Economical Cat Litter from Biomass

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Abstract*—Most commercially produced clay cat litters nowadays have raised issues to pet owners since they are non-biodegradable and have no natural odor controlling features. In this study, biomass materials; sawdust and corn husk, were compared and processed into cat litter formulations due to their good absorption capacity and the biodegradability properties. Both biomass were dried to remove moisture content and grinded to reduce their particle size. Each of the raw materials were then mixed with clumping agent (xanthan gum), deodorizer (sodium bicarbonate), and dust retardant (glycerol) to form mixtures of cat litter. The mixtures were then dried and pelletized to reduce the dust formation. Eight cat litter formulations of sawdust and corn husk, including the blending of the raw biomass cat litter with their consecutive hydrogel biochar products and pure hydrogel biochars, as well as the commercial bentonite clay cat litter were tested in terms of their clumping activity, absorption capacity, and dust formation. Meanwhile, BET analysis was done to compare the surface area, total pore volume and average pore size of the sawdust cat litter, biochar, and hydrogel biochar. The results from clumping and absorption rate showed the highest percentage in bentonite cat litter at 99.27% and 95.49% respectively while corn husk cat litter has the highest dust formation rate at 1.88%. Sawdust biochar has the highest BET surface area of 239.2001 m^2/g and showed a mesoporous structure with pore size 3.0089 nm. The results have provided an indication on the suitability of sawdust as cat litter material. Future work shall focus on the effort to speed up the degradation process of the biomass as cat litter material as well as to study the effect of pellet density on its moisture uptake.

Keywords— Sawdust; Corn husk; Bentonite clay; Hydrogel biochar, BET analysis

List of abbreviations	
SWD	Sawdust
HB	Hydrogel biochar
SWDHB	Sawdust hydrogel biochar
CH	Corn husk
CHHB	Corn husk hydrogel biochar
B	Bentonite

I. INTRODUCTION

Cats are among the popular domestic animals that are mostly kept as pets in many households. Since most of the pet cats stay indoors, the main concern for pet owners is the disposal of their waste and covering any disturbing odors from the waste [1] Therefore, most cat owners would provide litter boxes containing absorbent materials that could cover and absorb the cat's waste until it is disposed of [2]. Bentonite clay has good absorption properties and is commonly used as absorbent material of cat litter [3]. However, there are several negative impacts of using clay as cat litter since it is non-biodegradable and therefore, would lead to sewage piping blockage upon discharge through the toilet system [4]. Moreover, cats are exposed to the risk of ingesting the clay particles that contain silica and dust that could lead to health and respiratory problem [5].

Biomass is defined as the biodegradable products, waste and residues from agricultural activities, forestry industries, as well as municipal waste [6]. It is widely consumed around the world as a potential renewable energy source due to its abundance and wide range of applications from producing biofuel energy to household items [7]. Since the world is facing exhaustion of fossil fuel as the main source of energy and the alarming global warming problem caused by the exploitation of fossil fuel, biomass as an optional and reliable source of energy is gaining the attention of researchers to widen the methods of utilizing them. In addition, the utilization of biomass rather than fossil fuel could reduce the carbon dioxide emission to the atmosphere thus gives no significant contribution to the greenhouse effect [8].

Biomass or plant-based cat litter is the better alternative as an absorbent material because unlike clay material, it is biodegradable and can easily be flushed down the toilet without causing serious blockage in the sewer system [3], [9], [10]. Various types of biomass like wheat, oat hulls, corn cob, sawdust or recycled newspaper can be made into the environmental friendly cat litter [11]. Sawdust refers to the tiny-sized and powdery wood waste produced by the sawing of wood [12]. It is one of the biomass products that is widely marketed in the form of pellets for a variety of applications and have been used as animal litter material, besides chips, shavings, and cottonwood [13]. Statistically, about 10-13% of the total volume of the wood log is reduced to sawdust in milling operations and the utilization of the generated tropical wood sawdust becomes an urgent problem since the method of cleaning by the conventional incineration may produce environmentally hazardous pollutants such as polychlorinated dibenzo-dioxins and dibenzo-furans [14]. Thus, it is preferable to utilize the wood waste instead of demolishing it as a waste. Meanwhile, corn husk is a type of agricultural waste that is utilized for variety of applications like the making of degradable fiberboard [15] or even biodegradable film [16].

