Efficiency of Photocatalytic Pavements – A Critical Review

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***Abstract*— Increased automobile fleet generates pollutants which results in a progressive deterioration of environment. Most of the pollutants are organic compounds which emerge from the burning of fossil fuels. Titanium dioxide is a semiconducting material which can degrade the organic compounds in the presence of ultraviolet rays by photocatalysis process. Pavements in which Titanium dioxide is incorporated in order to reduce the SOx and NOx content in the atmosphere by the photocatalysis process is called photocatalytic pavements. TiO_2 can be applied to both concrete and asphalt pavements in the form of a thin layer coating on the surface. The efficiency of photoctalytic pavements depend upon pollutants flow rate, UV light intensity, contaminants present on the surface of pavements and relative humidity.**

Keywords*— Efficiency, Pavements, Photocatalyst, Titanium dioxide.

I. INTRODUCTION

Nitrogen oxides emitted from vehicle exhausts are associated with adverse health effects on the public. The use of titanium dioxide in photocatalytic pavements is a promising approach that can be adopted in order to reduce the NOx as well as SOx content in the air. Purification of air can be obtained through the photocatalysis process, in which air pollutants such as NOx and SOx gases oxidize to produce non hazardous by products in presence of UV light. Incorporation of TiO_2 to the surface of pavement can accelerate photocatalysis process and thereby reduce the amount of harmful gases. Due to the excellent oxidizing power and photo stability of TiO_2, it can be used as an exemplary semiconductor in photocatalysis. TiO_2 upon irradiation with UV light source generates electrons and holes, which helps in the free radical formation that can oxidize the pollutant compounds. The main factors that affect the photocatalytic efficiency of pavements includes relative humidity, flow rate, UV light intensity, contaminants, wear and abrasion, NO_2/ NOx ratio, etc

The potential of TiO_2 as a photocatalyst was discovered by Fujishima and Honda. The studies conducted by Fujishima et al. (2000) reveals that TiO_2 can decompose organic and inorganic pollutants completely and it have the ability to regenerate itself . Thus the application of TiO_2 coating on pavements came into account. Later Hassen et al. (2011) conducted the study on application of TiO_2 coating on concrete pavements. They also conducted another study on environmental performance of photocatalytic titanium dioxide on warm mix asphalt pavements.

II. EFFICIENCY OF PHOTOCATALYTIC PAVEMENTS

Photocatalytic efficiency indicates the efficiency of TiO_2 coating of pavements to reduce the amount of harmful NOx and SOx gases**.** Photocatalytic pavements have greater NOx removal efficiency compared to the normal pavements to cope with the increasing air pollution. It is found that the efficiency of pavements decreases as the time passes. It occurs due to various operational as well as environmental conditions that affect the efficiency of pavements. Hassen et al. (2013) conducted a study on the photocatalytic efficiency of the TiO_2 coated asphalt pavements. The environmental performance of the prepared sample was quantified in the laboratory by measuring the contaminants of NO, NO_2, NOx, and SO_2. Laboratory evaluation showed that TiO_2 was effective in removing NOx and SOx from the air stream with an efficiency ranging from 31 -55% for NOx pollutants and 4-20% for SO_2 pollutants.

A. Effect of relative humidity on photocatalytic efficiency of asphalt pavements .

Relative humidity is defined as the ratio of actual vapor pressure to the saturation vapor pressure. Relative humidity has a negative impact on NOx removal efficiency. Hassen et al.(2013) analyzed the NOx removal efficiency by using accelerated load test. The negative impact of relative humidity towards the efficiency of pavements is due the reason that water molecules interfere with NOx contact to the TiO_2 active sites on the surface. Therefore the technology would be more efficient in drier regions in which the annual relative humidity is between 25% and 40%. Another study conducted by Dylla et al. concluded that the optimum relative humidity for maximum photocatalytic efficiency is 25%. At a relative humidity less than 25% the lack of hydroxyl radicals hinders the photocatalytic oxidation. At a higher relative humidity the water molecules interfere with NOx contact to the TiO_2 active sites on the surface. Fig 1 represents the effect of relative humidity on the photocatalytic efficiency at a flow rate of $0.05 L/m^2$ [5]

