URUICST2016

URU International Conference on Science and Technology 2016

July 5, 2016

UTTARADIT, THAILAND

Ref. No. PA37-0014

Title: Acceptance Letter

To Wilaiporn Pongpein

On behalf of the organizing committee of URU International Conference on Science and Technology (URUICST2016) which will be held on 1-2 August, 2016 at Uttaradit Rajabhat University, Uttaradit, Thailand. I am pleased to inform you that your manuscript entitled "Electricity Production from Organic Wastes Fermentation by Microbial Fuel Cell Process", has met the accepted international academic standard of peer review, and has been accepted for Poster Presentation at URUICST 2016. Your manuscript will be published in the official conference proceedings after you edit according to the recommendations of reviewers.

For more detailed information about the conference and accommodation, please visit the conference website: http://uruicst2016.uru.ac.th

Thank you for your interest in participating in the conference. I am looking forward to meeting you at the conference.

Yours sincerely,

R. Wongla

Assist. Prof. Dr. Ruangdet Wongla
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Electricity Production from Organic Wastes Fermentation by Microbial Fuel Cell Process

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Keywords: Electricity Production; Microbial Fuel Cell; Organic Waste

Abstract. This research studied the electricity production from organic wastes fermentation by microbial fuel cell by using a single chamber microbial fuel cell (SCMFC). Two sizes (1 L and 10 L) of simple SCMFC were fabricated by using a cylindrical plastic tank which anode compartment and cathode compartment separated by plastic plate with hole and covered with cotton fabric. The anode electrode contacted with organic matter and microorganisms where anaerobic reaction occurred to generate electron and proton. The electrons transferred through an external circuit while the protons diffused through the solution to the cathode electrode for reducing oxygen to water. From the study of the effective of different type of electrodes (carbon graphite rod, zinc metal, and copper metal) to the electricity generation using the SCMFC size 1 L in the fermentation of the synthetic sweetness solution (22%Brix) with the effective microorganism (EM) for 36 hrs, it found that the fuel cell which used copper metal as electrode produced electricity increasing over times and has more efficient than the other electrode types. In the study of electricity generation from organic waste fermentation by using the SCMFC size 10 L and using copper metal as electrode, the results showed that the SCMFC with pineapple waste fermentation produced the current density, potential density, and power density higher than the fermentation of bananas and the fermentation of food garbage with EM. An optimal period of time for the production of electricity from this microbial fuel cell is the first five days of fermentation that the fuel cells has voltage of approximately 500 mV, the current density of 25.52 mA / m^2, potential density of 104.69 V / m^2 and power density of 12.59 mW / m^2, and then decline over time five days (120 hrs). Moreover the fermented liquid fertilizer and the residues by product from the fermentation in the fuel cell can be further used in agricultural because of the nutrient content (N, P, K), organic carbon and organic material available.

Introduction

The major part of all energy consumed for electrical production in most parts of the world comes from fossil sources such as petroleum, coal and natural gas. These non-renewable sources will be exhausted in near future. Moreover, transformation of these fossil sources to electricity is made via combustion process that causes of green house gases liberation. Thus, the search for alternative sources of renewable energy and sustainable energy for electrical energy production has gained importance [1]. A micro fuel cell (MFC) is a device that converts biochemical energy into electrical energy via the catalytic reaction of microorganisms [2]. Electricity generation from the MFC using anaerobic microbes is a recently technology with great potential for alternative green energy generation and environmental friendly. The MFC advantages over the technologies which used for generating energy from organic matter such as the direct conversion of organic substrate energy to electricity, operation at ambient temperature, not require gas treatment (only CO_2 emission), do not need energy input, and widespread application in location lacking electrical infrastructures [3]. A lot of organic substances are degraded by micro-organisms through anaerobic metabolism liberating electrons and protons in a biochemical cell using anode and cathode separated by ion exchange membrane. The electric current is generated through the flow of electrons via a complete electric circuit [4]. The microbes in the anode compartment oxidize organic substances generating electrons and proton as equation (1). Then electrons are transferred to the cathode compartment through the circuit and the proton through the membrane. At the cathode compartment, electrons and protons are used in the reduction reaction (as equation 2) for reducing oxygen to water [5-7].

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24H^+ + 24e^- \qquad (1)$$

$$6O_2 + 24H^+ + 24e^- \longrightarrow 12\,H_2O \qquad (2)$$

The MFC generally divided into two types of microbial fuel cells use a membrane (Membrane Microbial Fuel Cell, MMFC) and without a membrane (Membrane-less Microbial Fuel Cell, MLMFC). The microorganisms such as *Shewanella putrefaciens, Geobacter sulfurreducens, Geobacter metallireducens* and *Rhodoferax ferrireducens* show to generate electricity in the MFC without mediators by the electrochemically active redox enzymes on their outer membranes that transfer the electrons to the electrode without facilitate chemicals [8-10]. Several components of the MMFC are very expensive; ion exchange membrane and electrodes, also problems with strength on a large scale. Recently, a single chamber microbial fuel cell (SCMFC) has been developing to produce electricity by using single column reactor without both of ion exchanged membrane and mediators [11]. The SCMFC consists of column which divided of anode and cathode compartments without ion exchange membrane separation. At the anode part, the enrich microorganisms (the increasing number of infections microbial) is added into the organic waste to produce electron and proton by anaerobic reaction. Electrons are transferred through an external circuit while the protons diffuse through the solution to the cathode, where electrons combine with protons and oxygen to form water. The electrical producing potential of the SCMFC depends on several factors such as microorganism species, organic substances, operating condition, electrode metals, and carbon and nitrogen sources. Recently, the SCMFC technology is widely used in water treatment because not only waste water treatment but also generate electricity [12-14]. In Thailand, knowledge of organic waste fermentation to produce bio-fermented liquid for using in agriculture and health care have been created and developed by local wisdom scholars for long times ago. The simple equipments were used to construct the fermentation container similar to the SCMFC. The aims of this research were to study electricity generation from organic waste fermentation and properties of the fermentation by products.

