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IMPROVED BIOFUEL PRODUCTION FROM DRIED FECAL SLUDGE: A RESOURCE RECOVERY OPTION

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ABSTRACT

An improved version of fuel generated from solidified fecal sludge can replace the rural biomass burning practice, thus, introduce an environment-friendly energy source to the rural areas of Bangladesh. In this study dried fecal sludge was mixed with locally available organic matter in order to increasing the energy efficiency of the fuel. Here, the fecal sludge was first dried in open air and carbonized, and tested in a water boiling test. However, the result was not very satisfactory in terms of energy efficiency with 9766 j/kg of calorific value and it required 56 mins to bring the water to the boiling point. Thus, different organic matters were added to the sludge to improve the calorific value of the biofuel. In this study, some low-cost locally available raw materials such as rice husk, cow dung, sawdust, wood, and coal, were collected, processed, and carbonized. Then, eight different mixtures of sludge and organic matter with different ratios were prepared and briquettes were made. Then these briquettes were tested in a water boiling test and their calorific values were measured in a lab. The highest calorific value i.e. 14618 j/kg was achieved for the briquettes made of 50% of carbonized sludge combined with 50% of coal. This briquette was shown the highest efficiency in the water boiling test as well where it took only 14 minutes to reach the boiling point. The second highest result was obtained for the briquettes made of 50% of the sludge and 50% of cow dung with a calorific value of 14427 j/kg, and the boiling point was reached in about 23 minutes. As a result, it can simply be concluded that only sludge as a biofuel was not very efficient although it requires less cost for preparation and marketing. Hence, the most promising low-cost, high-efficiency biofuel was the briquette made of 50% of sludge combined with 50% of cow dung. It can add a new, environment-friendly biofuel to the rural energy market of Bangladesh.

***Key words**: biofuel, briquette, dried fecal sludge, resource recovery, fecal sludge management*

Introduction

Worldwide a recent concern was given to the proper management of fecal sludge and recovering nutrients from it and reusing it for fuel generation. Fecal sludge could be a future potential low-cost fuel source for developing countries like Bangladesh. Traditionally bio-solid waste e.g., Manure was being used as a fuel in rural area either in dried form or as bio gas. This practice could be replaced by an improved version of fuel generated from solidified fecal sludge. However, the efficiency of this fuel was low due to the low calorific value of the fuel content. For this reason, an experimental study was endeavored to test different method in order to increasing the calorific value of solidified fecal sludge that produced in the fecal sludge treatment plant of Khulna City Corporation at Rajbandh, Khulna. The study would be of great interest since reuse of waste was encouraged in Sustainable Development Goal (SDG) and biofuel generation had caught attention of many governments and non-government organization recently. Additionally, an efficient and low-cost fuel had great demand in the local market of Bangladesh. Also, this approach would reduce the waste load to the city, and instead it would produce environment friendly fuel that can contribute in meeting the energy demand of the country.

In addition to that, Bangladesh's per capita CO_2 emissions grew from average annual CO_2 emissions per person by 0.05 to 0.66 tons per capita in 1970 and increased to an average of 5.48 percent in 2019 (knoema, 2020). In 2012, the amount of GHG released in the atmosphere is 190 MtCO2 equivalent, 0.40% of total world's emission (USAID). It's a matter of fact that the amount of GHG released in the atmosphere is 62.37% from energy consumption. For this reason, countries were emphasizing on renewable energy sources such as solar, wind, hydro energy and of course biomasses. While world's non-renewable energy resources had been fading out rapidly, Bangladesh consumes about 2,099,900 tons of coal per year as of 2016 ranking 60th globally reported by worldmeters.info. Therefore, moving towards more clean, renewable energy options was considered by the Bangladesh Government. In this regard, improved biofuel production from fecal sludge would be a forwarding step in establishing a sustainable energy system in Bangladesh. It would also enhance the sanitation value chain and fecal sludge management.