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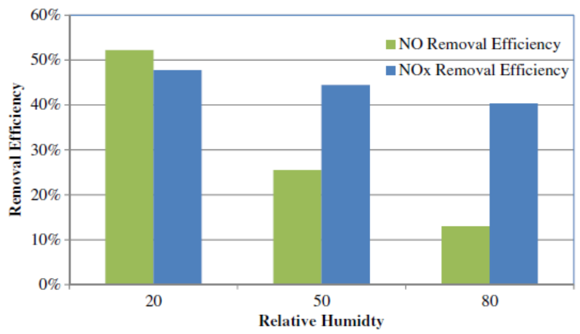

Fig 1 Effect of relative humidity on NOx reduction efficiency [6]

B. Effect of polluttant flow rate on photocatalytic efficiency of asphalt pavements

Flow rate of pollutants is defined as the volume of air pollutants which passes through a given pavement surface in a given unit time. The increase in flow rate had a significant impact on NOx reduction efficiencies. With faster flow rates, there is less contact time for the photo catalytic reaction to occur which results in lower reduction efficiencies. It is important to emphasize that the equilibrium concentration changed when the flow rate is changed. The amount of NO_2 reduced from the equilibrium concentration was great at slower flow rates. Hassen et al. (2012) got maximum NOx removal efficiency at a flow rate of 0.05L/n. Fig 2 represents the effect of pollutants flow rate on NOx

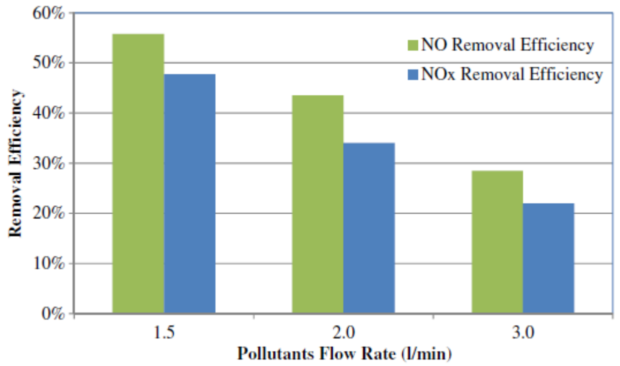

Fig 2. Effects of pollutants flow rate on NO_x reduction [6]

C. Effect of uv light intensity on photocatalytc efficiency of asphalt pavements

Ultraviolet (UV) is an electromagnetic radiation with a wavelength from 10 nm to 380 nm, shorter than that of visible light but longer than X rays. Since the photocatalysis process take place in presence of UV light, its intensity has a direct correlation with the efficiency of pavements. The increase in UV light intensity improved the NOx removal efficiency of the surface coating. Although the presence of UV light is necessary to initiate the photocatalytic reaction, the required light intensity is not known. The UV light intensity varies greatly throughout the day. Fig 3 shows a direct correlation between light intensity and NOx removal efficiency with greater pollutant abatements at higher UV light intensity.

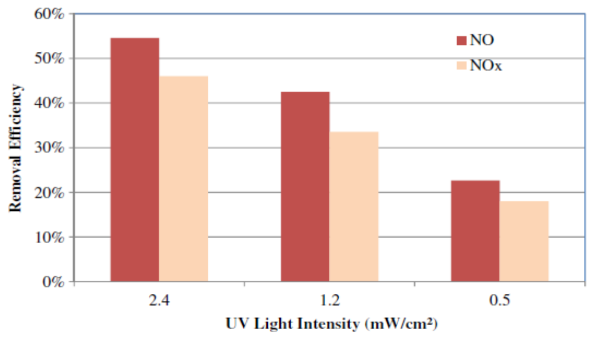

Fig 3. Effects of UV light intensity on NO_x reduction efficiency [5]

D. Effect of contaminants on photoctalytic efficiency of asphalt paements

Photocatalysis process take place effectively when there is direct contact between the TiO_2 and UV light. The presence of contaminants may prevent this direct contact. A study of contaminants on photocatalytic efficiency of pavements was conducted by Broveli et al. (2013). The contaminants selected were dirt, deicing solution and salt. Deicing solution was a mix of water and salt (commercially available as primary sodium chloride and added in 30% by weight of water) usually spread on roads during winter time. To simulate dusty conditions, a calcareous sand was determined considering the amount of dirt on three test road sections of $1m^2$ .In this survey .4 g dirt was applied on samples cored from slabs , a dosage of 6g deicing solution was chosen, a dosage of 0.2g/sample was chosen for salt. The result analyzed that all contaminants had a strong negative effect on NOx removal efficiency. Deicing solution showed the strongest impact due to the covering effect of water that avoided the photo catalytic reactions. On the other hand, dirt had no significant effect on photocatalysis process, where as salt had an intermediate effect.

