REDUCTION OF AIR POLLUTION FROM VEHICLES USING TITANIUM DIOXIDE

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Abstract - ***We are facing the pollution menace from vehicles to a greater extent, especially to the people who are living near roadsides. NOx is one of the major pollutant emitted from vehicles. NOx gases react to form smog and acid rain as well as being central to the formation of fine particles and ground level ozone, both of which are associated with adverse health effects. This project entirely focuses on how titanium dioxide coated tiles can reduce the effect of vehicle air pollution and how effectively it does so. This project demonstrates a setup showing the photo catalytic effect of titanium dioxide for reducing the effect of air pollution. This experimental setup consists of two wooden boxes (say A and B): Box 'A' is fitted with normal tiles and 'B' with titanium dioxide coated tiles, a pipe (for carrying smoke to the boxes), ultra violet light source and a gas analyser. Working of the setup is as follows: first passed the polluted air to both the chambers at the same amount, which is measured by using a gas analyser. The gas contained in box 'B' is exposed to ultraviolet light, then only the photo catalytic reaction of titanium dioxide with the pollutants takes place. This experiment is repeated by varying the concentration of Titanium Dioxide contained in the paint. Also the reaction of titanium dioxide under the absence of UV light is also tested. After the photo catalytic reaction, it seems that the amount of pollution presented in the box reduces considerably and it reaches to a saturation point after a particular time period. Also the results show that the reduction of pollution is more, when he amount of titanium dioxide presented in the paint increases.***

Key Words*: titanium dioxide, gas analyser, pollution control*

1. Introduction

With the rapid development in transportation related activities and the growth of population density in urban and metropolitan areas, we are now facing significant challenges in controlling air pollution and the associated problems in human health and living environment. Emissions from vehicle traffic cause air pollution problems throughout the world. There have been many attempts to reduce emissions. However, there are still emissions polluting the air to a significant level. A method of removing these pollutants at the street level once they are emitted to the atmosphere is an attractive air quality management. Similar to plant photosynthesis, photo catalytic compounds such as titanium dioxide (TiO_2) particles can be used to trap and absorb organic and inorganic particles in the air, removing (degrading and mineralizing) harmful pollutants such as nitrogen oxides (NO_X) and volatile organic compounds (VOC) into CO_2, H_2O and harmless inorganic compounds in the presence of UV light (sunlight). TiO_2 is one of the most investigated semiconductors in the field of chemical conversion. Its main properties are:

1) Low cost

2) Fast reaction at ambient operating conditions (room temperature, atmospheric pressure)

3) A wide spectrum of organic contaminants can be converted to water and CO_2

4) No chemical reactants must be used and no side reactions are produced. TiO_2 works as a catalyst and does not undergo change.

Therefore treating the surface of a pavement with TiO_2 can be a very promising approach to degrading harmful air pollutants, and improving the quality of the air.

2. BASIC PRINCIPLE

When a photon with energy of hν exceeds the energy of the band gap an electron (e^-) is promoted from the valence band to the conduction band leaving a hole (h^+) behind. In electrically conducting materials, i.e. metals, the produced charge carriers are immediately recombined. In semiconductors a portion of this photo excited electron-hole pairs diffuse to the surface of the catalytic particle (electron-hole pairs are trapped at the surface) and take part in the chemical reaction with the adsorbed donor (D) or acceptor (A) molecules. The holes can oxidize donor molecules (eqn. 1) whereas the conduction band electrons can reduce appropriate electron acceptor molecules (eqn. 2).

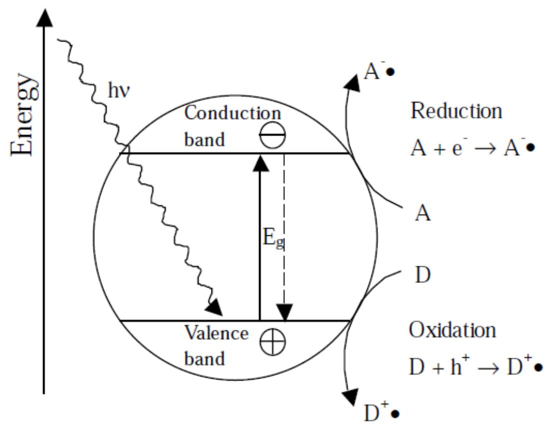

Fig-1: Operation of a photochemical excited TiO_2 particle.