Material and Method

Microbial Fuel Cell Fabrication

The SCMFC in this research was fabricated into two sizes for experimental. The first one was designed the chamber size about 1 L for study the factor of electrode metal types (carbon, zinc, and copper) to electricity generation by the SCMFC. The second chamber was designed size volume about 10 L for study the formula fermentation to electricity generation and some properties of the bio fermented water and the fermented solid waste from the SCMFC. Both of the two size chamber was designed by a similar manner as shown in Figure 1. The SCMFC was fabricated simply by using a cylindrical plastic tank with desire volumes. The anode compartment and the cathode compartment was separated by using plastic plate with hole and covered with cotton fabric. At the bottom part, the anode electrode contacted with organic matter and microorganisms that electrons and protons were produced via anaerobic reaction. Electrons transferred through an external circuit while the protons diffused through the solution to the cathode electrode at the upper part, where oxygen gas from air was filled to combine with protons and electron to form water. The generated currents and the electrode potential were recorded by using a digital multimeter (model UT61B, Guangdon, China).

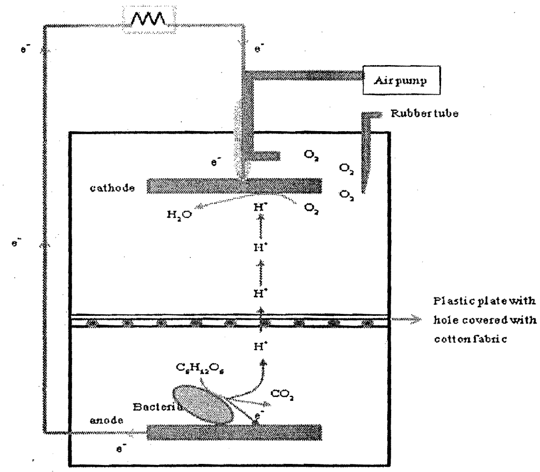

Figure 1 Representation a simply construction and working principle of the fabricated SCMFC

Chemical and Fermentation formula

The synthesis solution with the sweetness 22% Brix was prepared by mixing 250 mL of coconut juice with cane sugar 100 g and water to give the total solution volume of 500 mL. The bio fermented water from fruit was prepared by mixing 3 kg of ripe fruit with 1 kg of cane sugar. The bio fermented water from bamboo shoot was prepared by mixing 3 kg of bamboo shoot with 1 kg of molasses and 5 L of water. The bio fermented water from organic waste (garbage) was prepared by mixing 3 kg of organic waste with 1 kg of molasses and 5 L of water. Microorganisms used in this study were a natural microbial and an effective microorganism (EM) which purchased from the EMRO-Asia company (the EM composed of three microorganism group; lactic acid microorganism, yeast, and photosynthetic bacteria). In cases of fermentation with microbial, the microbial was added into the mixed solution by using 0.5 kg.

The study of different electrode types to the electricity generation

This experimental was studied by the simply microbial fuel cell set (total volume 1 L) by using plastic containers and air pump as shown in figure 2. The plastic container bottom was used for containing a synthetic sweetener solution volume 500 mL, a microbe, and the anode electrode. The plastic container above, its bottom was made small holes distribute around the area and cover with a cellulose membrane (dialysis membrane) and cotton fabric. This container was used for containing distilled water volume 500 mL and the cathode electrode and at the top of this container was made two small holes for oxygen as filling (by air pumps) and for gases venting. The carbon graphite rod, zinc metal, and copper metal were using as electrodes in electrochemical cells. The anode electrode and the cathode electrode terminals were separated by about 10 cm. The copper wires (long 55 cm) used for connecting the circuit between the electrodes through the digital multimeter to read.

The study of electricity production via organic waste fermentation

This step has manufactured a microbial fuel cell which expanding the quantity and size of containers used to ferment 10 L. In the oxidation reaction (anode), a copper rod inserted into the material for fermentation mash with brown sugar or molasses and microorganisms, the reduction reaction (the polar caps dial) was a copper rod immersed in a water tank inside the container. The copper rods, each with a radius of 5 mm and has a surface area of approximately 4,714 mm^2 used in the reaction. The bipolar electrodes were separated by about 10 cm, about 70 cm long copper wires connecting the circuit between the electrodes through the multimeter to read. Studying of the microbial fuel cells performance was carried out by using three formula of fermentation;

Formula 1: Fermentation of pineapple waste
Formula 2: Fermentation of bananas waste
Formula 3: Fermentation of food garbage + EM