Biochar is the solid product of biomass pyrolysis, which is rich in carbon content, fine-grained and has a large amount of pores with oxygen functional groups and aromatic surfaces [17]. Because of its high surface-to-volume ratio and strong affinity for non-polar sub- stances, biochar can be a potential sorbent for organic and non-organic pollutants [18]. Hydrogel is a 3-dimensional hydrophilic gel composed of polymer chains network that is used to absorb a huge volume of water or biological fluids [19]. It has flexible characteristics, which can sense change in the surrounding environment in terms of ionic strength, pH, temperature and chemical activity, and interact with adsorbents [20].

In this paper, the absorption properties of biomass waste;sawdust and corn husk is studied as cat litter absorbent material, alongside hydrogel biochars. A comparative assessment was done with these materials and a commercially available bentonite cat litter to act as absorbent material.

II. METHODOLOGY

A. Raw materials preparation and size reduction

An amount of sawdust obtained from the municipal council was dried under the sun for a week and further dried using the drying oven at 80℃ for 24 hours to ensure the moisture is eliminated from the material. Sawdust has a relatively high moisture content depending on the type of tree it was obtained. Generally, wood sawdust has a moisture content ranging from 11-13%, thus the sequential drying steps are essential to completely remove the moisture content of sawdust [21]. The corn husk is considered as the corn residue and its moisture content is obtained by proximate analysis by Zhang et al. (2012) obtaining 7.92% [22]. The value is comparable with a study of chemical composition of biomass which obtained 7.4% moisture content for corn straw [23]. Corn husk obtained from local corn suppliers was cut into smaller pieces to increase its surface area that could speed up the drying process and was dried under the sun for a week. Alternatively, the material can also be dried in the drying oven at 80℃ for 24 hours. The dried materials were then subjected to grinding process using the cutting mill before they were screened through a 6-mesh sieve to obtain a proper size distribution.

B. Mixing of raw materials with clumping agents and hydrogel biochar

The clumping formulation was started by heating the glycerol (20.0 g, R & M Chemicals) on a hot plate to 90℃. This is to reduce the viscosity of the glycerol, thus allowing it to be easily mixed. Glycerol was used in the mixing to help adhere the raw material to the gum besides acting as a dust suppressant [3], [24]. Xanthan gum (20.0 g, R & M Chemicals), which is a type of natural polysaccharide industrial gum that is commonly used as cat litter clumping agent was added into the glycerol [25]. Sodium bicarbonate (10.0 g, R & M Chemicals) was added into the solution and the stirring was continued. This agent helps neutralize and regulate the pH levels of material, thus reduces odor from cats' waste. The mixture was stirred continuously to form a homogenous suspension. 100.0 g of prepared raw materials (sawdust and corn husk) were thoroughly mixed, respectively with this solution, and the soft clumps formed were dried in the drying oven set at 50℃ for 24 hours. The dried cat litter produced was pelletized (Forest Research Institute Malaysia) for further testing.

Sawdust hydrogel biochar and corn husk hydrogel biochar were produced by cross-linking copolymerization of each biochar material with non-ionic monomer, acrylamide, AAm (Merck), a small amount of cross-linking agent, N,N'-methylenebis(acrylamide), MBAAm (Merck), and an initiator, ammonium persulfate, APS (R & M Chemicals) [26], [27]. The mixtures were dried in the drying oven at 100℃ for 10 minutes before they were cut into smaller cubic-like pieces. 50.0 g of pelletized cat litter of each material was mixed, with 50.0 g of their respective hydrogel biochar. The mixture products, as well as their respective pure hydrogel biochar were then set for further testing. A commercial bentonite clay cat litter was tested alongside the biomass materials in order to compare their performance effectiveness.