$$D + h^+ \rightarrow D^{\bullet+} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$A + e^- \rightarrow A^{\bullet-} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

A characteristic feature of semiconducting metal oxides is the strong oxidation power of their holes h^+. They can react in an one-electron oxidation step with water (eqn. 3) to produce the highly reactive hydroxyl radical (•OH). Both the holes and the hydroxyl radicals are very powerful oxidants, which can be used to oxidize most organic contaminants.

$$H_2O + h^+ \rightarrow \bullet OH + H^+ \ldots\ldots 3$$

In general, air oxygen acts as electron acceptor (eqn. 4) by forming the super-oxide ion $O2^{\bullet-}$.

$$O_2 + e^- \rightarrow O_2^{\bullet-} \quad \ldots\ldots\ldots\ldots 4$$

Super-oxide ions are also highly reactive particles, which are able to oxidize organic materials.

3. TiO_2 AS PHOTO CATALYST

Titanium dioxide is one of the basic materials in everyday life. It has been widely used as white pigment in paints, cosmetics and food stuffs. TiO_2 exists in three crystalline modifications: rutile, anatase, and brookite. Generally, titanium dioxide is a semiconducting material which can be chemically activated by light. The photoactivity of TiO_2 which is known for approx. 60 years is investigated extensively. For a long time there was a considerable problem especially what its application as pigment concerns. Under the influence of light the material tends to decompose organic materials. This effect leads to the well known phenomenon of "paint chalking", where the organic components of the paint are decomposed as result of photo catalytic processes. Compared with rutile and brookite, anatase shows the highest photoactivity. Therefore, the TiO_2 used in industrial products is almost exclusively from the rutile type. In the following, TiO_2 always denotes the anatase modification. Although TiO_2 absorbs only approximately 5% of the solar light reaching the surface of the earth, it is the best investigated semiconductor in the field of chemical conversion

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$$TiO_2 + h\nu \rightarrow h^+ + e^- \ldots\ldots.5$$

TiO_2 is a semiconductor with a band gap energy Eg = 3.2 eV. If this material is irradiated with photons of the energy > 3.2 eV (wavelength λ < 388 nm), the bandgap is exceeded and an electron is promoted from the valence to the conduction band. Consequently, the primary process is the charge carrier generation.

4. EXPERIMENTAL SETUP

Experimental setup consists of two wooden boxes (say A and B): Box "A" is fitted with normal tiles and "B" with TiO_2 coated tiles, a pipe (for carrying smoke to the boxes), ultra violet light source and a gas analyser. Working of this setup is as follows: First passed the vehicle smoke to both the chambers at the same amount, which is measured by using a gas analyser. The gas contained in box "B" is exposed to ultraviolet light, then only the photo catalytic reaction of titanium dioxide with the pollutants takes place. After a particular time i.e., after the photo catalytic reaction the pollutants will be converted into carbon dioxide and water, and thus the amount of pollution is get reduced. This is monitored by using the gas anlyser.

Fig-2: Experimental setup box with and without UV light

This experiment is repeated by varying the concentration of TiO_2 contained in the paint. Also the reaction of TiO_2 under the absence of UV light is also tested. In order to find out the leakage of air from the experimental setup, a leakage test is also conducted. During these tests it is found that the amount of pollution presented in the box reduces considerably and it reaches to a saturation point after a particular time period. Also the results show that the reduction of pollution is more when the amount of TiO_2 presented in the paint increases.

4.1 Design of an Experimental Setup with UV Light

Design of an experimental setup with UV light consists of tile pasted on the wooden box of dimension 27x17x17 cm with an opening at the top portion. The top portion of the wooden box is covered with a glass piece of the dimension 27x17 cm. A hole of 8mm is inserted at the center portion of the glass piece placed at the top of wooden box so as to insert the probe of the gas analyser. A UV light of 18W whose length is 24 inches is fixed at the inner portion of the glass piece which is facing towards the tile pasted on the wooden box.