The study of bio fermented fertilizer and solid waste properties investigation

The pH and conductivity of the liquid fertilizer were analyzed by using pH-Conductivity meter (GC700, EUTECH Singapore). In addition the nutrient content (N, P, K) percent of organic carbon (%OC) percent of organic material (%OM) and carbon nitrogen ratio (C/N ratio) of the liquid organic fertilizer and residues material were also determined. For total nitrogen content determination (%N) was analyzed according to the Kjeldahl method which consisted of digestion step by using sulfuric acid, distillation step, and titration step by using hydrochloric acid then the percent of total nitrogen was calculated. The total phosphorus content determination (%P) was analyzed according to the spectrophotometric molybdovanadophosphate method. This method, the sample was digested in the mixing solution of $HClO_4$: HNO_3 then it was formed color the vanadomolydate reagent. The resulting complexe substance (yellow color solution) was determined phosphate content by using UV-Vis sphectrophotometer (model UV-1700, Simadzu Japan) at 420 nm and compared with a standard solution of phosphorus. The total potassium content determination (%K) was analyzed flame photometric method. The sample was digested as same as the phosphate content dermination. Then the sample solution was determined potassium content by using atomic absorption spectrometer (model 3110, Perkin Elmer USA) at 766 nm [15]. The OC, OM, and C/N ratio were analyzed as follows: weighed 0.3-0.5 grams of sample a 250 ml Erlenmeyer flask and added 10 mL of 1 N potassium dichromate solution, 10 mL of 98% H_2SO_4, and 0.5 mL of o-phenanthroline ferrous sulfate into the mixed solution. Then the mixed solution was titrated with 0.5 N of ferrous sulfate until the end point of titration (the color of solution change from green color to brown-red color). From the weigh (m) of sample (g), the volume (V) of $FeSO_4$ in titration (mL) and the ratio of $K_2Cr_2O_7$ volume (mL) to the $FeSO_4$ volume (mL) for the titration with $K_2Cr_2O_7$ in the blank which represented by B value then the The %OC, %OM, and C/N ratio was calculated by following equations;

$$\%OC = \frac{0.3896 \times [B \times V] - 10}{m} \tag{3}$$

$$\%OM = \%OC \times 1.7241 \tag{4}$$

$$C/N = \%OC \times \%N \tag{5}$$

Results and Discussion

The effectiveness of different electrode types to electricity generation

The simply microbial fuel cell set used in this study as shown in Figure 2. The resistance of the completed circuit on the integrated electrodes of carbon electrode, zinc electrode and copper electrodes were 27 kΩ, 12 kΩ and 6 kΩ, respectively.

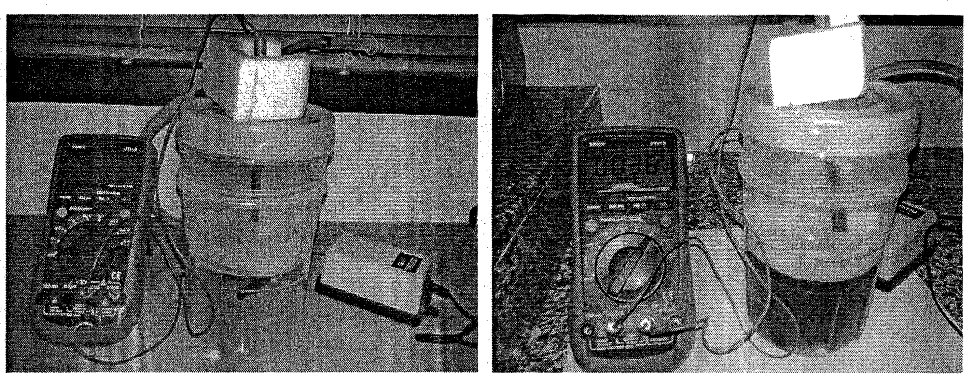

Figure 2 Representation a simply designed the SCMFC sets

From the performance of microbial fuel cell using a mild coconut mixed with sugar (sucrose) to give a sweetness about 22% Brix (concentrated solution of sucrose, about 20% wt/v), the mixed sweetener solution have a pH of 6.08 with conductivity 19.22 mS. The electric current, potential, current density, potential density, and power density of each electrodes as shown in Table 1 and Table 2.

Table 1 Represent electric current (I) and potential (V) of the cell as a function of times (hrs)

times (hrs)	Carbon electrode		Zinc electrode		Copper electrode	
	I (μA)	V (mV)	I (μA)	V (mV)	I (μA)	V (mV)
3	1.3	35.8	8.7	113.6	22.8	136.8
6	1.9	52.1	12.8	163.8	25.8	149.6
9	2.2	60.5	18.3	238.2	27.6	162.8
12	2.8	76.7	21.6	267.8	29.4	189.2
18	3.6	101.7	29.2	358.4	31.8	198.8
24	5.6	152.3	32.8	403.6	35.5	223.6
30	7.2	189.6	38.8	427.7	48.5	335.8
36	6.8	178.4	34.6	412.1	61.2	438.2

