An Experimental Study on Sugarcane (*Saccharum officinarum*) Bagasse and Corn (Zea mays L.) cob as a Potential Bio-adsorbent for Used Engine Oil

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Abstract: Oil pollution is one of the leading causes of detriment to water ecosystems. Bio-adsorbents have been studied for oil cleanup potential, but mixed bio-adsorbents have not been thoroughly studied yet. Thus, this study investigated Sugarcane (*Saccharum officinarum*) bagasse and Corn (*Zea mays*) cobs, two of the most underutilized agricultural wastes, as bio-adsorbents in their natural form. Five formulations were used, and used motor oil was utilized as the adsorbate. One gram of bio-adsorbent was used in a mixture of 3 grams of oil and 200 milliliters of water per trial. The oil sorption capacity (OSC) and water sorption amounts were collected to determine the efficiency in selectively adsorbing motor oil. Results showed that all formulations had similar oil sorption capacities, ranging from 288% to 298%, with pure bagasse (F1) having the highest and the formulation with a bagasse-cob mass ratio of 3:1 (F2) having the lowest. Statistical analysis posited that all group means for OSC are equal. Additionally, findings suggested that water sorption amount increases as the percentage by mass of bagasse in the formulation increases. F1 sorbed the most water with 5.80 grams, whereas the formulation with pure cobs (F5) sorbed the lowest with 2.09 grams, followed by the formulation with a bagasse-cob mass ratio of 1:3 (F4) with 3.22 grams. These results signified that not all mean water sorption amounts measured were equal, suggesting that formulations F4 and F5 are the most efficient in selectively absorbing oil.

Key Words: *Saccharum officinarum; Zea mays;* oil sorption capacity; bio-adsorbents

1. INTRODUCTION

Oil spills are one of the leading causes of water pollution worldwide, posing dangers to aquatic habitats, poisoning fishes, and affecting people's livelihoods in coastal communities (National Oceanic and Atmospheric Administration, 2019). The majority of these spills are caused by human activity, particularly the runoff from cars that leak motor oil. Though there are multiple ways of dealing with oil spills, the use of adsorbents is primarily seen as being most effective due to its flexibility and simplicity (Crini et al., 2018). Synthetic materials form the most significant proportion of all adsorbents, but while they are effective and yield a high oil sorption capacity, their non-biodegradability, cost, and disposal method may sometimes outweigh their benefits (Al-Jammal & Juzsakova, 2017). An alternative route may be the use of bio-adsorbents—adsorbents derived from biological material like agricultural wastes (agro-wastes) (Crini et al., 2018). While this method has been thoroughly researched, most procedures focus on chemically treating agro-waste via silanization, acetylation, and other treatments to make it less hydrophilic (Gorgulho et al., 2018). The hydrophilic nature of agro-waste due to its cellulose content is one of the major limiting factors in the mainstream use of adsorbents. Suitable adsorbents must repel water to prevent sinking, requiring a minimum water sorption amount (Guilharduci et al., 2017). However, recent papers have demonstrated the potential of certain agro-wastes to attain promising results without chemical treatments. In particular, Choi (2018) showed the potential of powdered corn cobs in adsorbing large amounts of oil due to their low hydroxyl action, making them naturally hydrophobic. Behnood et al. (2016) and Gorgulho et al. (2018), on the other hand, demonstrated the potential of sugarcane bagasse as a decent bio-adsorbent due to its floatability and high surface area.

Though these studies have laid the groundwork on the feasibility of bagasse and corn cob bio-adsorbents, no research to date has described the potential of the two agro-wastes when used together. Sugarcane bagasse and corn cob have different properties that play to their advantages separately, but it is unknown whether these properties would

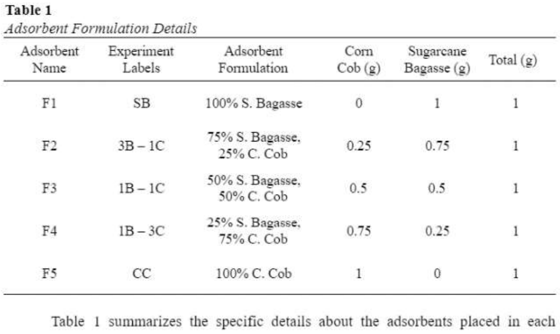


Table 1
Adsorbent Formulation Details

Adsorbent Name	Experiment Labels	Adsorbent Formulation	Corn Cob (g)	Sugarcane Bagasse (g)	Total (g)
F1	SB	100% S. Bagasse	0	1	1
F2	3B – 1C	75% S. Bagasse, 25% C. Cob	0.25	0.75	1
F3	1B – 1C	50% S. Bagasse, 50% C. Cob	0.5	0.5	1
F4	1B – 3C	25% S. Bagasse, 75% C. Cob	0.75	0.25	1
F5	CC	100% C. Cob	1	0	1

Table 1 summarizes the specific details about the adsorbents placed in each

interact constructively—leading to an increase in their capability to adsorb oil—or not. Additionally, both materials are the main underutilized agro-wastes of the Philippines and can be accessed easily due to the Philippines' large market for sugar and corn (Cajes, 2013; Baconguis and Pasagdan, 2013). Hence, this study aimed to identify whether a combination of bagasse and corn cob may increase Oil Sorption Capacity. It also aimed to determine what kind of formulation can serve as the most efficient adsorbent, which is the adsorbent with the highest oil sorption capacity and lowest water sorption capacity.

