

# Development of TiO<sub>2</sub> coated activated carbon foam as cooling pad for direct evaporative cooling system.

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## ABSTRACT

This research aims to examine the property of the ceramic (TiO<sub>2</sub>) coated activated carbon foam (TiO<sub>2</sub>-ACF) as a cooling pad. Efficiency of direct evaporative cooling system mostly depends on the cooling pad and hence, the material used in the cooling pad plays a very vital role. Here, the TiO<sub>2</sub>-ACF pad is fabricated by dipping activated carbon foam into the slurry of TiO<sub>2</sub> which has different loading mass. The physical property of the TiO<sub>2</sub>-ACF such as stability of the cooling pad under constant and vigorous flow of water, absorbability property and photocatalytic properties were analysed. It is concluded that TiO<sub>2</sub>-ACF cooling pad can be easily fabricated and have an excellent stability and absorbability property.

## INTRODUCTION

Recently, environmental issue, energy saving and efficiency have been the topics of discussion among scholars [1,2]. Note that, environmental issues especially greenhouse gas emissions is reflected by the energy production[2,3]. Nevertheless, the global energy consumption keeps increasing year by year. Therefore, the demand in research and development of new, cleaner and more efficient technologies have been increasing. As for that, ventilation and air conditioning has become one of the applications that in need of development since their application is consuming large amount of world's energy.

In the ventilation and air-conditioning system, the cooling process is the most energy-intensive processes[1]. For conventional cooling system which based on the vapour compression refrigeration

system that consumed substantial of energy and power, it requires high capital investment and operating costs[4,5]. Alternatively, evaporative cooling systems having low power consumption offers large energy savings[6]. As a result, researches and inventions on evaporative cooling system has become more intense.

Main principle of evaporative cooling system is based on the evaporation of a liquid that absorbs significantly more heat than the amount required for its temperature to rise by a few degrees. The best analogy to describe this phenomenon is like the feeling of cold sensation when coming out of an open-air swimming pool with windy condition in warm weather[6]. Another example is the water evaporation from the skin where heat is removed for the evaporation to take place and cool the skin.

Evaporative cooling system can be categorized into two categories based on the contact of water and air; (1) direct evaporative cooling (DEC) system and (2) indirect evaporative cooling (IEC) system. Water evaporation usually takes place on components such as wood wool fibres[7–9], cellulose papers[8], and metallic plate[7,10,11], cement which is known as cooling pad. Only few researches employ ceramic materials as cooling pad in evaporative cooling system. Therefore, this study is focused on fabricating an alternative material to replace other type of materials as a cooling pad.

## METHODOLOGY

### Fabrication of TiO<sub>2</sub>-ACF

The as-received activated carbon foam pad has been cut into several pieces with certain dimension uniformly. The weight of each samples are recorded. The deposition of the TiO<sub>2</sub> (R&M Chemicals) on the activated carbon foam pad was performed by immersing the activated carbon foam pad into a slurry of TiO<sub>2</sub> which has been prepared using the mixture of ethanol and water. The TiO<sub>2</sub> concentration within the impregnation solution was ranged from 80-320g/L.

The TiO<sub>2</sub> slurry was kept under stirring condition for 2 hours before turning off the stirring for the immersion the activated carbon foam. The impregnation process was triplicated, and the activated carbon foam is hold in the air using tweezer for several minutes until all the residual TiO<sub>2</sub> slurry removed. Then, followed by the drying process of the sample at 120 °C for 24 hours under vacuum condition. The TiO<sub>2</sub> coated activated carbon foam is assigned as TiO<sub>2</sub>-ACF-2, TiO<sub>2</sub>-ACF-4, TiO<sub>2</sub>-ACF-6 and TiO<sub>2</sub>-ACF-8 to represent TiO<sub>2</sub> loading of 80, 140, 200 and 320 g/L sample. The un-coated activated carbon foam is appointed as a reference sample and denoted by ACF.

Sample	TiO <sub>2</sub> loading(gram)
ACF	0
TiO <sub>2</sub> -ACF-2	80
TiO <sub>2</sub> -ACF-4	140
TiO <sub>2</sub> -ACF-6	200
TiO <sub>2</sub> -ACF-8	320

### Optical Observation on TiO<sub>2</sub> attachment

Optical microscope was used to observe the attachment of TiO<sub>2</sub> on the network of carbon foam. The effect of different loading TiO<sub>2</sub> on the coverage area of the carbon foam was observed through optical observation.

