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Photocatalytic concrete pavements: Laboratory investigation of NO elimination by using TiO_2 and flyash

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ABSTRACT

In recent years there is a change in atmospheric condition. One of the major reason behind this change is air pollution which is increasing day by day. Air pollution is mainly due to rapid industrialization and increases in a vehicular transportation system. The major components of air pollution such as Sox, NOx, CO, and many other gases are released due to the combustion of a vehicle engine. In developing country like India, roadways play a key role in the transportation system. Hence to curb the effect of this transportation system on our ecosystem new ways of elimination of this pollutants shall find out. Hence an attempt is made in this research to construct the pollution absorbing pavements i.e. to construct such pavements which will absorb these harmful pavements. The main aim of this research is to investigate the elimination of NOx i.e. Nitrogen Oxides by casting pavements of Cement, Flyash, Recycled Glass and Photocatalyst such as TiO2, i.e. Titanium Dioxide or Titanium (IV) oxide under varied conditions.

Keywords— *NOx, Titanium Dioxide, Photocatalyst*

1. INTRODUCTION

In developing country such as India vehicular pollution has grown very rapidly which have many adverse effects on human health and environment. Due to toxic gases such as Nitrogen oxides, Sulphur oxides and other gases released from trucks cars and other vehicles, there is a sudden change in atmospheric conditions. Around 40% of the total emission of NOx comprising NO and NO2 is only due to vehicles.

NOx is not very harmful to humans but when released from combustion engine high concentrations are often toxic. It affects the respiratory system and irritating of eyes. Even the ability to resist the bacterial infection were also affected due to significant concentration of Nitrogen Oxides (NOx) exposure. NOx is also responsible for acid rain, smog formation, and ozone depletion though the percentage is very low still the threat caused due to NOx cannot be ignored.

The photocatalyst, titanium dioxide (TiO_2), is a naturally occurring compound that can decompose gaseous pollutants with the presence of sunlight. Applying TiO_2 to pavement can help remove emission pollutants right next to the source, near the vehicles that drive on the pavement itself. However, surface coatings to traditional pavements may lose their effectiveness due to surface wear. When TiO_2 is applied to the pervious pavement, this provides two sustainable benefits in one material; air will be purified on sunny days, and water will be infiltrated on rainy days, in addition to having a rougher surface, which may retain more TiO_2. With this innovative idea, this paper aims to identify the effectiveness of applying TiO_2 to the surface of pervious concrete pavement to produce a greener urban road environment. Several coating methods were compared for their influence on permeability, pollutant removal effectiveness, and their resistance to extreme environmental conditions. Photocatalytic concrete is a recently developed technique which has the ability to absorb these NOx pollutants and reduce their concentration in air. It is the mixture of titanium dioxide which acts as catalyst and cement. It is used for the construction of pavements in many countries. Photocatalytic concrete is patented in the USA and Europe. Various researchers have used these concrete for their research purpose.

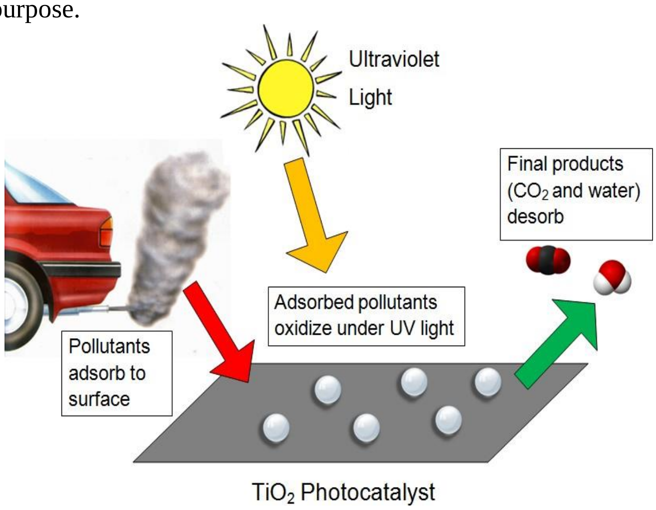


Fig. 1: Photocatalyst action of TiO2

In this project an attempt is made to prepare the pavements which will absorb the pollutants specifically NOx by using Cement, Flyash, Artificial Sand and mechanically crushed glass sand and also to study the effectiveness of TiO2 for elimination of NOx under varied combination of Flyash, Recycled Glass sand, Cement and Artificial sand along with fixed proportion of TiO2.