Biochar had been proven to be more environmentally friendly fuel than the common biomass fuels found around us. Biochar was enriched in carbon which results in higher burning capacity. Biochar is the lightweight black residue, made of carbon and ashes, remaining after the pyrolysis of biomass. It is defined by the International Biochar Initiative as "the solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment". Biochar briquettes would be convenient to burn in the locally available rural stoves in Bangladesh due to its user-friendly size. Briquette production from fecal sludge could be a reliable and sustainable future of fuel scenario in Bangladesh since the county produces huge amount of human waste annually. Bangladesh collected about 4,841.76 thousand tons of municipal waste in 2014 and currently on the rise exponentially. Briquette production from biomass is safe, contains less health hazard. It can be a viable energy source and will be able to provide work opportunities for rural community. This study was aimed to produce environmentally friendly briquettes from dried fecal sludge. Different organic matters ware added to the FS to improve the calorific value of the fuel. The objective of this study is to develop a low-cost biofuel from dried fecal sludge and improve its energy efficiency by mixing locally available organic matter. The dried fecal sludge sample was collected from the Fecal Sludge treatment Plant of Khulna City Corporation located in Rajbandh, Khulna, Bangladesh. Approximately, 450 tons of Fecal sludge was produced per day in Khulna City, which was being treated at the Raj bandh FST plant (Hasib and Rafizul, 2020).

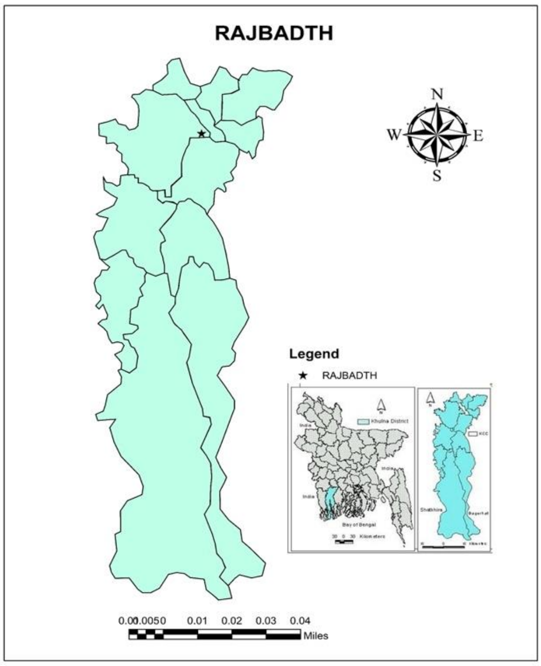

Figure 1: Study Area, Rajbandh, Khulna

Methods

The fecal sludge was collected from the municipalities of Khulna and disposed of in the drying beds of Rajbandh FST plant. The sludge has been dried up here for 14 and 21 days in open air. Different organic matters namely, saw dust, rice husk, cow dung and coal were procured from local markets, businesses, and merchants of wares made of wood. All the biomass then dried up in a greenhouse. The biomass was taken for carbonization once the moisture content had been lowered to a particular level (less than 15 percent). There were several mechanical devices for producing round-shaped carbonized briquettes. The devices included a hammer mill, rotating drum, different carbonization kiln and sludge dryer chamber. All devices were made locally. Besides, several tests were conducted with the combination of different input materials in the carboniza tion kiln (Figure 2).

Figure 2: Sludge emptying and drying bed

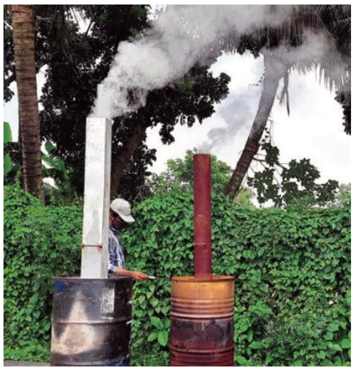

Figure 3: Carbonization kiln Single drum (right), Double drum (left)

Carbonization of the biomass

All of the dried biomass including the sludge were carbonized in a 1) single customized drum 2) double customized drum named as carbonization kiln. Biomass with different moisture contents were tried in the carbonization kiln to find out the optimum combination of moisture content and temperature requirement and time requirement. Higher the moisture content is the longer the carbonization time was observed. The sludge took 2.5 hours to be carbonized to 90% while approximately two hours were required to finish the carbonization of rice husk to 100%. Carbonization of sawdust was really a hard nut to crack in the single drum. It could only be carbonized to 20-30%. That was because the sawdust was so compacted when put inside the drum and also due to its highest cohesiveness. It was not even carbonized in the double drum, and the carbonization time of whatever amount that having was not showing any trend which would prescribe for maintaining the time duration. Finally, the best result was found when the moisture level was 2.5 and it took 3 hours to be carbonized up to (40-45) %. Then, the sawdust was blended with rice husk at a ratio of 2:1, and it was easily carbonized to 100% in the double drum after 3 hours. The carbonization of the dried cow dung took approximately 40 to 50 minutes to complete.