### Stability/adhesion test of TiO<sub>2</sub>-ACF

The adhesion test of the TiO<sub>2</sub> on the activated carbon pad foam was investigated under various condition; (1) immersion in water and (2) immersion with sonication treatment. The immersion in water test represents for the condition where the cooling pad is subjected to the constant flow of water, whereas immersion with sonication treatment represents for the cooling pas which is subjected to vigorous flow rate of water. Before starting the test, the initial weight ( $M_1$ ) of each sample is taken. Then, the sample is placed in a bottle containing distilled water. After a week, the sample is taken out and dried in oven at 120 °C for several hours, then the mass of the sample ( $M_2$ ) is taken again. The difference of weight between the  $M_1$  and  $M_2$  is recorded. The test is done for several runs in a gap of a week time for each reading to see how is the stability and adhesion of the TiO<sub>2</sub> on the activated carbon. Similar steps were done on the test for another condition of experiment (immersion with sonication treatment). The sample is placed in a bottle of distilled water and put in inside the ultrasonic bath with constant frequency of 20 Hz.

### **Absorbability Test of TiO<sub>2</sub>-ACF**

Absorbability test is done by immersing the sample into a water bath at room temperature and this step is repeated for three times to saturate the content of water to the sample. Then, the sample is hang on the clamp for 1 minute to remove the water residual from the sample. The weighing was done quickly in order to avoid the error due to evaporation. The weight of sample before and after immersion is recorded. The absorbability behaviour is investigated with respect to the various of TiO<sub>2</sub> loading on the activated carbon foam. ACF sample represents as a reference sample. The percentage of the water content to represent the absorbability of the cooling pad was determined using the following equation:

### **Photocatalytic Test of TiO<sub>2</sub>-ACF**

The photocatalytic activity of the TiO<sub>2</sub>-ACF was evaluated through photodegradation of the selected dyes under UV-light irradiation. The methylene blue dye is selected as a representative for the pollutant in air. The experiments were conducted in a photoreactor rectangle box which has aluminium foil covered in the inner side wall for maximum usage of the UV irradiation to the test sample. The photoreactor was irradiated with a UV lamp; light intensity: 18–23 W), and positioned at the centre of the photoreactor. Methylene blue with constant concentration of 0.01g/L is prepared for the photocatalytic test of the TiO<sub>2</sub>-ACF. The TiO<sub>2</sub>-ACF is placed in a beaker containing the methylene blue and positioned at the centre of the photoreactor. The height of the TiO<sub>2</sub>-ACF to the UV light is kept constantly for every test for each type of TiO<sub>2</sub>-ACF. The observation methylene blue colour is recorded by taking a picture for every 30 minutes. The changes of colour is compared for each sample of TiO<sub>2</sub>-ACF to see the effect of various TiO<sub>2</sub> loading on the ACF.

## **RESULTS AND DICUSSIONS**

### **Morphology observation of ACF-TiO<sub>2</sub> cooling pad**

Figure 1(a-e) show the optical view of the ACF and the four different loading of TiO<sub>2</sub> coated. The ACF has intertwined web-like structure which eventually makes up the carbon foam. As shown in the picture, it has a deep black colour and has no attachment on it. Figure 2a shows the visual of 2g TiO<sub>2</sub> loading. As seen from the image, a thin layer of TiO<sub>2</sub> attached onto the carbon foam (white layer). The thickness of the white layer attachment increases as the loading of the TiO<sub>2</sub> increases. This can be seen in the progression of the figure (1b) - (1e). The attachment of the TiO<sub>2</sub> onto the carbon with 8g of loading seems to be yielding the largest pigment of white layers onto the carbon foam. However, it can be clearly seen that the carbon foams are not completely covered by the TiO<sub>2</sub>. This is important to ensure the capabilities of the activated carbon itself can be for its usage in the evaporative cooling system.