2. METHODOLOGY

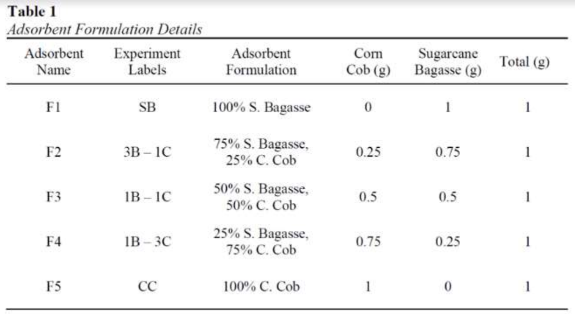
2.1. Materials

For the adsorbents, corn cobs were collected from fresh yellow corn bought from Biñan City Market. These collected corn cobs were used in natura or "in their natural state," only dried to eliminate moisture. The researchers collected sugarcane bagasse from "Tubo ko," a sugarcane juice stall in SM Sta. Rosa, also in natura.

Used motor oil, the adsorbate, was sourced from a mechanic shop from Santa Rosa, Laguna. Only one source vehicle for the used motor oil was used for consistency. The study used a synthetic blend motor oil with an oil grade of SAE 20W-40, which is one of the primary motor oil grades sold in the Philippines, and the oil grade available to the researchers.

2.2. Procedure

All sugarcane bagasse and corn cobs were thoroughly rinsed and washed with distilled water (Gorgulho et al., 2018) to get rid of impurities. They were cut with a thickness between 0.5 to 1.0 cm (Choi, 2018) and sun-dried for 24 hours. Afterwards, the adsorbents were weighed on a weighing scale and dried in an oven at 110°C for 2 hours. The measuring and drying processes were repeated until the adsorbents' mass plateaued and were brittle enough to be powdered (Ascutia et al., 2015). The dried sugarcane bagasse and corn cobs were reduced separately using a ceramic mortar and pestle, as adapted from Ascutia et al. (2015). A blender was used to process the dried materials further, and they were sieved separately using 24-mesh and 28-mesh sieves. Particles within the -24 +28 mesh range were used for the experiment.



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F4	1B – 3C	25% S. Bagasse, 75% C. Cob	0.75	0.25	1
F5	CC	100% C. Cob	1	0	1

Table 1 summarizes the specific details about the adsorbents placed in each container. Labels were used in conducting the experiment, where SB labels referred to F1, 3B-1C labels referred to F2, 1B-1C labels referred to F3, 1B-3C pertained to F4, and CC pertained to F5. This correspondence is shown in Table 1.

Figure 1. *Initial mixture set-up*

The experiment had three trials. The researchers poured 200 milliliters (mL) of distilled water and 3 grams (g) of used motor oil in each of the five glass containers for each trial, then were left for 30 minutes to allow the oil to spread more evenly on the water. This set-up is shown in Figure 1.

Formulations with mixed materials were mixed thoroughly after weighing the necessary components. After weighing all adsorbents accurately, they were placed onto the oil in the mixture evenly and were left in contact for four hours.

The adsorbents were recovered from the containers using a surgical scalpel and were placed directly onto the filter paper by wiping then weighed. The containers were placed beside a bag of desiccants and covered for drying. Once the mass did not change for at least 24 hours, the adsorbents were weighed to get the final mass.

2.3. Research Design

The study used an experimental research design with the five manipulated bio-adsorbent formulations as the independent variable and the Oil Sorption Capacity (OSC) as the dependent variable. The controlled variables were the amount and type of motor oil and water used in each container and the bio-adsorbents' initial mass.

2.4 Data Analysis Strategy

In determining the amount of oil adsorbed (A_{oil}) and water absorbed (A_{water}), calculations using the following formulas were used:

$$A_{oil} = M_f - M_i = (R_f - (C_{cont} + C_{paper}) - M_i)$$

$$A_{water} = M_w - M_f = (R_w - (C_{cont} + C_{paper}) - M_i)$$

where M_i is the initial mass of the adsorbents before placing in the mixture, the mass of the recovered adsorbents before drying is M_w, and M_f is their mass after drying. M_f and M_w are derived from raw data (which are C_{cont}, C_{paper}, R_w, and R_f). C_{cont} is the mass of the clean, empty recovery container. C_{paper} is the mass of the clean filter paper. The mass of the recovery container, filter paper, and recovered adsorbent before drying is denoted as R_w, and their mass after drying is R_f. The average amount of oil adsorbed and water absorbed of all adsorbent formulations were compared.

