EXPERIMENTAL ANALYSIS OF DIRECT CARBON DIOXIDE (CO_2) EMISSIONS FROM SOME OF THE BITUMEN TYPES NORMALLY USED IN INDIA

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ABSTRACT

Carbon dioxide (CO_2) emission from bitumen during road construction for Greenhouse Gas emission calculations presently is taken based on its embodied emission factor. The direct emission component which accounts for significant emissions arising during heating of bitumen for mixing with aggregate is not accounted for.

This Paper presents findings of an experimental work of measuring direct carbon dioxide emitted by different bitumen binders during heating using Non Dispersive Infrared Radiation (NDIR) technology based CO_2 analyzer.

Samples of various types of bitumen binders like Crumb Rubber Modified Bitumen (CRMB), Polymer Modified Bitumen (PMB), Viscosity Grade (VG)-30, and VG-40 taken from various sources were tested in the laboratory. Results from the experimental work show that there is direct, measureable emission of CO_2 from bitumen binders during heating for mixing, and that this information should form the basis for more detailed investigation for assisting a better informed selection criterion between the straight run and polymer modified variants of bitumen binders. Comparison of emissions at their respective mixing temperatures, as specified in the Codes, shows that PMB-40 has the highest direct CO_2 emission factor followed by CRMB-60, VG-30 and VG-40.

KEY WORDS

Bitumen, Direct CO_2 emission

INTRODUCTION

The experimental work was planned with the premise that bitumen binders must be emitting CO_2 on heating them to the mixing temperatures which is at present not accounted for. These direct emissions, besides the embodied emissions which is substantial, should be taken into account, along with other considerations of suitability and costs while making decision on the choice of bitumen for any road project work.

Samples of binders collected from various road construction sites, comprising Crumb Rubber Modified Bitumen (CRMB)-60 & Polymer Modified Bitumen (PMB)-40 from Ongole; CRMB-60 from Panipat; Viscosity Grade (VG)-30 & VG-40 from Hisar and Suratgarh; supplied from Indian Oil Corporation Limited (IOCL) Mathura and Mumbai refineries formed part of the experiment. These bitumen types are the one normally being used in India.

Physical properties were tested in the laboratory for each sample to ensure that these complied with IS 73-2013 for Paving Bitumen and IS I5462:2004 for Polymer and Rubber Modified Bitumen specifications. Results of the physical properties are given in **Table 1.**

TABLE 1 Physical Property of Samples Used for the Study

Types of binder	**Ductility@25 °C, cm**	**Softening point in° C**	**Penetration@ 25°C,100g,5s,0.1mm**
VG-30	46 (40minimum)	47 (47 minimum)	45 (45minimum)
VG-40	35 (25minimum)	50 (50 minimum)	40(35 minimum)
PMB-40	Na	75 (60 minimum)	50 (30-50)
CRMB-60	Na	60 (60 minimum)	40 (<50)

Note: Values in parenthesis are thresholds as per codes
Na= Not Applicable

THE EXPERIMENT

Forty nine samples from different batches of the four types were worked upon to finalize the testing procedure. Each test sample comprised of 500 grams (1.10 pound) of material extracted manually without heating the bitumen. The experiment was carried out by heating the individual samples in a closed chamber and passing the effluent gas through Non Dispersive Infrared Radiation (NDIR) based CO_2 analyzer. The setup of instrument is described in following section.

Instrument Set Up

Instruments used for the test consist of a heating chamber, external digital thermometer with sensor and NDIR based CO_2 analyzer as shown in **Figure 1.** The CO_2 analyzer is calibrated using gases comprising 16.20% CO_2 (balance nitrogen) and 0.000% CO2 (99.999% nitrogen). Resolution of the Analyzer is 0.001% with sensor range 0 to 20%. The digital thermometer has been calibrated at 50.41°C, 98.09°C, 145.15°C, 195.75°C and 240.4°C. The chamber can be heated up to 300°C. Volume of the heating chamber is 231.86 liters (51.00 gallon) connected to the analyzer with steel tube followed by silicon tube. With the flow rate of 0.47 liters per minutes (1Cubic feet per hour) as recommended by Manufacturer it would take around 8.22 hours for air or any gas in the chamber to be drawn out completely. Flow rate of 0.47 liters per minute describes light air condition at site as per Beaufort scale with the wind velocity of 2.25 km/hour when Smokes moves slightly with breeze and indicates the direction of wind. Volume of the connecting tubes is 0.37 liters (0.08 gallon) and air or gas takes 0.8 minutes or 47.25 seconds to reach the analyzer from the heating chamber.