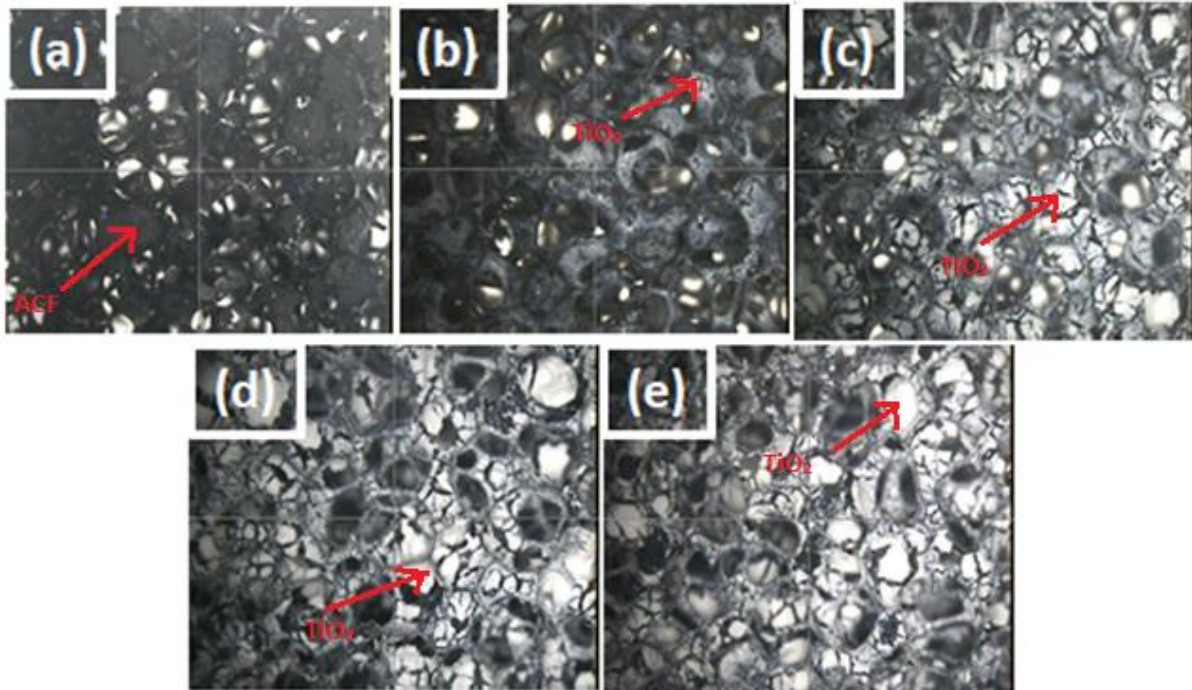


Figure 1:Optical observation of (a) ACF, (b)  $\text{TiO}_2$ -ACF- 2, (c)  $\text{TiO}_2$ -ACF-4, (d)  $\text{TiO}_2$ -ACF-6 and (e)  $\text{TiO}_2$ -ACF-8.

#### Stability/adhesion Test

The stability/adhesion test was done under two different condition; (1) stable and (2) vigorous water flow. Water flow rate has a significant effect on the cooling efficiency of the pad material in the evaporative cooling system. Hence, stability/adhesion test is needed to determine the stability of  $\text{TiO}_2$ -ACF cooling pad under such conditions. As seen from the Figure 2, 3 and Table 2, the  $\text{TiO}_2$ -ACF-8 sample has the highest mass loss rate under stable water flow condition. Similar observation obtained for  $\text{TiO}_2$ -ACF-8 sample under vigorous water flow. This could have been due to over loading of  $\text{TiO}_2$  on the ACF. The lowest of the mass lost rate would be 2g. This is maybe due to its higher surface of attachment to the carbon foam itself. However, the loading of 6g and 4g both shows a relatively unusual reading. The 6g loading has a lower mass loss rate than 4g loading. This maybe due to some error during measurements. However, the mass loss rate of 6g and 4g are relatively very close to each other.

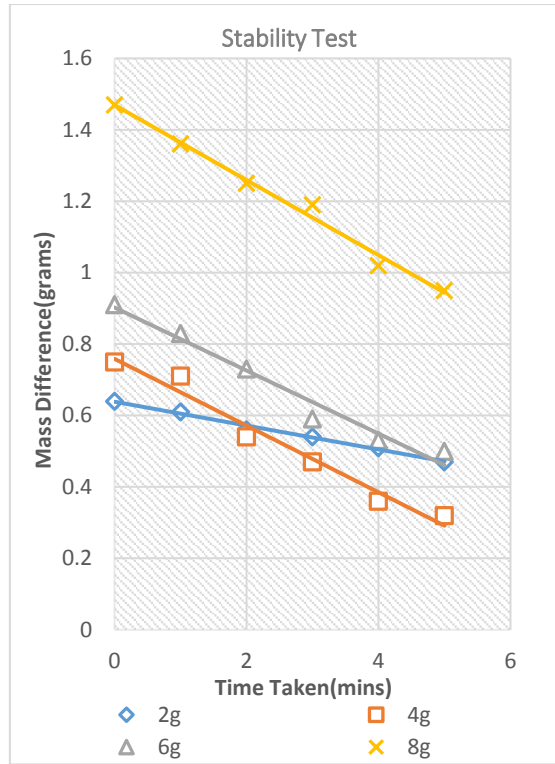


Figure 2: Stable/adhesion test under stable water flow.

