	1.21	8.4	0.8	0.006	0.001
	2001-2005	3.6	0.87	6.3	0.28	0.004	0.0008
	2006-2010	3.2	0.87	5.5	0.12	0.004	0.0008
BUS (k)	1986-1990	5.5	1.78	19	3	0.01	0.002
	1991-1995	5.5	1.78	19	3	0.01	0.002
	1996 -2000	4.5	1.21	16.8	1.6	0.006	0.001
	2001-2005	3.6	0.87	12.6	0.56	0.004	0.0008
	2006-2010	3.2	0.87	11	0.24	0.004	0.0008

** For gasoline MUV, EF are same as Passenger car gasoline, for Diesel MUV EF are same as passenger car diesel.*

Emission factors are categorized based on the following logic.

1986-1995 - Pre-controlled EF
1996-2000 -1996 norms
2001-2005 -2000 norms
2006-2010 -2005 norms

The deterioration factors used for the study are as follows:

Table: Deterioration factors for gasoline vehicles

Age of vehicles (years)	2W (CO, HC, NOx, PM)	3W (CO, HC, NOx, PM)	Passenger Cars Gasoline (CO, HC, NOx, PM)	MUV Gasoline (CO, HC, NOx, PM)
15-20	-	-	1.355	-
10-15	1.4	-	1.17	1.275
5-10	1.3	1.7	1.28	1.255
0-5	1.2	1.475	1.097	1.19

Table: Deterioration factors for gasoline vehicles

Age of vehicles	Passenger cars			Taxis			Buses			Trucks			MUV + LCV		
	PM	CO	HC &NOx	PM	CO	HC &NOx	PM	CO	HC &NOx	PM	CO	HC &NOx	PM	CO	HC &NOx
15-20	1.355	1.18	1	-	-	-	-	-	-	-	-	-	-	-	-
10-15	1.17	1.085	1	-	-	-	-	-	-	1.8	1.475	1	1.275	1.1	1
5-10	1.28	1.14	1	1.263	1.133	1	1.355	1.18	1	1.595	1.33	1	1.255	1.125	1
0-5	1.097	1.05	1	1.187	1.095	1	1.19	1.015	1	1.35	1.17	1	1.19	1.095	1

This study seems to be based on theoretical calculations and the data is not backed up by actual experimental studies. Hence use of this data for representing the actual field conditions may be not be plausible.

International Data:

A detailed literature review was carried for emission factor development methodology for California and UK. The literature review indicated that the emission factor development exercise began in the developed countries around 30 years ago and currently they have huge amount of data which is further being supplemented with continuous addition of data. The developed countries have advanced database of emission factors which are fine tuned by developing many city specific driving cycles of varying average speeds, temperature correction factors, gradient correction factors, AC correction factors, humidity correction factors, fuel correction factors, altitude correction factors, etc. Considering the advanced stages of emission factor development in developed countries, it would be impossible for India to replicate the complex methodology of the developed countries. However, as it was done in the developed countries also, we need to have some data which more or less is pertinent to the field situation in India, its mix of vehicles, technology classes, and then fine tune the emission factor data over a period of time as and when resources become available. ***The above conclusions can be ascertained from the details of methodology for development of emission factors in CARB and UK given below.***

2.1 Methodology of Emission Factor Development in CARB:

Introduction:

The on-road motor vehicle emission inventory can be summarized as the product of an emission rate (e.g., grams/mile) and an associated vehicle activity (e.g., miles/day). Emission rate data are collected on individual vehicles in a laboratory setting. These tests are performed primarily by the ARB and U.S. EPA[1]. Activity data are available from many sources, including the DMV, CALTRANS, and MPOs.

For planning purposes, it is necessary to predict emission rates, activity, and inventories for the future this necessitates the development of mathematical models. These models can then be used to develop emission inventories for conditions, places, and times that cannot be measured directly.

The emissions inventory is the foundation upon which the Air Resources Board regulatory strategy rests. Prior to the consideration of any new vehicle standard or in use emissions control program, an inventory assessment is made of that source's contribution to the overall inventory, and what properties and process lead to excess emissions. The inventory is used as one gauge by which progress toward attainment is measured, and by which each estimate of the cost effectiveness of control measures is assessed.

EMFAC is the model developed by CARB to estimate mobile source emission inventory in California. The underlying assumptions in EMFAC2000 are that the vehicle fleet can be categorized into unique technology groups with each technology group representing vehicles with distinct emission control technologies, that have similar in-use deterioration rates, and respond the same to repair. Further, vehicles in each technology group can be sub-divided into emission regimes. An emissions regime is defined such that emissions from vehicles within the regime do not increase with mileage accumulation. The emission regimes are analogous to quantum energy levels. The emissions characteristic of a vehicle technology group can be represented by these emission regimes, and vehicle deterioration can be simulated by the movement of vehicles among these regimes. In EMFAC2000, vehicles in each technology group are categorized into the following five regimes:

- Normals,
- Moderates,
- Highs,
- Very Highs,
- Supers.

In general, normal vehicles are those that maintain their emission levels at or below the vehicle's certification standards (FTP-standards). Moderate vehicles have emission levels that are between one and two times the FTP standards. Highs, very highs and super emission regimes have emissions levels that may be four, six and seven times the FTP standards, respectively. As vehicles age (or accumulate mileage), their emissions increase as a result of deterioration hence they migrate from normal emitting regimes to higher emitting regimes. The movement of vehicles into the higher emitting regimes is based on an analysis of CARB's in-use vehicle data, the final product of which is called the regime growth rates.

The following example illustrates how the model calculates the without I&M[2] hydrocarbon emission rates for 1966 model year vehicles in calendar year 1990. The intent of this example is to introduce the concepts of technology groups and emission regimes. The model first determines from the technology fraction file the type of vehicles sold in 1966 model year. Table 4-1 shows that vehicles sold in 1966 were equipped with two distinct technology groups.

TABLE 4-1 TECHNOLOGY GROUPS SOLD IN 1966

Tech. Group	Tech. Group Description	1966 Model Year Sales
1	Non-catalyst vehicles without air injection	92%
2	Non-catalyst vehicles with air injection	8%

The model calculates the total mileage accrued by these vehicles in the1990 calendar year. In this example, it is assumed that these vehicles have accrued approximately 200,000 miles. This mileage is then used in estimating the distribution of vehicles by emissions regime. Table 4-2 shows the percentage of vehicles in technology groups 1 and 2 by emissions regime. The weighted emission rate for technology 1 and technology 2 vehicles is 10.2 g/mi. and 8.2 g/mi., respectively. These rates are then multiplied by the respective sales fractions to arrive at a weighted rate of 10.04 g/mi. This process is then repeated for all model years up to and including the 1990 model year. The model year specific emission rates are then multiplied by the mileage accrued by these vehicles in 1990 calendar year the summation of which results in an inventory for the 1990 calendar year.

[2] I&M Inspection and Maintenance or Smog Check. The intent of these programs is to lower in-use deterioration rate by identifying dirty vehicles and repairing them.

TABLE 4-2 REGIME SPECIFIC POPULATIONS AND EMISSION RATES

Tech Group	Regime	Percent	Emissions (g/mi.)
1	Normal	0.0	3.1
	Moderate	83.3	5.9
	High	1.4	12.9
	Very High	7.8	26.6
	Super	7.5	40.9
	Weighted		**10.2**
2	Normal	34.3	4.0
	Moderate	50.5	5.3
	High	1.2	15.1
	Very High	7.1	23.8
	Super	6.9	33.6
	Weighted		**8.2**

Technology Groups used in EMFAC2000 model:

Technology Group Definitions for EMFAC2000 and Corresponding Technology groups			
Old Group	Tech Grou p	Model Years Included	Emission Control Configurations, Fuel Metering Systems, and Applicable Emission Standards
1	1	Pre-1975	Without secondary air
2	2	Pre-1975	With secondary air
3	3	1975 and later	No catalyst
4	4	1975-1976	Oxidation catalyst, with secondary air
5	5	1975-1979	Oxidation catalyst without secondary air
	6	1980 and later	Oxidation catalyst without secondary air
6	7	1977 and later	Oxidation catalyst, with secondary air
7	8	1977-1979	Three-way catalyst with TBI/Carb
8 and 9	9	1981-1984	Three-way catalyst with TBI/Carb, 0.7 NOx
	10	1985 and later	Three-way catalyst with TBI/Carb, 0.7 NOx
10	11	1977-1980	Three-way catalyst with MPFI
11	12	1981-1985	Three-way catalyst with MPFI, 0.7 NOx
	13	1986 and later	Three-way catalyst with MPFI, 0.7 NOx
12	14	1981 and later	Three-way catalyst with TBI/Carb, 0.4 NOx
13	15	1981 and later	Three-way catalyst with MPFI, 0.4 NOx
14	16	1980 only	Three-way catalyst with TBI/Carb
15	17	1993 and later	Three-way catalyst with TBI/Carb, 0.25 HC

16	18	1993 and later	Three-way catalyst with MPFI, 0.25 HC
none	19	1996 and later	Three-way catalyst with TBI/Carb, 0.25 HC, and OBD II
none	20	1996 and later	Three-way catalyst with MPFI, 0.25 HC, and OBD II
none	21	1994-1995	Transitional Low Emission Vehicles (TLEV), **no** OBD II
none	22	1996 and later	TLEVs with OBD II
none	23	1996 and later	Low Emission Vehicles (LEV)
none	24	1996 and later	Ultra-Low Emission Vehicles (ULEV)
none	25	1996 and later	Zero Emission Vehicles (ZEV)
none	26	1996 and later	Three-way catalyst with TBI/Carb, 0.7 NOx, and OBD II
none	27	1996 and later	Three-way catalyst with MPFI, 0.7 NOx, and OBD II
none	28	All	Low Emission Vehicles (LEV II)
none	29	All	Ultra-Low Emission Vehicles (ULEV II)
none	30	All	Super Ultra-Low Emission Vehicles (SULEV)

TBI/Carb: Throttle-body injection or carburetor fuel metering system
MPFI: Multi point fuel injection system
OBD II: Second generation on-board diagnostic systems. All 1996 and later vehicles (except Mexican vehicles) are assumed to be equipped with OBD II.
*Supergroups: (A) Non catalyst, (B) Oxidation catalyst, (C) Three-way catalysts with carburetors or throttle body injection, (D) Three-way catalysts with multi point fuel injection

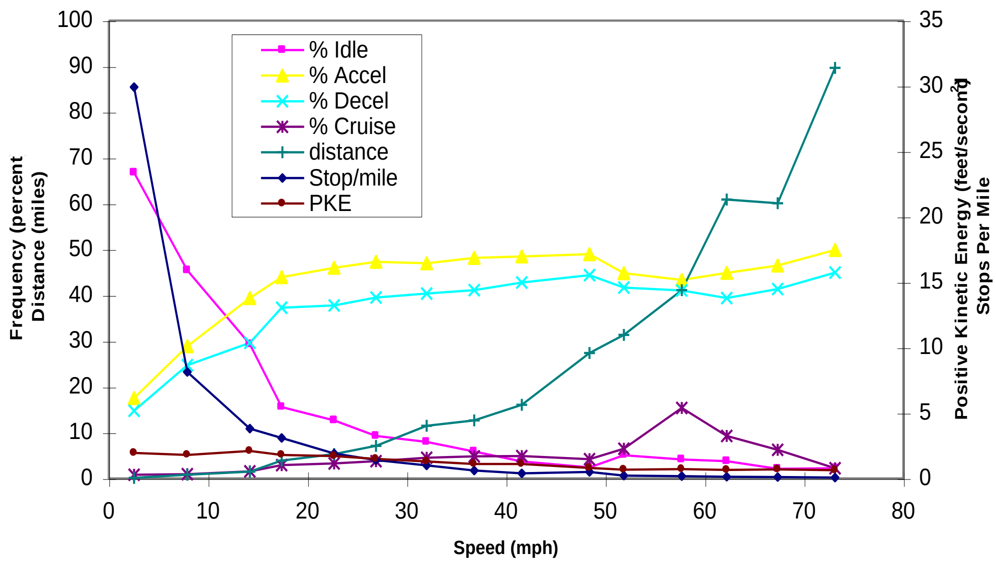
CORRECTION FACTORS

Correction factors are used to correct emissions from non-standard conditions. In a general sense, emissions can be described as:
ER = BER*CF1*CF2*CF3….etc.
For a given technology group. In EMFAC2000, the following correction factors are addressed:
Temperature correction factors (TCF) adjust exhaust emissions for temperatures other than 75F. Speed correction factors (SCF) adjust the UC-based BERs for other trip speeds. Fuel Correction Factors adjust for gasoline fuel characteristics (FCF). Air conditioning correction factors (ACCF) adjust the BER for usage of AC. Similarly, humidity correction factors adjust NOx emissions for humidity. Finally, Altitude correction factors adjust emissions for high altitude areas.
Cycle Correction Factor Development methodology:
This section discusses the development of cycle correction factors (CCF's) for use in EMFAC2000. The CCF's will be used to correct the basic emission rates to account for county specific speed distributions.

In prior versions of EMFAC, the FTP was used as the base cycle for developing basic emission rates, and the basic emission rates were corrected using speed correction factors (SCF's) to account for driving at different speeds. In the early 1990's, chase car and instrumented vehicle data collection efforts revealed that the FTP does not sufficiently represent contemporary driving[3,4,5]. With EMFAC2000 and subsequent versions, the Unified Cycle (UC) will be used for developing basic emission rates. However, EMFAC2000 will still need to account for county specific speed distributions through a speed correction methodology since the UC is based on driving that occurred during the 1992 calendar year. As driving behavior changes, the base UC emission rates will be corrected in EMFAC2000 through a set of CCF's. The CCF's will be developed from a set of 12 cycles referred to as Unified Correction Cycles (UCC's).

The 12 new UCC's were designed to be representative of an average trip for a given speed. The mean speeds of the UCC's range from approximately 2.4 mph to 59.1 mph at approximately 5 mph increments. The cycles were synthesized using ARB chase car data and ARB and EPA instrumented vehicle data. Prior to developing the cycles, the chase car and instrumented vehicle data were analyzed for several variables including mean speed, speed-acceleration frequency distribution, positive kinetic energy (PKE), load, maximum acceleration, maximum deceleration, percent idle, percent acceleration, distance, etc., and binned by trip mean speed. Analysis of the data indicated that there is a substantial difference in the noted driving characteristics on a per trip basis as shown in Figure 6.2-1.

FIGURE 2.1-1. DRIVING CHARACTERISTICS ON A PER TRIP BASIS.



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3 T.C. Austin, F.J. DiGenova, T.R. Carlson, R.W. Joy, K.A. Gianolini, J.M. Lee, *Characterization of Driving Patterns and Emissions from Light-Duty Vehicles in California*, Final Report to the California Air Resources Board from Sierra Research, Inc., Contract No. A932-185, Sacramento, California, November 12, 1993.

4 T.H. DeFries, S. Kishan, *Light-Duty Vehicle Driving Behavior: Private Vehicle Instrumentation*, Final Report to the U.S. Environmental Protection Agency from Radian Corporation, DCN 92-254-036-90-04, Austin, Texas, August 24,1992.

5 S. Magbuhat and J.R. Long, *Using Instrumented Vehicles to Improve Activity Estimates for the California Emissions Inventory Model*, VIP-45, The Emission Inventory: Applications and Improvement, Air and Waste Management Association, 1995.

The UCC's were developed in two phases. The first set of UCC's were developed using the ARB chase car data, and ranged in speeds from 15 to 45 mph[6]. Since the ARB chase car data did not contain trips of less than 15 mph or greater than 50 mph, the ARB and EPA instrumented vehicle data was used to evaluate and develop cycles on the high and low ends of the speed range.

Data Analysis

The vehicles used in this analysis were selected from surveillance projects 2S95C1, 2S97C1 and research projects 2R9513 and 2R9811. Technology and model year groups consistent with the EMFAC2000 technology group designations were used in this analysis. The vehicles chosen from surveillance project 2S95C1 were randomly selected for exhaust emission testing from a group of vehicles that were representative of the California fleet. For the remaining test projects, vehicles were selected to represent specific technology and model year groups.

The CCF equations were developed using exhaust emission test data from the UC and the UCC's. The UCC's were developed in two phases. The first phase of cycles (UCC15 to UCC45) were developed using chase car data. The second phase of cycles (UCC5, UCC10, and UCC55-UCC65) were developed using instrumented vehicle data. Since the UCC's were developed in two phases, there is an imbalance in the exhaust emission test data. Ten vehicles have been tested on the full range of UCC's, while over 130 vehicles have been tested on the UCC15 to UCC45. The CCF equations were fitted to the mean of the UCC divided by the mean of the UC for each individual speed bin. The CCF equations were developed using a methodology that curve fits the ratio of the mean data as opposed to the raw data.

Table below contains the coefficients for the CCF equations by emission category and technology group. The equations are second order for each emission category and technology group and are normalized to the Bag 2 UC mean speed (27.4 mph) emission rates. An example of the general equation for CCF's for any given emission category and technology grouping is shown in Equation below.

$$CCF(S)_{s,p,t,my} = EXP(A(S-27.4) + B(S-27.4)^2) \qquad (6.2\text{-}1)$$

Where:

$CCF_{s,p,t,my}$ = Cycle Correction Factor for a given speed "s", pollutant "p", technology group "t", and model year "my".

S = Trip mean speed from 2.5 to 65 miles per hour.

A,B = coefficients.

[6] R. Gammariello and J.R. Long, Development of Unified Correction Cycles, Sixth CRC On-Road Vehicle Emissions Workshop, San Diego, California, March 18, 1996.