Test Procedure

Each test was preceded by recording ambient CO_2 level by heating the empty chamber to the desired temperature and recording the CO_2 level in the chamber. This information was used at later stage in assessing CO_2 effluence in absolute terms. The emitted CO_2 levels as assessed based on the value recorded by the NDIR set up and corrected for the ambient value in percentage terms was converted to milligram per liter (mg/l). Taking account of the sample weight, the assessed emissions were converted to tonne of CO_2 per tonne of bitumen.
Confirmatory test using calcium hydroxide and water was also carried out for each group of samples to confirm the emission of CO_2 on heating bitumen up to mixing temperature. White

precipitates of calcium carbonate ($CaCO_3$) on the wall of the test tube were the confirmatory proof of the presence of CO_2 in the effluence.

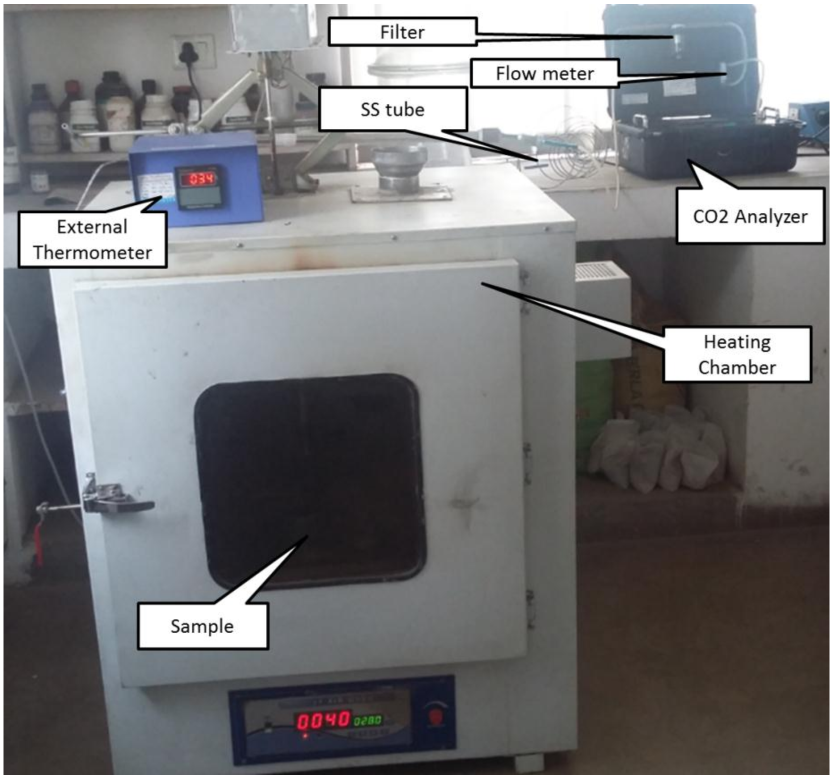

FIGURE 1 Instrument Set Up for Tests

Results

Data for each sample has been recorded for their respective temperature ranges from softening point to Mixing point. Data recorded on emission levels for different bitumen types at various temperatures are as given in **Table 2.** Direct CO_2 emission ranges from 0.0055 to 0.1011 tCo2/t in case of PMB-40, from 0.0027 to 0.0795 tCo2/t in case of CRMB-60, from 0.0029 to 0.0632 tCo2/t in case of VG-30 and from 0.0021 to 0.0587 tCo2/t in case of VG-40.

TABLE 2 Carbon Dioxide Emission Factor

Temperature (°C)	Emission factor (tCo2/t bitumen)			
	VG-40	**CRMB-60**	**PMB-40**	**VG-30**
47	Na	Na	Na	0.0029
50	0.0021	Na	Na	0.0030
60	0.0047	0.0027	0.0055	0.0058
70	0.0060	0.0047	0.0100	0.0100
80	0.0080	0.0067	0.0156	0.0107
90	0.0104	0.0079	0.0177	0.0116
100	0.0113	0.0097	0.0199	0.0141
110	0.0140	0.0133	0.0249	0.0186
120	0.0147	0.0140	0.0268	0.0214
130	0.0207	0.0194	0.0324	0.0281
140	0.0272	0.0281	0.0391	0.0388
150	0.0366	0.0339	0.0467	0.0464
160	0.0432	0.0424	0.0575	0.0587
165	0.0528	0.0487	0.0646	0.0632
170	0.0587	0.0527	0.0702	Na
180	Na	0.0679	0.0896	Na
185	Na	0.0795	0.1011	Na