Table 2: Rate of mass lost under stable and vigorous water flow.

Sample	Mass Loss Rate (g/week)	Mass Loss Rate (g/minute)
	Stable water flow	Vigorous water flow
ACF	0	0.0002
TiO <sub>2</sub> -ACF-2	0.0034	0.0005
TiO <sub>2</sub> -ACF-4	0.0934	0.0008
TiO <sub>2</sub> -ACF-6	0.0883	0.0007
TiO <sub>2</sub> -ACF-8	0.105	0.0038

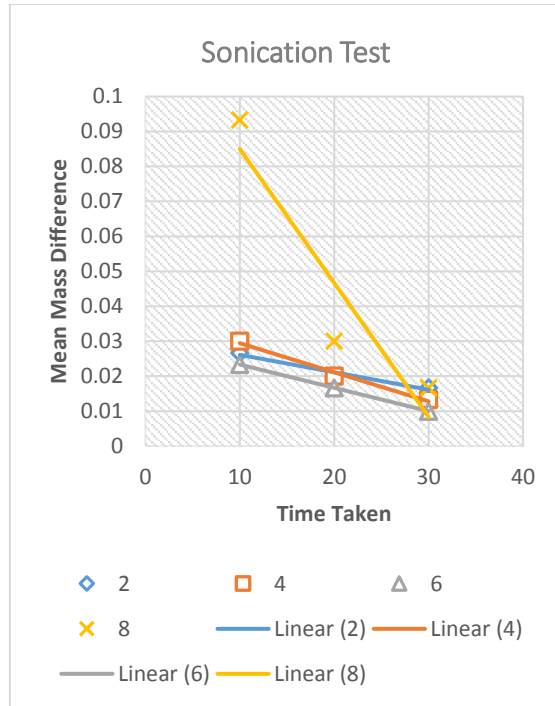


Figure 3: Stability/adhesion test under vigorous water flow.

**Absorbabilty Test**

Noted that the cooling efficiency of the pad depends upon the wettability of the pad because an excellent wettability pad material causes greater evaporation of water into air, thereby decreasing the air temperature[12]. When the pad is easy to be wetted, it shows that their water holding capability. The absorption test shows that the TiO<sub>2</sub> coating aids in the process of holding the water. However, pure carbon itself has shown to have a very high water absorption capability. As seen from the bar chart in Figure 4, the ability to withheld water increases as the loading of the TiO<sub>2</sub> increases. The 6g and 8g loading appears to have a very similar absorption capability. This may show that, the ability to absorb water is reaching its maximum capabilities. The 2g and 4g loading shows lower absorbing capabilities due to the coverage of TiO<sub>2</sub> over the carbon foam. This reduces the capability of the carbon foam to absorb water and thus relies on the capability of the TiO<sub>2</sub> to absorb water. Higher loading of TiO<sub>2</sub> which is 6g and 8g, shows is able to absorb water similar to that of pure carbon.