The CCF equations are bounded by the 2.5 mph and 65 mph speed ranges.

Table A

Cycle Correction Factor Coefficients by Emission Category and Technology Group				
Emission Category	Technology Group	CCF Technology Group Mapping	A Coefficient	B Coefficient
CO	CARB	1	-0.028971	0.001922
CO	FI	2	-0.016288	0.000054
CO	TB	3	-0.020787	0.000292
CO2	CARB	4	-0.025952	0.000309
CO2	FI	5	-0.026423	0.000744
CO2	TB	6	-0.023750	0.001056
HC	CARB	7	-0.031762	0.000908
HC	FI	8	-0.044726	0.001070
HC	TB	9	-0.036860	0.000664
NOX	CARB	10	0.008967	-0.000027
NOX	FI	11	-0.013763	0.000320
NOX	TB	12	-0.016610	0.000654

Table A also contains the CCF technology group mapping number for each CCF equation. Since there are fewer CCF technology group equations than are contained in the technology group designation for EMFAC2000, the CCF equations need to be mapped to the corresponding EMFAC2000 designation. The technology group designations for EMFAC2000 are shown in Table B along with the assigned CCF technology group mapping number. There are four CCF technology group mapping numbers applied to each technology group designation that correspond to the four mapped emission regimes (HC, CO, NO_X, and CO_2).

The CCF equations are shown graphically in Figure A through Figure (d) for HC, CO, NO_X and CO_2, respectively. The individual technology groups are shown on each graph for the respective emission type.

Table B

Cycle Correction Factor Equation Mapping to EMFAC2000 Technology Groups			
Technology Group	CCF Equation Mapping	Model Years	Emission Control Technology
1	1,4,7,10	Pre-75	LDV no AIR

2	1,4,7,10	Pre-76	LDV with AIR
3	1,4,7,10	1975+	LDV noncatalyst
4	1,4,7,10	1975-76	LDV OxCat with AIR
5	1,4,7,10	1975-79	LDV OxCat no AIR
6	1,4,7,10	1980+	LDV OxCat no AIR
7	1,4,7,10	1977+	LDV OxCat with AIR
8	3,6,9,12	1977-79	LDV TWC TBI/CARB
9	3,6,9,12	1981-84	LDV TWC TBI/CARB 0.7 NOx
10	3,6,9,12	1985+	LDV TWC TBI/CARB 0.7 NOx
11	2,5,8,11	1977-80	LDV TWC MPFI
12	2,5,8,11	1981-85	LDV TWC MPFI 0.7 NOx
13	2,5,8,11	1986+	LDV TWC MPFI 0.7 NOx
14	3,6,9,12	1981+	LDV TWC TBI/CARB 0.4 NOx
15	2,5,8,11	1981+	LDV TWC MPFI 0.4 NOx
16	3,6,9,12	1980	LDV TWC TBI/CARB
17	3,6,9,12	1993+	LDV TWC TBI/CARB .25 HC
18	2,5,8,11	1993+	LDV TWC MPFI .25 HC
19	3,6,9,12	1996+	LDV TWC TBI/CRB .25 OBD2
20	2,5,8,11	1996+	LDV TWC MPFI .25HC OBD2
21	2,5,8,11	1994-95	LDV TLEV MPFI .25HC
22	2,5,8,11	1996+	LDV TLEV OBD2 GCL
23	2,5,8,11	1996+	LDV LEV OBD2 GCL CARBC AFC
24	2,5,8,11	1996+	LDV ULEV OBD2 GCL CARBC AFC
25		ALL	ZEV
26	2,5,8,11	1996+	LDT TWC MPFI OBD2 .7NOx
27	3,6,9,12	1996+	LDV TWC TBI/CARB OBD2
28	2,5,8,11	2004+	LDV LEV II
29	2,5,8,11	2004+	LDV ULEV II
30	2,5,8,11	2004+	LDV SULEV II
40	1,4,7,10	Mex	LDV NoCat / NoAir
41	1,4,7,10	Mex	LDV OxCat with Air
42	3,6,9,12	Mex	LDV TWC TBI / CARB 0.7 NOx
43	2,5,8,11	Mex	LDV TWC MPFI 0.7 NOx

FIGURE (A) HYDROCARBON CYCLE CORRECTION FACTOR CURVES.

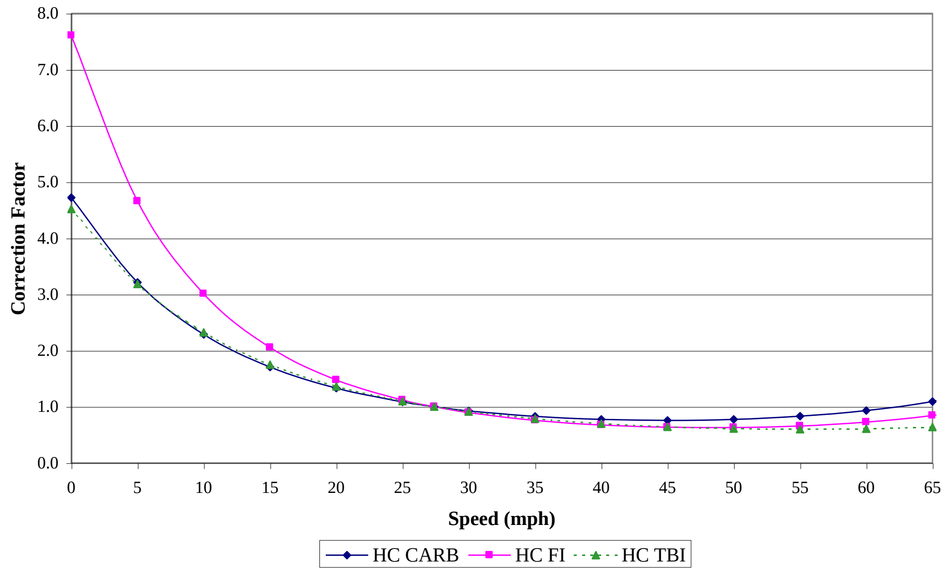


FIGURE (B) CARBON MONOXIDE CYCLE CORRECTION FACTOR CURVES.

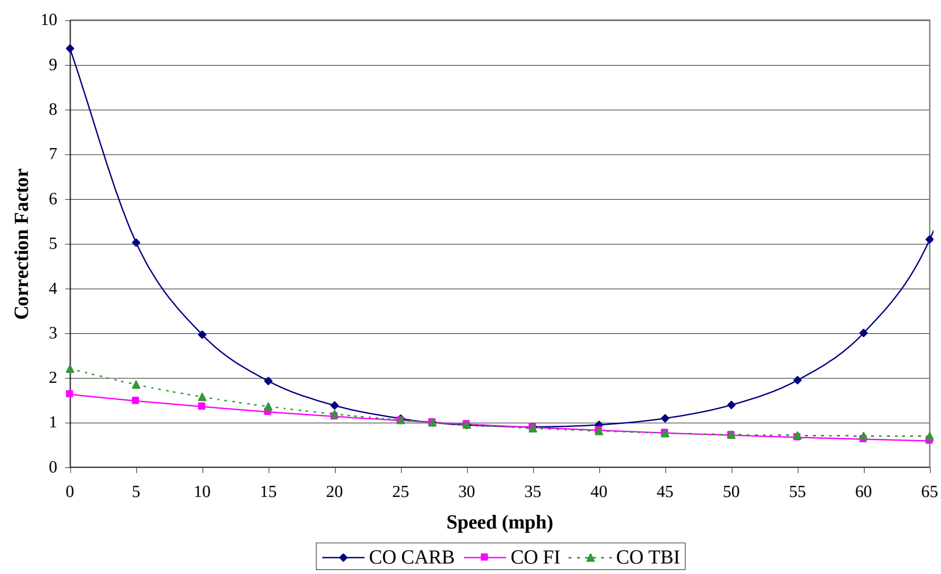


FIGURE (C). OXIDES OF NITROGEN CYCLE CORRECTION FACTOR CURVES.

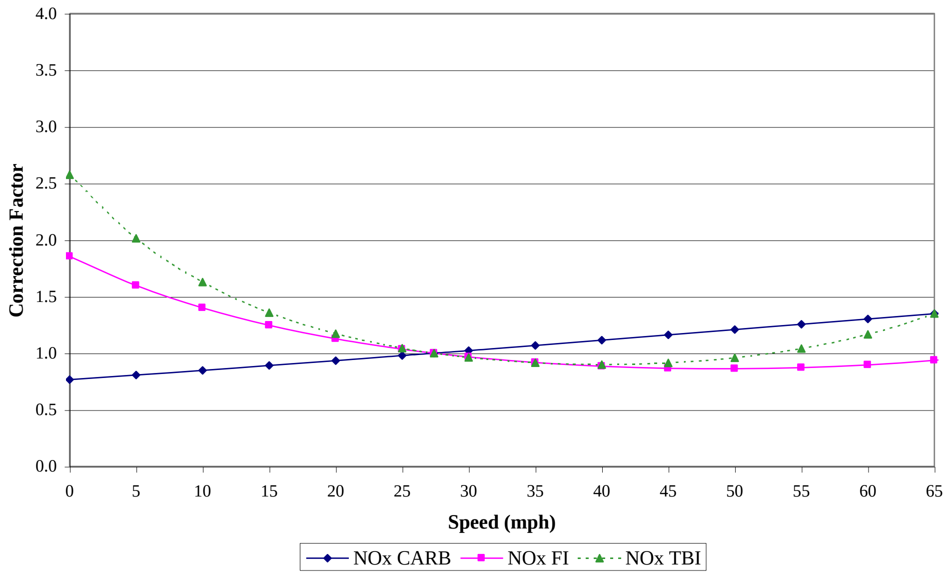
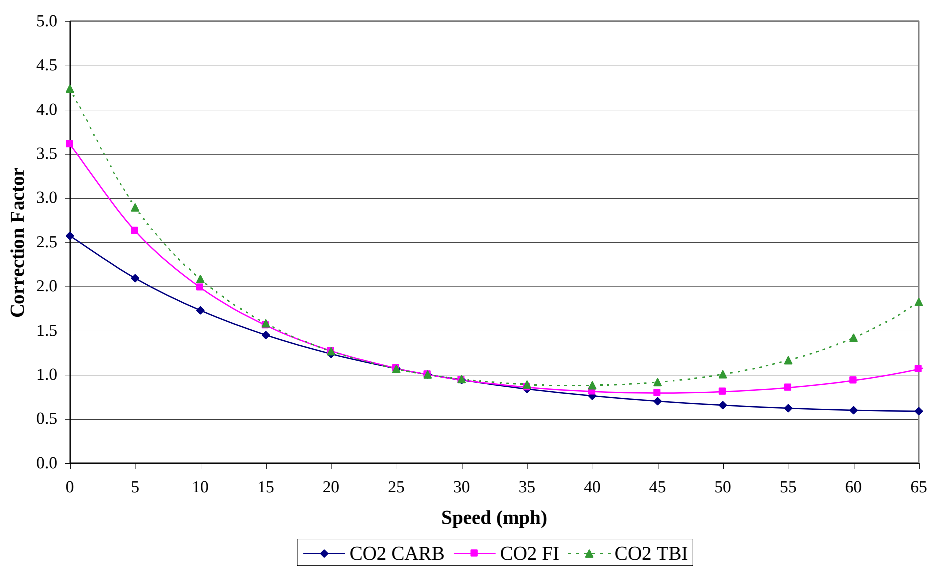


FIGURE (D). CARBON DIOXIDE CYCLE CORRECTION FACTOR CURVES.



2.2 Emission Factor Development Methodology in UK:

Pollutants covered include all major emission contributions from road transportation: Ozone precursors (CO, NOx, NMVOC), greenhouse gases (CO2, CH4, N2O), acidifying substances (NH3, SO2), particulate matter (PM), carcinogenic species (PAHs & POPs), toxic substances (dioxins and furans) and heavy metals. PM information is also distinguished to different particle sizes and further to mass, the particle number and surface concentration are reported.
All PM emission factors reported refer to $PM_{2.5}$, as the coarse fraction ($PM_{2.5-10}$) is negligible in vehicle exhaust. Also, fuel (energy) consumption figures can be calculated. For NMVOC, a speciation to 68 substances is provided.

Emissions of different vehicle categories as percentage of the EU Totals for road transport. In parentheses the range of dispersion of the countries (Estimates for Year 2002)

Category	CO	NOx	NMVOC	CH_4	PM	FC	CO_2
Gasoline PC	79.15 (90.8 -58.0)	28.23 (44.5 - 15.5)	58.69 (78.2 - 36.9)	77.29 (87.8 - 59.9)	0.00 (0.0 - 0.0)	46.61 (65.4 - 28.1)	45.43 (64.7 - 27.3)
Diesel PC	1.00 (3.9 - 0.1)	6.20 (20.0 - 0.4)	1.86 (5.8 - 0.1)	1.34 (4.6 - 0.1)	17.89 (35.7 -1.8)	8.37 (23.6 - 0.7)	8.68 (24.2 - 0.8)
Gasoline LDV	9.57 (27.8 - 0.9)	3.84 (9.6 - 0.2)	7.72 (23.2 -0.6)	4.32 (11.3 - 0.3)	0.00 (0.0 - 0.0)	3.55 (8.6 - 0.2)	3.26 (8.1 - 0.2)
Diesel LDV	1.17 (3.9 - 0.1)	7.65 (19.7 - 1.1)	1.54 (5.7 - 0.3)	0.73 (2.3 - 0.1)	21.65 (45.9 -4.4)	7.51 (20.5 - 0.8)	7.81 (21.0 - 0.9)
Diesel HDV	3.75 (7.6 - 1.3)	47.07 (71.4 - 28.9)	16.81 (30.8 -7.2)	8.94 (15.7 - 3.1)	55.83 (76.7 - 37.6)	30.46 (48.1 - 17.4)	31.56 (49.4 - 18.5)
Buses	0.43 (0.9 - 0.1)	6.70 (12.2 - 2.1)	1.18 (2.5 - 0.3)	1.19 (2.5 - 0.6)	5.39 (12.6 -1.2)	2.80 (6.4 - 0.9)	2.91 (6.6 - 1.0)
Coaches	0.04 (0.1 - 0.0)	0.85 (1.5 - 0.0)	0.18 (0.3 - 0.0)	0.16 (0.3 - 0.0)	0.69 (1.4 - 0.0)	0.49 (1.0 - 0.0)	0.52 (1.0 - 0.0)
Mopeds	1.91 (6.9 - 0.1)	0.02 (0.1 - 0.0)	8.80 (26.0 -0.7)	2.76 (11.4 - 0.2)	0.00 (0.0 - 0.0)	0.37 (1.6 - 0.0)	0.20 (0.8 - 0.0)
Motrocycles	3.69 (11.2 - 0.4)	0.20 (0.7 - 0.0)	3.86 (10.8 -0.7)	3.61 (13.5 - 0.3)	0.00 (0.0 - 0.0)	0.57 (2.3 - 0.0)	0.38 (1.5 - 0.0)

Classification of vehicles according to the UN-ECE is as given below. The main vehicle categories can be allocated to the UNECE classification as follows:

Passenger Cars	M1
Light Duty Vehicles	N1
Heavy Duty Vehicles	N2, N3
Urban Buses & Coaches	M2, M3
Two Wheelers	L1, L2, L3, L4, L5

The methodology covers exhaust emissions of CO, NO_x, NMVOC, CH_4, CO_2, N_2O, NH_3, SO_x, diesel exhaust particulates (PM), PAHs and POPs, Dioxins and Furans and heavy metals contained in the fuel (Lead, Cadmium, Copper, Chromium, Nickel, Selenium and Zinc). A detailed NMVOC split is also included to distinguish hydrocarbon emissions as alkanes, alkenes, alkines, aldehydes, ketones and aromatics. Particulate emissions in the vehicle exhaust mainly fall in the $PM_{2.5}$ size range. Therefore, all PM mass emission factors correspond to $PM_{2.5}$. Also PM emissions are distinguished in different particle sizes.