C. Clumping of litter formulation test

The clumping rate was studied by placing 20.0 g of each sample into petri dish, then dropping 5.0 ml of water into each plate. The plates were then set aside for absorption and clumping to occur, before they were placed in the drying oven set at 40℃ for 6 hours. The contents of each plate were sieved using a 6-mesh sieve and placed in the orbital shaker set at 250 rpm for 60 seconds. The clumping percentage of each litter was calculated as follows [3]:

$$\text{Clumping percentage} = \left(\frac{\text{Weight of clumps remained on the sieve}}{\text{Initial weight of mixture before clumping}}\right) \times 100\%$$

D. Absorption test of cat litter

The ability of the cat litter formulations as absorbent material was tested by a simple test to quantitate the amount of water being absorbed by each material. 20.0 g of each sample were placed in beakers, while 10.0 ml of water was poured into each beaker. The treatments were allowed to rest for 10 minutes for absorption to occur, before each content was filtered using filter paper in the filter funnel. The absorption rate of each sample was calculated as follows:

$$\text{Absorption rate} = \left(\frac{\text{Weight of filtered litter sample}}{\text{Initial weight of litter before absorption}}\right) \times 100\%$$

E. Dust control test of cat litter

The dust control test was conducted to determine the amount of dust produced by the final cat litter products. 50.0 g of each sample was placed into beakers and let sit for 2 hours. The contents were then sieved onto the 6-mesh sieve before being placed in the orbital shaker set at 250 rpm for 60 seconds. The dust content is determined using the equation:

$$\text{Percentage of dust content} = \left(\frac{\text{Initial weight of sample} - \text{Weight of sieved sample}}{\text{Weight of sieved sample}}\right) \times 100\%$$

F. BET analysis

In order to find the surface areas of the cat litter formulations, the BET (Brunauer, Emmett and Teller) analysis was used. The method was initially developed for multilayer-gas adsorption onto flat surfaces, and now used as a standard method for determining the surface areas from nitrogen adsorption isotherms [28]. In BET analysis, the volume of gas adsorbed to the surface of the particles is measured at the boiling point of nitrogen. The amount of gas adsorbed reflects the total surface area of the particles including the pores on its surface. Moreover, the method of gas adsorption also enables the determination of size and volume distribution of micropores. For this study, each sample was gassed out for 6 hours at 200℃ and the surface area was calculated by BET equation. The test was done on sawdust cat litter, biochar, and hydrogel biochar.

III. RESULTS AND DISCUSSION

A. Clumping percentages of cat litter formulations

The clumping percentages of eight formulations of cat litter from various raw materials are shown in Table 1.

Table 1: Clumping percentages and absorption rates of cat litter formulations with added glycerol/xanthan gum.

Litter formulation	Clumping rate (%)	Absorption rate (%)
SWD	99.18	92.07
SWD + HB	98.65	82.33
SWDHB	92.53	79.32
CH	98.53	93.07
CH + HB	98.32	84.49
CHHB	92.05	82.56
Bentonite	99.27	95.49
B + HB	94.32	89.59

According to Vaughn (2011), the acceptable clumping rate for animal litter products would have to be higher than 40% [3]. The results obtained show a high clumping rate in all formulations being tested. The clumping rate was noticeably lower in hydrogel biochar formulations from both sawdust and corn husk. Meanwhile, the highest reading of clumping was taken from the commercialized bentonite clay cat litter (99.27%). Upon drying of the treatment, bentonite clay formed hard clumps that stayed together during the sieving process. This phenomenon generally relates to the characteristic of clay, which acquires plasticity upon contact with liquid [29]. Interestingly, clay–water system with plastic-behavior requires force to deform its structure to a greater extent such as cracking. The plasticity of clays is related to the morphology of the plate-like clay mineral particles that slide over the others when water is added, which subsequently acts as a lubricant [30].