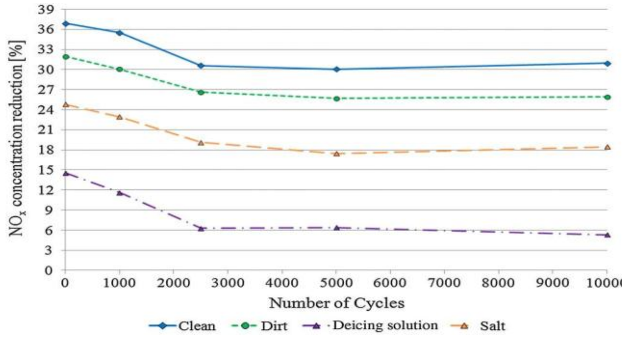

Fig 4 effect of contaminants on photocatalytic effectiveness [7]

E. Effect of mixed nitrogen dioxide and nirogen oxide gases on photocatalytic efficiency.

TiO_2 is more reactive to the unstable NO_2 gases. Hence the ratio of NO_2 to the NOx will definitely affect the photocatalytic efficiency in reduction of NOx gases. When NO_2/ NOx ratio increases there is a reduction in NOx removal efficiency occurs. This reveals the affinity of TiO_2 towards NO_2. A study was conducted on the effect of mixed nitrogen dioxide and nitrogen oxide gases on titanium dioxide photocatalytic efficiency in concrete pavements by Dylla et

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al. (2011). In this study, flow rate was fixed as 3L/min and the relative humidity at 20%. Under these conditions the average reduction of NOx was present as high as 75% when no NO_2 was present and as low as 42% with 70% NO_2. As the ratio of NO_2/ NOx increases, the overall NOx reduction efficiency decreases. This is the result of most of the NO_2 being scrubbed through reaction with concrete surface. Fig.5 represents the effect of NO_2/ NOx ratio on NOx reduction efficiency.

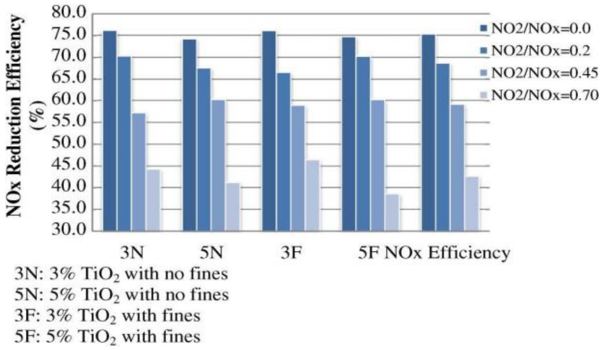

Fig 5. Effect of NO_2/ NOx ratio on NOx reduction efficiency.[4]

F. Effect of relative humidity on photocatalytic efficiency of concrete pavements Identify the Headings

Humidity can have both a negative and positive effect on NO_x reduction efficiency in which the optimum relative humidity is near 25%. At a relative humidity lower than 25%, the lack of water molecules required for the hydroxyl radicals hinders the photo catalytic oxidation. At a higher relative humidity, the water molecules interfere with NO_x contact to the TiO_2 active sites on the surface [4]. Fig 6 represents the effect of relative humidity on the reduction efficiency for different ratios of NO_2/ NOx.

