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Experimental Study and Energy Analysis of Biomass Briquettes Produced from Dried Tree Leaves, Sawdust, Sugar Bagasse, and Rice Husk Using Fish Oil as a Binder

[1]Sam Oeurn Cheng, [2, 2*]Kinnaleth Vongchanh, [3]Sarin Chan, [4]Pisal Ken, [5]Latin Heang

[1,4]ETM Master Student, [2]Lecturer Researcher, and Head of Thermal Laboratory , [3]Assistance Professor, [5]ETM PhD Student
[1]Department of Industrial and Mechanical Engineering,
[2*]Research and Innovation Center,
[1]Institute of Technology of Cambodia, Phnom Penh, Cambodia
[*]Corresponding author

Abstract: Electricity has been used to powering the processes of converting biomass wastes into biomass briquette. The whole briquetting process requires various machines in addition to the densification by the screw press with heated die. These lead to high production cost. This study aims to compare the benefits of briquettes to the total energy used for producing them from raw materials of rice husk, mixtures of tree leaves and sawdust, and rice husk and sugar bagasse, using fish oil as a binder. Energy analysis has been used to evaluate the performance of a biomass briquette system consisted of an electric stove, a cutting machine, a mixing machine, and a briquetting machine. Total electricity consumption of each machine for briquette production has been observed and the heating value of briquettes has been measured. The produced briquettes have been found to have substantially high heating values. The production of 4.4 kg of briquette from just rice husk required 1.84 kWh of electrical energy, while the same weight of briquette produced from mixtures including sawdust and tree leaves; and rice husk and sugar bagasse required higher input energy equaling to 2.18 kWh and 3.14 kWh, respectively. These due to additional preparation processes required for cutting tree leaves and sugar bagasse and for mixing the raw materials. As result, the energy efficiency of the system when producing briquettes from tree leaves and sawdust, rice husk and sugar, and rice husk were equal to 92.56%, 88.80%, and 92.29%, respectively.

***IndexTerms* – Biomass briquettes, Briquette system, Energy analysis, Energy efficiency, Electricity consumption.**

I. Introduction

Biomass fuels have emerged as a promising renewable energy source, yet their extensive utilization encounters obstacles. A primary challenge stems from the comparatively lower energy content of biomass in contrast to traditional fossil fuels, demanding a larger quantity of biomass to yield equivalent energy output. Moreover, the low density of biomass exacerbates handling complications, resulting in a significant increase in volume during transportation and storage. To overcome these hurdles, compaction or densification techniques provide a viable solution by enhancing the energy density of biomass, effectively alleviating handling difficulties and facilitating practical application [1]. High pressure is often applied to the raw material during the compaction process while briquetting agricultural and forestry leftovers. Two issues are brought on by the pressure, such as the driving motor's high electrical energy consumption and the machine parts' high rate of wear [2]. Converting residues into a densified form, on the other hand, offers the following advantages: the process enhances the net calorific value per unit volume, the densified product is easy to carry and store, the process helps to solve the problem of residue disposal, the fuel generated is uniform in size and quality, and the method also helps to minimize deforestation by providing a fire wood replacement [3]. Briquettes also release a higher amount of heat energy compared to uncompressed bio-waste, while generating significantly lower levels of air pollution [4]. An effective densification technique for small-scale applications in developing nations is screw press briquetting. When briquetting with a screw press, the raw material is transported from the hopper and compacted. Compared to piston presses, this method can generate briquettes that are denser and more durable [3]. Briquettes made by the screw briquetting machine have holes in the middle, which promotes easier combustion. Additionally, the briquettes feature a carbonized surface that increases their water resistance. However, existing presses consume a lot of power, and the screw wears out quickly [5]. For this study, screw press with heated die has been used to produce briquettes. Bhattacharya & Shrestha, 1990 claimed that with a heated-die screw press, the cost of electricity accounts for

Nomenclatures

η	Energy efficiency, %	$E_{processes}$	Energy used in all processes, kJ
$E_{briquette}$	Energy of briquette, kJ	HHV	High heating value, MJ/kg
$E_{briquetting}$	Energy of briquetting process, kJ	Abbreviations	
$E_{composition}$	Energy of composition, kJ	FO	Fish oil
$E_{cutting}$	Energy used in cutting process, kJ	RH	Rice Husk
$E_{heating}$	Energy used in heating process, kJ	SD	Sawdust
E_{mixing}	Energy used in mixing process, kJ	SB	Sugar bagasse
$E_{oil\ extracting}$	Energy used in oil extracting process, kJ	TL	Tree leaves

13.9–16.6% of the total cost of producing sawdust briquettes [6]. The primary contributor to electrical energy consumption in the briquetting process is the motor, accounting for approximately 62% of the total energy consumed. Despite this, the advantages offered by these machines, including the production of high-quality briquettes with enhanced combustion and water resistance, may outweigh the associated energy costs [2].