Summary of all vehicle classes covered by the methodology

Legislation classes

Vehicle Type	Class	Legislation
Passenger Cars	Gasoline <1.4l	PRE ECE ECE 15/00-01 ECE 15/02 ECE 15/03
	Gasoline 1.4 - 2.0l	ECE 15/04 Improved Conventional Open Loop Euro I - 91/441/EEC
	Gasoline >2.0l	Euro II - 94/12/EC Euro III - 98/69/EC Stage 2000 Euro IV - 98/69/EC Stage 2005
	Diesel <2.0l	Conventional Euro I - 91/441/EEC Euro II - 94/12/EC Euro III - 98/69/EC Stage 2000 Euro IV - 98/69/EC Stage 2005
	Diesel >2.0l	
	LPG	Conventional Euro I - 91/441/EEC Euro II - 94/12/EC Euro III - 98/69/EC Stage 2000 Euro IV - 98/69/EC Stage 2005
	2 Stroke	Conventional
	Hybrids <1.6l	Euro IV - 98/69/EC Stage 2005
Light Duty Vehicles	<3.5t	Euro I - 93/59/EEC Euro II - 96/69/EC Euro III - 98/69/EC Stage 2000 Euro IV - 98/69/EC Stage 2005
	Diesel <3.5t	Conventional Euro I - 93/59/EEC Euro II - 96/69/EC Euro III - 98/69/EC Stage 2000 Euro IV - 98/69/EC Stage 2005
Heavy Duty Vehicles	Gasoline >3.5t	Conventional
	Rigid <=7.5t	Conventional Euro I - 91/542/EEC Stage I Euro II - 91/542/EEC Stage II Euro III - 1999/96/EC Stage I Euro IV – 1999/96/EC Stage II Euro V – 1999/96/EC Stage III
	Rigid 7.5-12t	
	Rigid 12-14t	
	Rigid 14-20t	
	Rigid 20-26t	
	Rigid 26-28t	
	Rigid 28-32t	
	Rigid >32t	

	Articulated 14-20t	
	Articulated 20-28t	
	Articulated 28-34t	
	Articulated 34-40t	
	Articulated 40-50t	
	Articulated 50-60t	
Buses	Urban <=15t	Conventional Euro I - 91/542/EEC Stage I Euro II - 91/542/EEC Stage II Euro III - 1999/96/EC Stage I Euro IV – 1999/96/EC Stage II Euro V – 1999/96/EC Stage III
	Urban 15-18t	
	Urban >18t	
	Coaches standard <=18t	
	Coaches articulated >18t	
Mopeds	<50cm³	Conventional 97/24/EC Stage I 97/24/EC Stage II Euro III proposal
Motorcycles	2 Stroke >50cm³	Conventional 97/24/EC 2002/51/EC Stage I 2002/51/EC Stage II
	4 stroke 50 - 250cm³	
	4 stroke 250 - 750cm³	
	4 stroke >750cm³	

Types of emission

In principle, total emissions are calculated by summing emissions from three different sources, namely the thermally stabilised engine operation (hot), the warming-up phase (cold start) and due to evaporation. Evaporation is dealt with in the next chapter. It is also clarified that the word "engine" is used in place of the actual "engine and any exhaust aftertreatment devices". Distinction in emissions during the stabilised and warming-up phase is necessary because of the substantial difference in vehicle emission performance during those two conditions. Concentrations of most pollutants during the warming-up period are many times higher than during hot operation and a different methodological approach is required to estimate over-emissions during this period. In that respect, total emissions can be calculated by means of the equation:

$E_{TOTAL} = E_{HOT} + E_{COLD}$

where,

E_{TOTAL}: total emissions (g) of any pollutant for the spatial and temporal resolution of the application,

E_{HOT}: emissions (g) during stabilised (hot) engine operation,

E_{COLD}: emissions (g) during transient thermal engine operation (cold start).

Emissions under different driving conditions

Vehicle emissions are heavily dependent on the engine operation conditions. Different driving situations impose different engine operation conditions and therefore a distinct emission performance. In that respect, a distinction is made in urban, rural and highway driving to account for variations in driving performance.

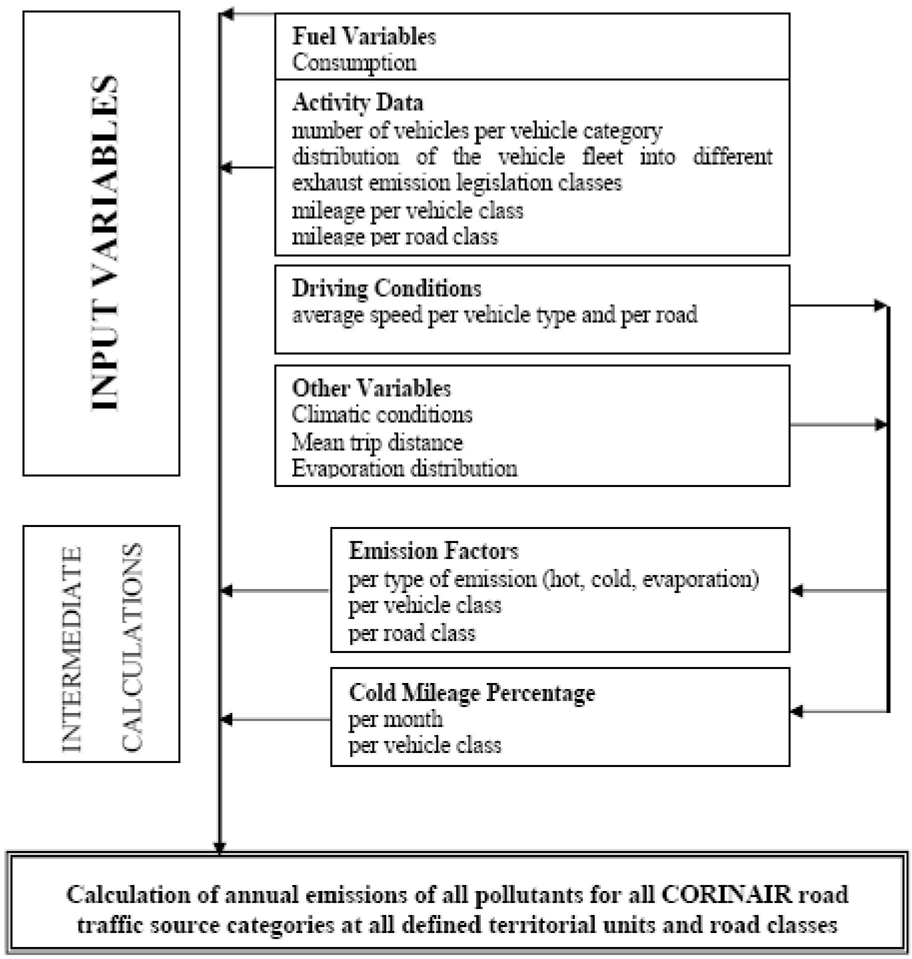
As will be later demonstrated, different activity data and emission factors are attributed to each driving situation. Also, by definition, cold start emissions are attributed to urban driving because the assumption is made that the large majority of vehicles starts any trip in urban areas. Therefore, as far as driving conditions are concerned (spatial desegregation), total emissions can be calculated by means of the equation:

$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY}$ (3)

where,

EURBAN, ERURAL, EHIGHWAY: total emissions (g) of any pollutant for the respective driving situation.

Calculation of total emissions is made by combining activity data for each vehicle category with appropriate emission factors. Those emission factors vary according to input data (driving situations, climatic conditions). Also, information on fuel consumption and specifications is required to maintain a fuel balance between user provided figures and calculations. A summary of the variables required and the intermediate calculated values is given in the flow chart of Figure below.



Accounting for vehicle speed

Vehicle speed, which is introduced into the calculation via the three driving modes, has a major influence on the emissions of the vehicles. Different approaches have been developed to take into account the driving patterns. With the emission factors presented in this chapter, the authors propose two alternative methods: to select one single average speed, representative of each of the road types "urban", "rural" and "highway" (e.g. 20 km/h, 60 km/h and 100 km/h, respectively) and to apply the emission factors taken from the graphs or calculated with the help of the equations, or to define mean speed distribution curves $f_{j,k}(V)$ and to integrate over the emission curves, i.e.

$e_{HOT;\,i,\,j,\,k} = \int [e(V) \times f_{j,k}(V)]\,dV$ (5)

where,
V: speed of vehicles on road classes "rural", "urban", "highway",
e(V): mathematical expression of the speed-dependency of $e_{HOT;\,i,\,j,\,k}$
$f_{j,k}(V)$: equation (e.g. formula of "best fit" curve) of the frequency distribution of the mean speeds which corresponds to the driving patterns of vehicles on road classes "rural", "urban" and "highway". $f_{j,k}(V)$ depends on vehicle class j and road type k.
It is evident that the first approach mentioned above is much easier and most likely the one to be chosen by most of the countries. Additionally, given the uncertainty in the estimation of the emission factors (see section 11), the improvement brought by the second approach cannot really be substantiated.

Emission corrections

Corrections can be applied to the emission methodology, as it has been described by the baseline equations above, to accommodate variation of emissions according to various environmental and technology effects. Specifically, the effect on emissions of the following parameters can be tackled:

a. Vehicle age (mileage). Baseline emission factors to be used in equation (4) ($E_{HOT;\,i,\,j,\,k} = N_j \times M_{j,k} \times e_{HOT;\,i,\,j,\,k}$) correspond to a fleet of average mileage (30-60 Mm) and an inherent degradation factor is implemented. Further emission degradation due to increased mileage should be modelled by additional degradation factors. However, for the sake of consistency between the Member States, it is proposed not to introduce such corrections when compiling a baseline inventory up to the year 2000 because of the relatively young fleet age. However, when inventories and forecasts for future years need to be made, it is advised to correct emission factors according to mileage to introduce the effect of vehicle age in the calculations.

b. Improved fuels. Improved fuel qualities have become mandatory in the European Union since year 2000. The effect on the emissions of current and older vehicles can be quantified again by means of relevant correction factors. Those corrections should only be applied in inventories compiled for years after the introduction of the improved fuels.

c. Road gradient and vehicle load on heavy duty vehicles emissions. Corrections need to be made to heavy duty vehicles emissions in cases of driving on non-flat roads. The corrections should only be applied in national inventories by those Member States where statistical data allow for a distinction of heavy duty vehicle mileage on roads of positive or negative gradient. Also, by default, a factor of 50% is considered for the load of heavy duty vehicles. In cases where significant deviations exist for the mean load factor of the heavy duty vehicle fleet, respective corrections should be brought by means of respective emission factors functions.

Emission degradation due to vehicle age

Correction factors need to be applied to the baseline emission factor to account for different vehicle age. This correction factor which is given by equation:

$MC_{C,i} = A_M \times M_{MEAN} + B_M$ (14)

where,
M_{MEAN}: the mean fleet mileage of vehicles for which correction is applied
$MC_{C,i}$: the mileage correction factor for a given mileage (M_{av}), pollutant i and a specific cycle
A_M: the degradation of the emission performance per kilometre
B_M: the emission level of a fleet of brand new vehicles
B_M is lower than 1 because the correction factors are determined using vehicle fleets with mileages ranging from 16,000 to 50,000 km. Therefore, brand new vehicles are expected to emit less than the sample vehicles. It is assumed that emissions do not further degrade above 120,000 km for Euro I and II vehicles and 160,000 km for Euro III and IV vehicles. The effect of average speed on emission degradation is taken into account by

combining the observed degradation lines over the two driving modes (urban, road). It is assumed that for speeds outside the region defined by the average speed of urban driving (19 km/h) and road driving (63 km/h), the degradation is independent of speed. Linear interpolation between the two values provides the emission degradation in the intermediate speed region. Table 8-67 presents the methodology parameters and the application of the scheme that are being discussed later on this document.

Fuel effects

Fuels of improved specifications become mandatory in Europe in two steps, January 2000 (Fuel 2000[1]) and January 2005 (Fuel 2005) respectively. The specifications of those fuels are displayed in Table 5-1 (Gasoline) and Table 5-2 (Diesel). Because of their improved properties, the fuels result in lower emissions from vehicles. Therefore, the stringent emission standards of Euro III technology (introduced ~2000) are achieved with fuel quality "Fuel 2000" and the more stringent emission standards of Euro IV and V with fuel quality "Fuel 2005". Table 5-3 shows the base emission fuel considered for each vehicle class.

Table 5.3 Fuel Specifications Gasoline

Property	**1996 Base Fuel (market average)**	**Fuel 2000**	**Fuel 2005**
Sulphur [ppm]	165	130	40
RVP [kPa]	68 (summer) 81 (winter)	60 (summer) 70 (winter)	60 (summer) 70 (winter)
Aromatics [vol. %]	39	37	33
Benzene [vol. %]	2.1	0.8	0.8
Oxygen [wt %]	0.4	1.0	1.5
Olefins [vol. %]	10	10	10
E100 [%]	52	52	52
E150 [%]	86	86	86
Trace Lead [g/l]	0.005	0.003	0.003

Table 5.2 Fuel Specifications Diesel

Property	**1996 Base Fuel (market average)**	**Fuel 2000**	**Fuel 2005**
Cetane Number [-]	51	53	53
Density at 15°C [kg/m3]	840	840	835
T_{95} [°C]	350	330	320
PAH [%]	9	7	5
Sulphur [ppm]	400	300	40
Total Aromatics [%]	28	26	24

Table 5-3: Base fuels for each vehicle class

Vehicle Class	**Base Fuel**	**Available Improved Fuel Qualities**
Pre- Euro III	1996 Base Fuel	Fuel 2000 , Fuel 2005
Euro III	Fuel 2000	Fuel 2005
Euro IV	Fuel 2005	-

However use of such fuels results in reduced emissions also from pre-Euro III vehicle technologies, for which the 1996 market average fuel is considered as a basis (Table 5-3). Those reductions are equally applied to hot and cold start emissions. To correct the hot emission factors proposed, equations derived in the framework of the EPEFE programme (ACEA and EUROPIA, 1996) are applied. Table 8-68, Table 8-69 and Table 8-70 display the equations for different vehicle categories and classes. The hot emission factors are corrected according to the equation:

$$FCe_{HOT;\, I,\, j,\, k} = FCorr_{i,\, j,\, Fuel} / FCorr_{i,\, j,\, Base} \times e_{HOT;\, i,\, j,\, k} \quad (15)$$

where,

$FCe_{HOT;\, i,\, j,\, k}$: the hot emission factor corrected for the use of improved fuel for pollutant I of vehicle class j driven on road types k

$FCorr_{i,\, j,\, Fuel}$: the fuel correction for pollutant i, vehicle category j, calculated with equations representing effect of fuel quality on emissions for the available improved fuel qualities

$FCorr_{i,\, j,\, Base}$: the fuel correction for pollutant i, vehicle category j, with equations representing effect of fuel quality on emissions for the base fuel quality of vehicle class j (Table 5-3)

It is mentioned that above equation (15) should not be used to provide the deterioration of emissions in case that an older fuel is used in a newer technology (e.g. use of Fuel 2000 in Euro IV vehicles by inversion of FC coefficients).

3. Objectives of the project:

The project work was initiated with the following objective

To develop "Emission Factors" for different category of vehicles to reflect the variance in fuel quality, vehicle technology & age, I & M practices, tailpipe treatment, etc by conducting exhaust mass emission tests, chemical characterization of PM for diesel vehicles, particulate size determination.

4. Scope of the project

The scope of the project encompassed the following:

- Determination of emission factors for each representative vehicle model considering vehicle technology, age and prevailing inspection & maintenance practices etc. including influence of fuel quality with or without tail pipe treatment.
- Emissions during idle in g/min on various vehicles.
- Constant speed mass emissions in g/min on various vehicles at three different speeds
- Exhaust gas chemical speciation with respect to Benzene, 1-3, Butadiene, PAH and Aldehydes of the exhaust gas collected during mass emission tests on gasoline and diesel vehicles
- Gravimetric and chemical characterization of particulate matter (Pm) from diesel vehicles.
- Measurement of particulate matter size (PM) from 2 stroke and 4 stroke 2 / 3 wheelers powered by gasoline engine but number of tests limited to 110 and from diesel vehicles.

5. Project Execution Methodology

The project had two major components of execution

1. Vehicle Sourcing
2. Vehicle testing

5.1 Vehicle sourcing

The vehicles for the testing (Test Matrix) as finalized by the Technical committee are given in Annexure-I. Based on the vehicle population and the availability of the vehicles at Pune, the vehicle models thus selected by ARAI are also indicated in the Test Matrix. A lot of effort was put in to source the vehicle models as per the desired models. However some of the vehicle models could not be located at all known sources such as ARAI employees, acquaintances, transport operators, dealerships, etc. Normally about five vehicle models of the same vintage and categories were identified for sourcing. However some of the vehicles (including old and newer vintages) were in bad condition and were not suitable for testing on dynamometer. Notably some of the problems faced with old vehicles were non-existent braking, torn silencer, non-operational clutch, vehicle stalling, unsteady engine running, etc. In cases where vehicle problems were manageable and vehicle owners were ready to repair the vehicle (e.g. brake liner replacement, silencer replacement/repair), such vehicles were sourced for testing only after ensuring that the vehicles were safe and suitable for dynamometer testing. In cases where desired model was not available or unsuitable for testing due to its condition, some other alternative models were tested.

Also in case of technology matrix consisting of vehicles meeting Euro-III (4-wheelers) and BS-II (2-/3-wheelers), most of the vehicle owners were not ready to lend their new vehicles for testing at ARAI. In such cases the vehicles available at ARAI for TA/COP testing were utilized. Maintenance was not carried out on such vehicles as they were prototype / new vehicles. Initially the CNG/LPG vehicles were to be tested at IOCL but later on the technical committee of the project decided that the CNG/LPG vehicles were also to be tested at ARAI. In case of CNG/LPG vehicles also due to their limited availability in Pune, vehicles available at ARAI for Type Approval were utilized. In a very few cases maintenance was not carried out as the CNG/LPG vehicles available at ARAI were pre-tuned for certification tests.

Also some of the old vehicles developed problems when they were brought in for testing at ARAI. Hence a number of test results had to be rejected due to the fact tests were not carried out on all fuels and the unreliability of test results due to the condition of vehicle. The vehicle owner in such cases had to be paid with compensation although the data was not used for the purpose of the project. In such cases all the tests were repeated subsequently on some other vehicle model.

The In-use vehicles were generally sourced locally from individuals, organizations, transport operators, PMC/PCMC, MSRTC, ARAI employees, Rickshaw unions and possible acquaintances. Initially by survey, the information on the in use vehicle availability for the selected vehicle models was obtained. Based on the information collected and the condition of the vehicle for the testing, vehicles were subjected to tests on dynamometer at ARAI. The information on the test vehicle maintenance and previous maintenance history was duly recorded. The necessary vehicle documentations like insurance, registration information, etc were also collected from the vehicle owner.