2. MATERIALS AND METHODS

Photocatalytic mortar slabs were casted to analyse the objective of the study. The size of the slabs was 150mm X 150mm X 25 mm. For this commercially available OPC Birla Shakti Cement 53 grade, Pozzolana Flyash C class, mechanically crushed recycled glass of size 0.002 mm size and artificially crushed sand along with Titanium Dioxide (nano-particle) of type B101 Anatase was used. The proportion of TiO2 was 2% by mass of Cement and Flyash combined, also artificial crushed sand was replaced by mechanically crushed glass in varied proportion. Even the proportion of the Flyash was kept varied. The table mentions the proportion of the material used. The water-cement ratio was taken 0.5. While casting the pavements sample, special care was taken while compacting the samples as there was a possibility that TiO2 will come to the surface along with water vibrator was not used, only hand compaction was done and excess finishing was avoided.

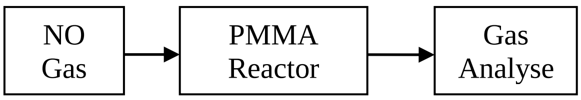
Table 1: Details of the proportion of samples

Sample	Flyash % of the weight of Cement	TiO2 % of the weight of Cement	Recycled Glass % of Weight of sand
A	0	0	0
B	20	2	25
C	25	2	50

Before testing the slabs for NO absorption they were oven dried at 60°C for 20 H. This procedure is same as mentioned in ISO 22197-1:2007(E), which governs the evaluation of NO removal by the photocatalytic material.

3. EXPERIMENTAL APPARATUS

PMMA that is Poly Methyl Metharylate Photo reactor (Plexi Glass) (Acrylic transparent sheet) was used as a basic primary component of apparatus along with NOx test gas supply system, Mass flow controller, UV-A light source and multi-gas analyser which is generally used for Pollution Under Control analysis. The setup was done as per International Standard ISO 22197- 1:2007(E). The test gas supplied was a mixture of breathing air and 51.6± ppmv. NO balanced in Nitrogen adjusted to NO concentration of 0.11-1.0 pmmv, and flow rate of 1.5-5.0 Lmin-1. A UV-A light was used which was placed at top of the transparent optical window photo reactor, which activated the photo catalytic properties of mortar slab.



Schematic Process Flow Diagram

The size of the reactor was 400 mm X 400mm X 200mm. At one side provision for Inlet of gas was done while at another end outlet of gas was provided.

3.1 Operational procedure

Operation of the experimental apparatus was divided into two phases: parameter setting and testing. While in the parameter setting phase, the test gas flowed through the photoreactor; however, the slab was not irradiated by UV light. This phase was used to set airflow rate, relative humidity, and pollutant concentration and lasted for approximately 10 min. After adjusting parameters to desired values, gas flow was maintained through the photoreactor for a period sufficient to reach steady-state conditions.

The testing period comprised two steps during which the UV light was turned off and on and concentrations of NO and NOX were measured. The UV on and off measurement cycle. Time to complete this cycle was limited to 3 hrs and 6 hrs to minimize the possible influence of slab degeneration (e.g., due to the adsorption of reaction products) on collected data. The change in concentration that occurred when the light was turned on or off was not instantaneous. The period between measurements permitted time for concentration stabilization after each parameter change.

4. RESULTS AND DISCUSSION

The test gas supply was adjusted so as to stably supply 0.8μL/L ± 0.05μL/L of NO at 27 °C ± 2.5 °C. The test gas was allowed to flow into the photoreactor, without photoirradiation, with a flow rate of 1.5 L/min ± 0.15 L/min, for 30 min whilst the change in the volume fraction of NO and NO2 were recorded. After 30 minutes, the gas flow was maintained and irradiation of the sample commenced.

The NO and NO2 volume fractions under photoirradiation were recorded for 3 h. After this 6 h period, irradiation was halted, but the test gas flow maintained for a further 30 minutes, during which time the NO fraction was seen to return to its original level.

Using the data recorded, by an AVL DITEST Multi Gas/ NOx analyser – Model 444, during the 3 h photo-irradiation, the amounts of NOx removed, NO2 generated, and therefore net amount of NOx removed by the test piece was calculated, units of ppmv %. NOx adsorbed, and NOx desorbed by the test piece supplied were found to be negligible.

The data recorded is firstly summarised by a histogram, shown in Figure 1, in units of ppmv of NO supplied to the reactor.

