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# Activating Carbon Fibers and Date Pits for Use in Liver Toxin Adsorption

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.71891>

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## Abstract

Acute liver failure (ALF) is a rare, potentially fatal complication of severe hepatic illness. It is a syndrome that triggers a cascade of events, leading to multiple organ failures and often death. The work aimed at demonstrating the usefulness of activated raw date pits and carbon fiber reinforced polymers (CFRP) in the management of ALF. The activated carbons produced are used for adsorption of albumin bound toxins from the liver of patients with ALF. The liver is not cured, however, patients are given the time they need to find a suitable donor. Initially, date pits are milled and epoxy is removed from the CFRP. Both materials then undergo pyrolysis and activation treatments. The activated carbon fiber (ACF) and powdered activated carbon (PAC) resulting are tested using FTIR and TGA analysis. FTIR spectrums provide information about functional groups present in the samples and TGA graphs illustrate weight loss as treatment temperature increases. From the data analysis carried out, it appears that the process of recycling both; date pits and CFRP was successful. This confirms the ability of PAC and ACFs to adsorb toxins and as potential candidates for consideration in the search for effective treatment options for liver failure.

**Keywords:** carbon fiber, pyrolysis, chitosan, adsorption, activation

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## 1. Introduction

Acute liver failure (ALF) is a rare, potentially fatal complication of severe hepatic illness resulting from various causes; it is a devastating syndrome that triggers a cascade of events, leading to multiple organ failure and often death. The work presented below aimed at demonstrating the

usefulness of activated raw date pits and carbon fiber reinforced polymers (CFRP) in the management of acute liver failure. Date pits are the seeds of *Phoenix dactylifera* L. (*Arecaceae*) that have been used in Arabic traditional medicine for centuries to treat diabetes. In the following pages, an overview is presented with a focus on artificial liver support systems including the roles of bilirubin toxin, activated charcoal and purified water.

### 1.1. Liver failure

Acute liver failure occurs when patients' livers cease to remove all the toxins in the blood stream therefore an increase in the level of toxins becomes an issue. Some of these toxins bind to certain proteins in order to travel through the blood stream without poisoning other cells and tissues [1]. Due to this strong bond between proteins, such as albumin serum and toxins, it is hard to eliminate them using conventional dialysis [2]. This is because dialysis is only capable of removing water-soluble toxins. However, date seeds are listed in folk remedies for treatment of various infectious diseases, diabetes, hypertension and cancer due to their hepatoprotective effects attributed to the antioxidant and free radical scavenging activities. In the absence of effective means to remove toxins from the liver, liver support devices are utilized to provide patients with the stability they need to either recover or the time they need for transplantation [3]. Liver support devices are categorized into Artificial liver support devices (ALSD) and Bio-Artificial liver support devices (BLSD). The difference being that ALSDs are purely mechanical, or in other words; not cell based, while BLSD include a cell element allowing the device to act as a replacement for some of the most important functions in the liver. Payable to this, ALSDs act as a bridge to transplantation and do not have the ability to allow the existing liver to recover. On the other hand, BLSD, while acting as a detoxifier also provides the ability to salvage the liver [4].

An example of an ALSD is MARS (Molecular Adsorbent Recirculating System), which is a device used to remove albumin-bound toxins by selectively adsorbing them through membranes in the machine. The toxins are adsorbed onto the surfaces of materials like activated carbon through the membranes [5]. Removing toxins in this manner is crucial for patients with end-stage liver failure due to the single option being liver transplant but lack of donors and the need for a suitable donor with the right blood type in time makes the situation life threatening [6]. The ability to remove these toxins is a temporary fix which gives patients the time they need to find a suitable donor [7]. Carbon is treated to form activated carbon (AC), which is characterized by low-volume pores and a large surface area. AC is one of the best adsorbents due to its large surface area that can be greater than 1000 m<sup>2</sup>/g, leading to its broad uses in many purification and medical applications.

### 1.2. Bilirubin toxin

Bilirubin toxin binds to a certain protein called albumin to travel through the blood stream. Such a bond is hard to break [8]. Thus, many researchers studied the effect of increasing the albumin concentrations on bilirubin adsorption [9]. This was accomplished by many different group studies. Annesi and his team [10] tested for bilirubin as well as tryptophan toxin adsorption using several AC samples with a particle size of 0.3 - 0.5mm. Results showed that

the presence of higher albumin concentrations played a role in decreasing the bilirubin adsorption. This indicates that in devices similar to MARS, the problem of adsorbing albumin over bilirubin might occur. However, in such a study the influence of changing AC concentrations on the efficiency of bilirubin adsorption was not considered. This means that the negative effect of increasing the albumin concentrations on bilirubin adsorption can be solved. Using higher concentration of AC is one of the possible solutions in which the effect of albumin concentrations will no longer affect the efficiency of bilirubin adsorption. Another very effective method could be coating the AC samples with high binding affinity solutions such as chitosan gel.

In addition, previous studies showed that granular AC does not have a high adsorption capacity for bilirubin toxin. Thus, preparing AC in powder form by grinding it will play a vital role in increasing the adsorption capacity of bilirubin toxin [11]. Using granular AC has its own drawbacks in which it does not utilize its full capabilities. This is due to the very small surface area and pore structure of the granular AC as opposed to the powdered AC which has such a high adsorption capacity. By comparing the granular and powdered AC, it can be clearly seen that the adsorption properties depend on two very essential and important elements which are the particle size and internal surface area.