At the next highest clumping rate, sawdust cat litter formed clumps with little remainings. The clumping activity in biomass material was assisted by the presence of xanthan gum as tackifier that dried up to form clumps. The rates of clumping in sawdust and hydrogel biochar (SWD+HB) and corn husk and hydrogel biochar (CH+HB) formulations were seen lower than the formulations that contain 100% of biomass due to poor contact of clumping agent with the hydrogel biochar. This results from the pelletized biomass material that reduces the blending capacity of the ingredients. The clumping activity in hydrogel biochar was the lowest and it was noticed that they formed small hard clumps but they tend to stick at the bottom of the container.

B. The absorption rate of the cat litter material

The absorption rates for each material to absorb water are shown in Table 1. Bentonite clay litter showed a rapid absorption and has the highest absorption rate at 95.49% since the clay material has been known to have a high retention, adsorption and absorption, and swelling capacities [31]. Furthermore, the small particle size of the bentonite cat litter increases the contact area between the material and the water thus alleviating the water take-up process.

The next highest absorption rate is the corn husk cat litter followed by sawdust cat litter. The absorption rates of both biomass materials are comparable, except the corn husk material has a slightly higher absorption capacity. This is due to the difference in hardness of pellets formed from both biomass materials. The sawdust pellets tend to be more compacted and has a high hardness with lower expansion volume. Thus, there are less gaps and spaces between sawdust particles in the pellet. The biomass materials did not show a rapid absorption of water, but, after a short while, they absorbed completely all the moisture without leaving any residue sticking to the container.

The corn husk possesses a highly fibrous characteristic of material, thus the configuration of particles in the pellets formed were slightly irregular and less compacted. The spaces between the voids help promote the relative movement of the particles within the pellet matrix. A similar test for biomass pellets was conducted by Jiang et al. (2016), when the moisture uptake rate of pure biomass pellets was tested to compare the effect of pellet compactness on the absorption capacity, showing a lower moisture uptake by a more densed pellet. The absoption capacity of the biomass is assisted by the hemicellulose contents in raw materials, which are considered as the main reason of a high moisture absorption ability of the raw materials.[32].

C. Dust control analysis

The analysis for dust control test is tabulated in Table 2. The pelletizing process helped in reducing the amount of smaller sized particles and dust content [33], which could be harmful to cats' respiratory system by prolonged inhalation [5]. Based on the tabulated data, the highest percentage of dust collected was corn husk cat litter. This relates to the morphology and matrix structure of the biomass. Due to its highly fibrous structure, the corn husk pellets formed were less densified, thus leads to the presence of tiny unrestrained particles. Augusto et al. (2014) conducted the SEM analysis on a longitudinal section of corn husk fiber where it showed an irregular cross-section with non-uniform surface, an amount of short microfibrils and some impurities on its surface [34].

Table 2: Dust percentages from various cat litter formulations.

Litter formulation	Dust collected (%)
SWD	1.03
SWD + HB	0.91
SWDHB	0
CH	1.88
CH + HB	0.99
CHHB	0
Bentonite	1.07
B + HB	0

A significant decrease in the percentage of dust collected from sawdust and bentonite cat litter was obtained with values 1.03% and 1.07% respectively. In contrast to the structure of corn husk fibers, both sawdust and bentonite has compacted properties that reduce the amount of dust formed. The hydrogel biochar formulations were dust free since it has a structure that imitates a sponge characteristics and behavior. Basically, all formulations of cat litter has a low percentage of dust, which only ranges from 0-1.88%, due to the pelletizing process and the use of glycerol as the dust suppressant.