Table 2 Represent current density, potential density, and power density of the cell as a function of times

times (hrs)	Carbon electrode			Zinc electrode			Copper electrode		
	I density (mA/m^2)	V density (V/m^2)	P density (mW/m^2)	I density (mA/m^2)	V density (V/m^2)	P density (mW/m^2)	I density (mA/m^2)	V density (V/m^2)	P density (mW/m^2)
3	0.94	25.92	0.0337	2.18	28.40	0.2471	5.70	34.20	0.7798
6	1.38	37.73	0.0717	3.20	40.95	0.5242	6.45	37.40	0.9649
9	1.59	43.81	0.0964	4.58	59.55	1.0898	6.90	40.70	1.1233
12	2.03	55.54	0.1555	5.40	66.95	1.4461	7.35	47.30	1.3906
18	2.61	73.64	0.2651	7.30	89.60	2.6163	7.95	49.70	1.5805
24	4.06	110.28	0.6176	8.20	100.90	3.3095	8.88	55.90	1.9845
30	5.21	137.29	0.9885	9.70	106.93	4.1487	12.13	83.95	4.0716
36	4.92	129.18	0.8784	8.65	103.03	3.5647	15.30	109.55	6.7045

The results indicated that the microbial fuel cell which used carbon rods, galvanized sheet metal (zinc metal), and copper sheet metal as electrodes have the current density of the fuel cell of different electrodes (over times 30 hrs) equal 5.21 mA / m^2, 9.70 mA / m^2 and 12.13 mA / m^2, respectively. After that, the current density of the fuel cells which used rods and galvanized sheet metal as electrode were decreasing. While as the fuel cell with copper sheet metal as electrode was increasing to 15.30 mA / m^2. In addition it is possible in the same way as for the potential density is detected and the power density was calculated using copper as electrodes. Therefore microbial fuel cell in this study which used the copper metal as electrodes produced electricity increasing over times and has more efficient than using of carbon or zinc metal as electrodes.

Electricity production from organic waste fermentation

The results of the power and voltage of the fuel cells generated from three formulas organic waste fermentation (the mixture found sugar not more than 15% Brix) are shown in Table 3.

Table 3 Fuel cells performance to generate current potential and power from fermentation

Formula/Day	Current (μA)	Potential (mV)	Current density (mA/m^2)	Potential density (V/m^2)	Power density (mW/m^2)
Formula 1: Fermentation of pineapple waste					
Day1 (24 hrs)	65.3	250.2	13.85	53.08	3.47
Day3 (72 hrs)	120.3	493.5	25.52	104.69	12.59
Day5 (120 hrs)	98.8	375.8	20.96	79.72	7.88
Formula 2: Fermentation of bananas waste					
Day1 (24 hrs)	60.2	200.4	12.77	42.51	2.56
Day3 (72 hrs)	112.7	465.1	23.91	98.66	11.12
Day5 (120 hrs)	73.3	287.3	15.55	60.95	4.47
Formula 3: Fermentation of food garbage + EM					
Day1 (24 hrs)	45.4	150.3	9.63	31.88	1.45
Day3 (72 hrs)	101.1	384.4	21.45	81.54	8.24
Day5 (120 hrs)	63.1	244.5	13.39	51.87	3.27

In this study, the microbial fuel cell generated electricity from the procedures of organic waste fermentation. The total resistance of the cell cycle electric power of approximately 4 kΩ. Each of cells carried out by using pineapple fermentation and banana fermentation has the cell voltage of approximately 500 mV. As the duration of fermentation over three days (72 hrs), the fuel cells prepared from pineapple fermentation has the current density of 25.52 mA / m^2, potential density of 104.69 V / m^2 and power density of 12.59 mW / m^2, and then decline over time five days (120 hrs). This results in a trend similar to the cells which carried out with bananas waste fermentation and food garbage + EM fermentation.

Properties of bio liquid fertilizer and solid residue investigation

After the fermentation had completed, the fermented liquid fertilizer and the residues were analyzed qualities. The results are shown in Table 4-5

Table 4 Physical properties, quantity of fertilizer, percent of OC and OM, and C/N ratio found in the of the bio fermented water

Fermentation formula	pH of the solution	Solution conductivity(ds/m)	Percent of fertilizer			Percent of		C/N ratio
			N	P	K	OC	OM	
Formula 1	3.77	17.81	0.25	0.04	1.35	1.47	2.52	5.88
Formula 2	3.81	15.62	0.25	0.03	1.73	1.46	2.52	5.84
Formula 3	4.03	13.16	0.25	0.12	3.08	8.96	15.41	35.84

Table 5 Quantity of fertilizer, percent of OC and OM, and C/N ratio found in the residues extracted from the bio fermented water

Fermentation formula	Percent of fertilizer			Percent of		C/N ratio
	N	P	K	OC	OM	
Formula 1	0.15	0.02	1.12	2.76	4.75	18.4
Formula 2	0.12	0.01	1.37	2.53	4.36	21.08
Formula 3	0.18	0.08	2.51	4.16	7.17	23.11

Conclusion

In this study, the fabrication of simple microbial fuel cells can generate electricity. The design of the fuel cell is SCMFC via the redox reaction. It found that using of a copper metal electrode can generates the current density, potential density, and power density higher than the using of a carbon electrode and a zinc metal electrode. From the study on the operation of the fuel cell (size volume 10 L) with using copper rod as electrodes, it found that the fermentation of fermented pineapple can produces the current density, potential density, and power density higher than the fermentation of bananas and the fermentation of food garbage with EM. A reasonable period of time for the production of electricity from this microbial fuel cell is the first five days of fermentation. Guidelines for use in microbial fuel cells as a source of electrical power can be made by individual cells connected in series to provide the voltage and power consumption increase for utilization. In addition, by-product from the production of electricity is fermented or bio-liquid fertilizer and residues waste left by the filter which can be further used in agriculture.