Nikolaev et al. [12] studied the efficiency of adsorbing bilirubin toxin of different types of AC. The different types of AC which were used in this research are Nitrogen based granular carbons, AC based on pyrolysis and fibrous AC. The tests were carried out for different particle sizes ranging between 7 and 9  $\mu\text{m}$  of fibrous AC and 0.5–1.0 mm for activated carbon which was prepared using the pyrolysis technique.

Furthermore, a previous study used surface modified chitosan beads to examine their binding affinities for bilirubin in buffer solutions as compared to AC. Throughout conducting this study, it was observed that chitosan beads adsorbed a bilirubin average of 1.18 mg/g of chitosan beads whereas AC adsorbed 0.74 mg/g [13]. Based on the information provided, it can be clearly concluded that combining powdered AC which has a porous structure and large surface area as well as high adsorption capacity with chitosan's high binding affinities for bilirubin could provide a large adsorption capacity for bilirubin. In other words, combining both could play an important role in increasing and enlarging the adsorption capacity for bilirubin than each functional alone. This method is still under testing in order to use it for the adsorption of protein bound toxins from the liver.

To test for bilirubin adsorption using AC, an albumin-bound bilirubin solution is prepared and mixed with PBS solution to form a stock which is left to stabilize for six hours. PBS is a solution similar to blood plasma which will provide an in lab alternative to using blood for testing. Bilirubin binds to high and low affinity sites on albumin. The AC is expected to adsorb the bilirubin bound to the low affinity sites. The stock will then be serially diluted into different concentrations at a PH of 7.4. a control is taken from each concentration as well as samples containing different amounts of AC. The samples are retained in amber bottles to avoid photo degradation of the bilirubin and are placed in a shaking water bath set at 140 rpm and 37°C. A spectrophotometer is then used to test for the albumin and bilirubin present in each sample every hour for the first four hours then after 16 hrs. Between readings, bottles are kept in a shaking water bath. The readings are taken for two wavelengths; 416 nm for bilirubin testing

and 350 nm for albumin testing. The albumin readings are expected to remain stable since AC adsorbs bilirubin and not albumin. Bilirubin on the other hand is expected to decrease with time in the bottles containing the AC.

### **1.3. Activated carbon**

#### *1.3.1. Date pit activated carbon*

AC can be prepared from many different raw materials depending on availability, surface area, pore size distribution and porous texture [14]. Some examples are wood, coal, coconut, rice husk, shells of plants, stones of fruits, asphalt, metal carbides, carbon blacks, and polymer scraps [15]. Due to the abundance of date palm biomass in the UAE, it can be used to prepare AC. Date pits have a mass varying between 10 and 15% of the total date fruit mass. Payable to their high nutritional value, date pits' utilization is highly requested by the date processing industries in raising their value-added products [16].

#### *1.3.2. Activated carbon fiber*

Carbon fiber reinforced polymers (CFRP) are widely used in many industries, most important of which are the aerospace and automobile industries [17]. This is due to their lightweight, very high strength and ability to endure impact [18]. Around 20% of yearly prepreg carbon fiber production goes to use in the aerospace field as well as 30% being facilitated to the automobile industry [19]. An increasing number of aircraft structures have become highly dependent on the use of these materials. Some of which are the Boeing 787 Dreamliner and Airbus A380 and A350 [20].

With an increase in demand for CFRP comes a larger amount of scrap generated. Scrap sources include end of roll, trim, out-timed and out-of-spec waste. Many manufacturers deal with this waste by disposing of it into landfills [21]. This is not only harmful for the environment but is also costly for manufacturers [22]. Therefore, methods of recycling these CFRP are being researched and some are being implemented on an industrial scale. Recycling CFRP can either be done thermally or chemically [23].

### **1.4. Applications of activated carbon fiber**

In today's world, activated carbon fiber (ACF) is a highly versatile material which has been a pioneer within a broad range of applications [24]. What was stated as an exotic material many years ago is nowadays playing an intrinsic role in our daily lives [25]. As outlined below, several applications of ACF will be discussed.

#### *1.4.1. Medical applications*

In the medical field, activated carbon fiber has many remarkable uses. It is normally linked with the adsorption of organic toxins in which it is widely used as an antitoxin in the treatment of kidney and liver disease. In other words, for blood dialysis in the treatment of liver and kidney disease, ACF is used as a filtering medium that adsorbs toxins from the blood stream of patients' bodies. Other uses in the medical field include the treatment of cholestasis during



pregnancy as well as lowering cholesterol levels. Several studies have been carried out on the possibility of utilizing ACF in the medical field. It was found that ACF can be used as an anti-flatulent in the abdominal radiography process. Other than that, activated carbon in general is a significant ingredient for stomach remedies. It helps in controlling diarrhea and flatulence, as well as lowering the toxin levels throughout the body.

#### *1.4.2. Purification of water*

Water makes up more than two thirds of human body weight and the earth's surface. This is evidence that water is one of the most essential substances on earth. In fact, if there was no water there would be no life on earth. However, that same water might be harmful to the human body if it was not purified. Thus, water purification is an important industry requirement in which water undergoes a number of treatments to be usable and drinkable. Water purifiers are designed to remove impurities and contaminants from water. Several materials are used in water purifiers to help removing these contaminants. ACF can be used as a media for water purification. It is a porous material with a high adsorption capacity by which it could adsorb the pollutants perfectly. Recently some studies have shown that ACF is popular in water purification industry and that is due to removing heavy metals like lead, as well as dissolving chemicals and some types of parasites.