D. BET analysis

The BET surface area analysis was determined on the SWD, SWD biochar (product of pyrolysis at 550℃), SWDHB, CH biochar, and CHHB. The surface area of the cat litter formulations is one of the important parameters to study because it strongly affects the behavior of the material when used as absorbent material [35]. The BET surface area, total pore volume, and average pore size of the five samples are shown in Table 3. The N_2 adsorption and desorption isotherms are shown in Figure 1 to 5. The amount of nitrogen adsorbed was plotted against the relative pressure of the gas. Based on the plots, it can be seen that most of the desorption curves overlap with the adsorption curves at higher relative pressure. The overlapping that can be seen between the two plots in Fig. 1, Fig. 3, and Fig. 5 is mainly due to the presence of slit-shaped pores. For the isotherm plots with desorption curves higher than the adsorption curves, that can be seen in all isotherm plots, this indicates that the nitrogen was not fully adsorbed during the desorption [17].

Table 3: BET surface area and porosity results

Material	BET surface area (m^2/g)	Total pore volume (cm^3/g)	Average pore size, nm
Sawdust cat litter	0.9086	0.00193	7.0500
Sawdust biochar	239.2001	0.16194	3.0089
Corn husk biochar	6.8730	0.00872	4.8332
Sawdust hydrogel biochar	3.2446	0.00474	6.0071
Corn husk hydrogel biochar	0.8349	0.00120	5.4103

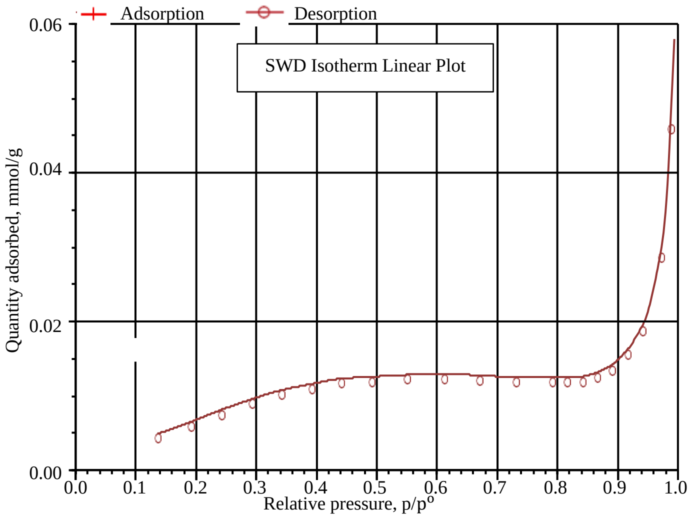

Fig. 1: Nitrogen adsorption and desorption isotherms of sawdust cat litter.

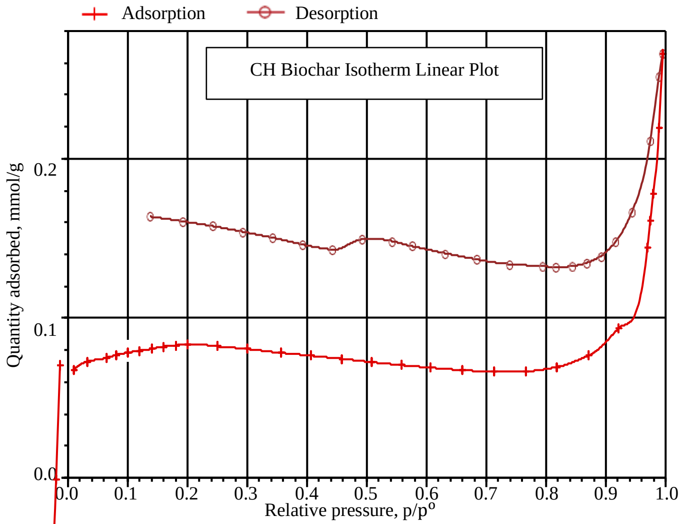

Fig. 4: Nitrogen adsorption and desorption isotherms of corn husk biochar.