The oil sorption capacity (OSC), denoted by Q, was computed using the following formula adapted from Choi (2018)

$$Q = \frac{M_f - M_i}{M_i}$$

M_f is the final mass of the recovered adsorbent after drying, and M_i is the adsorbent's initial mass before it was immersed in the oil-water mixture. However, OSC was expressed as a rate in % for this study by multiplying Q by 100. This formula measured how much oil the adsorbent can adsorb with respect to the adsorbent's initial mass. OSC values greater than 100% mean that the mass of oil adsorbed exceeded the initial mass of the bio-adsorbent before usage.

One-way analysis of variance (ANOVA) was employed to identify any differences in the mean OSCs and water sorption amounts. Tukey's HSD post hoc test was used to determine which adsorbent formulations differed if the one-way ANOVA test indicated an existing difference.

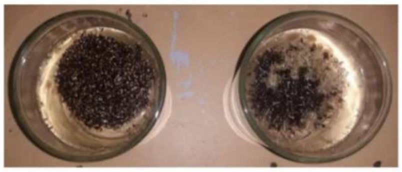


Figure 2. *Set-ups after placement of bio-adsorbents F5 (left) and F1 (right)*

Figure 3. *Set-ups after placement of bio-adsorbents F2 (left), F3 (middle), and F4 (right)*

3. RESULTS AND DISCUSSION

3.1 Documentation

Figure 4. *F1 bio-adsorbent, after 4 hours contact time*

Figure 5. *F2 bio-adsorbent, after 4 hours contact time*

Figure 6. *F3 bio-adsorbent, after 4 hours contact time*

Figure 7. *F4 bio-adsorbent, after 4 hours contact time*

Figure 8. *F5 bio-adsorbent, after 4 hours contact time*

3.2. Oil Sorption Capacity

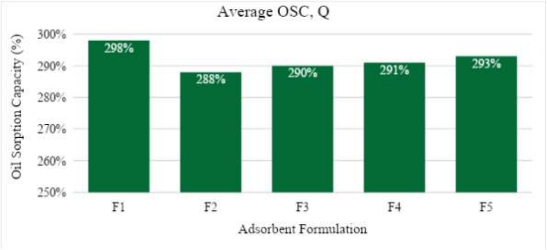


Figure 9. *Average oil sorption capacity by all bio-adsorbent formulations*

The mean OSC in % of the bio-adsorbents ranged from 288% to 298%. F1 showed the highest, and F2 had the lowest OSC, as illustrated in Figure 9. F3, F4, and F5 showed OSCs of 290%, 291% and 293%, respectively. The slight drop of F2's mean OSC from F1 and the upward trend of mean OSC starting from F2 until F5 may hint that the adsorption mechanism of corn cob and bagasse particles may be opposing each other. However, their values were relatively too close to each other for such a conclusion to be drawn.

One-way analysis of variance was conducted to identify any significant differences among the mean oil sorption capacity values. However, at $\alpha = 0.05$, results showed no statistically significant differences [F(4,10) = 1.78, p = 0.210]. This result signifies that all five bio-adsorbent formulations had similar mean OSCs. No further post hoc analyses were conducted since all group mean OSCs were found to be statistically equal.

3.3. Water Sorption and Total Sorption

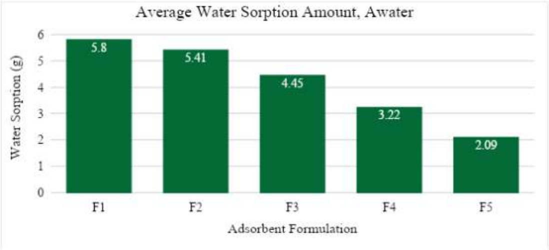
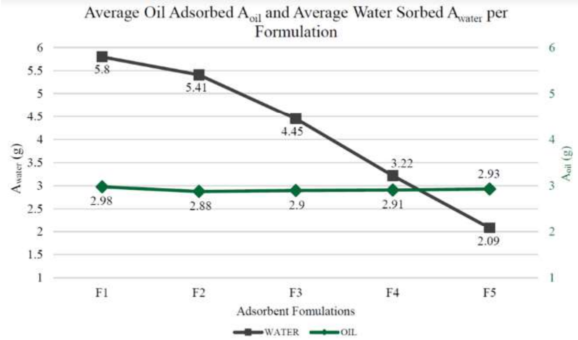


Figure 10. *Average water sorption amount by all bio-adsorbent formulations*

The mean water sorption amounts exhibited by all bio-adsorbent formulations ranged from 2.09 grams to 5.80 grams, as the graph of water amount sorbed in Figure 10 illustrates. The values followed a downward linear trend from F1 to F5. F1 sorbed an average of 5.80 grams of water, F2 sorbed 5.41 grams, F3 sorbed 4.45 grams, F4 sorbed 3.22 grams, and F5 sorbed only 2.09 grams of water.