## **2. Methods of recycling CFRP and removing epoxy**

### **2.1. Recycling CFRP**

There are three possible methods of recycling CFRP which include mechanical, thermal and chemical recycling. Mechanical recycling mainly involves size reduction methods, such as cutting, trimming or shredding. Thermal recycling comprises of material treatment at very high temperatures. The type of thermal recycling of interest in this work is pyrolysis, where the material is heated in a furnace in the presence of Nitrogen gas. Furthermore, the chemical recycling process revolves around the removal of the matrix using chemical dissolution reagents [26].

### **2.2. Removing epoxy from carbon fiber**

Carbon fiber reinforced polymers (CFRPs) are composite materials that are often coated by epoxy layers. These epoxy layers add to the carbon fiber properties in which it has been proved through different studies that epoxy contributes in the enhancement of the chemical resistance, strength and durability of the composite materials [27]. Although, the use of epoxy resin is beneficial in many aspects, it originates difficulties related to the removal of this very strong resin. Therefore, many methods are followed in order to remove epoxy from carbon fiber [28]. Using acetone as a solvent to dissolve the epoxy is one of the approaches that is followed during the curing process. A certain amount of acetone is added to the carbon fiber to dissolve an epoxy resin. In other words, acetone/epoxy solutions of different concentrations are prepared. The solution is then sonicated and stirred for an hour. After that, the mixture is exposed to heating at a certain temperature. Lastly, hardener is added to the mixture. Other studies

showed how adding acetone might impact the characteristics of epoxy. According to these authors, the occurrence of residual solvent might lead to some significant changes in the mechanical and physical properties as well as the thermal degradation.

In contrast, FTIR results showed that the presence of acetone does not affect the chemical properties of the material. According to the literature, it can be seen that a more efficient method of removing epoxy has been applied. This technique is based on using thermal processes in order to remove the epoxy from the carbon fiber. Thermal processes could include more than one method and technique such as pyrolysis. Pyrolysis is one of the most studied thermal processes due to its popularity in the commercial scale [29]. The process operates at different temperature ranges depending on what type of resin is used. For example, epoxy resin tends to be stronger than other types of resin which means it might require higher temperatures to be fully removed. One of the main drawbacks of using this technique is the remaining resin residue such as char. This char contaminates the fibers and thus a post treatment is needed to burn it. However, exposing this composite material to high temperatures during the treatment might lead to a significant reduction in the properties of the material. Different group works have studied the effect of raising the temperature on the properties of the carbon fiber. The results showed that for some types of fiber such as glass fibers a temperature of 1300°C is needed in order to remove the char completely and to produce a perfectly clean one but a reduction by up to 85% of the tensile strength was observed [30]. Thus, in order to produce an acceptable strength for the carbon fibers a maximum pyrolysis temperature in the range of 500–550°C is advisable.

Chitosan can be used in many different applications. In biomedical applications, Chitosan can act as an interaction site in order to increase the adsorption capacity [31]. Therefore, in this work chitosan was used in the coating process in which both activated carbon fiber (ACF) and date pit activated carbon (DPAC) samples were coated with Chitosan [32]. The chitosan used in coating both materials contains amino ( $-NH_2$ ) and hydroxyl ( $-OH$ ) groups on its chains [33]. These groups accomplished the main benefit of using chitosan. In other words, these groups helped in forming AC with a large adsorption capacity [34].

Chitosan is a natural source that is available abundantly in nature. It can be produced and found naturally in the cell walls of fungi, the shells of crustaceans and the shells of insects [35]. It is produced commercially in many different forms. Chitosan powder is one of the forms which can be used and found in the market [36]. Thus, in this work the chitosan powder is used in making chitosan gel which will be used to coat the samples of ACF and DPAC.

This work focuses on removing the epoxy from CFRP and activating, both date pit powder and CFRP at different temperatures. This will allow a comparison of the results under different conditions to find the optimum activating temperature for the materials. Chitosan gel is then prepared by mixing chitosan powder and dilute acetic acid. The resulting solution is used to coat both types of charcoal. It is expected that coating will increase the adsorption efficiency of the materials by providing a high binding affinity for carbon fiber. The resulting samples are all compared to conclude which material has a higher bilirubin adsorption capacity and the optimum activation temperature for the DPAC and ACF.

Further studies will later be conducted regarding the use of the different types of charcoal produced for the adsorption of albumin-bound bilirubin. Batch tests will be carried out on different samples to test for the effect of coated AC dosage on the adsorption capacity of the materials. Moreover, the contact time between the coated AC and bilirubin toxin will be tested to determine whether increasing the contact time will increase the amount of bilirubin adsorbed.

### 3. Experimental processing

#### 3.1. Materials

The aim of this work is to use thermal treatment by pyrolysis to remove the epoxy from the CFRP and prepare the material for activation. According to literature, some drawbacks to pyrolysis may be faced, including the loss of mechanical properties such as tensile strength and elasticity. Furthermore, the fibers released are likely to be covered in char, a black residue formed during the thermal degradation of the resin.

Several materials were utilized in the preparation, pyrolysis and activation processes of the CFRP.