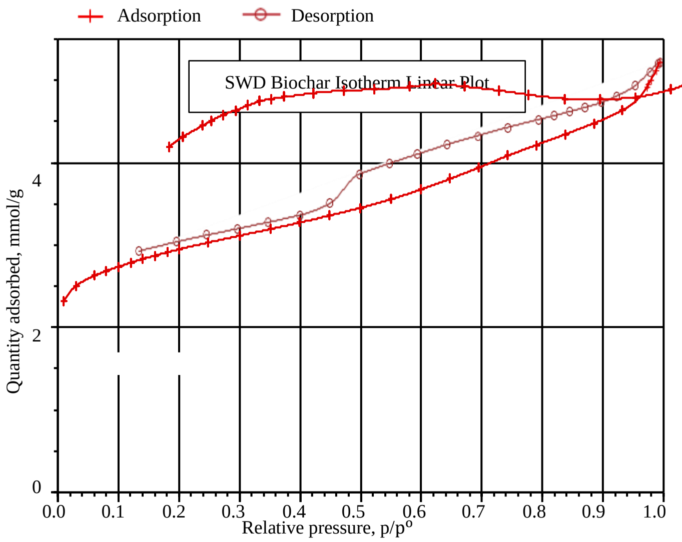

Fig. 2: Nitrogen adsorption and desorption isotherms of sawdust biochar (pyrolysis product).

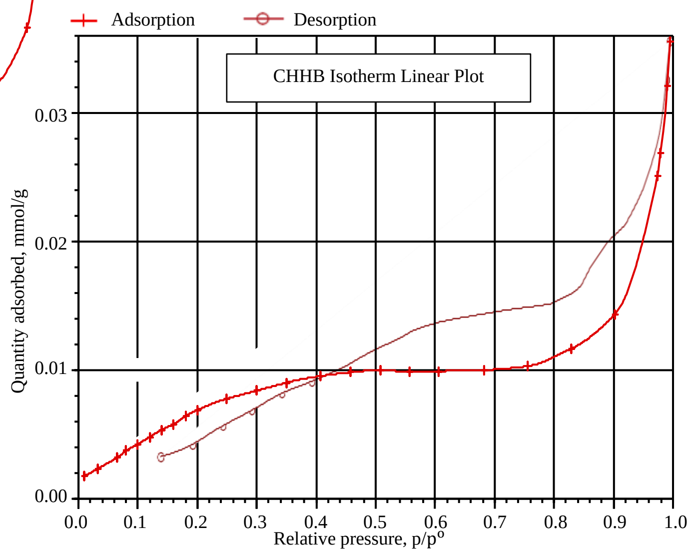

Fig. 5: Nitrogen adsorption and desorption isotherms of corn husk hydrogel biochar.

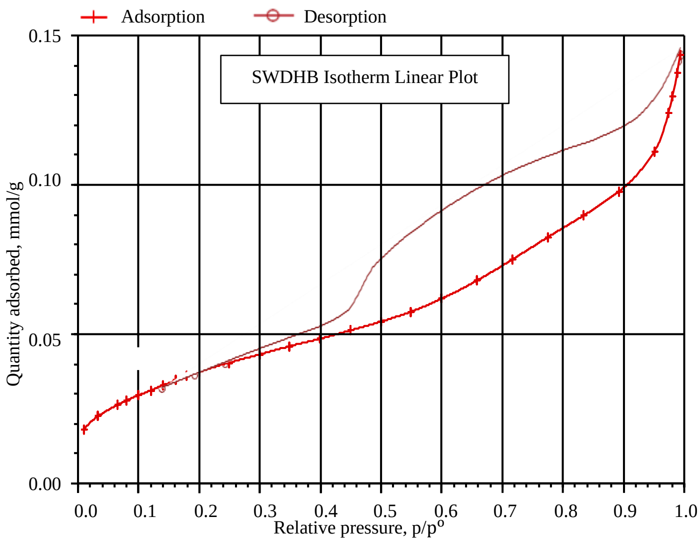

Fig. 3: Nitrogen adsorption and desorption isotherms of sawdust hydrogel biochar.