Note: 1 ton=2204.62 pound; Na=Not Applicable

Graphical presentation of the data for the samples of four bitumen types showing relationship between direct emission of CO_2 and the heating temperature is given in **Figure 2.**

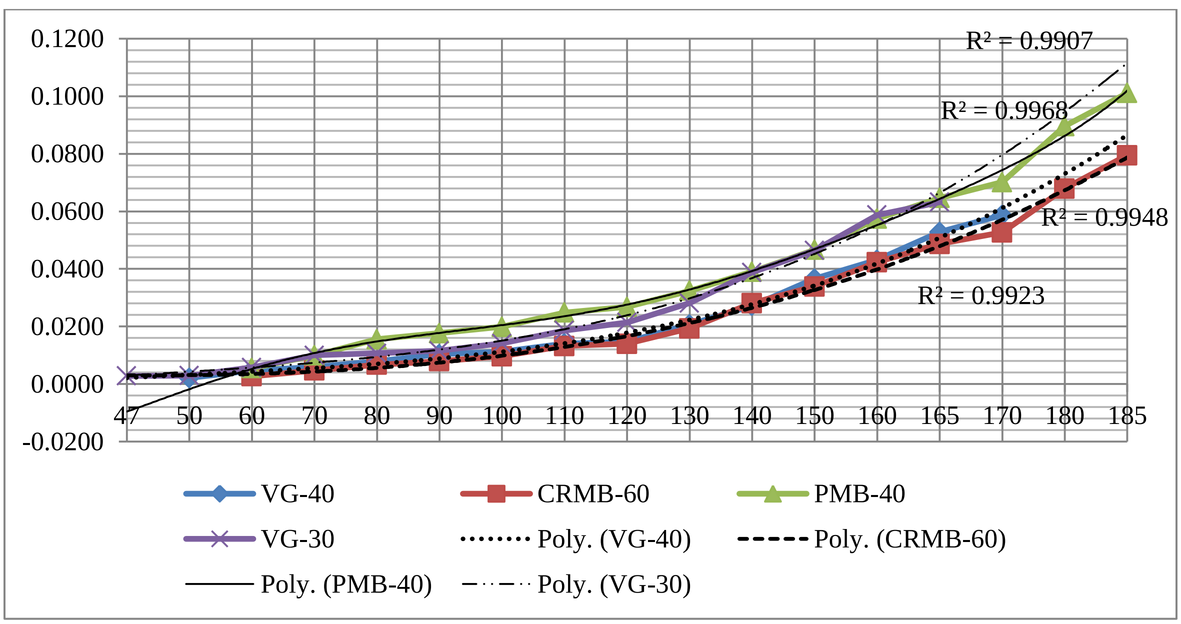

FIGURE 2 CO_2 Emission Factors for Different Types of Bitumen

ANALYSIS OF RESULTS

The result shows that for Hot Mix Asphalt (HMA) using PMB 40, the level of direct emissions is 0.1011 tCo2/t bitumen, which is quite a substantial amount, presently not being accounted for by the GHG emission assessment systems including CHANGER. This amount of emission for HMA at 185°C is actually 2.58 times the emission level of 0.0391 tCo2/t bitumen at 140 °C used for Warm Mix Asphalt (WMA). In case of CRMB-60 direct emission is 0.0795 tCo2/t bitumen at the temperature of 185°C (HMA) that is 2.8 times more than its emission at 140 °C (WMA). In case of VG-30 emission at 165°C (HMA) is 2.25 times more than its emission at 130 °C (WMA). Similarly in case of VG-40 emission at 170 °C (HMA) is 2.35 times higher than its emission at 135°C (WMA). This clearly brings out the advantage of going for WMA technology in place of HMA technology in terms of direct CO_2 emission of bitumen as well in India.

Comparison of emissions at their respective mixing temperatures, as specified in the Codes, shows that PMB-40 has the highest direct CO_2 emission factor followed by CRMB-60, VG-30 and VG-40.

