Activated Carbon from Bagasse for Syrup Decolorization as an Alternative for Waste Management and the Assessment of Carbon Footprint

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Abstract

The aims of this research were to produce activated carbon from sugarcane bagasse using carbon dioxide as an activating agent for syrup decolorization and to calculate its carbon footprint as an alternative waste management method. Sugarcane bagasse was prepared from carbonization process with a nitrogen flow rate of 0.2 L/min at temperatures of 500°C, 550°C, and 600°C for 20, 40, and 60 mins., respectively. A carbonization condition of 550°C for 40 mins was used to activate the sample with nitrogen and carbon dioxide at a temperature of 800°C. Activation time and ratios between nitrogen and carbon dioxide were compared to the existing chemical resin method for syrup decolorization. ICUMSA method was used at temperatures of 70°C-75°C and a pH of 7. Carbon footprint of 0.5 g activated carbon for syrup decolorization was 1.51 kgCO_2-eq and 66% of carbon footprint value come from utilization step.

Keywords: activated carbon/syrup decolorization/bagasse/waste management/carbon footprint

1. Introduction

Being concerned about global warming and climate change caused by greenhouse gases released into the atmosphere as a result of human activities such as: agriculture, and energy production, have become a driving factor for finding methods that can reduce the carbon footprint (CFP) of these activities. The measurement and calculation of greenhouse gas emissions have stated, that there are many activities such as electricity and water supply consumption, quantities of wastewater and garbage, and the amount of fossil fuels used causing greenhouse gas emission. The largest generators of greenhouse gases are: the use of electricity and solid waste (Aroonsrimorakot et al., 2013). Hence, power consumption and the amount of waste created should be focused upon (Aroonsrimorakot et al., 2013). Thailand is one of the main global food exporting countries and shares the worldwide concern about climate change, and as such it has initiated CFP and labeling in 2008 (Mungkung et al., 2012). CFP information is provided to follow consumers to choose products and services that minimize environmental impacts.

In sugar production, the production of refined sugar consists of five steps; affinated syrup, clarification, crystallization, centrifugal separation and drying. The clarification step is aimed to decolorize the refined syrups. the color of the finished product is the most important aspect. Ion exchange resin is normally used for sugar decolorization and it is regenerated by washing with saline water. Therefore, treatment, and disposal of the saline water are major production issues. Activated carbon (AC) can be produced from carbon sources such as coal (Ahmadpour and Do, 1996; Teng et al., 1996; Punsuwan, 2002), wood, peat, coconut shell and bagasse (Darmstadt et al., 2000; Kalderis et al., 2008) and sugar beet (Mudoga et al., 2008). Sugarcane bagasse was by-product of sugarcane industries obtained after the extraction process. This by-product was used in many processes such as fuel resources (Broek et al., 2000; Tippayawong and Nakpan, 2006), an additive for animal feed, silica source (Neaungjumnong et al., 2009; Worathanakul et al., 2009a, 2009b, 2011a, 2011b) and used as raw material for AC and application for decolorization process (Valix et al., 2004). AC can be produced by physical and chemical activation methods. For the physical activation method, steam (Bernado et al., 1997) and carbon dioxide can be used as an activating agent (Marsh and Reinoso, 2006). Bagasse can be used to produce AC for removal sugar colorant under carbonization at 700 °C (Pendyal et al., 1999). Qureshi and his co-workers (2007) used steam as activating agent at 700-900 °C in order to produce AC for sugar decolorization. They found that the sample was activated at 900 °C gave satisfactory decolorizing efficiency. Thummasorn (2007) found that 2.5 g of AC produced by bagasse reduced 50.97% of color in syrup at pH 8. Moreover, surface area of bagasse AC can be increased by preparation procedure. Devnarain et al. (2002) suggested that AC of baggasse obtained from pyrolysis process at 680 °C for 1 h following by steam activation process at 900 °C for 2 h gave AC with 995 m^2/g of surface area and iodine number 994 mg/g.

