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An Overview of Comparative Study of Various Methods used for Control of Emissions in Asphalt Mix Production

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ABSTRACT: Asphalt roads are most common type of roads which are paved using hot mix asphalt technique. This paper is aimed at evaluating the influence of operating parameter, temperature, asphalt content, additive, binder content and binder type used etc. during hot mix asphalt production. Several studies related to measurement of emissions from hot mix asphalt, warm mix asphalt, and half warm mix asphalt were conducted in laboratory, on field and both in laboratory and field are presented in this paper. At the same time comparison of their pollutants emissions were made. From all the comparative study this can be concluded that use of WMA and HWMA is beneficial to environment, as it reduces the concentration of pollutants in the atmosphere and thus reducing the risk of many harmful disease and global warming.

Key Words: hot mix asphalt (HMA), warm mix asphalt (WMA), half warm mix asphalt (HWMA), emissions, pollutants.

I. INTRODUCTION

It is a well established fact that roads are considered necessary part of progress and growth of any country. With the growing population, demand of good roads is increasing rapidly. Mostly asphalt roads are preferred which are paved using hot mix asphalt. Hot Mix Asphalt (HMA) is a combination of approximately 95% stone, sand, or gravel bound together by asphalt cement, a product of crude oil. More road construction lead to increase in emissions of various gases like CO_2, SO_2, CH_4, NMGOC, GOC, and solid particles. To control the increasing emissions, warm mix asphalt and half warm mix asphalt technologies is becoming more popular. The advantage is that asphalt pavement material may be mixed and placed at lower temperatures, thus helps in reducing emissions. Reduction of 10°C to 30°C have been documented. Such drastic reduction have the obvious benefits of cutting fuel consumption and decreasing the production of greenhouse gases. In addition, engineering benefits include better compaction on the road, the ability to haul paving mix for longer distances during construction, and extending the paving season by being able to pave at lower temperatures. In the specific case of asphalt binders and mixtures, health and safety of workers is endangered because of gaseous emissions generated during production and laying. Thus, gaseous emissions should be maintained below acceptable levels in order to limit their potentially harmful effects. Thus, when deviating from standard paving solutions, it is necessary to verify that the use of supplementary components (such as additives and recycled materials) or the adoption of different processing conditions (e.g. lower temperatures) do not lead to an increase of the risk associated to fume exposure. Comparative studies of HMA (hot mix asphalt), WMA (warm mix asphalt) and HWMA (half warm mix asphalt) is presented in this paper. Several factors like temperature, asphalt content, additives and their content is also presented in this paper. Emissions from hot mix asphalt is leading to adverse environmental effects and at the same time causing hazardous effects to the health of workers exposed to fumes. Residents living nearby an asphalt plant are also exposed same health hazards as workers. Children may be more sensitive than adults to certain chemicals. The exposure to asphalt fumes would depend on the plant emissions and the prevailing winds. Although, no studies have linked residential exposure to asphalt fumes with the development of deadly diseases like cancer or tuberculosis, but workers who are exposed to greater asphalt emissions, have reported irritation of the upper respiratory tract, fatigue, wheezing and shortness of breath dizziness, headache, and nausea.

II. WORKS CONDUCTED IN LABORATORY

A Laboratory Study on CO_2 Emissions from Asphalt Binder and its Reduction with the Use of Warm Mix Asphalt : Mallick and Bergendahl (2009) investigated the effects of the additive Sasobit, asphalt content and mixing/placement temperature on CO_2 emissions from binder with laboratory measurements. Parameters taken for experimental study are additive sasobit content, amount of asphalt and temperature.

Analysis of variance (ANOVA) of the entire dataset was done with the null hypothesis that any of the standardized coefficients of the independent variables was zero (Mallick and Bergendahl, 2009). Among temperature, additive sasobit content and asphalt content, only temperature had significant effect on the CO_2 emission. The result from this analysis prompted a second linear regression analysis including temperature as the only independent variable. Therefore, a constant amount of sasobit (1.5%) and asphalt (3%) were used in experiment to exhibit the effect of temperature. Table 1 and Fig. 1 present the experimental data and depict the reduction of CO_2 emission using WMA as compared to HMA.

Table 1: CO_2 reduction estimates for different temperature reductions (Mallick and Bergendahl, 2009).