5.2 Emission Testing

The vehicles as selected above were brought to ARAI for further emission testing. Initially, the vehicle was subjected to exhaust leak check and rectified if there is any exhaust leak. The fuel in the vehicle tank was drained off and the commercial fuel (as given in the fuel matrix) was topped up after necessary flushing. Then the vehicle was subjected to exhaust mass emission test on the chassis dynamometer. The standard vehicle exhaust mass emission tests was performed on Chassis dynamometer. The test procedure used for different vintages were as per the prevalent emission test procedure applicable for that category and vintage of the vehicle. The test cycle applicable for each category of vehicle is given in Table – I.

TABLE 1 TEST CYCLES

Vehicle Category	Test Cycle
2/3 Wheeler vehicles	Indian Driving Cycle (IDC) (See Annexure – II)
Pre 2000 Model year Four Wheeled vehicle with Gross Vehicle Weight (GVW) less than or equal to 3500 kg	Indian Driving Cycle
Post 2000 Model year Four Wheeled vehicle with GVW less than or equal to 3500 kg	Indian Driving Cycle and Modified Indian Driving Cycle (See Annexure II)
For vehicles with GVW above 3500 kg	Overall Bus Driving Cycle (OBDC) (See Annexure – II)

During the mass emission test, the exhaust mass emissions of CO, THC, NOx and CO2 were measured for all the vehicles tested. Additionally exhaust gas chemical speciation with respect to Benzene, 1-3, Butadiene, PAH and Aldehydes were measured at the time of mass emission tests on all vehicles. Additionally for diesel vehicles gravimetric PM was measured. The exhaust mass emissions is expressed in g/km. Particulate size measurement was carried out during the mass emission testing on all diesel vehicles and approx. 110 tests on 2stroke and 4-stroke gasoline 2-and 3-wheelers. On completion of the exhaust emissions, the idle emissions was sampled in CVS bag (Constant Volume Sampler) for 5 minutes and CO, HC, Nox and CO2 was measured and expressed in g/min. Constant speed mass emissions of CO, HC, Nox, CO2 for all vehicles was measured for 5 minutes at different speeds depending on the category of vehicles as shown in the table below. The constant speed mass emissions was also expressed in g/min.

TABLE 2: CONSTANT SPEED MASS EMISSION TESTS

Vehicle category	Speed of vehicle	Pollutants measured
2-W and 3-W Gasoline	20, 30, 40	CO, HC, NOX, CO2
3-W Diesel	20, 30, 40	CO, HC, Nox, CO2

Passenger cars (pre-2000)	40, 50,60	CO, HC, Nox, CO2
Passenger cars (post-2000)	40, 50, 60	CO, HC, Nox, CO2
LCV	40, 50, 60	CO, HC, Nox, CO2
HCV	30, 40, 50	CO, HC, Nox, CO2

The particulate filters from the exhaust mass emission test on driving cycle of diesel vehicles and identified gasoline vehicles were subjected to chemical characterization of particulate matter. The particulate matter on the filter paper was characterized into Soluble organic fraction (SOF) and Insoluble Organic Fraction (IOF) and was expressed in mg/test. The soluble Organic Fraction was further subdivided into Oil Derived and Fuel Derived Fraction. The total PM mass on the filter was also measured and expressed in mg/test.

On completion of the tests with commercial fuel, the vehicle was sent for the maintenance at authorized service station by ARAI personnel. During maintenance, the major component change was carried out but minimum checks and adjustments like spark plug cleaning, oil change, air filter cleaning, fuel pump cleaning, ignition-timing adjustment, PUC check was carried out as per the owners manual. After the maintenance, all the above-described exhaust mass emission tests were repeated with the commercial fuel wherever applicable. The tests with different fuel quality as applicable and as per the fuel matrix indicated in the table below were conducted.

TABLE 3: FUEL MATRIX

Fuel	Code	Description
Gasoline	**GA**	Commercial Gasoline without Ethanol 500ppm S and rest in line with meeting BS-II
	GB	Commercial Gasoline with Ethanol 500ppm S and rest in line with meeting BS-II
	GC	EUROIII Gasoline Imported from Haltermann
	GD	Gasoline with less than 100ppm sulphur and rest inline with BS-II
	GE	Commercial Gasoline with 30% Kerosene*
		** used only on petrol 3-wheelers*
Diesel	**DA**	450-500ppmS (Rest as per BS-II)
	DB	2000-2500 ppm S** (rest as per BS-I)
	DC	EUROIII Diesel Imported from Haltermann
	DD	350 ppmS rest BIS specs*** (Rest as per BS-II)
	DE	Euro IV Diesel Imported from Haltermann
	DF	50ppmS rest BIS specs*** (Rest as per BS-II)
		***Used only on pre 2000 vehicles* ****Used only on post 2000 vehicles*

Fuel	Code	Description
CNG	**CNG**	Commercially Avialable CNG
LPG	**LPG**	Commercially Avialable LPG

The gasoline and diesel fuels were supplied by the oil industry. For the gasoline with 5% ethanol, ethanol available at ARAI pune was used while the additives were supplied by the IOCL. For the gasoline with 30% kerosene to be used on 3-wheelers, locally available kerosene from the market was mixed in appropriate proportion with commercial gasoline. As IOCL did not have stock of EURO-III gasoline, it was used from the existing ARAI stock. For the tests with CNG/LPG, commercially available CNG/LPG was used.

5.2.1 *Inertia setting for different categories of vehicles*

For the purpose of mass emission testing and constant speed emission testing, the following inertia setting for the dynamometer was used.

- 2-wheelers: ULW (Unladen Weight) + 75 kg
- 3-wheelers gasoline: 225 kg (3 passengersX75)
- 3-wheeler diesel: GVW
- Passenger cars: ULW+225 kg(3 passengersX75 kg)
- Multi Utility Vehicles: ULW+450 kg (6 passengersX75kg)
- LCV
  - Bus: ULW + 1500 kg (equivalent to 20 passengers of 75 kg weight each)
  - Trucks: GVW (As specified by the vehicle manufacturer)
- HCV:
  - Bus – ULW + 4500 kg (Equivalent to 60 passengers of 75 kg each)
  - Trucks – GVW (To be limited to 20 ton max. for GVW > 20tons. If GVW is less than 20 tons, Inertia will be set to the maximum specified GVW)

The coast down equation for the dynamometer tests was used as per the available data with ARAI. For vehicles above 3.5 t GVW, empirical equations/ extrapolated equations were used.

6. Emission Factors for Indian Vehicles

1.0 Methodology

Emission Factors calculated as per decisions taken in Meeting of Expert Group on ‘Emission Factors’ held on 18-Oct-2006. The emission factors are reported as per the categories and format finalized in the above meeting. The vehicle categorization is given in the table below.

Fuel / Vehicles type	Gasoline		Diesel		CNG		LPG	
	Two Stroke	Four Stroke	Two Stroke	Four Stroke	Two Stroke	Four Stroke	Two Stroke	Four Stroke
Two wheeler	Less than 80CC; and	Less than 100CC;	-	-	-	-	-	-
	above 80CC	100 – 200CC; and						
		Above 200CC						
Three wheeler	Less than 200CC	Less than 200CC	-	Upto 500CC; and	-	Less than 200CC; and Above 200CC	-	Less than 200CC; and Above 200 cc
				Above 500CC				
Four wheeler (Car + multi-utility vehicles)	Less than 1000CC;		Less than 1600CC;		Less than 1000CC; 1000 – 1400CC; and Above 1400CC		Less than 1000CC; 1000 – 1400CC and Above 1400CC	
	1000 – 1400CC; and Above 1400CC		1600 – 2400CC; and Above 2400CC					
LCV	-		Less than 3000CC; and Above 3000CC		Less than 3000CC; and		Less than 3000CC; and	
					Above 3000CC		Above 3000CC	
HCV	-		Above 6000CC		Above 6000CC		-	

The emission factors report contains Index pages denoting vehicle category, engine cubic capacity, vintage, test vehicle model, etc. The subsequent sheets give the category-wise emission factors. In categories where there are no vehicle models available in market, it has been marked with NA. And in cases where the vehicle models are available but not tested under this project, it has been marked with NT.

2. Logical explanation

The suggested emission factors reported are based on the following logistics :

- While reporting the emission factors, it has been attempted to optimize the number of emission factors subject to vehicle category, vintage and cc. Wherever there are 2- 3 nos. of vehicle models in the same vintage and category, emission data of such vehicles has been averaged for before maintenance tests and after maintenance tests. Also tests results with different fuels as per the fuel matrix after maintenance are also provided for reference only.

- As deliberated in the Technical Committee meeting, the Average of Emission results of before and after maintenance are reported as emission factors. Wherever it is seen that the results are not as per the expected trend, results of such vehicles would be replaced with results available from Source Profiling of Vehicular Emissions project. Around forty eight different emission factors would be available under Source Profiling of Vehicular Emissions project ranging from moped 2S to HCV vehicles of 1991 vintage to Post 2005, so that better representation of data could be achieved. The data from Source Profiling of Vehicular Emissions would be considered for cases where ambiguous trends are observed. It also seen in some of the cases that although the vehicle is fitted with cat. con., the results are higher than previous vintages. In such cases it is seen that the vehicles are practically 5-6 old at the time of testing and efficacy of cat. Con. Is difficult to ascertain. Although the results were higher than the previous vintages, the mass emission results show less variability. In such cases also Source Profiling of Vehicular Emissions data will be considered for arriving at emission factors.

- In case of technology matrix, mass emission results of euro-III fuel were considered as emission factors. These vehicles being brand new vehicles, maintenance was not necessary and hence before maintenance effect does not reflect in the emission factors.
- CNG/LPG vehicles of various vintages are very difficult to source. So principal decision was taken to take those vehicles available at ARAI for certification Testing. These vehicles were tested for after maintenance tests After maintenance results are considered as Emission Factors.
- In case of passenger cars and MUV, of post 2000 vintage results on both IDC and MIDC are available. The 4 wheelers of pre 2000 were subject to mass emission testing on IDC and post 2000 cars/MUV were subjected to IDC and MIDC. In case of pre 2000 emission factors are based on IDC and in case of post 2000 vehicles MIDC results were considered for emission factors and IDC results were considered for comparative study. However, only MIDC results are to be considered as emission factors and IDC results can be referred for comparative study with earlier vintage emission factors.
- The literature review of CARB and UK emission factor reveals that compilation of emission factors is a continuous process and lot of effort is put in to test the vehicles year on year. Also the test cycles with different speeds ranging from 5 mph to 59 mph in steps of 5 mph are developed and the vehicles are tested on these cycles to arrive at speed dependent emission factors. The activity data is also collected such that the same can be used with speed dependent emission factors for compiling the Emission Inventory. Also as discussed in the Technical committee meeting, the need is felt to develop city based driving cycles and an initial proposal to this respect is already submitted. And since emission factor development should be a continuous process, further work on emission factors could be taken up as and when the city specific driving cycles are formulated.

3. Analysis and Interpretation

It may be noted that some of the results are unexplainable. This may be due to condition of engine, transmission, clutch or unstable behavior of engine. In view of this such results are marked as outliers. However technical committee took decision that such vehicle models of prevalent vintage will be subjected to the test under Source Profiling of Vehicular Emissions Project using commercial fuel. In many cases only one sample/ vehicle is subjected to test in each category, which is the limitation of this study. However this issue can be resolved in long term by increasing number of samples in each category of vehicles on continuous basis. For this study appropriate resources need to be planned. This will only result in achieving closer to real world condition to the extent possible. This is also the experience of the agencies that have been involved in carrying out similar studies. Thus the recommended Emission factors are always having the uncertainty due to reasons explained, which is an acceptable fact. However as suggested, we should have a positive and concrete plan to bridge this gap by doing continuous study.

The fact is to be noted that the emission factor studies in advanced countries was initiated around 30-35 years back and there was continuous updating the data to make it closer and closer to real world condition though there is a substantial gap as on date of estimating the real world condition. Hence the concept of off cycle emission is emerging in near future and methodology and instrumentation are being developed to bridge this gap further.

4. Discussions

In the technical committee meeting, another thought was introduced to establish Emission Factors on city specific Driving Cycle. However the Emission Factors, which are reported in this study, are based on prevailing Driving Cycles used as per regulations. Though use of city specific Driving Cycle will lead us to more closer EF to real world scenario, there are also uncertainties involved such as the Driving Cycle in different part of the city will not be same. There is continuous change in the road traffic pattern such as synchronization of traffic signal, construction of flyovers, one way traffic, restriction of entries of HCV in city areas and continuous increase in density of vehicles.

Thus formulation of city specific driving cycle is a complex phenomenon. This can be further seen with the fact that the regulation and certification cycles were formulated during seventies which is being used till today.

However the latest approach is to estimate correction factor based on certain field data co relation and efforts are being put in this direction, though the instrumentation used are not fully proven to measure the parameters such as CO, HC, NOx, PM on different vehicles/different routes in the city environment.

Even the regulatory Driving cycles are formulated more than 3 decades ago, which are being used as on date for certification. The world harmonized driving cycles are under discussions and expected to be adapted from 2010 onwards to 2015 for different categories of vehicles. In that scenario it will be mandatory to use single cycle for certification purpose all over the world.

The proposal for formulation of real world city specific driving cycles and further methodology of implementation and adoption is under discussion. As the automotive industry in India is envisaged to grow at about 15-20% CAGR, it was unanimously felt that the emission factors need to be evaluated on continuous basis and on city specific driving cycles. This will assist in keeping the emission inventory upto date on a continuous basis and will bridge the gap between estimated and real-world inventory. In this regard, the allocation of appropriate resources needs to be planned.

7. Annexure-I Test Matrix

The following few tables depict the test matrix used for the project. The available vehicle models are also indicated along with actually tested vehicles which are indicated in red font color.

7.1 2-wheeler Test Matrix

Category	No. Models *	Identified/ Tested Models (in red color)	Vintage		Fuel Matrix	No. of tests: Before Maintenance – With commercial fuel	No. of tests: After Maintenance – As per fuel matrix	Total no. of tests
Moped 2S	1(91-96)	Luna TFR Plus /TVS 50 XL /Bajaj Sunny	3	91–96	4	1	4	5
	1(96-00)	Luna TFR Plus /TVS 50 XL / Bajaj Sunny		96–2000	4	1	4	5
	1(>2000)	Luna TFR Plus/ TVS 50 XL/ Bajaj Spirit		2000	4	1	4	5
Moped 4S	1(>2000)	Hero Panther 4S/ Bajaj M80 Major 4S	1	2000	4	1	4	5
Scooters 2S	3 (91-96)	Bajaj Super Kinetic Honda Bajaj Super	3	91–96	4	3	12	15
	3 (96-00)	Bajaj Super Kinetic Honda TVS Scooty		96–2000	4	3	12	15
	3(>2000)	Bajaj Chetak/ Kinetic Zoom Kinetic Honda TVS Scooty		2000	4	3	12	15
Scooters 4S	1 (>2000)	Bajaj Saffire	1	2000	4	1	4	5
M/C 2S	1 (91-96)	Rajdoot/ Bajaj M 80/ TVS Max 100	3	91–96	4	1	4	5
	1 (96-00)	Rajdoot/ Bajaj M 80/ TVS Max 100		96–2000	4	1	4	5
	1 (>2000)	Rajdoot/ Bajaj M 80/ TVS Max 100		2000	4	1	4	5
M/C 4S	3 (91-96)	HHML CD 100 Bajaj 4S Champ HHML CD 100	3	91–96	4	3	12	15
	3 (96-00)	HHML CD 100 Bajaj 4S Champ HHML CD 100		96–2000	4	3	12	15
	3 (>2000)	HHML Splendor Bajaj Boxer TVS Victor		2000	4	3	12	15
							Total	**130**

7.2 3-Wheeler Test Matrix

Category	Models *	Identified/ Tested Models (in red color)	Vintage		Fuel Matrix	No. of tests: Before Maintenance with commercial fuel	No. of tests: After Maintenance As per fuel matrix	Total no. of tests
CNG OEM	1(>2000)	Bajaj 3W 4S RE CNG A/R	1	2000	1	0	1	1
CNG Retrofit	1 (96-00)	Babaj 3W 2S RE 5 Port CNG A/R	2	96–2000	1	1	1	2
	1(>2000)	Babaj 3W 2S RE 5 Port CNG A/R		2000	1	1	1	2
LPG OEM	1(>2000)	Bajaj 3W 2S RE 5 Port LPG A/R/3W 4S OE LPG	1	2000	1	1	1	2
LPG Retrofit	1(96-00)	Bajaj 3W 2S RE 5 Port LPG A/R	2	96–2000	1	1	1	2
	1(>2000)	Bajaj 3W 2S RE 5 Port LPG A/R		2000	1	1	1	2
Diesel	1(96-00)	BTL Minidor	2	96–2000	4	1	4	5
	1(>2000)	BTL Minidor		2000	5	1	5	6
Gasoline 2S	1(96-00)	Bajaj 3W 2S RE 5 Port A/R	2	96–2000	5	1	5	6
	1(>2000)	Bajaj 3W 2S RE 5 Port A/R		2000	5	1	5	6
Gasoline 4S	1(>2000)	Bajaj 3W 4S RE A/R	1	2000	5	1	5	6
							Total	**40**

7.3 Passenger Car Test Matrix

Category	Models *	Identified/ Tested Models (in red color)	Vintage		Fuel Matrix	No. of tests: Before Maintenance with commercial fuel	No. of tests: After Maintenance As per fuel matrix	Total no. of tests
CNG OEM	1(>2000)	Maruti 800/ Maruti Van CNG OEM/Maruti Wagon R	1	2000 (IDC)	1	1	1	2
				2000 (MIDC)	1	1	1	2
CNG Retrofit	1(96-00)	Maruti 800/ Van CNG Retrofit/Ambassador 1800ISZ	2	96–2000	1	1	1	2