The replacing AC derived from bagasse produced a lot of benefits for the environmental aspects, such as waste utilization and chemical reduction according to cleaner production concepts, and thereby sustainable development (Bonilla et al., 2010). However, the CFP information was limited both in food industry and household appliances. Therefore, the CFP of food

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products and its by product should be studied because the food industry is essential. CFP studies of sugar production and related products is very important from the environmental persective since Thailand is the fourth exporter of sugar and sugar product of the World (International Sugar Statistics, 2008). The CFP of sugar production process in the East of Thailand was 0.55 $kgCO_2$-eq per 1 kg sugar obtained from 0.49 $kgCO_2$-eq of cultivation and 0.06 $kgCO_2$-eq of milling process (Yuttitham et al., 2011). The estimated CFP value not only shows the quantity of expressed CO_2, but also carried out the hot spot environmental impact of products cycles and can be used for production process improvement.

Therefore, the production of AC from sugarcane bagasse using CO_2 as activating agent in different conditions for syrup decolorization is the main objective of this research. The CFP of AC for decolorization process was then compared with resin usage.

2. Material and methods

2.1 AC preparation

Bagasse was dried, crushed and then placed in a reactor inside the furnace. Bagasse was carbonized under 0.2L/min N_2 at 500°C, 550°C, and 600°C for 20, 40, and 60 mins in the reactor, respectively. The appropriated sample was activated at 800 °C with different ratios between N_2 and CO_2 of 70:30, 60:40 and 50:50 for 20 and 40 mins.

2.2 Characterization of AC

Proximate analysis was determined using thermo gravimetric analysis (Perkin Elmer TGA7). The samples were heated under N_2 with a heating rate 15 °C/min from 30 °C to 960 °C. Scanning Electron Microscope (JEOL JSM-6400) was employed for the observation of morphology. The BET surface area measurement was performed by N_2 adsorption using an Autosorb1-C and refractometer was brix measurement to find decolorization efficiency.

2.3 Syrup decolorization efficiency

Syrup was diluted with distilled water (30%w/w) and adjusted to pH 7.0. The solution was then heated up to 70–75 °C with stirring at 160 rpm. 0.5 g of AC was added into the solution. The obtained sample was collected and filtered in the range of 0–120 mins. The absorbancy was determined at a wavelength of 420 nm. The color was shown in ICUMSA (IU) unit by equation (1):

$$\text{Color (IU)} = \frac{10^8 * A}{b * c} \tag{1}$$

where A = absorbance at wavelength 420 nm.
b = length of the absorbant path (cm)
c = concentration of sample (g/ml)

Decolorization efficiency was calculated by equation (2)

$$\text{Decolorization efficiency} = \frac{IU_{initial} - IU_{final}}{IU_{initial}} * 100 \tag{2}$$

2.4 Carbon footprint of AC

The CFP assessment consists of four main steps according to ISO 14040.

2.4.1 Goals and scope

The research boundary began from raw materials acquisition, AC preparation, distribution, syrup decolorization and disposal step according to Business-to-Customer scope (Fig. 1). Input and output were mainly collected from laboratory data. It was assumed that there is no emission at the distribution stage. At the disposal stage, waste was assumed to be assigned to landfills. The functional unit was 0.5 g of AC with highest syrup decolorization efficiency.

2.4.2 Inventory analysis

There are five steps including; acquisition of raw materials, AC preparation, distribution, syrups decolorizatin and disposal steps. Bagasse, N_2 and CO_2 were raw materials. All materials were transported to the laboratory area. There is no transportation to distributors because of usage only in the laboratory. The AC was used for syrup decolorization with 0.5 g in each batch, then absorbance and brix value were needed. In the disposal stage, all waste was assumed to be transported to a landfill site.

2.4.3 Impact Assessment

The amount of greenhouse gases emissions for AC production and its application was calculated in $kgCO_2$-eq unit.

2.4.4 Interpretation

Interpretation was affected to environment concerns and gave information with the highest CFP (hot spot) step. This step can be changed and improved with an appropriate process in the future.