To prepare the CFRP sheets, obtained from the aerospace industry, for pyrolysis, the sheets of material are shredded into strips. This is to enable their placement in the furnace to carry out the thermal treatments. The steps toward activated carbon fiber are pyrolysis and activation, both carried out in a furnace (GSL – 1500X). The samples of CFRP are separately placed in the steel roll inside the furnace. For the pyrolysis process, nitrogen gas ( $N_2$ ) is passed through the sample and for activation, carbon dioxide ( $CO_2$ ) is passed into the steel roll. In order to control the operation temperatures inside the furnace, it is connected to a laptop with the PT software installed. The temperature program to be run is added to this software and the temperature rises and falls are monitored on the screen.

Following pyrolysis, samples of the treated carbon fiber are immersed in acetone to indicate the presence or absence of epoxy. In accordance to later tests, if the acetone turned into a yellow color, this is an indication of the presence of epoxy in the sample.

#### 3.2. Procedural setups

##### 3.2.1. Pyrolysis

The carbon fiber reinforced polymer is waste product obtained from the aerospace industry. It is attained in sheets, which are shredded before carrying out treatment and tests. The method followed for activating the material is physical activation to avoid contamination or poisoning in case the activated carbon fiber is to be used for purification or medical purposes. Physical activation involves a two-step process; pyrolysis and activation.

The aim of pyrolysis is to remove the epoxy in the material as well as provide an inert atmosphere for activation to take place. The process involves passing nitrogen gas through



the sample. The shredded CFRP is added to the steel roll, which is then inserted into the furnace. The steel roll is positioned correctly using a marked rod and the furnace is closed from both ends with tubes through which the nitrogen gas will flow. The gas enters and leaves the furnace passing through the CFRP sample. To ensure that approximately the right amount of gas is passing through the sample, the outlet tube is connected to a tilted water bottle and the bubbles created are observed. To change the gas flow rate, the valve on the nitrogen gas cylinder is controlled.

Passing an inert gas through the sample aims at removing impurities, such as hydrogen and oxygen to create a more stable and heat resistant compound composed mainly of carbon. The pyrolysis treatment is carried out by increasing the temperature inside the furnace while passing the gas through the steel roll. The temperature is kept at its peak for a specific period of time before it is dropped back to room temperature. To control the temperature rises and falls, the furnace is connected to a laptop with the PT software installed where a simple program is entered for the various temperatures and durations.

To find the optimum temperature for the pyrolysis and activation processes, they are executed at various temperatures; 600, 800 and 1000°C. Tests are later used to decide which treatment temperature is most effective.

### 3.2.2. Acetone test

One of the biggest challenges faced in this work is the removal of the epoxy in the material. This is because the exact nature of the epoxy is unknown due to restrictions from the aircraft manufacturers. Therefore, acetone testing is used after the pyrolysis process as a step to ensure that the epoxy has been eliminated from the material. Approximately 20 ml of acetone are added to a beaker and a sample of the material which has undergone pyrolysis treatment is added to the beaker and left to soak overnight. It is expected that the acetone of the sample containing epoxy turns yellow, as opposed to clear for the sample which contains no epoxy. This test is done on samples treated at all temperatures prior to activation.

### 3.2.3. Activation

During the next stage, carbon dioxide gas is passed through the sample to allow some carbon to react with it producing carbon monoxide gas, as shown in Eq. (1), which is then removed from the system through the water bottle with the excess gas. This process is known as gasification and develops porosity in the material by removing some carbon atoms. The furnace is operated in a similar way to the pyrolysis process with the only difference being the gas utilized. Since pyrolysis treatments will be carried out at three different temperatures of 600, 800 and 1000°C, the same will be done with the activation treatment.



It is expected, according to previous literature, that the carbon fiber will have a larger adsorption capacity of toxins than powdered activated carbon. In order to prove this, the adsorption

capacity of the activated carbon fiber will be tested and compared with the adsorption capacity of activated date pit powder.

#### 3.2.4. Chitosan gel preparation and coating

Chitosan gel is used to coat a sample of the DPAC to allow for comparisons with the ACF and uncoated DPAC. To prepare the chitosan gel, 198 ml of water are mixed with 2 ml of acetic acid in a reagent bottle to form dilute acetic acid. The outcome is a 1% concentrated acetic acid by volume. 100 ml of the solution is then measured using a measuring cylinder and poured into a beaker with a magnet placed inside and put on a magnetic stirrer to stir and heat the solution first. 0.5 g of chitosan powder is gradually added to the stirring diluted acid, to avoid splashes, clumping and achieve a more even distribution. The magnetic stirrer is set at a temperature around 45°C. Approximately an hour later, when the chitosan gel has reached the desired consistency, 5 g of the activated carbon are weighed and added gradually to the gel after turning off the heater so the mixture is only stirring. The carbon is then left to coat overnight as it stirs (for about 24 hours). The coating procedure is carried out three times while oven drying between each coating. This is done to ensure that the DPAC is fully coated [8].

### 3.3. Experimental techniques used

For determining the characterization of activated carbon fiber, FTIR and TGA analysis are conducted.

#### 3.3.1. FTIR (Fourier transform infrared spectroscopy)

The main benefits of using a Fourier Transform Infrared (FTIR) spectroscopy is that it is quick and takes measurements in a matter of seconds. It also has a very high sensitivity due to the extremely delicate detectors employed in the device. Infrared spectroscopy gives information about the chemical structure and functional groups of raw materials and the prepared activated carbon. The data obtained presented information about the interaction and polymeric association between chitosan and carbon. The Infra-red transmission spectra were recorded with a Perkin Elmer spectrophotometer ranging from 400 to 4000  $\text{cm}^{-1}$  using the KBr technique.