Acknowledgement

This work was subsidized by budgets of Phetchabun Rajabhat University which considered by the National Research Council of Thailand. Thank also to Faculty of Science and Technology, Phetchabun Rajabhat University for laboratory instruments support and facilitation in this study.

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Production of activated carbon from moldy damaged tamarind-pod

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Keywords: activated carbon, tamarind pod, pyrolysis

Abstract. This research studied production of activated carbon (AC) derived from tamarind pods damaged by mold. Folk wisdom kiln which manufactured from an oil tank size of 200 L was used for pyrolysis and carbonization of tamarind pod derived from sweet and sour tamarinds. The AC was produced by using chemical activation and thermal activation at the optimal condition. Then the physical and chemical properties of the AC were investigated. From the study, it was found that optimal condition for charcoal carbonization of the tamarind pod was 400 ^{0}C for 4 hrs. The optimal condition for thermal activation was 600 ^{0}C for 1-2 hrs. The phosphoric acid (H_3PO_4) showed higher effectiveness for activation than distillation water (H_2O), potassium hydroxide (KOH) and zinc chloride ($ZnCl_2$). The produced AC has specific surface area of 851.58-910.31 m^2/g (BET Theory), a pore volume of 2.24-2.32 cm^3/g with an average pore radius of 50.90 to 52.53 Å, iodine number of 613.9-654.8 mg /g, phenols adsorption of 61.7-83.1% and apparent density 0.4528 g/cm^3. The results from proximate analysis shown that the AC has the moisture content of 6.81-7.54%, the ash content of 6.58-7.31%, the volatile matter of 38.26-40.12% and the fixed carbon of 52.57-55.16%. The performance of the AC for acetic acid adsorption according to the Langmuir and Freundlich isotherm exhibited a monolayer adsorption isotherm and the AC adsorbed the acetic acid well and strength. Therefore the produced AC can be further used for filter material in small water treatment.

Introduction

Activated carbons (AC) are carbonaceous materials that can be used as an absorbent due to its capacity for adsorption [1]. These materials are characterized by their extraordinary large specific surface areas, well-developed porosity and tunable surface-containing functional groups [2-3]. Important applications relate to the AC surface properties, it has been using as adsorbents materials for removal of taste, color, odor, and undesirable organic and chemicals impurities in the waste water treatment from domestic and industrial [4-6]. In addition, it can be used as adsorbents materials for pollution treatment and some industrials processing such as sugar industry and beverage industry [7-9]. The AC production with an inexpensive cost is the challenges in commercial manufacturing. The using of inexpensive raw materials is one of the main factors to consider for both of application used and commercial manufacturing. Generally, the raw materials for the production of AC are those with high carbon but low inorganic contents materials such as wood, lignite, peat and coal [7]. In addition, a lot of agricultural waste and by product have successfully converted to AC for example macadamia nutshell, paper mill sludge [10-13]. In Phetchabun Province, Thailand, there are potential raw materials resources from agricultural for the production of the activated carbon. In this research, agricultural waste of moldy damaged tamarind pod which released from local sweet tamarind orchards was used to produce an activated carbon due to the availability and inexpensive material with high carbon and low inorganic content.

Experimental

Materials. The moldy damaged tamarind pods were collected from tamarind orchards (both of sweet tamrind pod and sour tamrind pod) in Phetchabun Province. Tamarind pod charcoal was prepared by using the folk wisdom kiln volume in pyrolysis process of the moldy damaged tamarind pod at charcoal carbonization condition of 400 ^{0}C for 4 hrs. After that the charcoal was crushed by ball mild machine in to a small granular and sieved to mesh size 8-14. All chemicals were of reagent grade.

Activated carbon production. The AC from tamarind pod was prepared by using phosphoric acid (H_3PO_4), Potassium hydroxide (KOH), and Zinc chloride ($ZnCl_2$) compared with distillation water in the charcoal activation. The test samples were divided into four portions; the first part mixed with 60% wt/v of H_3PO_4 (500 g of sample + 500 mL of H_3PO_4), the second part mixed with 60% wt/v of KOH (500 g of sample + 500 mL of KOH), the third part mixed with 60% wt/v of $ZnCl_2$ (500 g of sample + 500 mL of $ZnCl_2$), and the fourth part mixed with distillation water (500 g of sample + 500 mL of H_2O) and then left the mixed sample for 24 hrs at the room temperature. After that the activated charcoal samples were filtrated and oven dried at 110 ^{0}C for 3 hrs. All of the activated charcoal samples were pyrolysed at 600 ^{0}C for 1 hr in electric muffle furnace and then let it cool down to room temperature. The activated carbon samples were leached with distillation water many times until achieved a neutral pH. Finally, the activated carbon samples were dried in electric oven at 110 ^{0}C for 3 hrs and stored in a desiccant for use in further experiments.

Surface morphology and characteristics. Surface morphology of the activated carbon was characterized by scanning electron microscopy (SEM, JSM-6335F: JEOL, Japan). The activated carbon surface characteristics investigation was carried out by using the surface area & pore size analyzer by gas sorption (Autosorb 1MP: Quantachrome, USA) and operated under nitrogen gas condition at low temperature.