Fig-3: Experimental setup with UV light

A small pipe is connected at one side of the box so that the polluted air can be passed to the box through that pipe. After filling the experimental setup box with polluted air, the pipe is closed with a tight cap so as to avoid the air leakage from the experimental setup.

4.2 Design of an Experimental Setup without UV Light

Design of an experimental setup without UV light consist of a tile pasted on the wooden box of dimension 27x17x17 cm with an opening at the top portion. The top portion of the wooden box is covered with a glass piece of the dimension 27x17 cm. A hole of 8mm is inserted at the center portion of the glass piece placed at the top of wooden box so as to insert the probe of the gas analyser.

Fig-4 : Experimental setup without UV light

A small pipe is connected at one side of the box so that the polluted air can be passed to the box through that pipe. After filling the experimental setup box with polluted air, the pipe is closed with a tight cap so as to avoid the air leakage from the experimental setup. Insulation is provided between the glass and the wooden box so as to avoid the leakage of the polluted air through the same.

5. GAS ANALYSER

Exhaust gas analyser is used to measure exhaust gas composition. The amount of pollutant enclosed within the experimental set up was measured with the help of INDUS 5 GAS analyser. The analyser measures the concentration of CO, CO_2, HC, O_2 and NO_2 enclosed within the experimental set up.

Fig-5 : Gas analyser

INDUS Model PEA205 is a class I Gas Analyser designed and manufactured for testing the emissions from automotive engines, which run on diesel, petrol as well as CNG and LPG. The instrument can measure Carbon monoxide, Carbon dioxide and Oxygen in percentage, and Hydrocarbons and Nitrogen dioxide in ppm. It is generally supplied as a four gas analyser without the NO_2 Sensor. When NO_2 sensor is added PEA205 becomes a 5 Gas analyzer. The analyser uses the principle of Non-Dispersive Infra Red for measurement.

6. RESULTS

The experiments and analysis conducted as a part of the project concludes that the TiO_2 photo catalyst coated tiles can reduce the effect of vehicle air pollution to a greater extend. How effectively TiO_2 photo catalyst convert air pollution from the vehicle was determined by conducting various experiments such as leakage test, analysing the reaction of 25% TiO_2 mixed coating on the tile and the polluted air in the presence of UV light, analysing the reaction of 50% TiO_2 mixed coating on the tile and the polluted air in the presence of UV light, analysing the reaction of 50% TiO_2 mixed coating on the tile and the polluted air in the absence of UV light. From the results obtained by conducting the experiments, it is evident that the TiO_2 photo catalyst mixed paints are good for removing a large amount of NO_2 presented in the polluted air. Also it is noted that the amount of CO and the CO_2 presented in the polluted air remains the same during the photo catalytic reaction of TiO_2.

6.1 NO_2 Reduction Analysis

Results of various experiments conducted for a half an hour as a part of the project is shown graphically in the chart-1. From the chart it is clear that the TiO_2 photo catalyst helps to reduce a good percentage of NO_2 presented in the experimental setup.

6.1.1 Leakage Test

To find out the leakage of the experimental setup, a leakage test was conducted in the absence of UV light without any coating. Calculated percentage leak found out during the experiment is 2.94%. The test shows a small percentage of air leaks and it is shown in the chart-1.