HMA temperature (°C)	HMA emissions CO_2(ppm)	WMA temperature (°C)	WMA emissions CO_2 (ppm)	% Reduction CO_2
150	755.23	140	511.3	32.29
150	755.23	130	346.2	54.16
150	755.23	120	234.4	68.96

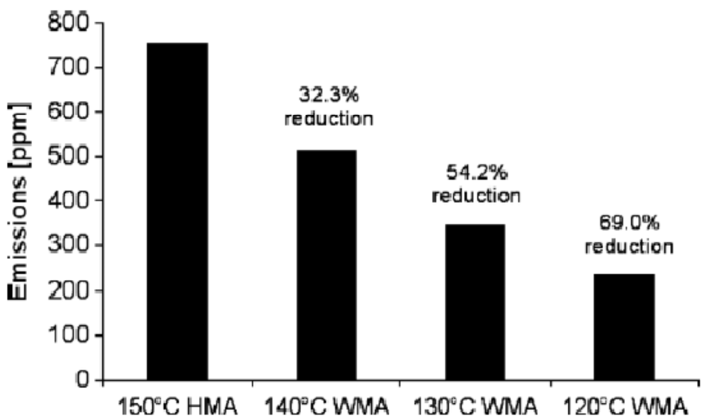

Fig. 1. Reduction in CO_2 emission with lower processing temperatures (Mallick and Bergendahl, 2009).

With these levels of sasobit, CO_2 emission reductions of around 32% from direct reductions and another 8% reduction from energy savings is possible. Therefore, an estimated joint reduction of about 40% is attained.

Energy Savings and Reduction of CO_2Emission Using $Ca(OH)_2$Incorporated Zeolite as an Additive for Warm and Hot Mix Asphalt Production: Sharma and Lee (2016) investigated the energy saving and CO_2 emission reduction properties of $Ca(OH)_2$ incorporated zeolite (CaZ), synthesized by a sol-gel method and used as an additive for ASCON (asphalt concrete) production at different temperatures (120, 140 and 180 °C).

Synthetic zeolite is hydro thermally crystallized and holds 21% (by mass) of water, which is one of the most common additives for WMA production. Hypothetically, the zeolite can release water vapour by creating foam which reduces the viscosity and increases the workability of asphalt mixing. Zeolite facilitates better coatings of the bitumen on aggregates leading to improved bonding between asphalt and aggregates. Wang *et al*. reported in 2011 that zeolite based composites are the best materials for capturing $CO_2$from the air environment.

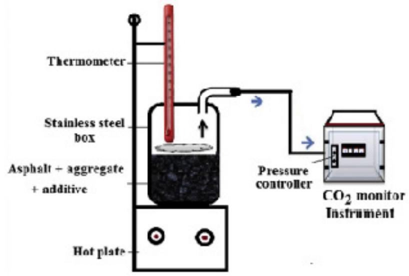

Fig. 2. Experimental set-up for CO_2 emission analysis during mixing of asphalt & aggregate with additive at different temperatures.

For recording amount of CO_2 released during HMA with or without additive, asphalt production was done inside a stainless steel box which is placed over a hot plate and thermometer was also inserted in the box to control the production temperature.

Then asphalt, aggregate and additive in this case zeolite or CaZ is mixed and amount of CO_2 released is measured using CO_2 monitor instrument.

When CaZ nano-composite is used as additive in ASCON production significant changes were noticed. The percentage of added zeolite and CaZ in the asphalt mix was increased from 2 to 6 wt.% of asphalt for which 7.2% to 34% reduction in CO_2 emissions were noticed for zeolite addition, and from 9.7% to 53% for CaZ addition, compared to that without addition of the additives. Moreover, it can be seen from the Figure 1.3 that with decreasing temperature the CO_2 emission was also reduced. Also, as the concentration of doses of Caz and Zeolite increases CO_2 emission decreases with minimum CO_2 emission at 6%. Finally from Fig. 3 and Table 2 it can be said CaZ will have less CO_2 emission if used as additive than Zeolite and HMA with no additive will have maximum CO_2 emission.

Table 2: Emission reduction of CO_2 at different temperatures with zeolite and CaZ additive dose (Sharma and Lee, 2016).

	CO_2 emission			% Reduction in CO_2 emission					
	Emission at No additive (HMA) (PPM)			Zeolite (Dose 2-6%) (WMA with Zeolite)			CaZ (Dose 2-6%) (WMA with CaZ)		
Temp (°C)	180	140	120	180	140	120	180	140	120
CO_2	7300	1100	700	4.9-33	2.5-35	7.2-34	11.8-71	7.1-68	9.7-53