#### 3.3.2. TGA test

TGA (Thermogravimetric analysis) is an essential method used in materials characterization. It is a technique in which the mass of a substance is measured as a function of temperature or time as the sample is monitored under a controlled atmosphere. This technique provides useful information about chemical phenomena such as solid–gas reactions and thermal decomposition, as well as physical phenomena including phase transitions, absorption and desorption. A typical TGA analyzer consists of a sample pan that is backed by a precision balance inside a furnace. The temperature inside the furnace is programmed under a controlled temperature. The mass of the sample is monitored during the experiment. This experiment may occur under different conditions in which it could be conducted under a variety of atmospheres including: inert gas, carburizing gases, ambient air, vapors and vacuum. Also, the experiment might take place under a variety of pressures such as high vacuum, high pressure,

and constant pressure. The data collected from the thermal reactions which occur inside the TGA are represented into a plot. That plot is indicating the thermal curve which is displayed as time or temperature in the x-axis and as weight (mg) or weight percent (%) in the y-axis. The TGA thermal curve provides different useful information about the characteristics of the materials. The purity of the sample is one of the characteristics that can be determined using the TGA thermal curve. This can be accomplished by calculating the formula weight through substituting the atomic mass in the formula and then comparing the measured values with the calculated ones. To further characterize the sample, an extrapolated onset temperature that represents the temperature at which the weight loss starts can be calculated. Another useful calculation that illustrates one of the characterization of the sample is the peak calculation of the first derivative of the weight loss curve. The peak of the 1st derivative shows the inflection point which is basically represents the point of greatest rate of change on the weight loss curve. The temperature range at which thermolysis would be performed is determined by analyzing the samples thermogravimetrically.

## 4. Results and discussion

### 4.1. FTIR analysis

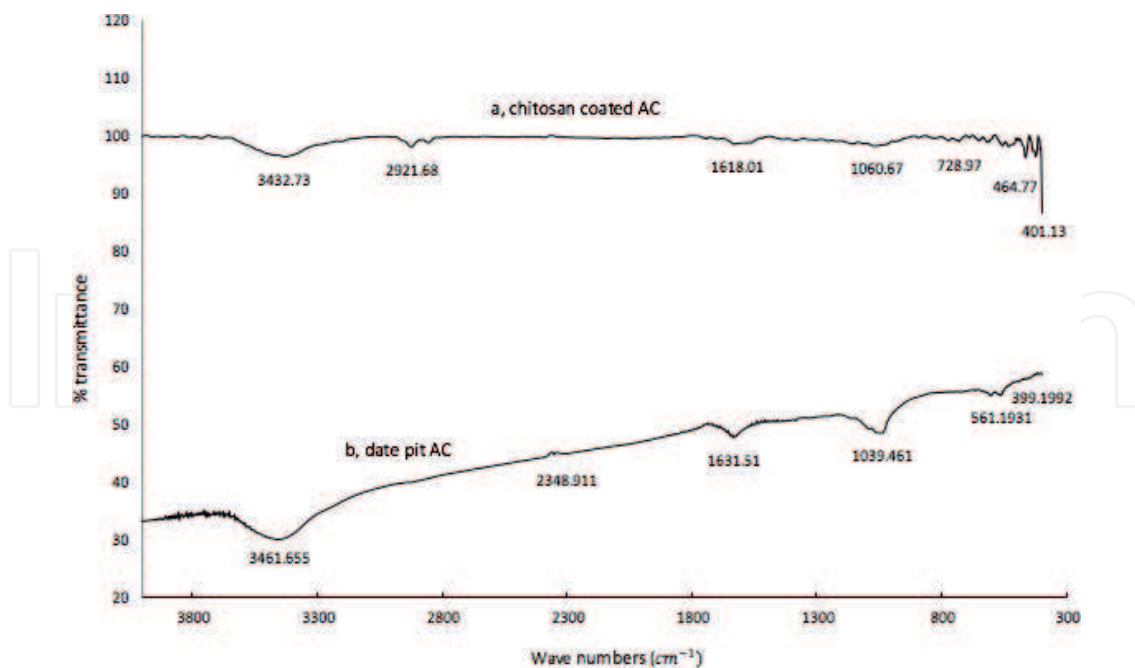
#### 4.1.1. *Date pits activated carbon*

FTIR Analysis, was conducted for further identification of the functional groups present in activated carbon. **Figure 1** depicts the corresponding FTIR range of the date pit activated carbon that primarily concludes that phenols, carboxylic acids, and carbonyl functional groups are the ones present, all of which are categorized as typical acidic functional groups.