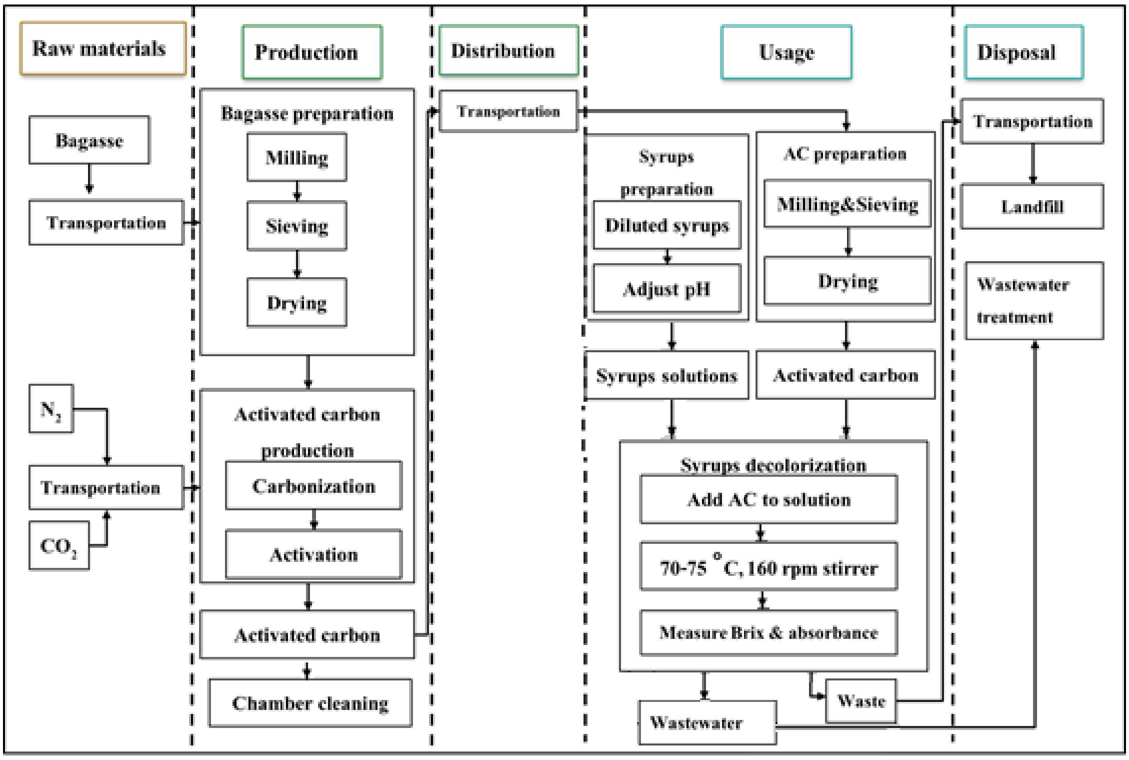

Figure 1: Boundaries of AC production for syrup decolorization

3. Results

3.1 Yield of AC

AC yield was the amount of original material remaining after pyrolysis and activation treatment (Broek et al., 2000). The yield of AC was 25-30% with different ratios of N_2 and CO_2. The yield of AC was decreased when activation time was increased. For the N_2 and CO_2 ratio with 70:30, the yield percentage was decreased from 30.48 to 25.61 when the activation time increased from 20 to 40 mins, respectively.

3.2 Proximate analysis

The proximate analysis of bagasse and AC was shown in Table 1. Found that AC production was composed of ash, volatile matter and fixed carbon in the range of 10-12%, 24–34% and 55–61% by weight, respectively.

Table 1
Proximate analysis of bagasse and AC

Sample	% composition (by weight)			
	Volatile matter	Fixed carbon	Ash	Moisture
BG	73.91	17.51	6	2.32
BG[a]	80.69	15.24	4.07	-
BG[b]	72.08	13.72	3.72	10.60
AC_70:30_20	12.51	61.17	25.76	-
AC_60:40_40	10.85	55.79	33.36	-
AC_50:50_20	10.15	55.97	33.88	-
AC_50:50_40	10.11	55.65	34.24	-
AC[a]	10.49	50.68	38.83	-
AC[b]	30.93	39.05	30.01	-

[a]Singchiwvong, 1994
[b]Thummasorn, 2007

3.3 Scanning electron microscope (SEM)

SEM images in Figure 2 showed the carbon physical structure of AC after activation for different conditions. It was found that AC surface disorganized pore spaces both large and small. Therefore, the prepared AC possessed high surface area and adsorptive capacity because of well-developed pores (Alam et al., 2008).