Energy analysis is known as the conventional approach to evaluating energy usage in a process that involves the physical or chemical manipulation of materials, as well as the transfer and/or conversion of energy [7]. Energy analysis allows for the evaluation of the overall energy efficiency of the biomass briquette system operated with a screw press machine. Energy efficiency and conservation have always played significant roles in energy policy discussions, and their importance has been revitalized in light of increasing concerns regarding global climate change [8]. By analyzing the energy inputs and outputs, researchers can quantify the system's efficiency in converting biomass into usable energy. This information helps identify areas for improvement, optimize machine settings, and enhance the overall energy conversion process. In their 2010 study, Wessapan et al. presented a compact screw-press briquetting machine that integrates crushing, mixing, and briquetting functions into a single unit. The paper highlights the machine's focus on energy efficiency, achieved by eliminating the requirement for separate machines and optimizing energy transfer. The compact design and efficient crushing and mixing mechanisms of the machine contribute to reduced energy consumption [9]. This study examines the energy efficiency of biomass briquette systems with three different mixing ratios. It is believed that such a study will contribute to briquette producers identify and address energy-related problems in the briquetting process.

II. METHODOLOGY

2.1 Material and Preparation

In this study, five types of raw biomass materials were used to produced briquettes, dried tree leaves, sawdust, sugar bagasse, rice huck, and fish fat. These are good choices for biomass briquette raw material because they are abundant, renewable, easy to process, environmentally friendly, and cost-effective. In all cases, 4 kg of raw materials were combined with fish oil of 400 g (10% of 4kg) for producing briquettes. Sugar bagasse was dried after collection because the moisture content of sugar bagasse after coming out of the juicer machine is too high for briquette production. We used traditional sun drying method to dry sugar bagasse, it is the simplest and most cost-effective method. The material is spread out in a thin layer and allowed to dry in the sun approximately 8 hours for 3 days. Tree leaves and sugar bagasse were cut into small pieces, each less than 8 mm in size, for the raw material to operate smoothly with a screw press machine.

Tree leaves and sawdust were mixed with percentages by weight of 30% and 70%; and then mixed with fish oil binder. This composition ratio had been found to provide the best results over other mixing ratios [10].

Rice husk and sugar bagasse were mixed with percentages by weight of 50% and 50%; and then mixed with fish oil binder. This composition ratio had been found to provide the best results over other mixing ratios [11].

Rice husk of 4 kg was mixed with 10% of fish oil as a binder. This composition was found to be more suitable for commercial applications in terms of cost-effectiveness [11].

2.2 Experimental Procedure

Figure 1, briquette system consisted of an electric stove, a cutting machine, a mixing machine, and a briquetting machine. Electric stove was used to extract the oil from fish fat by boiling fish fat. Cutting machine was used to cut tree leaves and sugar bagasse from its initial size to smaller than 8 mm. Mixing machine was used to mix raw materials with binder, while briquetting machine was used to produce briquette.

Boiling fish fat	Cutting machine	Mixing machine	Screw press machine

Figure 1. Briquette system

In the current study, a single extrusion heated-die screw press type of briquetting machine was utilized. The primary components of the machine include a driving motor, screw, die, and die heater. When the motor is started and the raw material is fed to the screw, it gets compressed and extruded through the die. To raise the temperature of the die to 300 °C, an electric coil heater was attached to its outer surface. The electrical heater was equipped with a thermostat, ensuring that the temperature remained constant throughout the process. Started from switch on the heater about 22 minutes, after temperature reached 300 ℃, turned on the motor and put the composition into hopper.

Fish oil of about 2.8 kg was extracted from fish fat 3.5 kg by boiling fish fat in a pot using an electric stove for 1 hour, then filtering the oil for use. The amount of fish oil extracted from fish fat was different depending on the type of fish the fat belongs to.