4.1 Results of 3 hrs retention time

Table 2: Result at 3 hrs retention time

		Unit % of NO Supplied in PPMV		
Sample	**Sub Sample**	**NO supplied (at inlet)**	**NO removed by test samples**	**NO (recorded at the outlet)**
A	A1	100	0.7	99.3
	A2		0.4	99.6
	A3		0.3	99.7
B	B1	100	13.20	86.20
	B2		15.15	84.85
	B3		16.75	83.25
C	C1	100	13.5	86.5
	C2		10.25	90.75
	C3		7.55	92.45

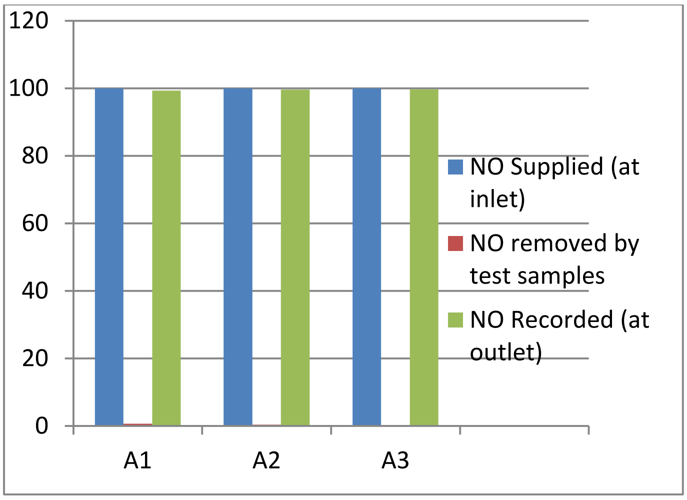


Fig. 2: Histogram illustrating the ability of supplied test pieces sample A to remove NOx from a 1.5 L/min air stream containing 0.41 ppm NO over a 3 hour period, in accordance with ISO 22197-1:2007 (units: % of NO supplied to the reactor). The supplied sample was of photocatalytic concrete pavement

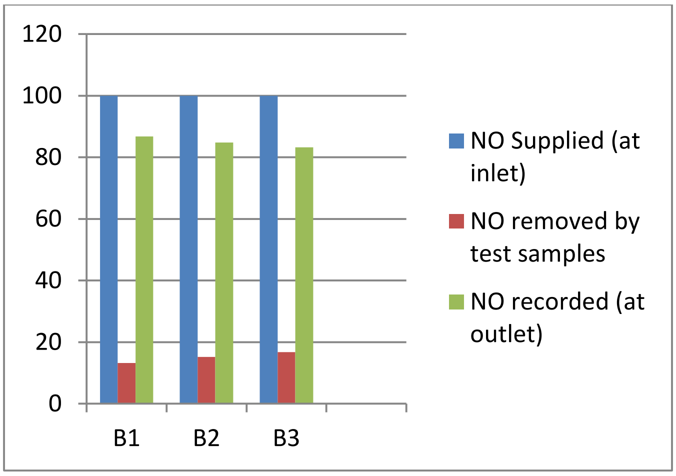


Fig. 3: Histogram illustrating the ability of supplied test pieces sample B to remove NOx from a 1.5 L/min air stream containing 0.41 ppm NO over a 3 hour period, in accordance with ISO 22197-1:2007 (units: % of NO supplied to the reactor). The supplied sample was of photocatalytic concrete pavement

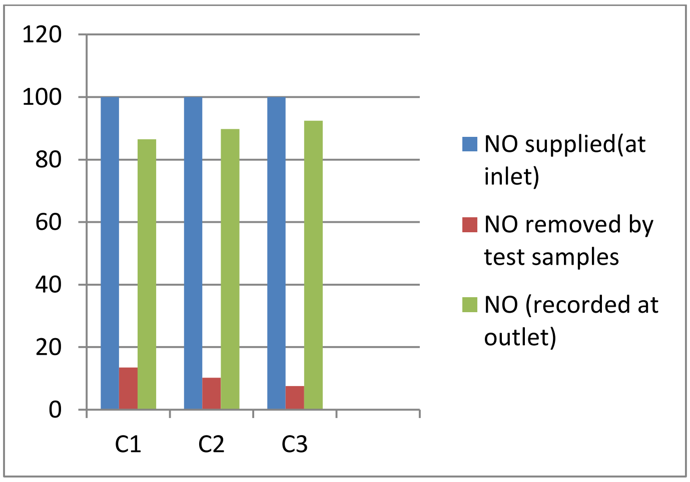


Fig. 4: Histogram illustrating the ability of supplied test pieces sample C to remove NOx from a 1.5 L/min air stream containing 0.41 ppm NO over a 3 hour period, in accordance with ISO 22197-1:2007 (units: % of NO supplied to the reactor). The supplied sample was of photocatalytic concrete pavement