Category	Models *	Identified/ Tested Models (in red color)	Vintage		Fuel Matrix	No. of tests: Before Maintenance with commercial fuel	No. of tests: After Maintenance As per fuel matrix	Total no. of tests
	1(>2000)	Maruti 800/ Van CNG Retrofit /Maruti Baleno		2000(IDC+MIDC)	1	0	2	2
LPG OEM	1(>2000)	Maruti 800/ Van LPG OEM	1	2000 (IDC)	2	1	1	2
				2000 (MIDC)	2	1	1	2
LPG Retrofit	1(96-00)	Maruti 800 / Ambassador LPG Retrofit/Santro LPG Retrofit	2	96–2000	2	1	1	2
	1(>2000)	Maruti 800 / Ambassador LPG Retrofit/Baleno		2000(IDC+MIDC)	2	0	2	2
Diesel	2 (96-00)	Ambassador/ Fiat 137 D / Tata Indica	2	96–2000	4	2	8	10
		Ambassador/ Fiat 137 D / Tata Indica						
	2 (>2000)	Ambassador/ Tata Indica		2000 (IDC+ MIDC)	5	2	10	12
		Ford Ikon/ Tata Indica			5	2	10	12
Gasoline	3 (91-96)	Maruti 800	3	91–96	4	3	12	15
		Premier Padmini/ Maruti 800						
		Ambassador / Maruti 800						
	3 (96-00)	Maruti 800		96–2000	4	3	12	15
		Premier Padmini/ Maruti 800						
		Ambassador / Maruti 800						
	3 (>2000)	Santro		2000 (IDC+ MIDC)	4	3	12	15
		Maruti Zen						
		Maruti Esteem / Ford Ikon			4	3	12	15
							Total	110

7.4 LCV/MUV and HCV Test Matrix

Category	Models*	Identified/ Tested Models	Vintage		Fuel Matrix	No. of tests: Before Maintenance with commercial fuel	No. of tests: After Maintenance As per fuel matrix	Total no. of tests
LCV /MUV Diesel	3 (91-96)	TATA 407 Bajaj Tempo Traveller Mahindra LCV Commander	3	91–96	4	3	12	15
	3 (96-00)	TATA 407 Bajaj Tempo Traveller Mahindra LCV Commander/ Bajaj Tempo Trax		96–2000	4	3	12	15
	3 (>2000)	Eicher		Post 2000	5	1	5	6
		Qualis		2000 MUV (IDC+MIDC)	5	2	10	12
		Mahindra Bolero/ Scorpio/ Savari)/ TATA Spacio			5	2	10	12
							Total	60
HCV Diesel Bus	2 (91-96)	AL Bus Telco Bus	3	91–96	4	2	8	10
	2 (96-00)	Al Bus Telco Bus		96–2000	4	2	8	10
	2 (>2000)	Al Bus Telco Bus		2000	5	2	10	12
HCV Diesel Truck	2 (91-96)	Al Truck Telco Truck	3	91–96	4	2	8	10
	2 (96-00)	Al Truck Telco Truck		96–2000	4	2	8	10
	2 (>2000)	Al Truck Telco Truck		2000	5	2	10	12
HCV CNG OEM	1(>2000)	TELCO CNG OEM/AL CNG BUS (TERI Proj)	1	2000	1	1	1	2
HCV CNG retrofit	1(96-00)	AL Retrofit Bus/ AL OEM CNG BUS (TERI Proj.)	1	1996–2000	1	1	1	2
							Total	68

7.5 2-Wheeler , 3-Wheeler and 4-Wheeler Technology Matrix

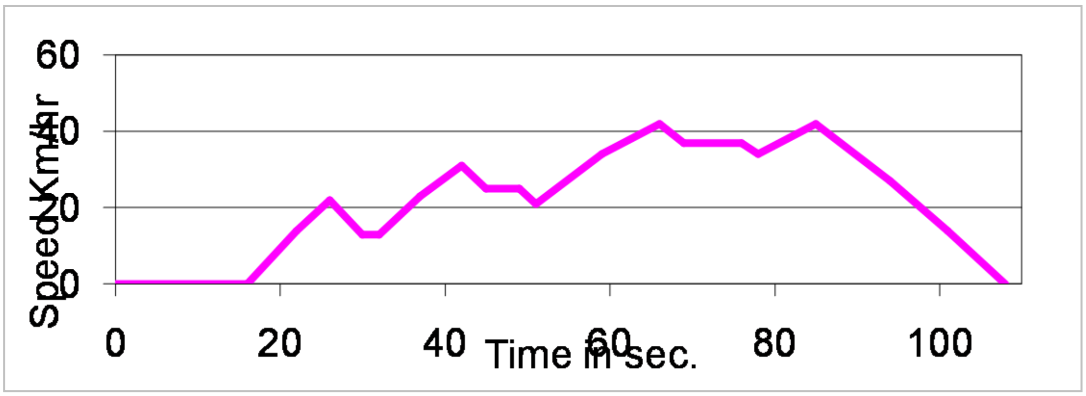
Category	No. Models *	Identified/ Tested Models (in red color)	Vintage		Fuel Matrix	No. of tests		Total no. of tests
						Before Maintenance	After Maintenance	
						With commercial fuel	As per fuel matrix	
Moped 2S	1(>2005)	TVS Champ50cc, Kinetic Luna, Bajaj Spirit	1	2005	1	0	2	2
Moped 4S	1(>2005)	No Vehicle Model Available	0	2005	0	0	0	0
Scooters 2S	1 (>2005)	Bajaj Chetak145cc, Kinetic Honda, TVS Scooty	1	2005	1	1	2	3
Scooters 4S	1 (>2005)	Bajaj Chetak 4S, Honda Activa92cc, Kinetic Nova, TVS Scooty Pep	1	2005	1	0	2	2
M/C 2S	(>2005)	No Vehicle Model Available	0	2005	0	0	0	0
M/C 4S	1 (>2005)	Bajaj CT 100 / TVS Max 100/ HHML CD Dawn/ Bajaj Pulsar DTSFI220cc/HHML Karizma/ HHML Splendor/ HHML Ambition/Bajaj Discover/ TVS Victor/ TVS Star	1	2005	1	0	2	2
Total Tests on2-wheeler (BS-II)								**9**
Diesel	1(>2005)	Bajaj Goods Carrrier, Ape, Minidor, Mahindra Champion/Kumar Motors G3W1K Pick Up 422cc	1	> 2005	2	0	4	4
Gasoline 2S	1(>2005)	Bajaj 3W 5 Port RE Autorickshaw	1	> 2005	1	0	2	2
Gasoline 4S	1(>2005)	Bajaj 3W 4S RE Autorickshaw	1	> 2005	1	1	2	3
Total Tests on 3-Wheeler (BS-II)								**9**

Sr. No.	Category	Technology	Fuel	Models	Year	Fuel Type	No. of Vehicles	Fuels	No. of Tests
1	Passenger Car	(Technology Matrix EURO-III)	Gasoline	Mercedes E Maybach, W211E200 /Toyota Corola 1.8G80 /Tata Indigo Glx	2005+	Gasoline	1	2	4
2	Passenger Car	(Technology Matrix EURO-III)	Diesel	Hyundai Accent/Tata Indica	2005+	Diesel	1	4	8
3	LCV	(Technology Matrix EURO-III)	Diesel	Terracan CRDI/Nissan X-Trail	2005+	Diesel	1	4	8
4	LCV	(Technology Matrix EURO-III)	Diesel	Scorpio CRDI/GM-Tavera/Tata Sumo/Tata Safari	2005+	Diesel	1	4	8

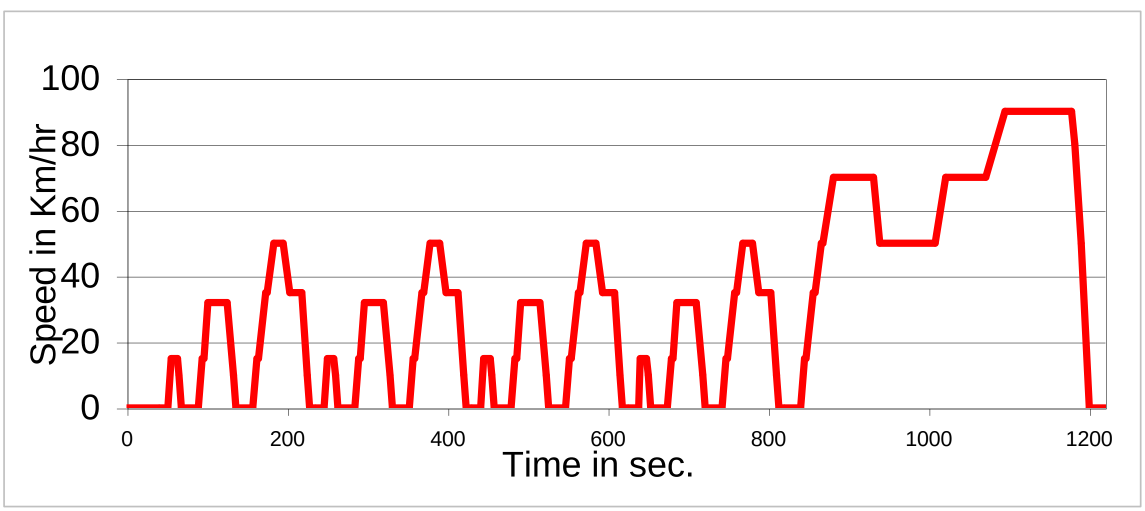
Sr. No.	Category	Technology	Fuel	Models	Year	Fuel Type	No. of Vehicles	Fuels	No. of Tests
5	HCV	(Technology Matrix EURO-III)	Diesel	Eicher Bus	2005+	Diesel	1	4	4
6	HCV	(Technology Matrix EURO-III)	Deisel	TELCO Bus/AL Bus	2005+	Diesel	1	4	4
					Total		6		36

8. Annexure II Driving Cycles

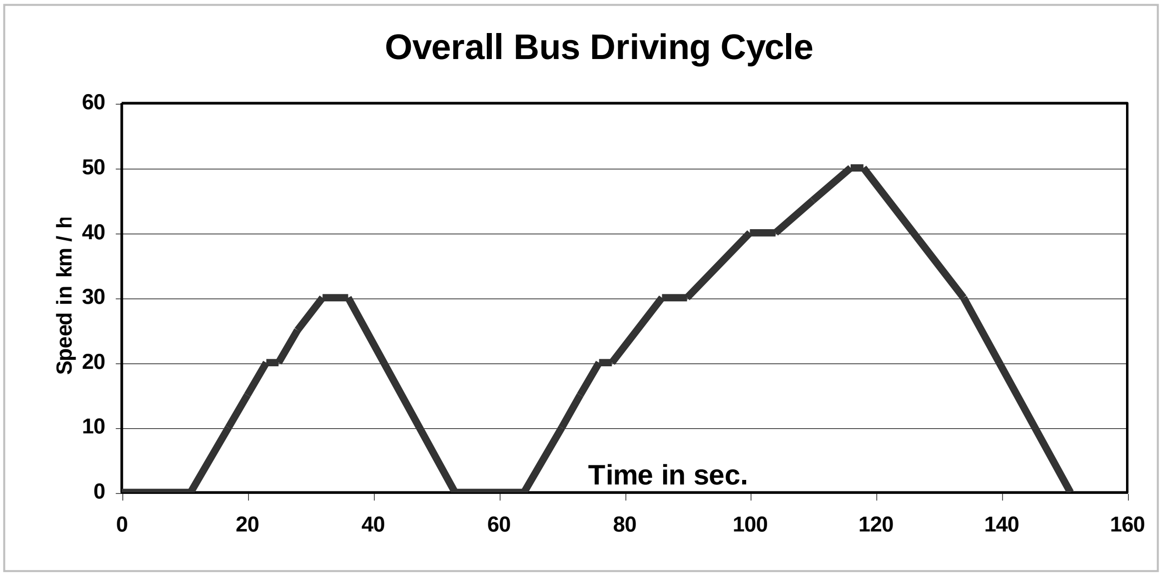
8.1 Indian Driving Cycle (2-/3-wheelers, passenger cars and MUV)



8.2 Modified Indian Driving Cycles for passenger cars and MUV (Post 2000)



8.3 Overall Bus Driving Cycle for LCV and HCV



9. Annexure III: Applicable Vehicle Models

9.1 Mopeds:

Moped (2 Stroke)	< 80cc	1991-96	HERO PUCH 3G/Automatic 65cc
			Tvs Xls Super 70
			Avanti 3 Gear
			Tvs Euro Champ 50cc
			LUNA TFR PLUS /Super/Magnum
			Kinetic Safari (V2)
			Hero Puch 50 Cc
Moped (2 Stroke)	< 80cc	1996-2000	Hero Puch 65 Cc 2g/Super Shakti 3g
			Tvs Xl Super 70
			Tvs Champ 60
			Tvs 50 Xl Electronic
			LUNA SUPER ELECTRONIC/TFR Plus
			Kinetic Safari V2
			Hero Puch Automatic 65 Cc
Moped (2 Stroke)	< 80cc	Post 2000	Bajaj Sunny Spice
			Super 70, Luna Elec
			Kinetic Style
			Kinetic Safari V2
			Hero Gizmo 60
			Hero Panther 60
			Shakti 2g 50 Cc
			TVS Champ/50xl (49cc)
Moped (2 Stroke)	< 80cc	Post 2005	All TVS 2S Mopeds
			All Bajaj 2S Mopeds
			All Kinetic 2S Mopeds
Moped (4 Stroke)	< 80cc	Post 2000	Hero Panther 4S

9.2 Scooters:

Scooter (2 Stroke)	< 80cc	1996-2000	Kinetic Style
			Kinetic Spark

			Kinetic Pride
			KINETIC SAFARI V2
Scooter (2 Stroke)	< 80cc	Post 2000	Kinetic Style
			KINETIC SAFARI
Scooter (2 Stroke)	> 80cc	1991-96	Bajaj Chetak
			Chetak Classic (145.45cc)
			LML Vespa(150cc)
			Bajaj Cub (100cc)
			Bajaj Stride
			Bajaj Rave
			Kinetic Marvel
Scooter (2 Stroke)	> 80cc	1996-2000	Bajaj Chetak
			Chetak Classic (145.45cc)
			LML Vespa(150cc)
			Bajaj Super (3 port)
			Bajaj Cub (100cc)
			Bajaj Stride
			Bajaj Rave
			Kinetic Marvel
Scooter (2 Stroke)	> 80cc	Post 2000	Kinetic ZX Zoom
Scooter (2 Stroke)	> 80cc	Post 2005	All Bajaj 2S Scooters, All TVS 2S Scooters
Scooter (4 Stroke)	>100cc	Post 2000	HHML Street(100cc)
			Kinetic K4(100cc)
			Honda Activa(102cc)
			Bajaj Legend(116cc)
			Honda Dio(102cc)
			BAL Chetak 4s
			BAL Bravvo 4S
Scooter (4Stroke)	>100cc	Post 2005	All Honda 4S Scooters
			All Bajaj 4S Scooters
			All Kinetic 4S Scooters
			All TVS 4S Scooters

9.3 Motorcycles:

Motorcycle (2 Stroke)	< 80cc	1991-96	Hero Puch
			TVS Max
			Yamaha Rajdoot
			Yamaha RX 100
			TVS Shogun
			Bajaj KB 100
Motorcycle (2 Stroke)	> 80cc	1996-2000	Bajaj M80
			Yamaha Rajoot
			Yamaha RX series
			TVS Shogun
			KB125
			Escort Ace
			TVS Samurai
			TVS Shaolin
Motorcycle (2 Stroke)	> 80cc	Post 2000	Bajaj M-80
			Yamaha Rajdoot 154
			Yamaha RX series
Motorcycle (4 stroke)	<100cc	1991-96	Bajaj 4S Champ
			HHML Sleek
			HHML Splendor
Motorcycle (4 stroke)	<100cc	1996-2000	Bajaj 4S Champ
			HHML Splendor
			Bajaj Caliber
			Yamaha YBX
Motorcycle (4 stroke)	<100cc	Post 2000	CD 100
			Passion
			Dawn
			KEL Challenger
			Yamaha Crux
			Bajaj Byk
			Yamaha Libero
			TVS Centra, Star

Motorcycle (4 stroke)	100-200cc	Post 2000	Pulsar
			BAL Wind/ Avenger

			Bajaj Discover
			Eliminator
			Yamaha Enticer
			Unicorn
			HHML Ambition/ CBZ

Motorcycle (4 stroke)	>200cc	Post 2005	Karisma
			Bullet

9.4 3-Wheelers:

Three Wheelers (2 Stroke)	<200cc	1996-2000	All Bajaj 3-W 2S Models
Three Wheelers (2 Stroke)	<200cc	Post 2000	All Bajaj 3-W 2S Models
Three Wheelers (2 Stroke)	<200cc	Post 2005	All 2S Bajaj A/R BS-II
Three Wheelers (4Stroke)	<200cc	Post 2000	All Bajaj 3-W 4S Models
Three Wheelers (4 Stroke)	<200cc	Post 2005	All Bajaj 4S petrol 3-W