Proximate analysis of activated carbon. The proximate analysis of the AC which derived from tamarind pod was carried out according to ASTM D3173-95 (for moisture analysis), ASTM D3175-95 (for volatile matter analysis), ASTM D3174-95 (for ash analysis), and fixed carbon (100- ash % - volatile matter %). The apparent density of the AC sample was obtained by weighting 5 g of the activated carbon and transferring it into a 10 mL graduated cylinder. The cylinder was tamping with a rubber pad while activated carbon was being added until the entire original sample was transferred to the cylinder. Tamping was continued for 5 minutes until there was no further settling produced. The volume was recorded and the apparent density was calculated on the dry basis:

$$\text{Apparent density} = \frac{\text{weight of the sample (g)}}{\text{volume of the sample (l)}} \tag{1}$$

All the experiments were carried out in triplicate and averages were presented. The results were compared with commercial activated carbon in local market.

Iodine value and phenol adsorption of the activated carbon. Iodine adsorption form liquid phase is considered a simple and quick test for evaluation the surface area of the activated carbons associated with pores larger than 1 nm. The iodine value (defined as the amount of iodine adsorbed per gram of activated carbon at an equilibrium concentration of 0.02 N) was measured according to the procedure established by the ASTM D4607-94. Phenol adsorption on the AC was studied by the standard method AWWA B600-86. The residual filtrated phenol concentration was determined by using UV-Visible spectrophotometer (UV-1700: Simadzu, Japan). The adsorbed phenol was calculated from percent of residual filtrate phenol. Each experiment was carried out in triplicate under identical conditions.

Acetic acid adsorption characteristics. The acetic acid adsorption (in batch experiments) on the AC was studied as follows; The AC was dried at a temperature of 110-120 ^{0}C for one hour, then leave to cool. Weighing approximately 2 ± 0.01 grams of the AC into seven Erlenmeyer flasks. Different acetic acid concentrations: 0.5, 0.4, 0.2, 0.1, 0.04 and 0.02 M (volume of 100 ml) was added into each flask and covered. All samples were shaken for 2 hrs in an orbital shaker at room temperature. Then all the samples were filtered through Whatman No.1 filter paper. The filtrated solution was titrated with 10.0 mL of 0.3 M sodium hydroxide (the actual concentration was determined by potassium phthalate standard solution) by using phenolphthalein as indicator. The obtained data was used to create graphs according to the Langmuir isotherm and the Freundlich isotherm.

Results and Discussion

Surface morphology and characteristics

The AC in this research was prepared from sweet and sour tamarind (*Tamarindus indica L.)* pods damaged by mold by using the homemade kiln in pyrolysis process. Most of molds found in tamarind pods are group of bacteria such as *Phomopsis* sp., *Aspergillus sp.,* and *Aspergillus niger* [14]. In the AC production, the mold damaged tamarind pods (Fig.1(a)) was carbonized at 400 ^{0}C for 4 hrs to give the tamarind pod charcoal (Fig. 1(b)). Then it was pulverized by ball mill machine to produce a small granular and sieved to mesh size 8-14. After that the granular charcoal (Fig.1(c)) was activated by using chemical and thermal at 600 ^{0}C for 2 hrs to give the activated carbon as in the Fig. 1(d).

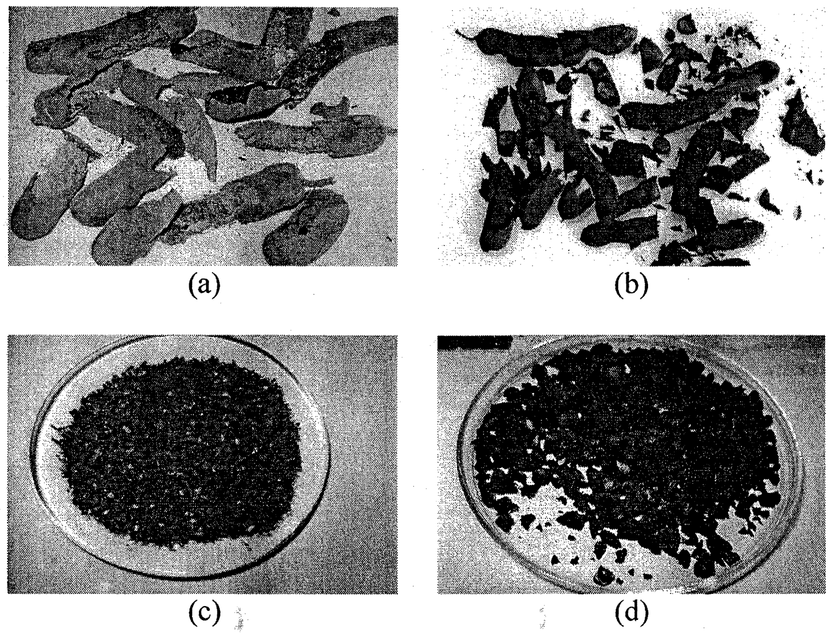

Fig. 1 shows images of (a) the moldy damaged tamarind pods (b) the tamarind pod charcoal (c) the granular charcoal and (d) the granular activated carbon.