4.2. Results at 6 Hrs retention time

Table 3: Results at 6 Hrs retention time

		Unit % of NO Supplied in PPMV		
Sample	**Sub Sample**	**NO supplied (at inlet)**	**NO removed by test samples**	**NO (recorded at the outlet)**
A	A1	100	1.2	98.8
	A2		1.2	98.8
	A3		1.1	99.9
B	B1	100	18.65	81.20
	B2		18.85	81.15
	B3		18.45	81.55
C	C1	100	15.5	84.5
	C2		16.25	83.75
	C3		16.55	83.45

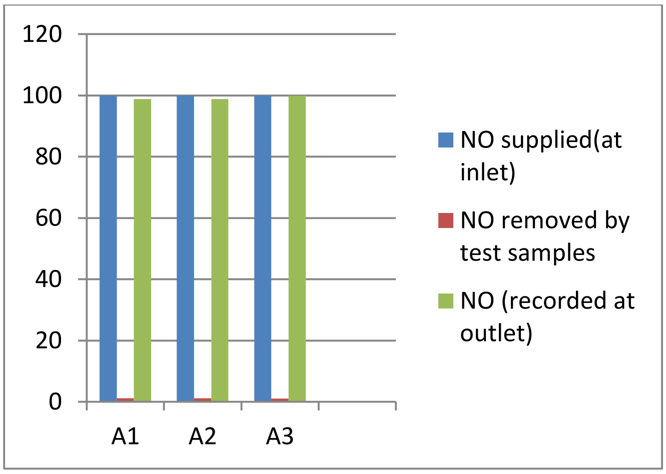


Fig. 5: Histogram illustrating the ability of supplied test pieces sample A to remove NOx from a 1.5 L/min air stream containing 0.41 ppm NO over a 6 hour period, in accordance with ISO 22197-1:2007 (units: % of NO supplied to the reactor). The supplied sample was of photocatalytic concrete pavement.

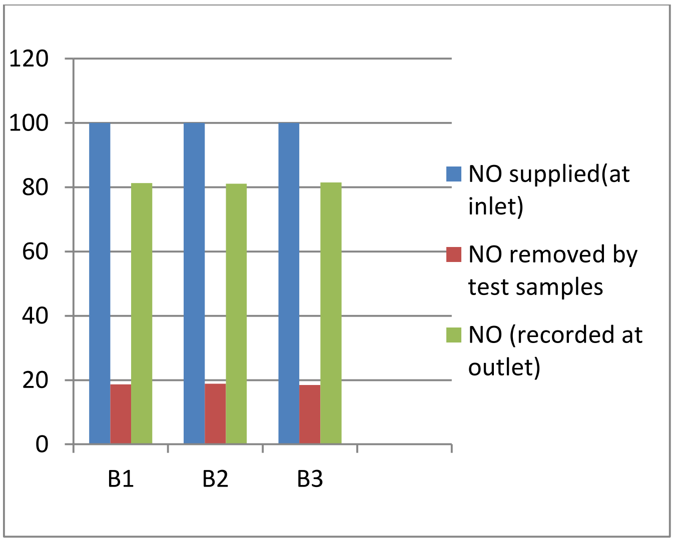


Fig. 6: Histogram illustrating the ability of supplied test pieces sample A to remove NOx from a 1.5 L/min air stream containing 0.41 ppm NO over a 6 hour period, in accordance with ISO 22197-1:2007 (units: % of NO supplied to the reactor). The supplied sample was of photocatalytic concrete pavement.

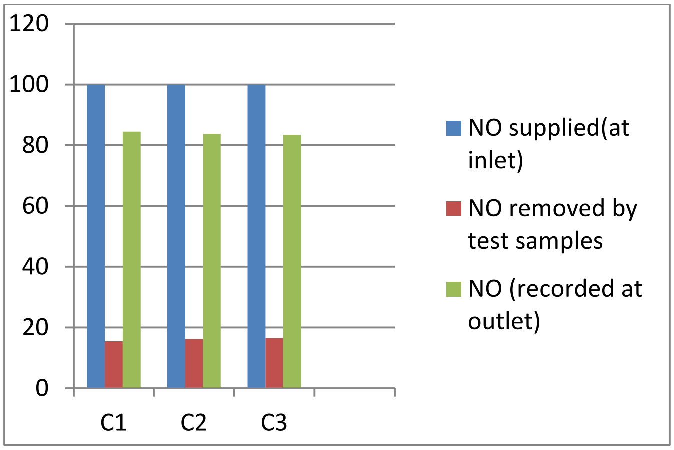


Fig. 7: Histogram illustrating the ability of supplied test pieces sample A to remove NOx from a 1.5 L/min air stream containing 0.41 ppm NO over a 3 hour period, in accordance with ISO 22197-1:2007 (units: % of NO supplied to the reactor). The supplied sample was of photocatalytic concrete pavement