Based on the surface area analysis of samples in Table 3, sawdust biochar obtained from pyrolysis process showed the highest BET surface area (239.2001 m^2/g) and total pore volume (0.16194 cm^3/g) but has the lowest average pore size (3.0089 nm). This is because the pyrolysis process followed by the chemical activation on the sawdust biochar causes a release of volatile compounds, such as water and smaller hydrocarbons from its surfaces [36]. The large surface area formed on the biochar product is influenced by the pyrolysis temperature, which was 550℃. Ghani et al. (2013) explained that the surface area of biochar would increase with an increasing temperature due to deformation that occurs in the material structure [17]. In addition, Ghani et al. (2013) also studied the surface area of the rubber-wood sawdust by BET analysis and the surface area obtained at pyrolysis temperature 550℃ was approximately 200 m^2/g. However, the surface area obtained for corn husk biochar was 6.8730 m^2/g. The difference of surface areas obtained from two biochar sources is obvious, due to the different types of samples, which possesses different compositions of elements including ash content. The non-woody feedstocks have higher ash content, proved by the elemental composition analysis with high Si percentage, which filled or blocked the access to micropores, resulting in a relatively low surface area [37]. A study was conducted by Rafiq et al. (2016) on the influence of pyrolysis temperature on the physicochemical properties of corn stover biochar. The BET surface area results showed a range of 3.0-5.0 m^2/g for pyrolysis temperature of 300-500℃ [38], thus, proving that the corn husk biochar surface area obtained from this research falls close to the values reported in the technical literature for corn stover. The results of sawdust and corn husk biomass are also comparable with other types of biomass. Jindo (2014) conducted a BET surface area analysis of biochars of woody feedstocks;apple tree branch and oak tree, and non-woody sources of biomass;rice husk and rice straw. The results from the findings showed that the all types of biochars developed larger surface areas as the pyrolysis temperature increased. Nevertheless, the woody biochars had a wider range of surface areas from 5.0-550.0 m^2/g while the rice residues showed a range of 40.0-300.0 m^2/g.

Meanwhile, the sawdust cat litter formulation has the lowest BET surface area, which is 0.9086 m^2/g. This cat litter formulation was produced from raw sawdust without any chemical treatment to promote the formation of pores. Besides the possible presence of ashes and dust, the formulation is mixed with a few other ingredients like glycerol, xanthan gum, and sodium bicarbonate that might occupy the existing pores on raw sawdust. The BET surface area of sawdust hydrogel biochar obtained was 3.2446 m^2/g while the corn husk hydrogel biochar showed a reading of 0.8349 m^2/g. The surface areas for the hydrogel biochars are much lower than the biochar products as the hydrogel components has occupied the porous surface on biochar. Based on the average pore size of all samples, the porous surfaces on the materials are considered mesopores since the sizes of pore obtained fall in the range of 2 to 50 nm [39].

IV. Conclusion

In this research, it has been shown that biomass materials particularly sawdust and corn husk are suitable to be used as cat litter. Based on the analysis results of both materials, they have a good clumping ability and absorption rate, and a low dust formation. A comparison of cat litter formulations between biomass materials and a commercial bentonite clay cat litter was done obtaining comparable results of all materials prossessing good clumping and absorption capacities. Biomass, however, is favored due to its biodegradability and abundance, which make it easy to obtain and economically advantageous. The infusion of hydrogel and biochar as an additional absorbent material gave out a satisfying results, though the use of hydrogel biochar as cat litter material would increase the cost. The pelletization process could reduce transportation costs and provides better handling of the cat litter with less dust formation.

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