As shown in Figures 10 and 11, this declining trend in water sorption indicates that an increasing proportion of bagasse in the bio-adsorbent formulation leads to higher water sorption. This trend showed the higher hydrophilicity of sugarcane bagasse, as discussed by Gorgulho et al. (2018) and Guilharduci et al. (2017). Consequently, formulations that contained more corn cob particles by mass sorbed less water. This observation was also reported by Choi (2018) in her paper, stating that corn cobs are less attracted to water than other agricultural wastes due to their lower hydroxyl action.

Upon employing one-way analysis of variance to see any significant differences among the mean water sorption amounts, at $\alpha = 0.05$, it was shown that there were indeed significant differences in the five group means [F(4,10) = 23.40, p = 0.000046]. Upon conducting Tukey's HSD as the post hoc test, results showed that the water sorption of F4 was significantly lower than those of F1 and F2. The mean water sorption of F5 was also shown to be lower than those of F1, F2, and F3. These results signify that, in general, formulations F4 and F5 had significantly lower water sorption amounts, one of the characteristics of an ideal oil bio-adsorbent. Considering that all bio-adsorbents had similar oil sorption capacities, these two formulations can then have more efficiency in adsorbing oil, especially in larger scales of oil spill cleanup.

4. CONCLUSIONS

4.1 Summary of Findings

The average OSCs of all bio-adsorbent formulations ranged from 288% to 298%, where F1 achieved the highest and F2 had the lowest with 288%. Upon conducting one-way analysis of variance on the five bio-adsorbent formulations (at $\alpha = 0.05$), it was found that there were no statistically significant differences in the mean OSCs among all formulations. For the water sorption amount, there was a downward trend from F1 with the highest water sorbed of 5.80 grams, where it decreased from then on with F5 as the lowest (2.09 grams). These findings point to the higher hydrophobicity of corn cob particles and higher hydrophilicity of bagasse. Upon conducting a one-way analysis of variance (at $\alpha = 0.05$), it was shown that at least one pair of formulations had significant differences between their mean water sorption amounts. Therefore, using Tukey's HSD as the post hoc test, it was shown that, in general, F4 and F5 formulations had significantly lesser water sorption amounts compared to the F1, F2, and F3 formulations.

4.2 Conclusions and Recommendations

This study explored the novel idea of combining sugarcane bagasse and corn cob to create an effective bio-adsorbent and hypothesized that at least one bio-adsorbent formulation would have a differing mean oil sorption capacity, as well as for water sorption amount.

Results indicated that the mean OSCs of all bio-adsorbent formulations are relatively similar in effectiveness when adsorbing oil. Additionally, upon statistical analysis, it was also proven that there are no significant differences between the mean OSCs.

Statistical analysis proved that there are indeed significant differences between the water sorption of F4 and F5 formulations with a lower amount than F1, F2, and F3 formulations. Thus, F4 and F5 have different mean water sorption amounts than the rest.

Because of their similar OSCs, all formulations have great potential in adsorbing oil and can be used for oil spill cleanup. However, since lower water sorption indicates more efficiency for exhibiting greater selective attraction to oil, F4 and F5 can be more efficient than the rest.

The ideal interaction from all mixed bio-adsorbents was exhibited by the F4 formulation, which had the highest mean OSC among all mixed bio-adsorbents while having one of the lowest water amount sorbed. These characteristics shown by bio-adsorbent formulation F4, as well as F5, are the ideal attributes of an oil bio-adsorbent. In general, for a larger scale oil-adsorption, formulations F4 and F5 may be a better choice than the rest due to less attraction to water and a better exhibition of selective attraction to oil. Regardless, corn cob and sugarcane bagasse can be used as effective bio-adsorbents without chemical treatment and may be used interchangeably or in conjunction with each other for any oil spill cleanup applications, without compromise in their oil sorption capacity.

It is recommended for future researchers to delve into other formulations to analyze the interactions between sugarcane bagasse and corn cobs. Additionally, further studies can emphasize different oil concentrations in the oil-water mixture. This recommendation also brings the possible need to standardize the oil-sorbent ratios in sorbent testing. Lastly, future research may also focus on exploring the influence of contact times on a sorbent's OSC and its tendency to sink.

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