Cutting machine operated for 5 minutes 38 seconds and 9 minutes 25 seconds to cut tree leaves 1.2 kg and sugar bagasse 2 kg, respectively. And to mix raw materials and binder homogeneously, the composition of tree leaves and sawdust, rice husk and sugar bagasse were mixed for 3 minutes before adding fish oil and were continued mixing for 5 minutes. For 4 kg of rice husk, it was mixed with fish oil for 5 minutes.

The composition of tree leaves and sawdust took 40 minutes to complete the briquette production. The composition of rice husk and sugar bagasse required 1 hour and 4 minutes to finish the briquette production. The rice husk composition alone took 36 minutes to complete the briquette production.

During the experiment, electricity consumption was recorded using KEW 6305 digital power meter with an accuracy of ±0.3%rdg ±0.2%f.s, voltage test leads, and clamp sensors were connected to the power source, then electricity consumption was recorded.

2.3 Energy analysis

Energy efficiency of briquette system:

$$Energy\ efficiency = \frac{Energy\ output}{Energy\ input} \times 100\% \quad \text{(Eq. 1)}$$

For energy used in the process, human labor is neglected.

$$\eta = \frac{E_{briquette}}{E_{composition} + E_{processes}} \times 100\% \quad \text{(Eq. 2)}$$

The energy of briquette:

$$E_{briquette} = HHV_{briquette} \quad \text{(Eq. 3)}$$

The energy of composition:

$$E_{compostion} = HHV_{compostion} \quad \text{(Eq. 4)}$$

The energy used in all processes is the sum of energy used in oil extracting process, cutting process, mixing, heating process, and briquetting process.

$$E_{processes} = E_{oil\ extracting} + E_{cutting} + E_{mixing} + E_{heating} + E_{briquetting} \quad \text{(Eq. 5)}$$

Where energy of each process is equal to power consumption during each process.

2.4 Heating Value (HV)

The heating value, also known as calorific value, represents the amount of heat released during the complete combustion of a fuel, excluding the condensation heat of water vapor present in the smoke [12]. The calorific value was determined using an Oxygen Bomb Calorimeter 6772 at room temperature ranging between 25°C and 28°C. The procedure involved placing a sample weighing 1.5g inside the oxygen bomb and pressurizing it with oxygen at 30 atm. Subsequently, the bomb was immersed in 2000g (±5g) of distilled water, which was maintained at a temperature 1°C to 2°C below the room temperature. It was important to check for any gas bubbles leakage that could potentially cause equipment explosion. Next, the oxygen bomb was connected to the calorimetric ignited electrode and operated for 15 minutes. The mass of the sample and the remaining fuse afterburn were recorded and inputted into the system. The final result of the gross calorific value (wet basis) was provided by the calorimeter.

III. RESULTS AND DISCUSSION

3.1 Electricity Consumption

Figure 2 shows the load profile of the cutting machine, mixing machine, screw press machine, and heater for producing briquette 4.4 kg from tree leaves and sawdust with fish oil as a binder. The black line, purple line, blue line, and red line represent the load profile of cutting machine, mixing machine, screw press machine, and heater, respectively. Screw press machine's power consumption was 1.4 kW when the motor started driving the screw, before dropped to around 1.3 kW, then started rising steadily to almost 1.5kW in 40 mins of operation. The heater had to be turned on to reach a die temperature of 300°C before we could start producing briquettes. Heater's power consumption started from 0.8 kW to 1.1 kW in the first minute before it remained steady until its temperature reached 300°C in around 20 mins. After that, the graph rose up again indicated the process of feeding composition into the hoper and the machine started to convert composition into briquette, the total duration of heater operation was 60 mins. Cutting machine spent about 5 mins to cut dried tree leaves for making briquette 4.4 kg, and it consumed power around 0.9 kW every second. Mixing machine consumed power around 0.5 kW for 8 mins to mix raw materials thoroughly. It was observed that dried tree leaves and sawdust mixed really well together, the composition absorbed constant heat from heater to produce briquette according to the graph. Power consumption of screw press machine increased over time due to energy lose to surrounding environment. Power consumption of cutting machine decreased at the end of the process. And power consumption of mixing machine went up slightly.