The reason for PMB emitting the highest is probably lower melting point (<150°C) of Plastomeric Thermoplastic polymers (Polyethylene (PE), Ethylene Vinyl Acetate (EVA), Ethylene Butyl Acrylate (EBA), Ethylene Methyl Acrylate copolymers (EMA) as per IRC SP:53-2000) that are blended with VG-10 as additives to produce PMB. In case of CRMB the emission is lesser than PMB probably because rubber has a high ignition temperature of 260°C - 316°C.

Another trend observed is that VG-30 has lower viscosity and higher emission compared to VG-40. CRMB and PMB are produced using VG-10 that has even lower viscosity and emitting higher than VG-30 and VG-40. Apart from additives being responsible for emission, viscosity seems to have an inversely proportionate relationship to it. This is however a matter of further research.

Emission factors have a high positive correlation with the temperature. Correlation co-efficient of CRMB-60 and VG-40 is 0.91, VG-30 is 0.94 and PMB-40 is 0.93. This shows that direct CO2 emission increases with the increase in temperature.

Each of them also shows polynomial trend of increase in emission factor with very high (0.99) coefficient of determination. CRMB-60 and VG-40 shows almost similar emission levels till 160 °C and then VG-40 shows higher emission at 170 °C than CRMB-60. However, 180°C and 185°C value of emission factor of CRMB -60 exceeds what VG-40 shows at 170°C i.e. its maximum mixing temperature. It is inferred that if VG-40 is further heated up to 185°C, it might show a higher value of >0.08 t CO_2/t VG40 than CRMB 60 following polynomial growth trend. Compared to VG-40 and CRMB 60, VG-30 higher emission and is almost similar to that of PMB-40 till 70°C. Thereafter it almost shows lower emission than PMB-40. It is inferred that in case VG-30 is heated till 185°C, its emission level will be around 0.11 t CO_2/t VG30.

It has been observed that samples taken from same batch of one type of bitumen also shows variation in results despite all sampling conditions being the same. Deviation observed in case of

PMB-40 is 0.69%, CRMB-60 is 0.51%, VG-40 is 0.13% and VG-30 is 0.021% CO_2. This is probably because their fractional composition differs irrespective of their sources and batches.

Embodied emission factor, with cradle to gate boundary, of straight run bitumen currently being used by GHG calculators including CHANGER ranges from 0.43 to 0.55 t CO_2 e /t bitumen. Once cumulated with direct emission factors the total emission factor would increase by 14 to 18% or 75,706 grams/t bitumen, which is a substantial figure and cannot be ignored. Similar trend is anticipated in case of PMB- 40 and CRMB- 60 also.

CONCLUSION

It is inferred from the study that at the highest mixing temperature as per codes, PMB-40 has the highest direct CO_2 emission factor during mixing followed by CRMB-60, VG-30 and VG-40. However, it would not be right to conclude that PMB-40 is the most CO_2 emission intensive bitumen followed by others as indicated above. The direct emission factor of material is only one criterion along with embodied emission factor of material. Other factors used for calculation of total GHG emission are distance of source of material from project site, weight of material transported and mode of transportation etc. All these factors if common to various alternatives, the comparison would be done based on embodied and direct emissions. The experiments also reveal that cumulated value of embodied and direct emissions of bitumen will lead to a substantial increase in the emission factors. In case of straight run bitumen it is higher by 14 to 18 %. Hence incorporation of direct emission factors of bitumen while GHG estimation from road construction will lead to more accuracy and informed decision making.

FURTHER PROPOSED WORK

Use of direct emission factors of bitumen in assessing GHG emission of road construction will be a new milestone. The concept is proposed to be synthesized in the Indian version of GHG calculator CHANGER. Since there is a variation in emission levels for each binder type based on their batches and sources, before incorporating the values into CHANGER as Carbon Dioxide equivalent, additional sampling from different sources is planned for continuing the Study.

The mixing temperatures for HMA and other mixes indicated in IRC/MoRTH Specifications are based on the work done elsewhere. These temperatures are actually arrived at based on certain level of Viscosity which should be attained, and the temperature at which this viscosity gets achieved is the mixing temperature. These mixing temperatures for Indian bitumen types need to be determined. Once that is done it would be more authentic to bring out the CO_2 emission levels at their mixing temperatures per tonne of HMA. The aim of the Study is to incorporate the authentic factors for bitumen used in India to be a part of the Indianized CHANGER

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