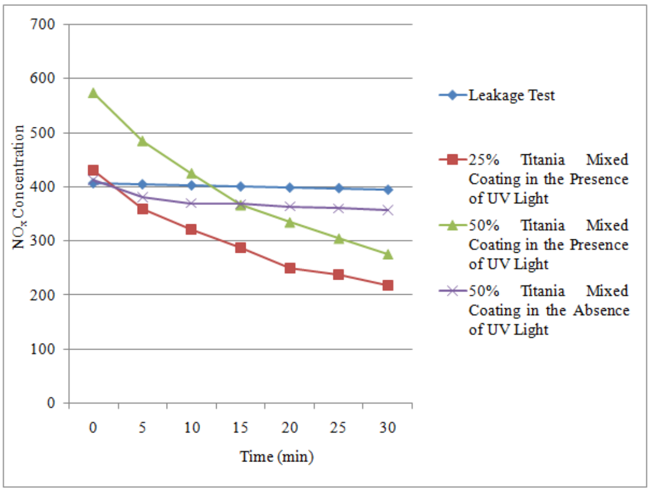

Chart-1: Results of various tests conducted for 30 minutes

6.1.2 Reaction of 25% TiO_2 Mixed Coating in the Presence of UV Light

To find out the efficiency of TiO_2 in removing the NO_2 concentration presented in the experimental setup in the presence of UV light source, a test was conducted by coating the experimental setup with 25% TiO_2 mixed paint. Allow the UV light to fall on the TiO_2 surface. Taken the readings at regular intervals. This reading shows that the TiO_2 photo catalyst helps to reduce large amount of NO_2. For a half an hour, the amount of NO_2 seems to reduce to 49.53%. It proves that the amount of pollution will get reduced if we are coating TiO_2 photo catalyst mixed paints on the areas which is exposed to heavy pollution. Thus we can reduce most of the environment and health related problems.

6.1.3 Reaction of 50% TiO_2 Mixed Coating in the Presence of UV Light

In this experiment the paint is mixed up with 50% of TiO_2 and coated on the experimental setup. Filled the experimental setup with polluted air. Allowed the UV light to fall on the TiO_2 coated surfaces. Values of various pollutants presented in the experimental setup were measured at regular time intervals. It shows that the values of CO and the CO_2 remain the same. Also the result shows a good percentage reduction in the concentration of NO_2 enclosed in the experimental setup. During the test period, that is within 30 minutes it seemed that 52.09% of NO_2 is get reduced. Also the test results shows that the reaction of pollution with TiO_2 will be faster as the concentration of TiO_2 photo catalyst mixed up with in the paint increases. Reduction in the amount of NO_2 gas enclosed in the experimental setup with time is shown graphically in the chart-1.

6.1.4 Reaction of 50% TiO_2 Mixed Coating in the Absence of UV Light

This experiment is conducted to know about the reaction of TiO_2 in the absence of UV light source. This experiment shows how TiO_2 photo catalyst mixed paint reacts during the night. This experiment is conducted by coating the experimental setup with 50% of TiO_2 mixed paint. Allowed the polluted air to pass in to the experimental setup and measured the rate of reduction of concentration of pollutant presented with in the experimental setup. The results show that the concentration of CO and CO_2 remains the same throughout the experiment. At the same time the experimental results shows a small reduction in the amount of NO_2 concentration enclosed within the experimental setup.

6.2 Saturation Point Analysis

To find out the saturation point a test was conducted. The result of the test shows that the reduction rate of the pollution reaches to saturation after a particular time interval. This test was conducted on 25% and 50% Tio_2

mixed paint coated experimental setup in the presence of UV light.

6.2.1 Saturation Point Analysis of 25% TiO_2 Mixed Paint Coated Tile in the Presence of UV Light

A test was conducted to analyse the saturation point of 25% TiO_2 mixed paint coated tile in the presence of UV light. The result shows that the rate of reduction of the polluted air enclosed in the experimental setup reaches to a saturation point after a particular time period. The result of the experiment is shown graphically in the chart-2. From the experimental result we can conclude that a 70.07% NO_2 is getting reduced with in 140 min and it tends almost to saturation level after 120 minutes. This shows TiO_2 photo catalyst mixed paints are good for reducing the amount of pollution enclosed within the experimental setup.

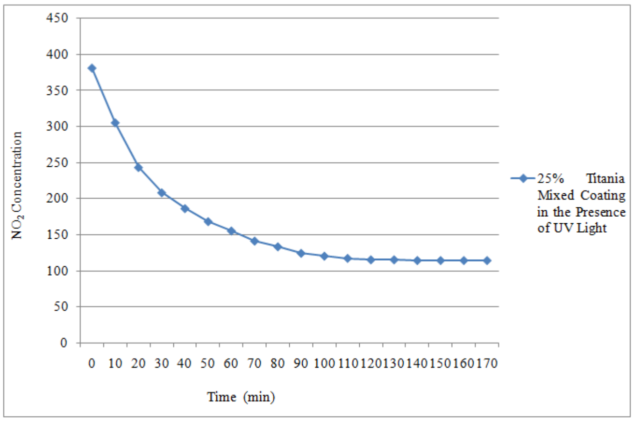

Chart-2: Reduction of Concentration of NO_2 when polluted air exposed to 25% of TiO_2 Mixed Paint Coated Tile in the Presence of UV light.