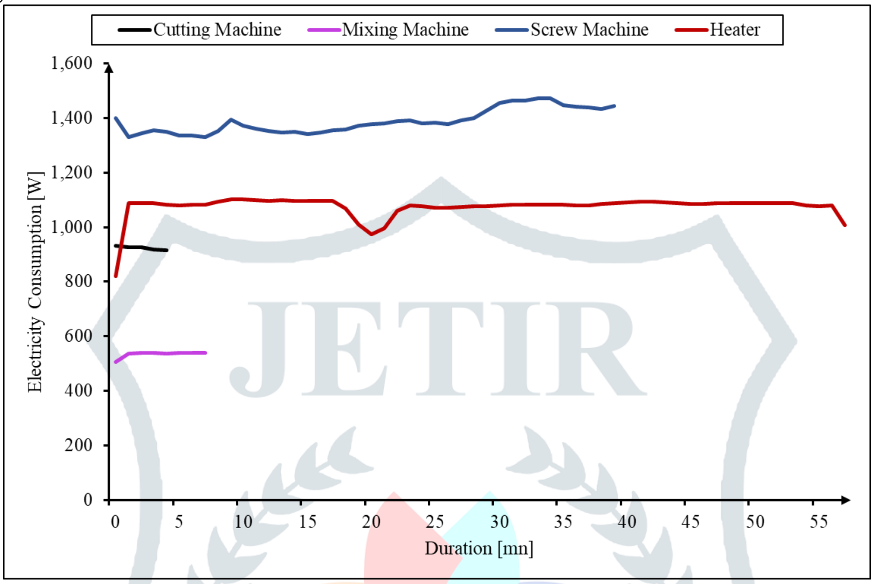

Figure 2. Load profile for producing briquette from tree leaves and sawdust

Figure 3 shows the load profile of the cutting machine, mixing machine, screw press machine, and heater for producing briquette 4.4kg from rice husk and sugar bagasse with fish oil as a binder. The black line, purple line, blue line, and red line represent the load profile of cutting machine, mixing machine, screw press machine, and heater, respectively. Screw press machine's power consumption started rising from 1.2 kW when the composition was being compressed, and it rose bumpily to approximately 1.5 kW in 64 mins of operation. The heater had to be turned on to reach a die temperature of 300°C before we could start producing briquettes. Heater's power consumption started from about 0.8 kW to 1.1 kW in the first minute before it remained steady until its temperature reached 300°C in around 23 mins. After that, the graph rose up again indicated the process of feeding composition into the hoper and the machine started to convert composition into briquette. The consumption went up and down between 0.6 kW and 1.1 kW continuously, until the end of the process, the total duration of heater operation was 87 mins. In this experiment, cutting machine operated for about 8 mins, and consumed power around 0.9 kW every second. And mixing machine operated for 8 mins and consumed power between 0.5 kW and 0.6 kW. It was observed that the force composition needed for compression was not constant and the duration for producing briquette is longer than other type of materials in this study due to the characteristic of sugar bagasse. The combination of sugar bagasse and rice husk made the heat absorption by composition not even, the inner surface of the die provided heat differently when sugar bagasse and rice husk come into contact. Power consumption of cutting machine changed slightly during the process. While power consumption of mixing machine increased midway and decreased at the end of the process.