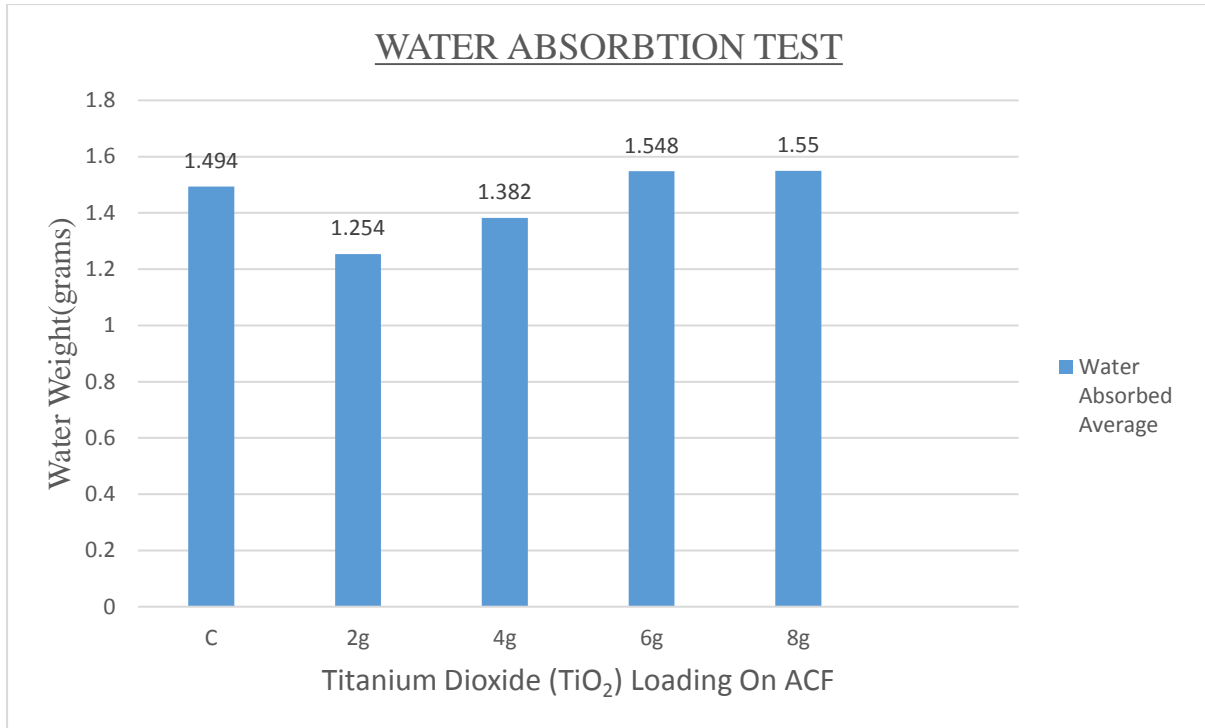


Figure 4: Bar chart of absorbability of sample

#### PHOTOCATALYTIC TEST OF TiO<sub>2</sub>-ACF COOLING PAD

Cooled air may bring dust and pollen into the space, causing discomfort for allergy sufferers. Growth of microorganisms such as molds on the cooler pads may cause allergy problems in sensitive individuals, as evaporative coolers use on-site water[13]. Therefore, it is an urgency to have anti-bacteria properties as an additional to the existing carbon pads. The carbon pads which were coated with the TiO<sub>2</sub> were immersed into dimethyl blue solution to observe the decolourization due to the photocatalytic properties of the TiO<sub>2</sub>. However, the photocatalytic properties of the samples seem to reducing with the increase of the TiO<sub>2</sub> loading as shown in Figure 5. Carbon on its own has a photocatalytic property. The TiO<sub>2</sub> used in the experiments were of commercial based. It is not of the most effective version to produce photocatalytic properties. Usually, TiO<sub>2</sub> which is of 70% Anatase and 30% of Rutile structure would have better photocatalytic properties. Since the commercial, one is of unknown composition, it may not be of the suitable one that is needed for the most effective photocatalytic properties. Next, there is also the unexposed layer of the TiO<sub>2</sub>. The TiO<sub>2</sub> loading in the 2g has a higher surface exposed to the UV light. The TiO<sub>2</sub> loading on its other extreme has a lower surface exposure compared to the 2g loading. This is because, most of the TiO<sub>2</sub> would be underneath the first later and this makes it unable to receive energy from the UV light and thus the dimethyl blue does not decolourise as quickly as the 2g loading.

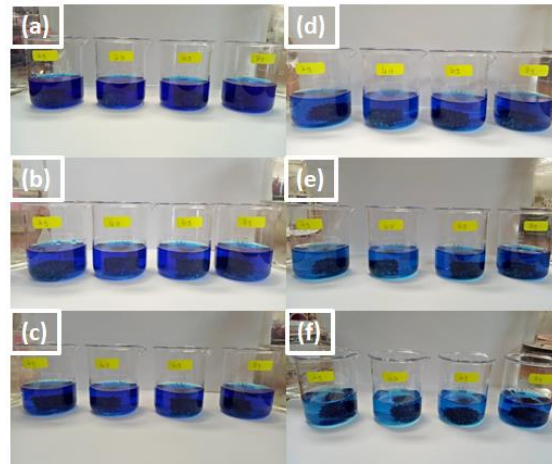


Figure 5: Photocatalytic of  $\text{TiO}_2/\text{ACF}$  sample (Loading from left: 2g, 4g, 6g, and 8g) for UV exposure time of (a) 0, (b) 1, (c) 2, (d) 3, (e) 4 and (f) 5 hours.

## CONCLUSIONS

As per the results shown, it is very clear that, the  $\text{TiO}_2$  used in the experiments were not the optimum composition. The correct composition used, which is 70% Anatase and 30% of Rutile structure, would have shown a much better results for the photocatalytic experiment. Next, the mass of the ACF with  $\text{TiO}_2$  decreased as the water washes away some of it. This can be reduced by introducing some binder to the sample. Binders such as polyvinyl alcohol can act as glue which would hold the  $\text{TiO}_2$  onto the carbon foam.

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