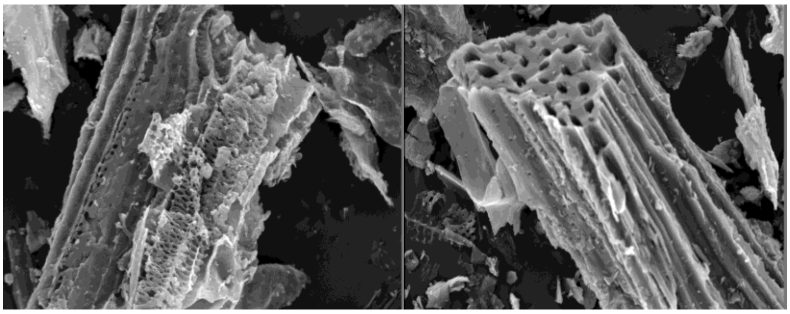

Figure 2. SEM of AC with ratio N_2:CO_2 = 60:40 for activation time 20 mins (a) and 40 mins (b)

3.4 Surface area, total pore volume and pore size

The char was prepared under by carbonization process with 0.2 L/min N_2 at 500 °C for 40 mins. AC was then activated at 800°C under N_2 and CO_2. Total surface area and pore volume of the AC was increased after activation step. The surface area was increased from 199.5 m^2/g to 370 m^2/g and pore volume was increased from 0.13 cm^3/g to 0.2 cm^3/g for char and AC, respectively.

3.5 Syrup decolorization efficiency

Syrup solutions were decolorized with 0.5 g AC loading from different conditions as shown in Figure 3. The results clearly showed that decolorizing performance of AC was increased when contact time increases to 80 mins. Moreover, decolorization efficiency was increased when activation time and CO_2 content increases. Both 60:40_40 and 50:50_40 samples exhibit around 20% decolorization efficiency. However, 60:40_40 sample was the best decolorizing performance (Figure.3) from this study and was further used to vary AC loading.

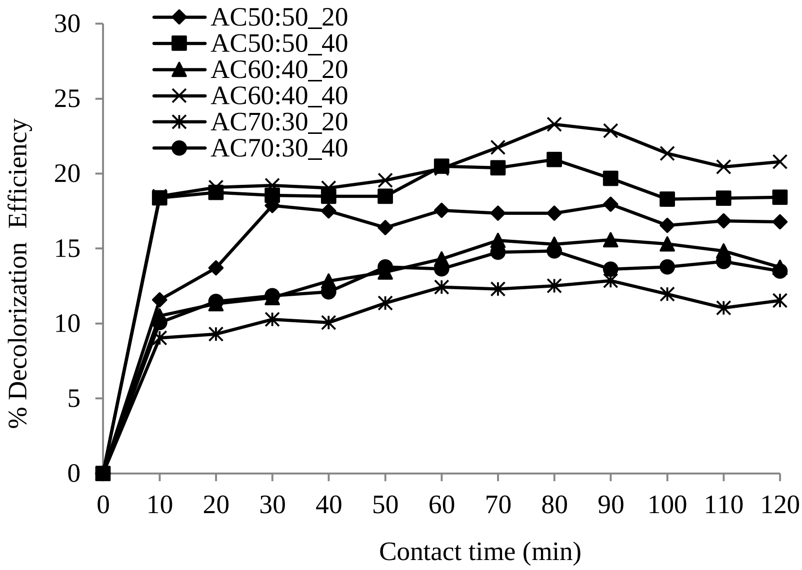

Figure 3. % Decolorization efficiency of different conditions of AC

The decolorization efficiency results of the AC under N_2:CO_2 ratios of 60:40 for 40 mins with different AC loadings were shown in Fig. 4. It showed that the adsorption equilibrium was 80 mins with 23-61% decolorization efficiency for 0.5-2.5 g. It is according to the quantity of loading that affected on the efficiency directly (Thummasorn,2007).