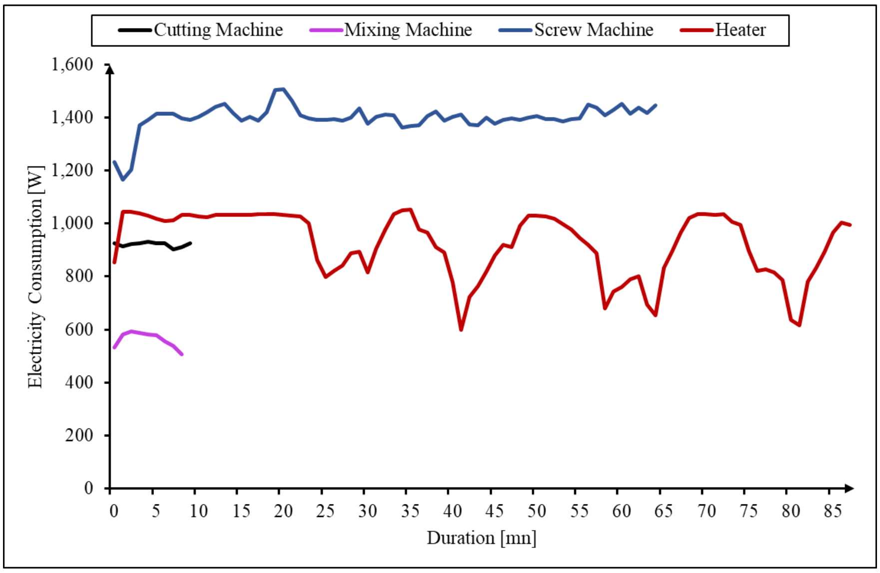

Figure 3. Load profile for producing briquette from rice husk and sugar bagasse

Figure 4 shows the load profile of the cutting machine, mixing machine, screw press machine, and heater for producing briquette 4.4 kg from rice husk with fish oil as the binder. The purple line, blue line, and red line represent the load profile of mixing machine, screw press machine, and heater, respectively. Screw press machine consumed 1.3 kW of power at the start before dropping to less than 1.2 kW in the first minute. In this experiment, it took only 36 mins to finish the producing briquette and power consumption jumped to approximately 1.45 kW for a short period of time. It then dropped to less than 1.2 kW and rose to 1.3 kW at the end of the process. The heater had to be turned on to reach a die temperature of 300°C before we could start producing briquettes. Heater consumed power around 1 kW from start to finish except for the time when the die first reached 300℃, composition was fed into the hoper and the machine started to convert composition into briquette, the total duration of heater operation was 56 mins. There is no cutting process in this experiment and mixing process only operated for 5 mins, its power consumption was 0.5 kW. It is observed that briquette produced from rice husk consumed power and time less than other materials. The maximum power consumption when rice husk was compressed to push the remain briquette in the die out was a little over 1.4 kW, and it absorbed constant heat from heater to produce briquette according to the graph. Power consumption of mixing machine went up slightly.

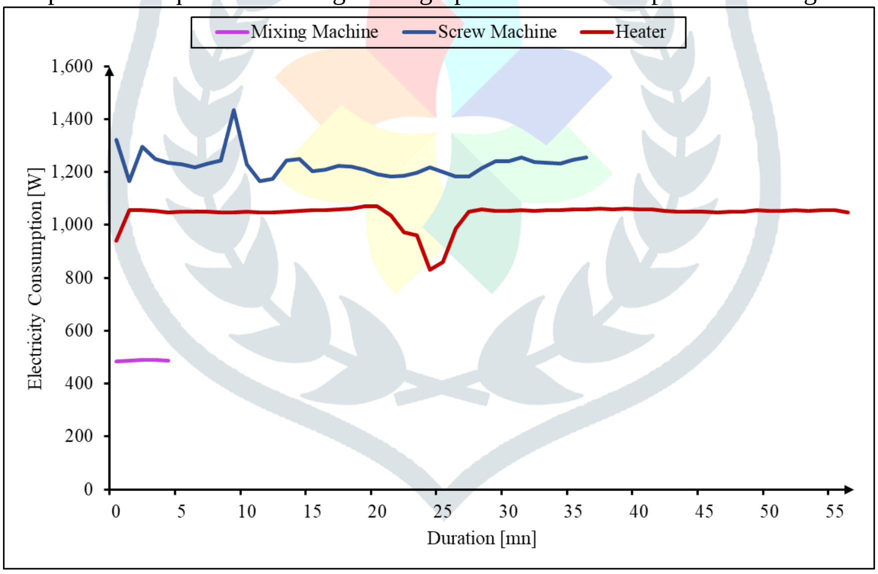

Figure 4. Load profile for producing briquette from rice husk

Figure 5 shows the load profile of an electrical stove in the process of fish oil extraction for 1 hour. It occurred that the electric stove needed 11 mins to make fish fat in the pot reach boiling temperature. The consumption started at 0.9 kW and stabilized at about 0.4 kW.