Three Wheeler Diesel	<500cc	1996-2000	BAL 3W Diesel A/R
			Greaves 360
			KAL Diesel A/R
			SIL Vikram Diesel A/R
Three Wheeler Diesel	<500cc	Post 2000	BAL 3W Diesel A/R
			Greaves 360
			KAL Diesel A/R
			SIL Vikram Diesel A/R
			M&M Champion A/R
			APE Cargo and Pass. A/R
Three Wheeler Diesel	<500cc	Post 2005	Ape D3S (395
			Ape Goods Carrier(422)
			Bajaj GC (416)

			Mahindra Champion (510cc)

Three Wheeler CNG (OEM)	<200cc	Post 2000	All Bajaj OEM CNG 4S 3W (Post 2000)

Three Wheeler CNG (Retrofit)	<200cc	Post 2000	All Bajaj Retrofit CNG 4S 3W (Post 2000)

Three Wheeler LPG	<200cc	1996-2000	Bajaj 3-W LPG Retrofit Models (1996-2000)

Three Wheeler LPG	<200cc	Post 2000	Bajaj 3-W LPG Retrofit Models (Post 2000)

9.5 Passenger Cars:

Passenger Cars (Petrol)	<1000cc	1991-96	Maruti Omni
			Maruti Gypsy
			Premier Padmini
			Premier 118NE
			Ambassador
Passenger Cars (Petrol)	<1000cc	1996-2000	Maruti Omni
			Fiat Uno
			Maruti Gypsy
			Premier Padmini
			Premier 118NE
			Daewoo Matiz
			Maruti 1000
			Ambassador
Passenger Cars	<1000cc	Post 2000	Zen

(Petrol)			Alto
			Santro
			Matiz

Passenger Cars (Petrol)	1000-1400	Post 2000	Fiat Palio
			Wagon R
			Getz
			Tata Indica
			Esteem

Passenger Cars (Petrol)	>1400cc	Post 2000	Skoda Octavia
			sonata
			accent
			beleno
			corolla
			Camry
Passenger Cars (Petrol)	>1400cc	Post 2005	Indica
			Ford Ikon
			Maruti Swift
			Hyundai Getz
			Fiat Palio
			Esteem
			Hyundai Ascent
			honda city

Passenger Cars (Diesel)	<1600cc	1996-2000	Fiat 137D(1366cc)
			Ambassador (1500cc)
			Maruti Zen (1527cc)
Passenger Cars	<1600cc	Post 2000	Zen Diesel(1527cc)

(Diesel)			Esteem Diesel(1527cc)
			Indigo (1405cc)
			Accent(1493cc)
			Ambassador(1489cc)
			Zen Diesel(1527cc)
			Esteem Diesel(1527cc)
			Indigo (1405cc)
			Accent(1493cc)
			Ambassador(1489cc)
Passenger Cars (Diesel)	<1600cc	Post 2005	Indica
			Palio
			Skoda Superb
			Hyundai Ascent
			Ambassador
			Mercedes C Class
			Hyundai Elantra
			Ford Ikon

Passenger Cars (Diesel)	1600-2400cc	1996-2000	Ford Escort Diesel (1800cc)
			Fiat Uno (1700cc)

Passenger Cars (CNG)	1000-1400cc	Post 2000	Maruti Esteem retrofit CNG
			Lancer Retrofit CNG
			Maruti 800 CNG
			Maruti OMNI CNG

Passenger Cars (CNG)	>1400cc	1996-2000	Ambassador retrofit CNG
			Ford Escort Retrofit CNG
Passenger Cars (CNG)	>1400cc	Post 2000	Maruti baleno retrofit CNG

Passenger Cars (LPG)	1000-1400cc	Post 2000	Maruti Esteem retrofit LPG
			Maruti 800 LPG
			Maruti OMNI LPG

Passenger Cars (LPG)	>1400cc	Post 2000	Maruti Esteem retrofit LPG
			Lancer Retrofit LPG
			Indigo LPG Retrofit
			Ambassador Retrofit LPG

9.6 MUV:

MUV Diesel	<3000cc	1991-96	Trax (2399cc)
			Sumo(1948cc)
			Matador
MUV Diesel	<3000cc	1996-2000	Sumo(1948cc)
			Tata Sierra(1948cc)
			M&M Commander(2523cc)
			Marshal(2523cc)
			Qualis(2446)
MUV Diesel (MIDC)	<3000cc	Post 2000	M&M CL 550 MDI(2523cc)
			Scorpio(1998cc)
			Ford Endeavour(2500cc)
			Sumo(1948cc)
			Safari(1948cc)
			Trax(2399cc)
			Pajero(3200cc)
			Terra can (2902cc)
			Innova(2494cc)
MUV Diesel (MIDC)	<3000cc	Post 2005	Scorpio CRDI (2.6 ltr)
			Safari (2.95ltr)
			Innova (2.5 ltr)
			Tata 207 (2.95ltr)
			Spacio (2.95ltr)
			Endeavor (2.5)
			Tavera (2.5 ltr)
			Tourister (2.6 ltr)

9.7 LCV:

LCV Diesel	<3000cc	1991-96	Eicher 10.70 (3298cc)
			BTL Excel (2650cc)
			M&M DI Load Carrier(2523cc)
			M&M Loadking(2609cc)
			Telco SFC410 (2956cc)
			Telco LPT712(3783cc)
			Eicher Skyline(3298cc)
			M&M DI Express(2523cc)
			M&M Tourister(2609cc)
			AL PSV3 LYNX(3839cc)
			Tata SFC 407 minibus(2956cc)
			Telco LP709minibus(3783cc)
			HM RTV(3.3 and 2ltr)
LCV Diesel	<3000cc	1996-2000	Eicher 10.70 (3298cc)
			BTL Excel (2650cc)
			M&M DI Load Carrier(2523cc)
			M&M Loadking(2609cc)
			Telco SFC410 (2956cc)
			Telco LPT712(3783cc)
			Eicher Skyline(3298cc)
			M&M DI Express(2523cc)
			M&M Tourister(2609cc)
			AL PSV3 LYNX(3839cc)
			Tata SFC 407 minibus(2956cc)
			Telco LP709minibus(3783cc)
			HM RTV(3.3 and 2ltr)

LCV Diesel	>3000cc	Post 2000	BTL Traveller (2650cc)
			M&M DI Express(2523cc)
			M&M Tourister(2609cc)
			AL PSV3 LYNX(3839cc)
			Tata SFC 407 minibus(2956cc)
			Telco LP709minibus(3783cc)
			HM RTV(3.3 and 2ltr)

9.8 HCV:

HCV Diesel Bus	>6000cc	1991-96	Eicher 20/16RHD(4.9lt)
			TELCO LF936CE(5.9ltr)
			TELCO LP1510(5.9lt)
			Eicher 20/16RHD(4.9lt)
			TELCO LF936CE(5.9ltr)
			TELCO LP1510(5.9lt)
			AL 3/1 COMET (6.54Lit)
HCV Diesel Bus	>6000cc	1996-2000	Eicher 30.25RHD(4.9lt)
			TELCO LPT2515(5.9lt)
			TELCO LP/LPO /LPS/SE/SK(5.9lt)
			Eicher 30.25RHD(4.9lt)
			TELCO LPT2515(5.9lt)
			TECO LPT 2518(5.9lt)
HCV Diesel Bus	>6000cc	Post 2000	Volvo FM9, B7R (9.4lt)
			Volvo FM12 (12.3lt)
			TECO LPT 2518(5.9lt)
			TELCO LPT2515(5.9lt)
			Volvo FM9, B7R (9.4lt)
			Volvo FM12 (12.3lt)
			TECO LPT 2518(5.9lt)
			TELCO LPT2515(5.9lt)
HCV Diesel Bus	>6000cc	Post 2005	Volvo FM9, B7R (9.4lt)
			Volvo FM12 (12.3lt)
			TATA NOVUS
			TATA LPT2515

HCV Bus CNG	>6000cc	Post 2000	All TATA and AL CNG Buses

HCV Diesel Truck	>6000cc	1991-96	Eicher 20/16RHD(4.9lt)
			TELCO LF936CE(5.9ltr)
			TELCO LP1510(5.9lt)
			ALCO 3/1 COMET (6.54Lit)
			Eicher 20/16RHD(4.9lt)
			TELCO LF936CE(5.9ltr)
			TELCO LP1510(5.9lt)

			ALCO 3/1 COMET (6.54Lit)
HCV Diesel Truck	>6000cc	1996-2000	Eicher 30.25RHD(4.9lt)
			TELCO LPT2515(5.9lt)
			TECO LPT 2518(5.9lt)
			Eicher 30.25RHD(4.9lt)
			TELCO LPT2515(5.9lt)
			TECO LPT 2518(5.9lt)
HCV Diesel Truck	>6000cc	Post 2000	Volvo FM9, B7R (9.4lt)
			Volvo FM12 (12.3lt)
			TECO LPT 2518(5.9lt)
			TELCO LPT2515(5.9lt)
			Volvo FM9, B7R (9.4lt)
			Volvo FM12 (12.3lt)
			TECO LPT 2518(5.9lt)
			TELCO LPT2515(5.9lt)

Annexure IV: Emission Factor Report for Indian Vehicles

Summary of Emission Factors for Indian Vehicles With BS-II Fuel

Summary of Emission Factors for Indian Vehicles With BS-II and BS-III Fuels

Summary of Emission Factors for Indian Vehicles With BS-III Fuel

10. Annexure V: Test Procedure, Equipment Details and Calibration Details used for Mass Emission Testing in the project:

10.1 Test Equipment:

The main equipments used for Mass emission testing are chassis dynamometer, CVS System, Analyzers which are supported by additional equipment such as dilution tunnel (for PM measurement), weighing balance, ELPI (for particulate size measurement), idling CO, HC analyzer, Smoke meter, sampling equipment for unregulated pollutant measurement, cooling blower, etc.

10.1.1 *Specifications of Test Equipment:*

The following section gives a brief technical specifications of the important equipment used for emission testing under emission factor determination project.

Chassis Dynamometer:

10.1.2 *Parameter*	**FCL make 2-Wheeler**	**BEP make 3-wheeler**	**BEP make 4-wheeler**	**FCL make HCV**
Type	DC Machine	AC Machine	AC Machine	DC Machine
Maximum power	5 kW absorption / motoring	50 kW absorption / motoring	149 kW absorption / motoring	155 kW absorption / motoring
Maximum Speed	100 km/h	200 km/h	200 km/h	100 km/h
Maximum tractive effort	250 N	2233 N	5844 N	14000 N
Vehicle inertia range	Up to 335 Kg.	100-450 kg for 2-Wheeler, 400- 1500 kg for 2-Wheeler	120-5443 kg Universal dyno for 2W, 3W & 4W	Up to 32000 Kg.
Roller diameter	610 mm	610 mm	1220 mm	2500 mm.
Width over rollers	--	1900 mm	2742 mm	2800 mm.
Space between the rollers	--	Single roller	Single roller	800 mm

Constant Volume Sampler system:

Parameter	**Horiba CVS 51**	**Fisher Rosemount CVS with dilution tunnel**	**HORIBA CVS with Dilution Tunnel – 7400T**	**Beckman CVS with dilution tunnel**
Venturi Sizes	1, 2, 3, 4.5, 6, 9 m^3 / min	2, 3, 4.5, 6, 9, 12 m^3 / min	4.5, 6, 9 & 12 m^3 / min	200, 400, 600, 1000 SCFM
Tunnel diameter	--	10 inches	10 inches	18 inches
Filter Holder Assembly	--	70, 47 mm Ø	70, 47 mm Ø	70, 47 mm Ø
Propane Injection	CFO type	CFO type	Gravimetric Method	CFO type

Analyzers:

Analyzer		**Horiba 9200 F**	**Fisher Rosemount NGA Analyzers**	**Horiba 7200 H**
Low Co	Model	AIA-120	A1A-721A	MLT-A1
	Range	0 – 100, 300, 1000, 3000 ppm	0 – 50 …. 5000 ppm	0 - 50 …… 2500 ppm
High Co	**Model**	AIA – 120	A1A-722	--
	Range	0 – 0.6, 1, 3, 10%	0 - 0.5 …… 12%	--
CO_2	**Model**	AIA 120	AIA - 722	MLT-B3
	Range	0 – 1, 2, 6 and 8%	0 – 0.5 ……. 20%	0 – 0.5 ……… 5%
NOx	**Model**	CLA 155	CLA – 750A	C-A-A10
	Range	0 – 10, 20, 50, 100, 200, 1000, 2000, 5000 ppm	0 –10 ….10000 ppm	0 – 10 ………. 800 ppm
THC	Model	--	FIA – 720	F-A-A10
	Range	--	0 – 10 … 20000 ppmc	0 – 50 …… 10000 ppmc
THC heated	**Model**	FIA 125	FIA 725-A	HFID
	Range	0 – 20, 50, 100, 200, 1000, 2000, 5000, 10000 ppmc	0 – 10 ……50000 ppmc	0 – 50. 10000 ppmc
Methane (GC)	**Model**	--	GFA -720	MC-120
	Range	--	0 – 100 … 2500 ppmc	0 – 50. 10000 ppmc
Heated HC with Methane Cutter	**Model**	--	721 HA	h-a-b10
	Range	--	0 – 10 …… 5000 ppmc	0 – 50. 5000 ppmc

ELPI: Electrical Low Pressure Impactor

Particle size range	0.030-10 µm, 0.007-10 µm with filter stage
Number of stages	12 with electrical detection, total 13
Volumetric flow rate	10 or 30 l/min
Impactor dimensions	ø 65 mm x 300 mm
Collection plate diameter	25 mm
Lowest stage pressure	100 mbar
Pump requirements	7 m^3/h at 100 mbar (10 lpm), 21 m^3/h at 100 mbar (30 lpm)
Operation temperature	5-40 ºC
Operation humidity	0-90 % RH Non-condensing
Response time	below 2-3 seconds
ELPI unit dimensions	H 540 x W 400 x D 230 mm
Unit weight	35 kg
Charger voltage	5 kV
Charger current	1 µA

MOUDI – Micro- Orifice Uniform Deposit Impactor Specifications:

Sr. No.	Description	Specification
1	**Make: MSP Corporation**	**Model: 110**
2	Sampling Flow Rate	30 l/min
3	Particle size range	0.056 – 15 µm
4	Number of Stages	10

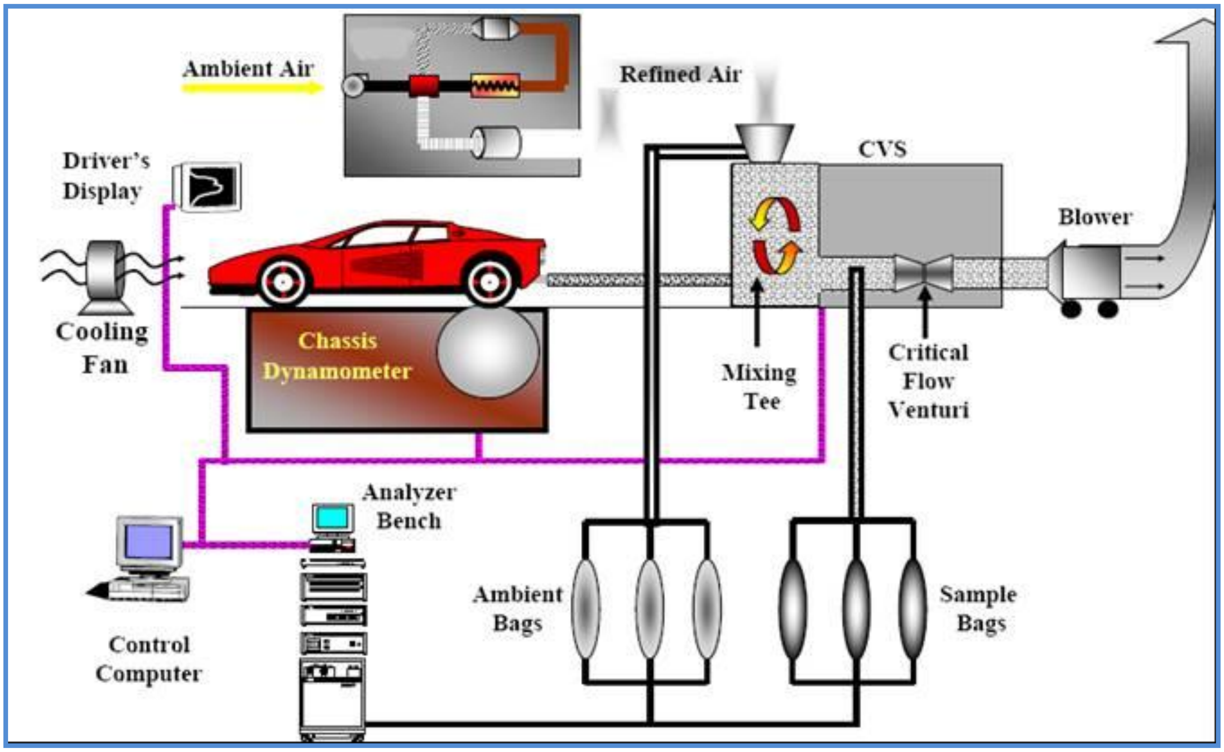
10.2 Test Procedure:

Emission cycles are a sequence of speed and load conditions performed on an engine or chassis dynamometer. Emissions measured on vehicle (chassis) dynamometers are expressed in grams of pollutant per unit of travelled distance, expressed in g/km. In a transient cycle such as the one used for the chassis dynamometer testing, the vehicle follows a prescribed driving pattern, which includes accelerations, decelerations, changes of speed and load, etc. The final test results are obtained by analyzing exhaust gas samples collected in polyurethane bags over the duration of the cycle.