4.3 Summary of results

Table 4: Summary of the average of samples of the result at 3 hour Retention Time

		Unit % of NO Supplied in PPMV		
Sample	**Sub Sample**	**NO supplied(at inlet)**	**NO removed by test samples**	**NO (recorded at the outlet)**
A	A1	100	0.7	99.5
B	B1	100	13.20	84.7
C	C1	100	13.5	89.9

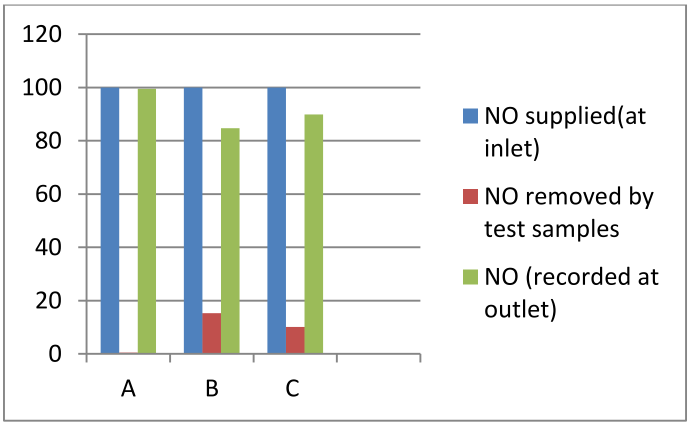


Fig. 8: Histogram illustrating the ability of supplied test pieces sample A, B, and C to remove NOx from a 1.5 L/min air stream containing 0.41 ppm NO over a 3 hour period, in accordance with ISO 22197-1:2007 (units: % of NO supplied to the reactor). The supplied sample was of photocatalytic concrete pavement.

Table 5: Summary of the average of samples at 6 hrs retention time.

		Unit % of NO Supplied in PPMV		
Sample	**Sub Sample**	**NO supplied (at inlet)**	**NO removed by test samples**	**NO (recorded at the outlet)**
A	A	100	1.2	98.8
B	B	100	18.65	81.3
C	C	100	15.5	83.9

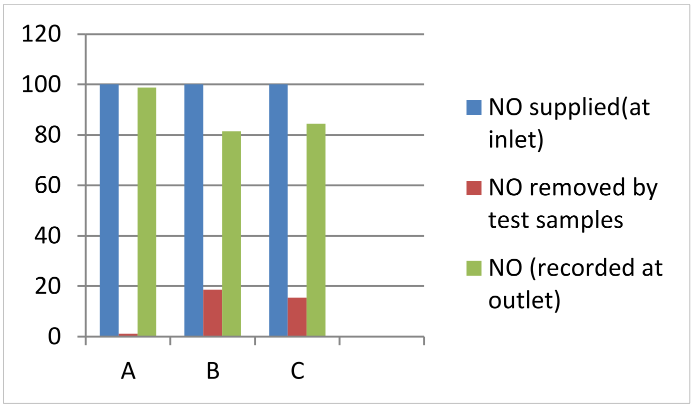


Fig. 9: Histogram illustrating the ability of supplied test pieces sample A, B, and C to remove NOx from a 1.5 L/min air stream containing 0.41 ppm NO over a 6 hour period, in accordance with ISO 22197-1:2007 (units: % of NO supplied to the reactor). The supplied sample was of photocatalytic concrete pavement.

5. CONCLUSION

It is observed that with an increase in the content of Flyash and recycled crushed glass sand the efficiency of absorption of NO by the sample at 3 hr retention decreases and 6hrs retention decreases. The use of recycled crushed glass sand in pavement above 25% is not recommended.

6. FUTURE SCOPE

Though the research shows that Flyash and Cement mixture along with TiO2 adsorbs the NOx, various parameters are yet be determined. The effect of temperature can change the results which are not considered in this paper.

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