Furthermore, the spectrum consisted of an IR band of around  $3427\text{ cm}^{-1}$  which is assigned to a vibration stretch of hydroxyl group denoted as OH. Additionally, C=O group frequency is observed at a wavelength of  $1720\text{ cm}^{-1}$  while aliphatic groups at around  $2923$  and  $2855\text{ cm}^{-1}$ , along with  $1033\text{ cm}^{-1}$  which corresponds to C—O stretching, as tabulated in **Table 1**. In elucidating chitosan coated carbon's FTIR spectra that merely represent the adsorption of both chitosan and carbon, it has been noted, as **Figure 1** demonstrates, that the stretching vibration of O—H and N—H functional groups are observed at a frequency of  $3433\text{ cm}^{-1}$ . The bands at around  $2923$  and  $2855\text{ cm}^{-1}$  correspond to the asymmetric and symmetric stretching. Moreover, the peaks in the range of  $1630$ ,  $1157$ ,  $1381$ ,  $1017$  and  $890\text{ cm}^{-1}$  assigned to N—H bending, C—N stretching, O—H in plane bending, C—C—C Skeletal in the backbone and  $\text{CH}_3\text{—C—OH}$  stretching respectively as recorded in **Table 1**. Bands around  $647$  and  $496\text{ cm}^{-1}$  indicate the presence of OH and C—C bending vibrations respectively [19].

#### 4.1.2. *Activated carbon fiber*

Fourier Transform Infrared Spectroscopy (FTIR) analysis is done in order to identify the functional groups associated with the activated carbon fiber. The **Figure 2** illustrates the FTIR spectrum obtained from the carbon fiber before and after activation at different temperatures of  $500$ ,  $600$ ,  $800$  and  $1000^\circ\text{C}$ . The spectrum shows an IR band of  $3600$  and  $3200\text{ cm}^{-1}$  is assigned



**Figure 1.** FTIR spectrum of the date pit activated carbon.

to the hydroxyl (OH) group and the peak at  $2329\text{ cm}^{-1}$  is related to the  $\text{C} \equiv \text{C}$  stretching as the data in **Table 1** presents. Furthermore, the frequency observed at a wavelength of  $1843\text{ cm}^{-1}$  is due to the CHO stretching.  $1450\text{--}1479\text{ cm}^{-1}$  are related to the vibrations of the CH bonds. Peaks at  $1068\text{--}1148\text{ cm}^{-1}$  and  $1565\text{ cm}^{-1}$  are attributed to the vibrations at  $\text{C--O--C}$  and  $\text{N--H}$  stretching respectively. Moreover, the non-symmetric vibration absorption of  $\text{C=O}$  is illustrated in the peak at  $1840\text{ cm}^{-1}$ , as well as the stretching vibration of the  $\text{C=O}$  or  $\text{C=N}$  present at  $1750\text{--}1640\text{ cm}^{-1}$ . The peaks at around  $1403$  and  $650\text{ cm}^{-1}$  are due to the  $\text{CH}_2$  bending and OH bending vibration frequency respectively. According to the data illustrated for the ACF, it is observed that the spectrum at different temperatures portrays similar patterns but the intensity of the absorption bands is increased as the treatment temperature is increased.

## 4.2. TGA (Thermogravimetric analysis)

### 4.2.1. Date pits activated carbon

Thermogravimetric analysis (TGA) and differential thermogravimetric analysis (DTG) profiles of the DP-AC are shown in **Figure 3**. The TGA curve gives an approximation about the weight loss of the sample with respect to temperature, while the DTG curve indicates the decomposition temperature as well as the oxidation temperature of the sample. The first decomposition stage occurred between  $21.5^\circ\text{C} \approx 99^\circ\text{C}$  where a weight loss of 10.4% was observed. This loss was due to the release of surface bounded water and volatile matters. The highest rate of degradation in this stage was indicated by the peak on the DTG curve at a maximum rate of decomposition temperature of  $54^\circ\text{C}$ . The next stage showed a slower rate of weight loss with only 10.6% change over a wide range of temperature between  $100^\circ\text{C}$  up to  $900^\circ\text{C}$ . Most of the weight loss in this stage was due to the decomposition of hemicellulose and cellulose constituents. While for temperatures above  $\approx 450^\circ\text{C}$ , the weight loss was due to decomposition of

Functional Group	Wavelength
<b>Activated Carbon Fiber</b>	
OH	3600 $\text{cm}^{-1}$ – 3200 $\text{cm}^{-1}$
$\text{C}\equiv\text{C}$ stretching	2329 $\text{cm}^{-1}$
CHO stretching	1843 $\text{cm}^{-1}$
CH bonds	1450 $\text{cm}^{-1}$ – 1479 $\text{cm}^{-1}$
C-O-C vibrations	1068 $\text{cm}^{-1}$ – 1148 $\text{cm}^{-1}$
N-H stretching	1565 $\text{cm}^{-1}$
C=O	1840 $\text{cm}^{-1}$
C=N	1750 $\text{cm}^{-1}$ – 1640 $\text{cm}^{-1}$
$\text{CH}_2$ bending	1403 $\text{cm}^{-1}$
OH bending vibration	650 $\text{cm}^{-1}$
<b>Chitosan Coated AC</b>	
N-H bending	1630 $\text{cm}^{-1}$
C-N stretching	1157 $\text{cm}^{-1}$
O-H bending	1381 $\text{cm}^{-1}$
C-C-C	1017 $\text{cm}^{-1}$
$\text{CH}_3\text{-C-OH}$	890 $\text{cm}^{-1}$
OH	647 $\text{cm}^{-1}$
C-C	496 $\text{cm}^{-1}$
<b>Date Pit AC</b>	
OH	3427 $\text{cm}^{-1}$
C=O	1720 $\text{cm}^{-1}$
C-O	1033 $\text{cm}^{-1}$
Aliphatic Groups	2923 $\text{cm}^{-1}$ – 2855 $\text{cm}^{-1}$