Surface morphology of the AC was characterized by SEM technique showed in Fig. 2. From the photographs, the AC derived from the tamarind pod (activation by H_3PO_4) showed open micro-porous structure and many holes on the carbon surface with broken edges (Fig.2 (a)-(b)). Compared with the commercial activated carbon (derived from coconut shell), it showed cracking hole between the carbon surface and has dense microstructure (Fig.2(c) which is different from the AC derived from the tamarind pods.

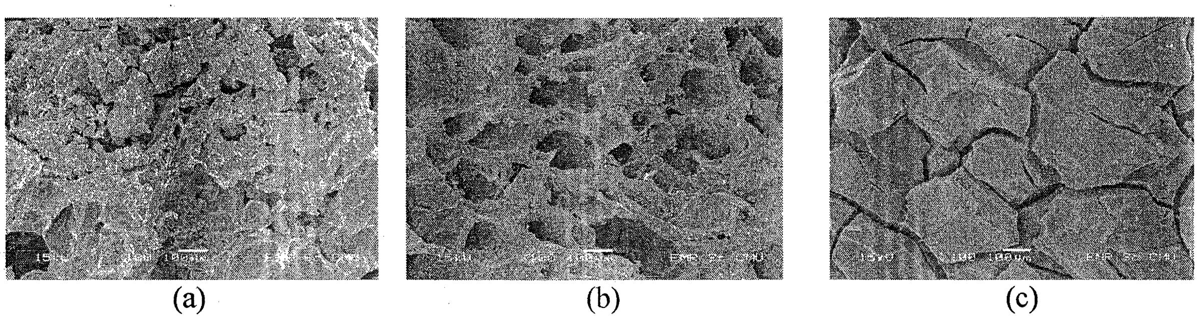

Fig 2. SEM images of (a) microstructure of the AC derived from the tamarind pod (b) open micro-porous structure and many holes on the carbon surface and (c) the surface of commercial activated carbon (derived from coconut shell).

From BET surface area analysis of the AC derived from the tamarind pod which using H_3PO_4 as the activation chemical, the results showed in table 1.

Table 1. BET surface area of activated samples

The AC material from	Surface analysis of sample		Porosity analysis of sample	
	Specific surface, S_t (m^2/g) BET Theory	Surface area per gram of sample (m^2/g)	Pore volume, V_p (cc/g)	Average pore size(Å)
sweet tamarind pod with H_3PO_4 activation	851.58	6202.33	2.24	52.53
sour tamarind pod with H_3PO_4 activation	910.31	6644.59	2.32	50.90

From the table, the AC sample has surface area as 851 - 910 $m^2\ g^{-1}$ (BET Theory) and surface area per gram of samples equal 6202.33 $m^2.g^{-1}$. The results from porosity analysis found that it has porosity in the range of 2.24 cc g^{-1} and average pore radius in the range of 52.53 Å. While the commercial activated carbons (used for filtration) which are sold in the local market generally have specific surface area of approximately 1100 $m^2\ g^{-1}$ (BET Theory). Thus the AC from tamarind pod which produced in this study has a surface area close to the commercial grade activated carbon.

Proximate analysis of activated carbon

The data on proximate analysis of the AC derived from sweet tamarind pod are present in table 2.

Table 2. Proximate analysis of the AC derived from sweet and sour tamarind pod

Proximate analysis	The activated carbon derived from	
	Sweet tamarind pod	Sour tamarind pod
Moisture (% wt)	7.54	6.81
Ash (% wt)	6.58	7.31
Volatile matter (% wt)	38.26	40.12
Fixed carbon (% wt)	55.16	52.57

The apparent density of the AC is about 0.4528 g cm^{-3} which in the range of the Thai industrial standard institute (900-2547) which not allows the apparent density lower than 0.20 g cm^{-3} and the moisture higher than 8%. Thus, the prepared AC by using this process produces the AC which has quality under acceptable of the Thai industrial standard for commercial. In addition the production cost of the AC in this process is lower than 145 baths per kilogram.

Iodine value and phenol adsorption of the activated carbon

In the present study, different activating agents are expected to significantly affect the extent of activation the charcoal derived from sweet tamarind and sour tamarind. The effect of different activating agents (H_3PO_4, KOH, $ZnCl_2$, and H_2O) on the iodine value (iodine number) and phenol adsorption were evaluated and compared as shown in table 3.

Table 3. The effect of chemical activation agents to iodine adsorption and phenol adsorption

Chemical activation agent	Sweet tamarind pod		Sour tamarind pod	
	Iodine adsorption (mg/g)	Phenol adsorption (%)	Iodine adsorption (mg/g)	Phenol adsorption (%)
H_3PO_4	641.1	83.1	654.8	81.5
KOH	625.6	65.6	633.5	61.7
$ZnCl_2$	613.9	68.2	618.4	67.8
H_2O	630.7	72.4	625.1	70.5

The results show that the activation with H_3PO_4 gives the highest iodine adsorption value and phenol adsorption of the AC which derived from both of sweet tamarind and sour tamarind. For the sweet tamarind, activation with only H_2O can produces the AC with iodine adsorption value and phenol adsorption higher than the activation with KOH and $ZnCl_2$. The iodine adsorption values in this experiment are higher than 613 mg/g and the phenol adsorptions are higher than 70% that is a characteristic of the AC derived from tamarind pod.