In order to determine the emission of a vehicle, the vehicle was tested in ARAI's emissions test cell under conditions which accurately simulated the driving cycle as applicable to the vehicle category under test (see 5.2).

A schematic layout of the test cell with vehicle is given in figure below.

Figure: Schematic Test Cell Layout



Each test vehicle was mounted with its drive wheels on the rollers of the test bed whose rotational resistance was adjusted to simulate friction and aerodynamic drag. Inertial masses were added to simulate the weight of the test vehicle as per the category of the vehicle (see 5.2.1). A variable speed vehicle cooling blower mounted at a short distance in front of the vehicle provided the necessary cooling. The test vehicle was then soaked (i.e., cooled to bring it to ambient temperature and conditions and maintained in that state till the commencement of the test) on the chassis dynamometer to get the vehicle and the engine conditions to the test cell ambient conditions. Before starting the Test, the chassis dynamometer was warmed up for 30 minutes with the vehicle mounted on the chassis dynamometer and the engine in OFF condition. After the warm up chassis dynamometer was calibrated to compensate the frictional losses and then the vehicle was ready to undergo test. The same procedure was followed for all the vehicles.

A highly skilled driver was enlisted to drive the test vehicles on the chassis dynamometer. The same driver strictly followed the test cycle by maintaining the speed and also changing the gears and the acceleration and deceleration of the vehicle as displayed on the driver's aid monitor.

After ensuring the calibration of the test cell, the driver started the engine and remained idling for prescribed period as per the applicable regulatory test procedure depending upon the vintage and category of the vehicle. Thereafter, the exhaust sampling was started. The exhaust gases produced by the test vehicle were diluted with fresh air using a DT (dilution tunnel) and a criticalflow venturi-type CVS (constant volume sampler). For gaseous emission measurement, a constant proportion of the diluted exhaust gas was extracted for collection in one sample bag. The pollutant concentration in the sample bag at the end of the test corresponded exactly with the mean concentration in the total quantity of fresh air/exhaust mixture that was extracted. As the total volume of the fresh air/mixture could be defined, the pollutant concentrations were used as the basis for calculating the pollutant masses produced during the course of the test. For THC (total hydrocarbon) emission measurement for diesel vehicles, the diluted exhaust gas was sampled through a heated (191°C) and measured continuously by using heated FID THC analyser. The exhaust gas emission analysers were calibrated before the gas analysis. The gas analysis of each sample bag was done immediately after each test. The gases in the sampling bag was analysed for concentrations of CO (carbon monoxide), NOx (nitrogen oxides), THC (gasoline) and CO2 (carbon dioxide), and the emissions were expressed in g/km.

Additionally, for tests where PM was measured, the particulate filters were analysed for SOF (soluble organic fraction) and IOF (insoluble organic fraction) in order to identify the source of PM emission, whether oil or fuel. Basically, this elemental analysis of PM is not a mandatory requirement. The soxhelt extraction method was used to carry out the elemental analysis of the total particulate matter. The extracted particulate samples were analysed with the use of High pressure liquid and Gas chromatographic analyser to determine the SOF and IOF.

For PM measurement, the flow capacity of the CVS and DT system was such that the temperature at the particulate sampling point was below 52 °C during the test. The particulate emissions were collected on the primary and back up filters. Before starting the test the primary and secondary particulate filters were conditioned as per the procedure given in EEC directives. They were then weighed and mounted on the filter holder assembly and then installed in the particulate sampling system. At the end of the test the filters were removed and again conditioned as per the procedure given by the EEC and weighed.

Recognizing the importance of measuring particulate size distribution on mass basis, ARAI had purchased a 10 stage MOUDI (Micro-Office Uniform Deposit Impactor). MOUDI is internationally used as a cost effective device to measure the mass of PM deposition for different sizes of particles. The device was installed to take the diluted exhaust gas sample from the dilution tunnel to measure the mass of PM deposition for the distribution of different sizes of fine (18, 10, 5.6, 2.5, 1.8, 1, 0.56, 0.32, and 0.18 micron) and ultra-fine particles (0.1 and 0.056 micron) in the exhaust of the test vehicles. Sampling for the MOUDI (Micro Orifice Uniform Deposit Impactor) is taken from the same cross- section at which the sample is taken by dilution tunnel and at the same dilution ratio. The portion of the diluted exhaust from the primary tunnel was continuously transferred by the sampling pump to the MOUDI equipped for the first stage, in which the first stage, the larger particulates were separated. As the exhaust stream proceeded further, smaller particulates were separated, and so on, up to 10 stages. At the end of the test, the filter papers were removed from the different stages and weighed on the microbalance to obtain the mass of the particulates' size distribution.

As a part of the project on "Emission Factor Determination for Indian vehicles as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies ", ARAI had procured ELPI (Electrical Low Pressure Impactor) to measure PM size and number. ELPI was used to measure PM from all diesel vehicles and some of the gasoline vehicles.
The Electrical Low Pressure Impactor (ELPI) enables real time particle size distribution and concentration measurement in size range 30 nm up to 10 µm With an accessory the measurement range can be extended down to 7 nm. ELPI can be used in any application where a wide size range and fast response times are required, including combustion aerosol studies, filter testing and aerosol research in general. With ELPI it is possible to measure transient particle size distributions in a wide size range of particles and concentrations.
A precisely known charge given to particles in the charger is measured in real time with highly sensitive multichannel electrometers as the particles impact the collection plates. An interactive user interface enables monitoring of total concentration and particle size distribution in several different modes. These modes include parallel real-time size distribution and total concentration monitoring even from several units at the same time in the same window. Instant and continuous feedback as a function of particle size makes the particle removal device development illustrative and more efficient.

10.3 Brief Description of Test Set-up at ARAI

2-Wheeler Test Cell:

The Test Cell has facility for Type Approval /COP/Development Tests on gasoline two wheelers (Gasoline) as per BS-II and BS-III, EURO, EPA norms and as per customer requirements with customized test cycles. The 5 kW DC machine chassis dynamometer with inertia simulation from 80 kg to 320 kg is used for complete road load simulation, measurement of vehicle emission, constant speed fuel consumption and vehicle performance. The exhaust emission analyzer, constant volume sampler are suitable for measurement of all 2 wheelers.

Figure: Schematic of 2-Wheeler Test Cell

3-Wheeler Test Cell:

The set up has facility for Type Approval /COP/Development Tests on three wheelers (Gasoline/CNG/LPG/Diesel) as per BS-II and BS-III, EURO and EPA norms and as per customer requirements with customized test cycles. The 50 kW AC machine chassis dynamometer having 24-inch dia roller, With inertia simulation from 100 to 1500 kg is used for complete road load Simulation, measurement of vehicle emission, constant speed fuel Consumption and vehicle performance. The Dilute Diesel / Gasoline / CNG / LPG Exhaust Gas Analyzer, constant Volume sampler and 10 inches dia. dilution tunnel are suitable for Measurement of all 3 wheelers.

Figure: Schematic of 3-Wheeler Test Cell

4-Wheeler Test Cell:

The set up has facility for Type Approval /COP/Development Tests on four wheelers (Gasoline/CNG/LPG/Diesel) as per BS-II and BS-III, EURO and EPA norms and as per customer requirements with customized test cycles. The 150 kW AC machine chassis dynamometer having 48 inch dia single roller with inertia simulation from120 to 5443 kg is used for complete road load simulation, measurement of vehicle emission, constant speed fuel consumption and vehicle performance. The latest generation Dilute Diesel / Gasoline / CNG / LPG Exhaust Gas Analyzer, constant volume sampler and 12 inch. dilution tunnel are suitable for measurement of all 4 wheeler passenger cars and light commercial vehicles.

Figure: Schematic of 4-Wheeler Test Cell

HCV Test Cell:

This Emission Test Cell at ECL has facility for Development test for mass emission, fuel consumption and performance evaluation of oil and lubricants on trucks and buses. During the measurement of particulate matters for HCV. Applications, A secondary dilution tunnel along with 18” primary dilution tunnel allows complete testing of Bus and trucks on chassis dynamometer for particulates.

Figure: Schematic of HCV Test Cell

Figure: Schematic of ELPI

10.4 Test Conditions:

During the test, the test cell temperature was maintained between 293 K and 303 K (20 and 30°C). The absolute humidity (H) of either the air in the test cell or the intake air of the engine was maintained such that: $5.5 \leq H \leq 12.2$ g H2O/kg dry air
For post 2000 vehicles, the soak period was maintained for at least 6 hours and upto a maximum of 30 hours at 20-30 deg. C.

10.5 Mass Emission Calculations:

The mass emission of pollutants are calculated by means of the following equation:

$$Mi = \frac{(Vmix * Qi * k_H * Ci * 10^{-6})}{d}$$

Mi = Mass emission of the pollutant i in g/km
Vmix = Volume of the diluted exhaust gas expressed in m3/test and corrected to standard conditions 293 K and 101.33 kPa
Qi = Density of the pollutant i in kg/m3 at normal temperature and pressure (293 K and 101.33 kPa)
kH = Humidity correction factor used for the calculation of the mass emissions of oxides of nitrogen. There is no humidity correction for HC and CO.
Ci = Concentration of the pollutant i in the diluted exhaust gas expressed in ppm and corrected by the amount of the pollutant i contained in the dilution air.
d = distance covered in km

10.6 Calibration of Important Test Cell Equipments:

Chassis Dynamometer:

Sr. No.	Particulars	Requirement	Frequency
1	Load cell	1% Full Scale	1 month
2	Speed Calibration of dynamometer	1 kph	6 months
3	Cooling blower	5 kph	1 year

Analyzers:

Sr. No.	Particulars	Requirement	Frequency
1	Linearity	2% point	1 month
2	NOX Conversion Efficiency	>95%	Weekly

CVS:

Sr. No.	Particulars	Requirement	Frequency
1	CVS LFE Venturi Cal	<0.3%	6 months
2	Propane Injection	5%	6 monthly

11. ANNEXURE VI: Brief Description of Unregulated Emissions Measurement Procedure, Equipment used and Calibration Details

11.1 Summary of non-regulatory pollutants analysis used for the Project

Sr. No.	Parameter	Standard Ref. Method	Test procedure/ SOP	Analytical Technique/ Method	Calibration standards Details	Calibration Periodicity
1	Poly-Aromatic Hydrocarbons (PAH)	As per NIST SRM 1647d	TP-148-AML	High Performance Liquid Chromatography (HPLC) with UV Detector	NIST SRM-1647d 16 component PAH-Mix. Acceptance criterion of +/- 5 % of the NIST Standards	Intermediate checks with NIST standard before analysis of set of samples.
2	Carbonyls (Aldehydes & Ketones)	EPA Method 1004	TP-140-AML	High Performance Liquid Chromatography (HPLC) with UV Detector	Accustandard (NIST Traceable) for Carbonyl Compounds at DNPH Derivatives-13 component. Acceptance criterion of +/- 5 % of the NIST Standards	Intermediate checks with NIST standard before analysis of set of samples.
3	VOC (Benzene and 1,3-butadiene)	EPA Method TO-17	TP-146-AML	Auto Thermal Desorber-Gas Chromatography Method (ATD-GC-FID)	Benzene 1.2 ppm and 1,3 Butadiene 1.9 ppm mixture in nitrogen. Alchemie Gases and Chemicals	yearly
4	PM-Soluble Organic Fraction (SOF)	Institute of Petroleum Method -IP PM CA/96	TP-145-AML	Soxhlet Extraction Gravimetric Method	External Weight Calibration of microbalance by calibration cell	yearly
		Institute of Petroleum Method -IP PM BZ/96		Gas Chromatography-FID Method	Calibration using fuel and oil as per -IP PM BZ/96	6 monthly
5	PM-Inorganic Fraction (IOF)	American Society for Testing and Materials ASTM E 1131-93	TP-144-AML	Theromogravimetry Method	System Calibration Weight calibration-external by calibration cell	yearly
					System Calibration-Temperature Calibration	6 monthly

11.2 Sample Collection Procedure For Vehicle Exhaust

11.2.1 *SCOPE*

The following procedure is defined for the collection of background and sample from vehicle exhaust of diesel and gasoline fueled vehicles tested at ECL and AED Department of ARAI, Pune. Background and samples are collected for particulate Matter (PM), aldehydes and ketones, Polyaromatic Hydrocarbons (PAHs) and volatile organic species like benzene and 1,3-butadiene. The samples are collected during the mass emission tests carried out at the above mentioned departments.

11.2.2 *REFERENCES*

The method for analysis from following standards are taken
1) For aldehydes & ketones: EPA CARB Method-1004
2) For Benzene & 1,3-butadiene: EPA method TO-17
3) For PM analysis: IP PM/BZ 96 and IP PM/CA-96
4) For PAH analysis: NIST SRM 1647d method

11.2.3 *EQUIPMENT*

1) Envirotech 850 sampler equipped with dry gas meter, U tube manometer, time totaliser, temperature indicator and flow meter.
2) Impingers to collect aldehyde & ketone and gaseous phase PAH.
3) Sorbent tubes- Carbotrap^{TM} 300 to collect 1,3-butadiene & benzene
4) Low Flow sampler Gilian LFS-1130 (5-200 ml/min constant flow) and flowmeter for adsorbent tube sampling

11.2.4 *CHEMICALS*

1) 80:20 mixture of HPLC grade benzene and methanol for gaseous PAH collection, 2 impingers in series with 20 ml volume in each.
2) 0.11 % w/v solution of dintrophenyl hydrazine (DNPH) in HPLC grade acetonirile, with 0.02 M perchloric acid solution in water, 2 impingers in series with 15 ml each.
3) Adsorbant tubes: Air Toxics tubes or Carbotrap tubes for collection of benzene and 1,3-butadiene.

11.2.5 *PROCEDURE*

1) The background and the samples are collected during the mass emission tests. During these tests the dilute continuous exhaust sample is connected to the sampler and the exhaust gas is passed simultaneously, under suction, with specified flow rate mentioned below, for the total time of the test into the respective impingers filled with reagent solutions. Benzene and 1,3-butadiene are collected at the flow rate of 50 ml/min in the sorbent tube from tedler bag separately for better analysis output.
2) Aldehydes and ketones are sampled at the flow rate of 1.0 LPM into the impingers filled with the DNPH-acetonitrile reagent
3) Gas phase PAHs are sampled at flow rate of 0.5 LPM into the impingers containing the benzene methanol (80:20) mixture.

11.3 Determination Of PAH Compounds In Automotive Exhaust By High Performance Liquid Chromatography

11.3.1 *SCOPE*

The procedure is applicable to automotive engine exhaust and ambient air.

11.3.2 *REFERENCE DOCUMENT*

2.1 NIST SRM 1647 standard document for analysis method
2.2 Operating Manual of Series 200 Liquid Chromatograph.
2.3 Applicable MSDS for proper handing storage use disposal of chemicals for Acetonitrile, Water, Benzene and Methanol

11.3.3 *CALIBRATION*

3.1 Standard: NIST SRM 1647d- Priority pollutant Polycyclic Aromatic Hydrocarbons. 16 component PAH-Mix in Acetonitrile
3.2 Frequency: Intermediate checks with NIST standard before analysis of set of samples. Acceptance criterion of +/- 5 % of the NIST Standard.
3.3 Calibration Record: In the form of a Calibration Test Report

11.3.4 *APPARATUS*

The designated chemist, engineer will select the appropriate testing reforming master list of instruments. The general instruments are as follows.

4.1 Series 200 High Performance Liquid Chromatograph (HPLC) (AML/INST/136)
4.2 Balance (AML/INST/117 & AML/INST/118)
4.3 Envirotech APM 850 machines (AML/INST/138)

11.3.5 *REAGENTS*

All reagents are HPLC grade unless otherwise stated.
5.1 Acetonitrile
5.2 Water
5.3 Benzene
5.4 Methanol

11.3.6 *SUMMARY OF TEST PROCEDURE*

The sample is received by the laboratory in sample collection impinger and particulate matter filter paper. Separate analysis of gaseous PAH sample collected in impingers and PM- PAH samples on filter papers was carried out. The filter paper is extracted in Benzene: Methanol (80:20) mixture. Impinger and extracted samples are dissoved in 1ml of acetonitrile separately. The sample injected in High Performance Liquid Chromatography (HPLC) and analysed by using Ultraviolet detector and suplecosil and C-18 columns. Conc. Of target carbonyl compound in the sample under test is determined by calibrating the HPLC using a traceable Certified Reference Material (CRM).

11.3.7 *DETAIL PROCEDURE*

- Switch on the equipment as per Work Instruction No. CHL/WI/136.
- Open HPLC method in respective mode.
- Place the vials containing blank, working standard, control standard and test samples into the auto sampler for subsequent injection into HPLC.
- The peak integrations are corrected as necessary in the data system.
- Calculate and record the peak areas.
- Calculate the conc. of target each PAH compound in the CRM and the sample under test. The HPLC equipment is said to be in a known state of calibration if result obtained on the CRM (not used for the calibration) (when treated as unknown sample) is within ± 5% value reported by certified authority. OR its retention time.
- Record the result of the calibration in the form of enclosed format.

11.3.8 *CALCULATIONS*

- The mass of each target carbonyl compound is determined by the following equation :

$X_{Mass} = A \times B$

Where, X_{Mass} = Mass of target PAH compound in the CRM, µgms.
A = Area of the peak PAH compound
B = Response factor for the PAH compound.

$$\text{Response factor for PAH Compound} = \frac{\text{(Conc. of PAH comp. in CRM) } \mu\text{gm/ml}}{\text{Peak Area of the CRM}}$$

11.3.9 *REPORT*

Report the concentration of target carbonyl compound in µgm

11.3.10 *Calibration Test Report:*

Determination of PAH compounds in Automotive source samples by High Performance Liquid Chromatograph.