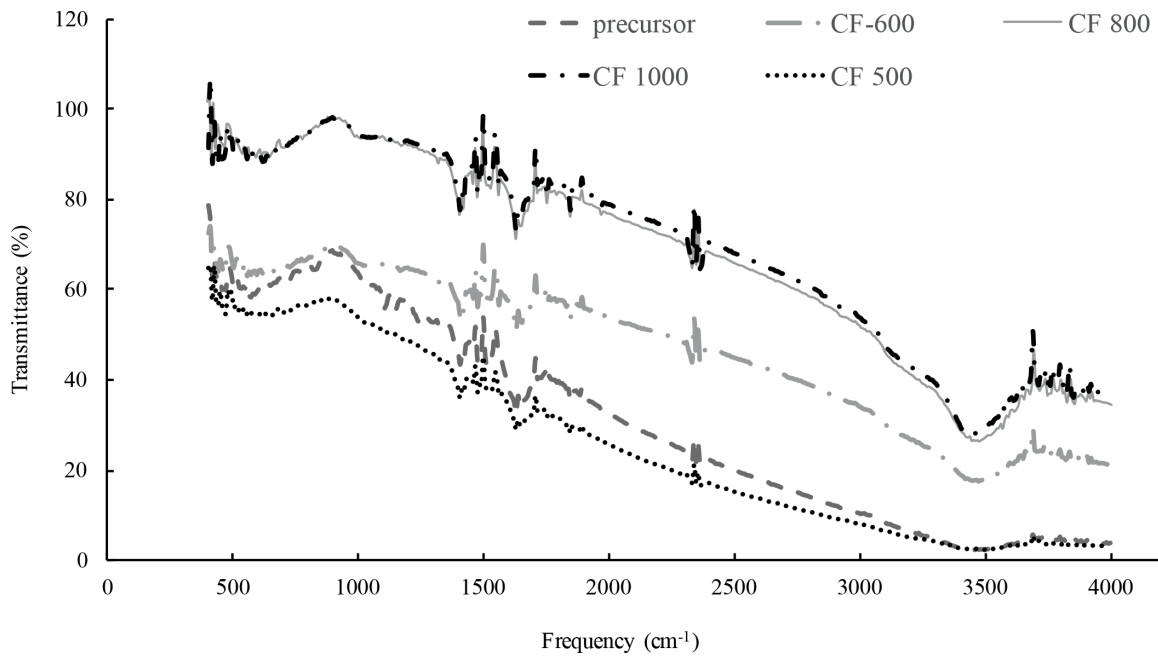
**Table 1.** Functional groups associated with wavelength bands.

lignin. At temperature 900°C, the amount of ash residual was 79% which is considered as indication for the thermal stability of the material (date pits activated carbon) under investigation over a broad range of temperatures.

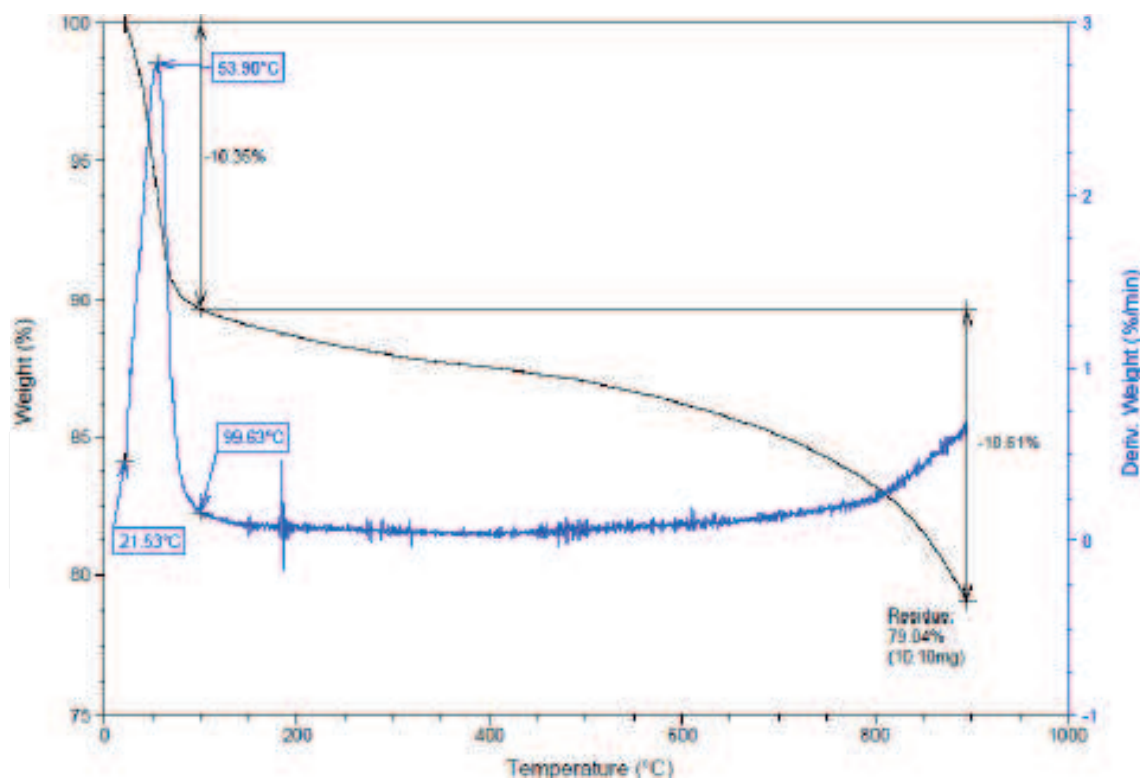
#### 4.2.2. Activated carbon fiber

Thermogravimetric analyses (TGA) were conducted in a TA (schimadzu Q40) equipment. The samples of the activated carbon fiber were heated up to 600°C at a heating rate of 10°C/min under nitrogen atmosphere (flow rate 100 mL/min). Using the data obtained, TGA curves were prepared as shown in **Figure 4**. The TGA curve produced shows the weight loss versus time curves for several temperatures. The temperatures at which the activated carbon fibers were prepared during the pyrolysis are indicated in **Figure 4**. Based on **Figure 4**, it can be clearly