Acetic acid adsorption characteristics

The performance of the AC for adsorption can be obtained from plotting graph according to Langmuir and Freundlich adsorption isotherms. The Langmuir isotherm linear equation derived a relationship for the amount of solute adsorbed per weight of adsorbent (X/m which represent by q_e) and the remaining concentrations in the solution (C_e) at equilibrium [3,7-8]. These are based on some reasonable assumptions: a uniform surface, a single layer of adsorbed material, and constant temperature. Langmuir isotherm assumes that the number of adsorption site is fixed and that adsorption is reversible. The Langmuir equation in the adsorption of solute on adsorbent surface was linearized as follows:

$$\frac{C_e}{q_e} = \frac{1}{kN_m} + \frac{C_e}{N_m} \tag{2}$$

From the Langmuir isotherm, the relationship between specific surface area of the adsorbent (A) and maximum moles of solute per unit mass of adsorbent (N_m) shown in equation (3). Whereas N_o is Avogadro constant and δ is the area of acetic acid is adsorbed on the surface of the adsorbent equal 21 Å.

$$A = N_m N_o \delta \times 10^{-20} \text{ m}^2 \tag{3}$$

Freundlich isotherm is one of the most popular empirical equation which is used to express the mathematic relationship between the quantity of impurity remaining in solution versus the quantity adsorbed. The Freundlich equation was linearized as follows:

$$\log(q_e) = \log k + \frac{1}{n}\log C_e \tag{4}$$

Plotting values of X/m (represent by q_e) vs. C_e on log-log paper, the isotherm is obtained. The interception of the graph indicates log k and the slope of the line indicates 1/n. The k and n are constant value of Freundlich isotherm. In this present study, adsorption of acetic acid (organic solute) on the AC derived from the sweet tamarind was studied. The plotting graph according to the Langmuir equation and the Freundlich equation was exhibited as Fig. 3 and Fig.4.

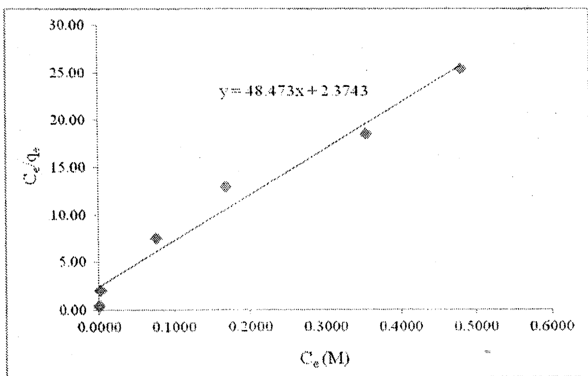

Figure 3. The plotting graph according to the Langmuir equation of acetic acid adsorption

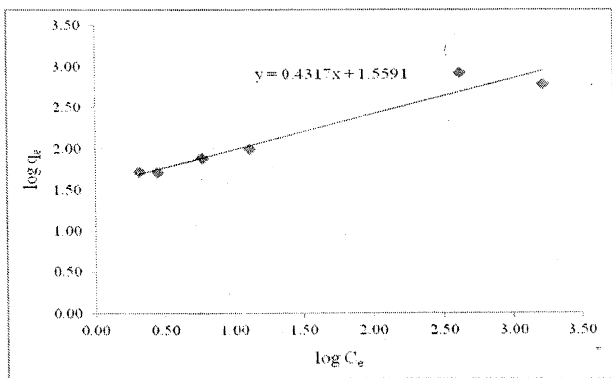

Figure 4. The plotting graph according to the Freundlich equation of acetic acid adsorption

The results of acetic acid adsorption on the AC according to the Langmuir linear equation shown that the N_m equal 0.0206 (slope = $1/N_m$). The specific surface area of the AC equals 2608 m^2. The graph plotted by the Freundlich equation has log k equal 1.5591 then the k constant is 36.2326. The k constant indicated adsorption capacity of the solute on the AC surface. The high k constant related to high adsorption of solute on adsorbent surface. Then there is higher acetic acid concentration adsorbed on adsorbent surface (higher of X/m). The value of 1/n indicated the strength of adsorption. From the graph, the 1/n value equal 0.4317 then the n value equal 2.3164 indicated that there is high strength of adsorption on the AC surface and show a good adsorbent characteristic [3].

Summary

In this study, tamarind pod damaged by mold was used for the AC production. Carbonization of the tamarind pod was carried out by using the folk wisdom kiln size of 200 L in carbonization at 400 ^{0}C for 4 hrs. Then the activation process was done by using chemicals and thermal activation at 600 ^{0}C for 2 hrs. The H_3PO_4 showed higher efficiency for activation than others chemical. The produced AC has apparent density of 0.4528 g/cm^3, specific surface area higher than 851 m^2/g, pore volume of 2.24-2.32 cm^3/g, and average pore radius of 50.90-52.53 Å. It has iodine number more than 613 mg/g and phenols adsorption approximately 61-83%. From acetic acid adsorption investigated by the Langmuir isotherm and the Freundlich isotherm showed monolayer adsorption isotherm and the activated carbon can adsorbs the acetic acid well and strength. Therefore the AC which produced by using tamarind pod and activation at the optimal condition can be applied for commercial material utilization next.

Acknowledgement

This work was subsidized by budgets of Phetchabun Rajabhat University which considered by the National Research Council of Thailand. Thank also to Faculty of Science and Technology, Phetchabun Rajabhat University for laboratory instruments support and facilitation in this study.

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