Acceptance Criteria : Result of standard sample should be within ± 5% of specified value.

Reference : Operation Manual of Series 200 HPLC
Observations :
The observations in the form of actual results obtained are compared to a specified value for each of the target PAH compound and percentage deviation is noted.

11.4 Determination Of Aldehydes And Ketones Compounds In Automotive Source Samples By High Performance Liquid Chromatography (Method 1004)

11.4.1 *SCOPE*

The procedure is applicable to automotive engine exhaust and ambient air.

11.4.2 *REFERENCE DOCUMENT*

- EPA method 1004.
- Operating Manual of Series 200 Liquid Chromatograph.
- Applicable MSDS for proper handing storage use disposal of chemicals for Acetonitrile, 2,4 Dinitrophenyl hydrazine, Sulphuric acid / Perchloric acid (Refer file No. CHL/MSDS/74)

11.4.3 *CALIBRATION*

- Standard: Carbonyl Compounds as DNPH Derivatives from AccuStandard Inc. Product/ Catalog No. M-1004
- Frequency: Intermediate checks with NIST standard before analysis of set of samples. Acceptance criterion of +/- 5 % of the NIST Standard.
- Calibration Record: In the form of a Calibration Test Report

11.4.4 *APPARATUS*

- Perkin Elmer Make Series 200 High Performance Liquid Chromatograph (AML/INST/136)
- Balance (AML/INST/117 & AML/INST/118)
- Envirotech APM 850 series Sampler (AML/INST/138)

Figure: Perkin Elmer Make Series 200 High Performance Liquid Chromatograph

11.4.5 *REAGENTS*

All reagents are HPLC grade unless otherwise stated.

- Acetonitrile
- Water
- 2,4-Dinitrophenyl hydrazine purified
- Sulfuric acid analytical grade
- Perchloric acid analytical grade
- Carbonyl / 2,4-dinitrophenyl hydrazone (DNPH) complexes

11.4.6 *SUMMARY OF TEST PROCEDURE*

The sample is received by the laboratory in sample collection impinger. The absorbing solution (2,4 DNPH) complexes the carbonyl compounds into their diphenyl hydrazone derivatives. The solution in impinger is transferred to a sample bottle. Impinger rinsed to make total 30 ml volume. An aliquot of sample is injected in High Performance Liquid Chromatography (HPLC) and analysed by using Ultraviolet detector [Spheri – 5 RP–8 or equivalent column with guard column] and Conc. Of target carbonyl compound in the sample under test is determined by calibrating the HPLC using a traceable Certified Reference Material (CRM).

11.4.7 *SAMPLING PROCEDURE*

Collect sample as per procedure given below

- Prepare absorbing solution by dissolving 0.11-0.13 gms. of recrystallized DNPH in 1 liter of HPLC grade acetonitrile.
- Pipette 15 ml of the DNPH absorbing solution into each of two impingers for emission test. Add 0.15 ml of 3.8 M perchloric acid to each Impinger & seal the Impingers.
- Collect vehicle exhaust sample at 1 liter / min using Envirotech APM 850 sampler and cap the impingers.
- After receiving the samples for analysis make up volume to 30 ml. with acetonitrile.
- If sample are not analyzed the same day as received, they must be refrigerated at a temperature below 40^0F. Refrigerated samples, must analyzed within 30 days.

11.4.8 *ANALYSIS PROCEDURE*

Switch on the equipment as per Work Instruction No. CHL/WI/136.
Prepared sequence file as per method given below

Analytical column	– Spehri 5 RP–18, 5 μM	250 mm X 4.6 mm.
Guard column	– Validate C-18 5 μM	20 mm X 4.6 mm.
Column temperature	– 40^0C	
Detector	– UV / VIS at 360 nm.	
Sample volume	– 10 μL	
Solvent A	– Acetonitrile	
Solvent B	– Acetonitrile in water (35 % v/v)	
Program	– 23 % A, 77 % B (Initial)	
	– 23 % A, 77 % B (0-5.5 minute)	
	– 46 % A, 54 % B (5.5-20.2 minute)	
	– 23 % A, 77 % B (20.2 –50.7 minute)	

- Place the vials containing blank, certified reference material and test samples into the auto sampler for subsequent injection into HPLC.
- The peak integrations are corrected as necessary in the data system.
- Calculate and record the peak areas.

- Calculate the conc. of target carbonyl compound in the CRM and the sample under test. The HPLC equipment is said to be in a known state of calibration if result obtained on the CRM is within ± 5% value reported by certified authority if result is beyond + 5 % of specified value then check leakage, clean column, clean pump, clean detector, etc. till result of targeted carbonyl compound is within + 5 % of specified value.
- Record the result of the calibration in the form of enclosed format.

11.4.9 *CALCULATIONS*

The mass of each target carbonyl compound is determined by the following equation:

$^{X}Mass = A \times B \times C \times D \times E$

where, $^{X}Mass$ = Mass of target carbonyl compound in the CRM, μgms.

A = Area of the peak target carbonyl compound

B = Ratio of the molecular weight of the targeted carbonyl compound to its 2,4-DNPH derivative.

C = Response factor for the targeted carbonyl compound.

D = Impinger volume

E = Total number of impinger

$$\text{Response factor for target Carbonyl Compound} = \frac{\text{(Conc. of 2,4 DNPH derivative of target carbonyl comp. in CRM) } \mu\text{gm/ml)}}{\text{Peak Area of the CRM}}$$

11.4.10 *REPORT*

Report the concentration of target carbonyl compound in μgm.

11.4.11 *RECORDS*

- INTERNAL: Calibration of HPLC in soft copy. Soft copy of sample chromatogram. Maintenance Records of HPLC in Maintenance file.
- EXTERNAL: Report to customer. Copy of report in Test Report file.

11.4.12 *CALIBRATION TEST REPORT*

Determination of Aldehydes and Ketones compounds in Automotive source samples by High Performance Liquid Chromatograph (Method 1004).

Acceptance Criteria : Result of standard sample should be within ± 5% of specified value.

Reference : Operation Manual of Series 200 HPLC
Observations :
The observations in the form of actual results obtained are compared to a specified value for each of the target carbonyl compound and percentage deviation is noted.

11.5 Determination of Benzene, 1,3 butadiene (Volatile Organic Compounds) in exhaust gases using Active sampling onto sorbent tubes.

11.5.1 *SCOPE*

This test procedure is applicable for the determination of Volatile Organic Compounds like Benzene and 1,3 butadiene present in automobile exhaust as well as in ambient air.

11.5.2 *REFERENCE DOCUMENT*

2.1 As per guidelines of EPA TO-17
2.2 Operating Manual of Turbo matrix ATD and Auto system XL HRGC.
2.3 Refer file No. CHL/MSDS/74 for applicable MSDS for proper handing, storage, use and disposal of chemicals for
- Benzene and 1,3 butadiene
- Helium, Air and Hydrogen

11.5.3 *CALIBRATION*

3.1 Standard: Following standard gas cylinders were used
- Benzene 1.2 ppm and 1,3 Butadiene 1.9 ppm mixture in nitrogen from Alchemie Gases and Chemicals. Capacity 3.0 Ltr. Certification Accuracy +/- 5%
- Benzene 4.5 ppm and 1,3 Butadiene 6.5 ppm mixture in nitrogen from Chemtron Science Laboratory. Capacity 0.5 Ltr. Certification Accuracy +/- 5%
- Benzene 1.67 ppm and 1,3 Butadiene 1.44 ppm mixture in nitrogen from Chemtron Science Laboratory. Capacity 0.5 Ltr. Certification Accuracy +/- 5%

3.2 Frequency: One yearly
3.3 Calibration Record: In the form of a Calibration Test Report.

11.5.4 *APPARATUS*

The general instruments are as follows

4.1 Perkin Elmer Auto system XL High Resolution Gas Chromatograph with Flame Ionization Detector
4.2 Perkin Elmer make Turbo matrix Automated Thermal Desorber
4.3 Low-flow Sampler Gilian LFS-1130 with flow measuring device.
4.4 Stainless Steel Adsorbent sampling tubes-Carbotrap™300.

Figure: Perkin Elmer Auto system XL High Resolution Gas Chromatograph with Flame Ionization Detector with Turbo matrix Automated Thermal Desorber

11.5.5 *REAGENTS*

5.1 Gas Cylinders -- Hydrogen, Air and Helium 99.99% pure.
5.2 Calibration Gas Mixtures of Benzene and 1,3 butadiene

11.5.6 *SUMMARY OF TEST PROCEDURE*

The method involves drawing of a known volume of exhaust gas through a Stainless Steel tube to collect VOC's like Benzene & 1,3 butadiene followed by a Thermal Desorption – Capillary GC- FID analytical procedure. Adsorbent material of the tube used to concentrate desired analytes are selected on the basis of their affinity towards the analytes as recommended in EPA TO-1, TO-2, TO-3 & TO-14 test methods.
Extraction of Benzene, 1,3 butadiene by Thermal Desorption involves use of heat & a flow of inert (Carrier) gas to extract volatiles from a solid matrix directly into the carrier gas & transfer them to downstream system of High resolution Capillary GC column.

11.5.7 *DETAIL PROCEDURE*

- Sampling Procedure**:**

Adsorbent tubes for sampling are prepared by conditioning as mentioned below

For Automated Thermal Desorption Unit: -

(a)Temperature.		(b) Time		(c) Carrier Gas Helium	
Tube	345 ^{0}C	Purge	1 min	Desorbs Flow	30 ml/min
Valve	100 ^{0}C	Desorbs	60 min	Pressure	22 psi
Transfer line	100 ^{0}C				

- Exhaust gas is drawn through labeled adsorbent tube at a constant flow rate of 50 ml/min using pump and flow meter assembly.
- Field blank should always be taken along with sample following the same sample collection procedure.
- Laboratory blanks, must be taken before sampling.
- After collection of sample, tubes should be sealed properly and should be refrigerated & analyzed within 30 days of sample collection.

- GC- ATD Analysis:

After collection of sample tubes are placed on ATD unit under standard conditions for analysis of sample for Benzene & 1,3 butadiene as follow-

For Automated Thermal Desorption Unit: -

(a) Temperature.		(b) Time		(c) Carrier Gas Helium)	
Tube	325 ^{0}C	Purge	1 min	Outlet Split	60 ml/min
Valve	175 ^{0}C	Desorbs	10 min	Desorbs Flow	30 ml/min
Transfer line	200 ^{0}C	Trap hold	7 min	Pressure	22 psi
Trap	-30 to 325 ^{0}C				

For Gas Chromatograph: -

(a) Oven Program.			(b) Detector Program		(c) Carrier Gas	
Rate (^{0}C/min)	Temperature (^{0}C)	Hold Time (min)	Temperature (^{0}C)	250	**Pressure**	22 psi
	50	2.00	Range	1		
10	200	10.00	Attenuation	8 & 64		
30	250	1.00				

- Calibration using external standard method:

2ml of concentrated pressurized gas phase standard with (+/- 5%) accuracy is used for calibration by passing it through conditioned blank adsorbent tube for 5 min.at constant flow rate of 50 ml/min. Then the tube is subjected for analysis under the same conditions as used for sample tubes. This procedure should be repeated at least three times for repeatability. If the results (peak area) show variation beyond the +/- 5% check for leakage, condition of trap, column till the result of target compound is within +/- 5%. Record the result of calibration.

11.5.8 *CALCULATIONS*

Measure the areas of peaks of 1,3 butadiene & Benzene for unknown sample & arithmetically correlate with standard peak areas of known calibration mix. Subtract the field blanks & laboratory blanks from the sample tube areas before arriving at final areas. Accordingly the concentration of sample in PPM or Micrograms can be calculated.

Concentration of Benzene or 1,3 Butadiene (microgram) = A * B / C

Where as,

A= Peak area of Sample

B= Concentration of Standard (microgram of Benzene or 1,3 Butadiene)

C= Peak area of Standard.

11.5.9 *REPORT*

Report the concentration of Benzene and 1,3 butadiene in microgram (μg).

11.5.10 *RECORDS*

- Internal record: Calibration of Flow Meter of sampling pump, GC and ATD Maintenance record.
- External record: Report to concerned officer of project.

11.5.11 *CALIBRATION TEST REPORT*

Acceptance Criteria: Result of standard sample should be within $\pm$ 5% of specified value.

Reference Standard: Operating manual of GC –ATD.

Observations:

The percentage deviation is recorded for the target compound by comparing the actual result obtained with the specified value of that compound and results are recorded.

11.6 Determination Of Soluble Organic Fraction (Fuel And Oil Derived Hydrocarbon) In Particulate Matter Sample Collected On Filter Paper By High Resolustion Gas Chromatograph .

11.6.1 *SCOPE*

This method covers the measurement of Fuel & oil-derived Soluble Organic Hydrocarbons (SOF), from particulate matter collected on primary & secondary filter paper.

11.6.2 *REFERENCE DOCUMENTS*

- IP PM BZ/96
- IP PM CA/96
- Instrument Operating Manual of High Resolution Gas Chromatograph.
- Refer file No. CHL/MSDS/74 for Applicable MSDS for proper handing storage use disposal of chemicals for Methanol, Benzene , Hydrogen Gas, Helium Gas, Air

11.6.3 *CALABRATION*

- Standard: System Calibration- External Weight calibration of microbalance by calibration cell. GC calibration- using fuel and oil as per -IP PM BZ/96
- Frequency: Weight calibration- One yearly and GC calibration- 6 monthly

11.6.4 *APPARATUS*

The general instruments used are as follows.

- Thermogravimetric Analyser with Microbalance.
- Soxhlet Extraction Apparatus
- High Resolution Gas Chromatograph.

11.6.5 *REAGENTS*

1) Benzene (HPLC grade)
2) Methanol (HPLC grade)
3) 99.9 Pure Nitrogen Gas
4) 99.9 Pure Hydrogen Gas
5) 99.9 Pure Helium Gas
6) 99.9 Pure Air

11.6.6 *SUMMARY OF TEST PROCEDURE*

The primary and secondary filter paper holding the particulate matter are soxhlet extracted with a 80:20 benzene: methanol mixture for 4 hrs. The extraction is carried out within 72 hrs after collection of the particulate matter. The extract is then concentrated by purging with nitrogen gas at room temperature till the solvent is completely removed. 1 ml of benzene is added to this concentrated extract. An aliquot of 0.5 μl in injected into the gas chromatograph fitted with a flame ionization detector (FID). The fuel and oil fractions of SOF are determined as described in the procedure 6.0 below.

11.6.7 *DETAIL ANALYSIS PROCEDURE*

- Weigh the primary, secondary and blank filter papers carefully
- Extract each of the weighed papers in soxhlet apparatus using a 80:20 benzene : methanol reagent mixture for a period of 5 hrs or extract the filter through at least 10 cycles of siphoning.
- Concentrate the extract by purging pure nitrogen gas at room temperature to remove the solvent
- The extracted filter papers are dried at 70^0C for 3 hrs.
- The weights of the dried filter paper are taken to determine the soluble and the insoluble organic fractions in the diesel particulate matter
- 1 ml benzene is added to the concentrate extract and an aliquot of 0.5 μl is injected into a HR-GC fitted with a FID detector and analyzed.
- Similarly topped fuel (Distilled in accordance with IP 123 to remove all components boiling below 315^0C or the first 90% of fuel's distillation range, whichever is achieved first) and fresh engine oil are analyzed by HR-GC as per conditions given below. The HR-GC analysis conditions for samples analyzed in step 6.6 and 6.7 are the same.
- Oven Temperature
  Initial Temperature: 60^0C for 5 min
  Ramp 1:60^0C to 300^0C with the ramp of 15^0C/min
  Hold Time: 40 min
  Detector Temperature: 300^0C
  Injector Temperature: 250^0C
  Carrier Gas: Helium at 50 psi
- The GC chromatograms obtained from topped fuel and engine oil are overlapped to find out cut off time for fuel and oil derived fractions. The mass of fuel and oil derived organic fractions are determined as shown in the calculations.

11.6.8 *CALCULATIONS*

- The mass of SOF on the filter paper is calculated as follows

$SOF = P[(M_o-M_1)-(B_o-B_1)]$
Where
P = reciprocal of the fraction of filter paper taken
M_o= mass of filter paper before extraction
M_1 = mass of filter paper after extraction
B_o = mass of blank filter paper before extraction
B_1 = mass of blank filter paper after extraction

- Calculate the mass of fuel and oil derived hydrocarbon using the following equation

$$M_F = [\{(A_F \times D/C)\}-A_o] / [\{(A \times D)/C\}-B]$$

$$M_o = \{A_o-(M_F \times B)\}/D$$

Where
M_F = Mass of Fuel Derived Hydrocarbons (SOF_{fuel}) in mg.
M_o = Mass of Oil Derived Hydrocarbons (SOF_{oil}) in mg.
A = Area before cut off point per mg of topped fuel
B = Area after cut off point per mg of topped fuel
C = Area before cut off point per mg of oil
D = Area after cut off point per mg of oil
A_F = Area before cut off point for particulate matter sample
A_o = Area after cut off point for particulate matter sample

11.6.9 *RECORDS:*

- Internal:
  - Calibration of balance, measuring cylinder,
  - Sample weight reading and in-process inspection records in operator's logbook,
  - Soft copy of chromatogram.
- External: Report to customer, copy of report filed in Test report file.