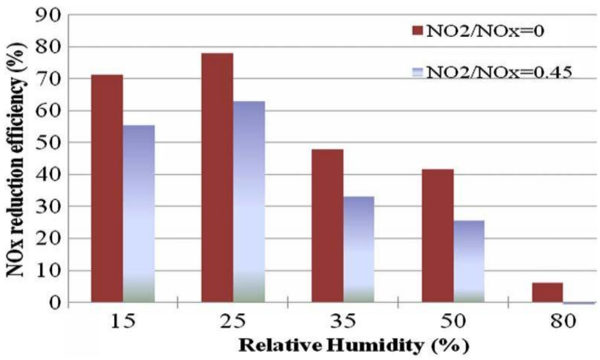

Fig 6 Effect of relative humidity on the reduction efficiency for different ratios of NO_2 / NOx [4]

G. Effect of flow rate on photocatalytic efficiency of concrete pavements

The flow rate had a significant effect on NO_x reduction efficiencies. With faster flow rates, there is less contact time for a reaction to occur, which results in lower reduction efficiencies. To evaluate this trend when NO_2 is introduced, the flow was varied from 1, 3, and 8 L/min at four different NO_2/NO_x ratios. Fig.2.7 shows the relationship between flow rates, NO_2/NO_x ratio and NO_x reduction efficiency. As shown in this figure, the increase in flow rates and NO_2/NO_x ratios resulted in a decrease in NO_x reduction efficiency. It is important to emphasize that the equilibrium concentrations changed when the flow rate changed. The amount of NO_2 reduced from the equilibrium concentration was greater at slower flow rates. In fact, when the inlet stream was completely NO_2, the majority of the NO_2 was scrubbed at the concrete surface without photocatalytic degradation. This further supports the theory of a reaction such as heterogeneous hydrolysis taking place between the unstable NO_2 and the concrete surface.

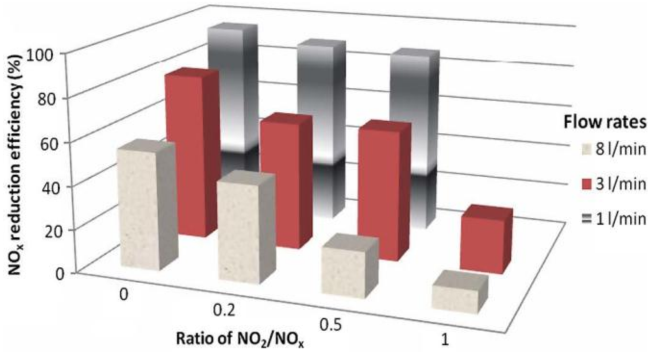

Fig.7. Effect of flow rates on NO_x reduction efficiency of concrete pavements [4]

H . Effects of weathering and abrasion on no removal efficiency of pavements

Weathering and abrasion have negative impact on NO Removal Efficiency. Due to weathering and abrasion the direct contact between TiO_2 and UV light get reduce. This results in reduction of NOx reduction efficiency of pavements. According to the study conducted by Hassan et al (2010), figure 3.8 presents the average NO removal efficiencies for the original, weathered, and abraded samples (loaded-wheel test and rotary abrasion samples). As shown in this figure, it seems that the LWT slightly improved the NO removal efficiency of the different samples with the exception of the samples with 5% TiO_2, which experienced a small decrease in efficiency. This may be due to the weathering action simulated using the LWT, which exposed part of the embedded titanium dioxide particles at the surface, and therefore, improved its NO removal efficiency. In contrast, rotary abrasion seems to result in a decrease in NO removal efficiency for the 5% TiO_2 coating and the PT product while the efficiency slightly improved or remained constant for the other specimen types. In general, the coating with 5% TiO_2 and the PT product were the most efficient in removing nitrogen oxide from the air stream. The highest NO removal efficiencies in the original and rotary abraded states were measured for the coating with 5% TiO_2. On the other hand, the highest NO removal efficiency in the LWT state was measured for the samples treated with the PT product.

III CONCLUSION

The use of nano-titanium dioxide in photocatalytic pavements to combat air pollution has received considerable attention in recent years. Since the technology is applicable to existing pavements, it is widely spreading throughout the road transportation network. Since it controls and reduces atmospheric pollution, it is recognized as a sustainable technology for pavements. Most of the research focused on the effects of environmental and operational parameters on photocatalytic efficiency and its performance under lab and field conditions. TiO_2 is effective in removing NOx and SOx from the air stream with an efficiency ranging from 31 -55% for NOx pollutants and 4- 20% for SO_2 pollutants. Photocatalytic efficiency is indirectly proportional to relative humidity, flow rate, contaminants, NO_2/NOx ratio, wear and abrasion, while efficiency is directly proportional to Intensity of UV light.

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