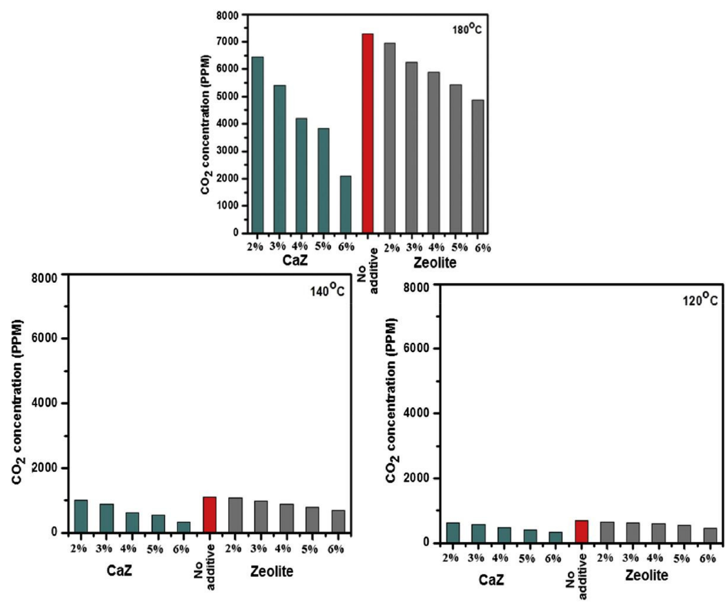

Fig. 3. Emission reduction of CO_2 with addition of additive at different temperatures (Sharma and Lee, 2016).

Field evaluation of wma technologies: Sargand *et al.* (2012) conducted test using Aspha-min, Sasobit, and Evotherm on three test sections. Furthermore, a control section was also produced so that a side-by-side comparison could be made between WMA and HMA mixtures, so overall test on four sections were conducted. Industrial hygiene testing was performed to monitor emissions during the paving operation of the four test sections. Samples were collected using six low-volume air-sampling pumps attached to the paver.

In addition, two sampling pumps were also mounted on tripods to monitor background air conditions as reported in the paper by Sargand et al. (2012). The quantity of different pollutants released during the production of each of the evaluated mixtures were measured by using stack emissions tests. The pollutants considered during those tests included sulphur dioxide (SO_2), nitric oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs). Table 3 presents a summary of the stack emissions test results, Sargand *et al.* (2012).

Table 3: Results of Stack Emissions Tests at Asphalt Plant (Sargand *et al.,* 2012).

	Mixture			
Emittant	**Control HMA**	**Evotherm**	**Aspha min**	**Sasobit**
SO_2 kg/h (lb/h)	0.11 (0.24)	0.17 (.37)	0.02 (0.04)	.02 (0.04)
Change from HMA		54.20%	-83.30%	-83.30%
NO_x kg/h (lb/h)	2.4 (5.2)	2.3 (5.1)	1.6 (3.6)	1.87 (4.1)
Change from HMA		-1.92%	-30.80%	-21.20%
CO kg/h (lb/h)	28.6 (63.1)	22.8 (50.3)	11 (24)	10.5 (23.2)
Change from HMA		-20.30%	-62.00%	-63.20%
VOC kg/h (lb/h)	3.5 (7.8)	9.2 (20.2)	1.3 (2.9)	1.7 (3.8)
Change from HMA		159.00%	-62.80%	-51.30%

Table 4 presents the results of the industrial hygiene tests that were performed during the paving operation of the four test sections. The three WMA mixtures resulted in significant reduction in emissions. The total particulate matter was reduced by at least 67% when WMA mixtures were used as compared with the HMA mixture. In addition, the use of WMA resulted in 72 to 81% reduction in benzene soluble matter (BSM).

Table 4: Results of Emissions Tests at Construction Site (Sargand *et al.,* 2012).

Mixture	TPM (mg/m^3)	Changes from HMA (%)	BSM (mg/m^3)	Changes from HMA (%)
Control HMA	1.25		1.05	
Evotherm	0.29	76.8	0.29	72.4
ASpha-min	0.41	67.2	0.2	81.0
Sasobit	0.33	73.6	0.21	80.0

Work conducted both on field and laboratory by performing comparative analysis of emissions of hot and half – warm mix asphalt: Rubio *et al.* (2012) analyzed the environmental benefits derived from a cleaner production technology for manufacturing asphalt mixes. This study measured polluting emissions during the construction of two consecutive stretches of highway on which a hot mix and a half-warm mix were spread. Combustion gases (CO, NO_x, O_2, CO_2), total organic carbon (TOC), particles, volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs), were measured during the manufacturing of hot and half-warm asphalt in plant and also during the spreading and compaction processes. Asphalt mix classification according to manufacture temperature is shown in Fig. 4.

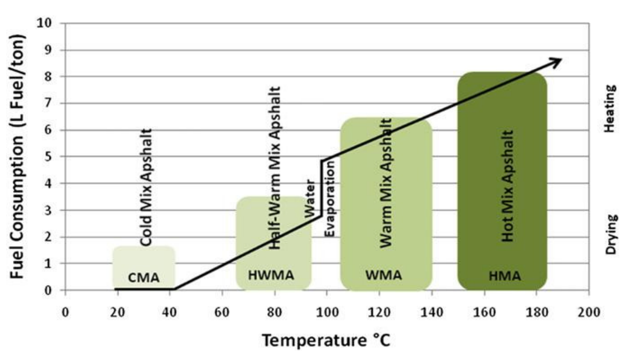

Fig. 4. Asphalt mix classifications according to manufacturing temperature (adapted from D'Angelo *et al.*, 2008).