From the graph shown in the chart-2 it is clear that there is a considerable reduction in the amount of NO_2 concentration enclosed within the experimental setup with the increase in time.

6.2.2 Saturation Point Analysis of 50% TiO_2 mixed paint coated tile in the presence of UV Light

Result of the experiment conducted to find out the reduction rate and saturation point of the NO_2 concentration when the experimental setup was coated with 50% of TiO_2 and the experiment was conducted under the presence of UV light source is shown in the chart-3.

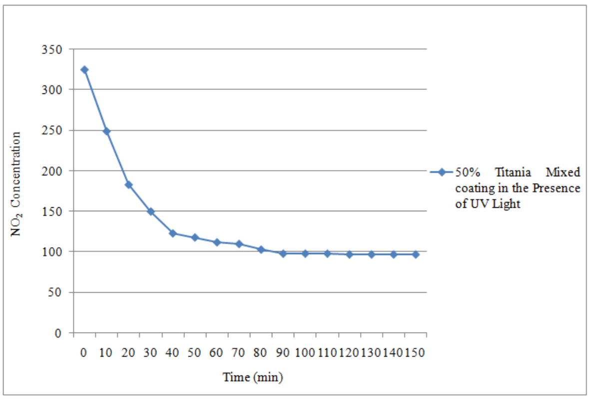

Chart-3: Reduction of Concentration of NO_2 when polluted air exposed to 50% of TiO_2 Mixed Paint Coated Tile in the Presence of UV light.

From the graph shown in the chart-3, it is clear that as the time increases the concentration of NO_2 enclosed within the experimental setup decreases considerably and reaches to a saturation point after a particular time period. It seems that a 70.15% of NO_2 concentration is get reduced within 120 minutes. After 90 minutes the readings shows almost saturated values.

6.3 SEM Test

A scanning electron microscope is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition.

6.3.1 SEM of 25% TiO_2 Mixed Paint

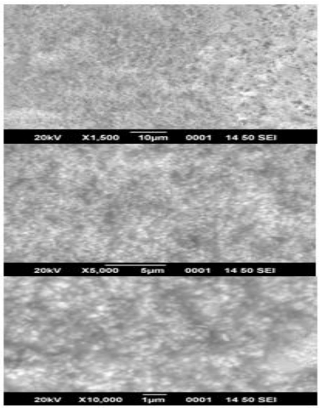

Fig-6: SEM of 25% TiO_2 Mixed Paint

After conducting the test on 25% TiO_2 mixed paint coated tile in the presence of UV light a sample of the paint coating was collected in the sample bottle and sealed it. This sample was analysed for SEM test at STIC lab. The result of SEM of 25% TiO_2 mixed paint is shown in the figure 6.

6.3.2 SEM of 50% TiO_2 Mixed Paint

After conducting the test on 50% TiO_2 mixed paint coated tile in the presence of UV light a sample of the paint coating was collected in the sample bottle and sealed it. This sample was analysed for SEM test at STIC lab. The result of SEM of 50% TiO_2 mixed paint is shown in the figure 7.