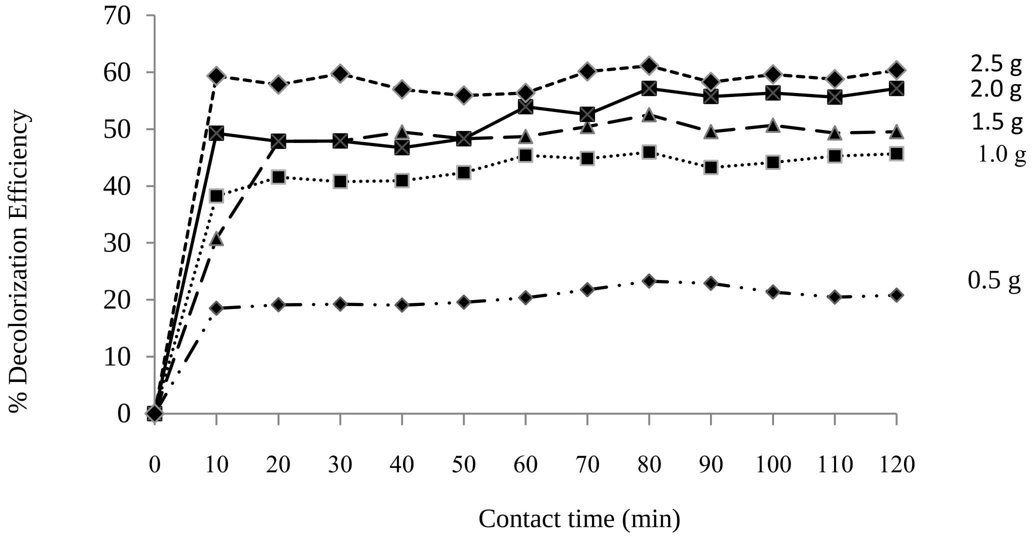

Figure 4. Decolorization efficiency of AC 60:40_40 with different loadings

3.6 Carbon footprint of AC from bagasse

The main results from this research study were focused on CFP evaluation part. In this work, AC with 60:40 of N_2:CO_2 ratio and 40 mins. were selected with because of its highest decolorization efficiency. The CFPs value of each stage and their transportation were calculated as shown in Table 2. The CFP of 0.5 g AC from bagasse for syrup decolorization was 1.51 kgCO_2–eq. The results showed that the highest CFP was syrup decolorization stage equivalent to 1.00 kgCO_2-eq approximately, accounting for 65.77% of total CFP. AC preparation process stage was the second one with 0.477 kgCO_2-eq, representing 31.45% followed by disposal and raw materials stages. This work could be further used for the process development for CFP reduction in each stage as well.

Table 2
Carbon footprint of AC in each stage for syrup decolorization

Activity	Carbon footprint (kg CO_2-eq)
Raw materials	6.26E-03
AC preparation	4.77E-01
Syrup decolorization usage stage	9.97E-01
Disposal	3.60E-02
Transportation for raw materials	1.11E-04
Transportation for usage stage	3.05E-03
Transportation for disposal stage	1.45E-11
Total carbon footprint of 0.5 g AC	1.51

CFP of the AC produced from bagasse with various loadings for syrup decolorization process were shown in Table 3. The results expressed that the CFP was increased when the amount of AC was increased. However, the decolorization efficiency was increased with AC loading too. Therefore, the balancing between environmental concern and process efficiency should be demonstrated.

Table 3
Carbon footprint of AC for syrup decolorization at different quantities

AC (g)	Decolorization efficiency (%)	Carbon footprint (kg CO_2-eq)
0.5	23.28	1.51
1.0	45.95	2.01
1.5	52.52	2.51
2.0	57.12	3.01
2.5	61.13	3.51

3.7 Carbon footprint comparison between AC and ion exchange resin

The CFP of ion exchange resin for syrup decolorization with 65% efficiency (The Purolite Company, 2009) was selected to compare CFP with AC derived from bagasse (Table 4). The results indicated that CFP of resin was less than that of the bagasse. The CFP of resin was calculated to be 2.59 $kgCO_2$-eq from raw materials, 0.728 $kgCO_2$-eq from utilization and 0.034 $kgCO_2$-eq from resin regeneration. The assumption from this calculation based on 90.83 g of resin, 250 ml of syrup solution and was then regenerated with 10% by weight saline water.