The test was done over the stretch of total length 13.85 km of which 2.26 km stretch was paved with AC-16S HMA and the remaining stretch was paved with AC-16S half warm mix asphalt. Both the section of road was paved at the same day and simultaneously humidity, wind speed and temperature readings were monitored at the asphalt mix plant and at the job site. The temperature range was 35 °C- 39° C; winds were 7-14 kmph and there was a total absence precipitation with relative humidity of 42%-47%, Rubio et al. (2004). Test data is tabulated and plotted in the form of graph as shown Table 5 and Fig. 5.

Table 5: Summary of results (Rubio *et al.*, 2004).

	AC-16 S HWMA	AC-16 S HMA	Limit values
In-point source emissions Combustion gases and total suspended particles			
CO_2 (%)	1.7	4.1	
NO_x (ppm)	17	51	300
CO (ppm)	51	628	1445
SO_2 dry base (mg/m^{3}N)	1.1	1025.9	850
Particles, dry base (mg/m^{3}N)	12.9	30.3	150
TOC (mgC/Nm^3)	26.48	18.47	150
VOCs (16 compounds, µg/L)	<0.30	0.67	3.5
PAHs (16 compounds, µg/L)	<0.059	0.019	3.5
Non point source emissions (Mean value of emission measurements at the entry and exit of the dryer drum and when the mix is unloaded from the mixer) **Total suspended particles**			
Estimated 24-h mean value (µg/m^3)	613.8	5725.4	150
Volatile fraction (%)	29.7	21.7	
Mineral fraction (%)	70.3	78.3	
VOCs (16 compounds, µg/L)	<0.11	N/D	3.5
PAHs (16 compounds, µg/L)	0.015	0.013	3.5
At the job site **Total suspended particles**			
Estimated 24-h mean value (µg/m^3)	73.3	149.8	150
Volatile fraction (%)	97	100	
Mineral fraction (%)	3	0	
VOCs (16 compounds, µg/L)	<1.86	0.20	3.5
PAHs (16 compounds, µg/L)	2.80	0.32	3.5

From the Table 5 it can be easily assessed that CO_2 emissions reduction in case of half warm mix asphalt are significant. From the paper presented it can be said using HWMA for in point source there was considerably reduced combustion gases in percentages ranging from 58% for CO_2 to 99.9% for SO_2. It also reduced the particles emitted into the atmosphere though same cannot be said about for VOCs and PAHs. For non-point source no clear conclusion can be made as measured near asphalt plant and on situ during the spreading process and hence effected by the dispersion of gases and the particles in atmosphere.

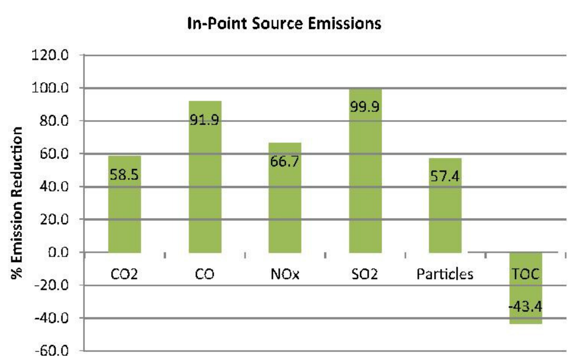

Fig. 5. Percentages of emissions reduction for the HWMA manufacturing process (Rubio *et al.*, 2004).

III. CONCLUSION

This can be concluded from the overall review of the papers that modern methods used to reduce pollutants emissions from HMA which were increasing with the advent of technology are satisfactory and necessary. It has become utmost important to introduce new techniques such as WMA and HWMA as suggested by many researcher. In both the techniques additive is incorporated during the HMA production at different temperatures. Mallick and Bergendahl (2009) used sasobit as an additive and used WMA techniques which resulted in 30-60% CO_2 reduction, Sharma and Lee (2016) used Zeolite and CaZ as an additive and recorded 2% to 6% reduction in CO_2 emissions, Sargand *et al*. (2012) also used WMA technique and tested four different test section using aspha-min, evotherm and sasobit as an additive and noticed 70% to 80% reduction of various pollutants in comparison to HMA and Rubio *et al. (*2012) used HWMA techniques and find out 58% reduction of CO_2 to 99% reduction of SO_2. From all the results this can be concluded that use of WMA and HWMA is beneficial to environment, as it reduces the concentration of pollutants in the atmosphere and thus reducing the risk of many harmful disease and global warming.

At the same time using WMA and HWMA in comparison to HMA is also advantageous in terms of cost, since production temperature is reduced considerably amount of fuel required get reduced, thus making it more economical.

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