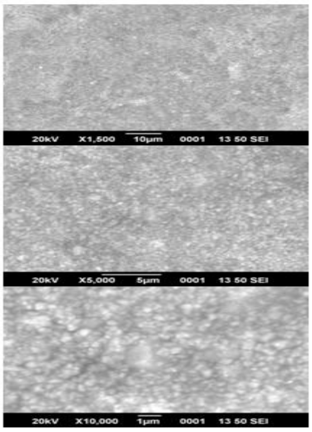

Fig-7: SEM of 50% TiO_2 Mixed Paint

7. CONCLUSION

From the experiments and analysis conducted as a part of the project, it is concluded that the TiO_2 photo catalyst in the presence of UV light is a good solution for rising air pollution problems. TiO_2 photo catalyst helps to reduce a major portion of NO_2 which is a dangerous pollutant presented in the atmosphere in the presence of UV light. It seems that the TiO_2 photo catalyst doesn't have major role in reducing the concentration of CO and the CO_2 . It seems that as the amount TiO_2 contained in the paint increases, the rate of reaction of the pollutants with the paint also increases. Hence more concentration of pollution is get reduced with less time period. Also it is concluded that the TiO_2 photo catalyst is not active during the absence of UV light. So the activity of TiO_2 remains inefficient during night time. Also it is noted that the reduction rate of pollution in the presence of UV light with the help of TiO_2 photo catalyst reaches to a saturation point after a particular time period. This saturation point is also depended on the amount of TiO_2 contained in the paint. When the amount of TiO_2 photo catalyst contained in the paint is less, and then rate of reaction will be slow. Hence more time is required to reach at the saturation point. If the amount of TiO_2 photo catalyst contained in the paint is more, the rate of reaction will be more. Hence it takes less time to reach at the saturation point. Overall it is concluded that TiO_2 photo catalyst is good for reducing the major amount of NO_2 presented in the atmosphere which is a dangerous gas.

REFERENCES

] J.S. Dalton, P.A. Janes, N.G. Jones, J.A. Nicholson, K.R. Hallamand G.C. Allen, "Photocatalytic Oxidation of NO_x Gases using TiO_2: A Surface Spectroscopic Approach", Elsevier-Environmental Pollution, pp. 415-422, 2002.

[2] Prof. Jimmy Chai Mei Yu, "Ambient Air Treatment by Titanium Dioxide (TiO_2) Based Photocatalyst in Hong Kong", Technical Report Prepared for the Environmental Protection Department, pp. 8-41, February 2002.

[3] Gina Barkalow, "Evaluation of Titanium Dioxide as a Catalyst for Removing Air Pollutants", PIER Energy-Related Environmental Research, pp. 1-4, January 2007.

[4] Gotz Husken, Martin Hunger and J.H. Brouwers, "Comparative Study on Cementitious Products Containing Titanium Dioxide as Photo-Catalyst", Proceedings of International RILEM Symposium on PhotoCatalysis-Environment and Construction Materials, pp. 147-154, October 2007.

[5] Kazuhito Hashimoto, Hiroshi Irie and Akira Fujishima, "TiO_2 PhotoCatalysis: A Historical Overview and Future Prospects", AAPPS Bulletin, Vol. 17, pp. 12-28, December 2007.

[6] HashemAkbari and Paul Berdahl, "Evaluation of Titanium Dioxide as a Photocatalyst for Removing Air Pollutants", Public Interest Energy Research, pp. 1-13, January 2008.

[7] WANG Nan, WU Zhijiang and ZHU Gongsheng, "Experimental Study of Nanometer TiO_2 Photocatalysis Material in Air Purification", International Conference on Energy and Environment Technology, pp. 56-59, 2009.

[8] Arafa Awadalla, Muhammad Fauzi Mohd Zain, Abdul Amir and Zeinab Abdalla, "Titanium Dioxide as PhotoCatalyses to Create Self Cleaning Concrete and Improve Indoor Air Quality", International Journal of the Physical Sciences, Vol. 6, pp. 6768-6774, November 2011.

[9] Pandey Bhawana and Fulekar M.H., "Nanotechnology: Remediation Technologies to Clean up the Environmental Pollutants", Research Journal of Chemical Sciences, Vol. 2, pp. 90-96, February2012.

[10] Adrian Burton, "Titanium Dioxide Photocleans Polluted Air", Environmental Health Perspectives, Vol. 120, pp. 6, June 2012.

[11] A. El Zein and Y. Bedjanian, "Interaction of NO_2 with TiO_2 Surface under UV Irradiation: Measurements of the

Uptake Coefficient", Atmospheric Chemistry and Physics, pp. 1013–1020, 2012.

[12] Sreekumaran Nair, Khinand Jagadeesh Babu Nair, "Overview of NanoMaterials for Cleaning up the Environment", Energy & Environmental Science, pp. 8-6, November 2012.

[13]C.L.Bianchi, S. Gatto, S. Nucci, G. Cerrato and V. Capucci, "Self Cleaning Measurements on Tiles Manufactured with Microsized Photoactive TiO_2", Advances in Materials Research, Vol. 2, pp. 1-11, 2013.

BIOGRAPHIES

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