Table 4

Carbon footprint comparison between AC and resin for syrup decolorization

Properties	%Efficiency	footprint(kg CO_2-eq)
AC	61.13	3.51
Ion exchange resin	65.00	3.36

4. Discussion

4.1 Yield of AC

The results of AC and char 500_40 yields was found that AC yield was slightly less than char yield about 2-7%. Katyal and his co-researchers (2003) reported that the yield percentage was slightly reduced about 3-5% by weight at 500-700 °C carbonization steps. Thus, this AC production procedure was one of the effective methods giving 10% yield percentage higher than that of Singchiwvong's and Thummasorn's works (Singchiwvong, 1994; Thummasorn, 2007).

4.2 Proximate analysis

AC and bagasse results found that the composition of volatile matter in bagasse was decreased after activation because of cellulose and lignin decomposition. The material was more stable due to fixed carbon increased from volatile matter removal (Katyal et al., 2003). In addition, ash content was increased. This is due to organic matter were burnt out and left some minerals such as: silica, aluminum, iron, magnesium, and calcium (Qureshi et al., 2007).

The results were found that the volatile matter, fixed carbon and ash of AC in this research were higher than Singchiwvong's and Thummasorn's works (Singchiwvong, 1994; Thummasorn, 2007) as shown in Table 1. In conclusion, it could be shown the suitable condition for AC with high fixed carbon within N_2 and CO_2 ratio of 70:30 activated for 20 mins.

4.3 Surface area, total pore volume and pore size

In the activation process, the reaction between CO_2 and carbon in the sample occurred and CO was released leading to new pores as shown in SEM images (Fig.2). Moreover, activation under high temperature was found that the remaining tar in pores was released thus the surface area and total pore volume of the AC became higher than char (Ngernyen et al., 2006).

The surface area of AC in this research also concurred with other research (Singchiwvong, 1994; Devnarain et al., 2002; Thummasorn, 2007). However, the preparation AC method should be concerned about their different physical properties.

4.4 Syrup decolorization efficiency

Decolorization efficiency was increased when AC loading increases. This may be come from more active sites of adsorbent, therefore, the surface area was directly proportional to the amount of the AC. From our research, filling of AC 2.5 g can give a decolorization efficiency of 51% higher than others (Thummasorn, 2007).

4.5 Carbon footprint of AC from bagasse

Based on the practical application of the sugar industry, using existing heat within the factory system, it was found that the CFP of 0.5 g AC from bagasse for syrups decolorization was 0.687 $kgCO_2$-eq., which is decreased when compared to the AC from this research. This is due to AC being produced for the laboratory requiring an external energy source for the heaters and stirrers but there is recycled energy within the factory,which can be utilized..The highest proportion of CFP of the production was 69.5% of total CFP from electric furnace usage. In order to reduce the use of external energy, steam was used a stimulant instead of carbon dioxide, which can save more energy.

4.6 Comparison carbon footprint between AC and ion exchange resin

The CFP of the ion-exchange resin was less than AC because the assessment of CFP in the production step did not include starting from the acquisition of raw materials, syrup decolorization usage, regeneration and disposal. However, the value of CFP of AC production on a commercial scale may be less than AC produced in this research due to the use of remaining heat from the furnace in the sugar operation plant. Moreover, the chamber should be re-designed to a larger size for more AC loading in the operation. From this study, the prepared material can be an alternative environmentally friendly material to achieve waste utilization purposes for the sugar industry in the decolorization process.

5. Conclusions

The AC was prepared from bagasse by carbonization process at 500 °C for 40 mins and activated by different conditions. The yield of AC with different N_2 and CO_2 ratios was around 25-30% and activation time. Total surface area and pore volume of the AC was increased after the activating step. Decolorization efficiency of the 60:40_40 and 50:50_40 samples were 20% approximately. The suitable time of decolorization with 80 mins. decolorization efficiency was 23, 46, 52, 57 and 61 for 0.5, 1.0, 1.5, 2.0 and 2.5 g of AC, respectively. CFP of 0.5 g AC was 1.51 kgCO_2-eq. CFP of AC was higher than resin. However, the value of CFP of AC production on a commercial scale could be reduced. From this study, prepared material can be alternative waste utilization from the sugar industry and can be applied for environmentally friendly products during the decolorization process. However, the factory should consider the chamber design capacity and be concerned about the direct re-use of heating from the plant.

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