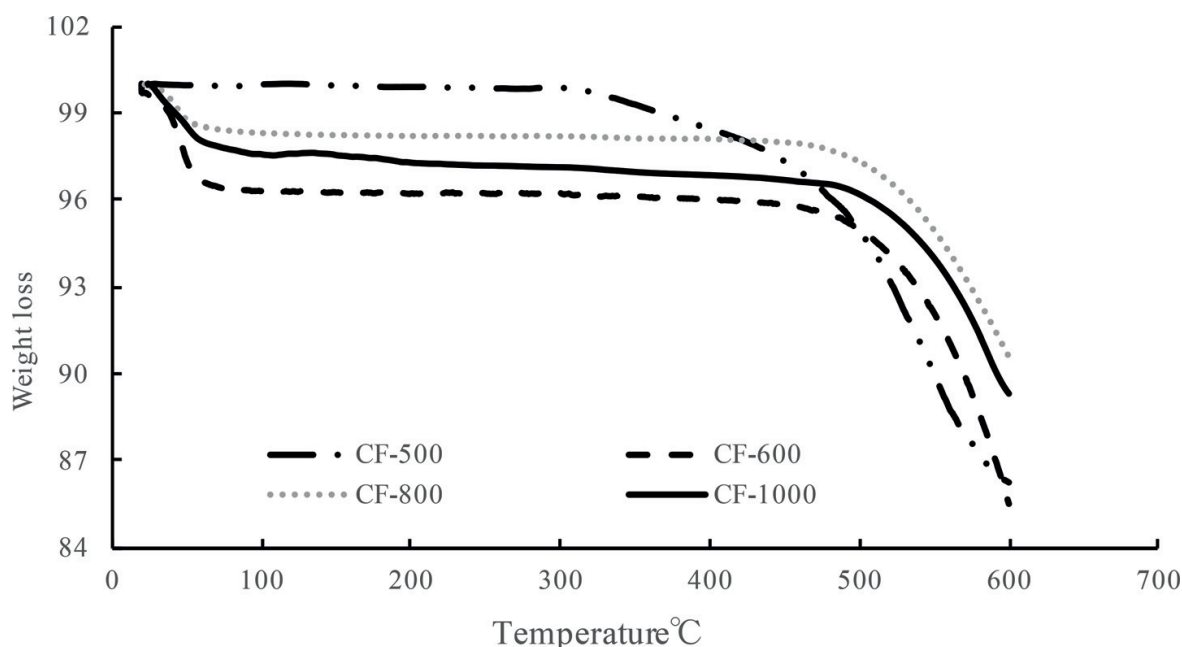


**Figure 2.** FTIR spectrum of the activated carbon fiber.



**Figure 3.** TGA profile of date pit activated carbon.

seen that the TGA test was done for several samples of activated carbon fiber at different temperatures. These temperatures are 500, 600, 800 and 1000°C. TGA curve shows a weight loss due to the release of moisture at 200°C. Only one prominent weight loss peak around 300



**Figure 4.** TGA profile of activated carbon fiber.

to 550°C was observed in the derivative mass loss curve. The corresponding weight loss between 300 to 550°C is related to the pyrolysis of the material. Similar patterns were observed for all the samples at various temperatures.

FTIR results give information about the functional groups present on the two materials; DPAC and ACF. This test allows for comparisons between the composition and makeup of the activated carbon. The TGA tests allow observations related to the material behavior under temperature conditions and drawing conclusions based on the variation of the activated material. Consequently, these assessments acknowledge important aspects of the ACs and provide a means for their comparisons. However, the adsorption capacity for bilirubin was not tested and therefore, direct conclusions regarding which material is a better adsorbent for bilirubin could not be drawn. Therefore, this test will be studied and conducted in further research.

## 5. Conclusion

The results presented above show that activation of date pits and CFRP was successful. The preparation of ACs from date pits and CFRPs and their characterization pave the way for their applications in the field of clinical practice, notably, for the adsorption of bilirubin, which is considered a toxin secreted by patients suffering from liver failure.

Data generated from the processes of activation and characterization showed that the rates of absorption for activated carbon fiber materials, as expected, were higher as compared to the date pits AC. This was noticed by the visibly larger peak frequencies on the FTIR graphs indicating higher absorption of the CFs. Furthermore, TGA graphs illustrated higher thermal properties meaning that the CF is a better adsorbent.

These findings also confirm the ability of date pits AC and CFRPs as adsorbent of toxins and potential candidates for consideration in the search for effective treatment options for liver failure.

## Acknowledgements

The authors would like to thank UAEU for their support of the project. This work has been financially funded by the SURE program at UAE University, Al Ain.

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