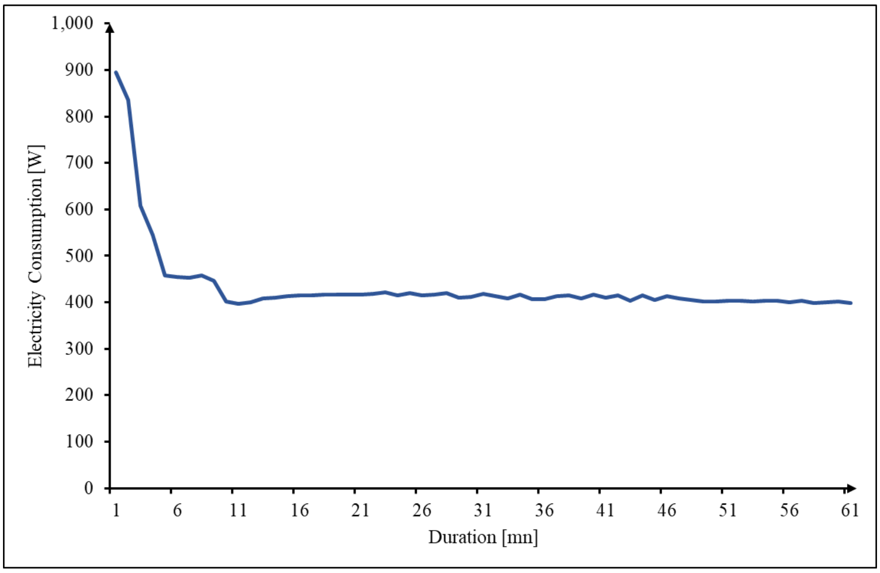

Figure 5. Load profile of electrical stove

3.2 Exergy Efficiency

The energy of briquette product and composition was equal to the HHV of briquette and composition. The energy used in each process was equal to electricity consumption of each process.

The amount of energy consumed in each step to create briquette from rice husk, fish oil, and sugar bagasse, as well as tree leaves and sawdust, is shown in Table 1 Rice husk and sugar bagasse utilized the largest energy for briquette manufacture, amounting to 11,305.3 kJ, followed by sawdust and tree leaves with 7,838.5 kJ. Rice husk utilized the least amount of energy for briquette production, which was 6,609.05 kJ.

Table 1. Energy used for producing briquette 4.4kg

Process	Energy used for TL&SD (kJ)	Energy used for RH&SB (kJ)	Energy used for RH (kJ)
Oil extracting	223.53	223.53	223.53
Cutting	304.28	552.61	0.00
Mixing	257.16	274.80	146.45
Heating	3,311.36	5,397.10	2,698.54
Briquetting	3,742.16	4,857.26	3,540.52

The quantity of energy used to create briquette and the amount of energy produced by them are both displayed in Table 2. The maximum energy was produced by the briquette made of sawdust and tree leaves, amounting to 97,460 kJ. This was followed by the briquette made of rice husk and sugar bagasse, with 89,672 kJ, and the briquette made of rice husk, with 79,112 kJ. As a result, the energy efficiency of the briquette system was 92.56% for making briquettes from tree leaves and sawdust, 88.80% for rice husk and sugar bagasse, and 92.29% for rice husk.

Table 2. Energy of briquette and exergy used to produce briquette

Briquette	Energy of briquette 4.4kg (kJ)	Energy used in all processes (kJ)
TL30SD70FO	97,460	7,838.50
RH50SB50FO	89,672	11,305.3
RH100FO	79,112	6,609.05

IV. Conclusion

The experimental results demonstrate that cutting and mixing operations required less time to create 4.4 kg of briquette than other processes, resulting in significantly lower power consumption for these two processes than for other processes. For the purpose of extracting 2.8 kg of fish oil from fish fat with an electrical stove, 0.43 kWh of electricity was consumed. The fish oil was then utilized as a binder to create 30.8 kg of briquette. To generate 4.4 kg of briquette from tree leaves and sawdust, 2.18 kWh was used. In contrast, 3.14 kWh was needed to produce the same amount of briquette from rice husk and sugar bagasse. Briquette production from rice husk required just 1.84 kWh. The process of making rice husk briquette with fish oil as a binder required fewer steps than the other two. In comparison to the other two, it also consumed less time and electricity. The energy efficiency of the briquette system was 92.56% for making briquettes from tree leaves and sawdust, 88.80% for rice husk and sugar bagasse, and 92.29% for rice husk. Briquette production from rice husk using fish oil as binder is recommended for commercial applications as the process required fewer steps than the other two. In comparison to the other two, it also consumed less time and energy.

V. Acknowledgment

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