Table 1: Carbonization parameters of different biomass

Material	**Moisture**	**Volume**	**Duration in hour**	**Smoke Color**	**Oxygen Flow**	**% Of Carbonization**	**Result Product**
Sludge (Thin)	3.5	2.86	2.5	Transparent	Moderate	80	Carbon
Sludge (Thick)	9.0	2.86	3.0	Transparent	Moderate	90	Carbon with 10% Ash
Sludge (Thick)	13.5	2.86	3.5	Transparent	Moderate	90	Carbon with 10% Ash
Rice Husk	5.5	2.86	2	Whitish	Moderate	100	Carbon
Rice Husk	8.5	2.86	2	Whitish	Moderate	100	Carbon
Rice Husk	10.0	2.86	2	Whitish	Moderate	100	Carbon
Saw Dust	3.5	2.86	Over night	Transparent	Moderate	40	Carbon
Saw Dust 1/3 Rice Husk 2/3	4.0-5.5	2.86	3	Transparent	Moderate	100	Carbon
Cow dung	10-15	2.86	40-50 min	Transparent	Moderate	100	carbon

Milling, Mixing and Briquetting process

After carbonization, the biomasses were grinded into powder by a milling machine. All the powdered biomasses were kept in large bags. the powdered materials were weighted and mixed in a half-cut drum as per specified ratios. Here, molasses (i.e., Chita Gur) acts as binding material or adhesive and keeps

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the particles intact. The molasses is generally mixed with water with the ratio of 10:1. There were 8 different mixtures of biofuel prepared with different ratio that included Coal 50%: Sludge 50%, Coal 40%: Sludge 60%, Coal 30%: Sludge 70%, Rice Husk 50%: Sludge 50%, Saw dust 50%: Sludge 50%, Cow Dung 50%: Sludge 50%, Rice Husk 40%: Sludge 60%, and Sludge 100%. Then the briquetting process took place in the agglomerate or rotating drum. The rotator drum revolves and being mixed with molasses produces round-shaped briquettes. The rotation of the agglomerate was kept 17-19 RPM. Later the briquettes were air dried for 3 days where the moisture content decreased to 10-15%.

Figure 4: Milling, Mixing, agglomeration and final briquettes

Analyzing the energy efficiency of biochar briquettes

To test the energy efficiency of biochar, these briquettes were tested in water boiling test in 5 different cookstoves. For each of the cookstoves paper was used as the kindling material. Also, calorific values of the briquettes were measured in laboratory to determine which of the eight varied mixes produced the most efficient briquettes.

Result

Water Boiling test

The biochar briquettes that took the less amount of time to bring the water into boiling point was considered the most efficient in this test. As, indicated by figure 5, the best water boiling test result was found for 50% coal mixed with 50% sludge and it took only 14 minutes to reach the boiling point. Another best result was for 50% cow dung mixed with 50% sludge and it took 23 minutes to reach the boiling point.

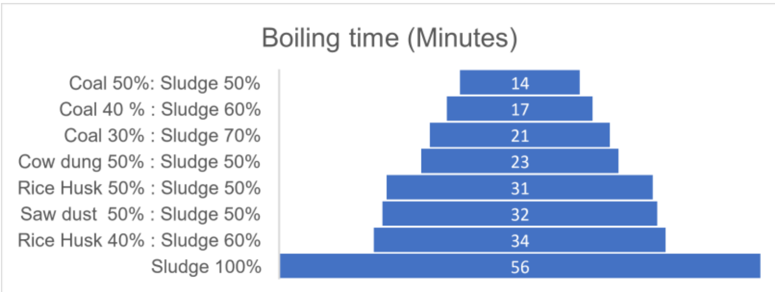

Figure 5: Result of water boiling test

Calorific value of briquettes

The calorific values of the briquettes were tested in a lab to identify the most efficient biofuel. The result indicates (figure 6) that the briquette which contain 50% coal mixed with 50% sludge has the highest calorific value (14618 j/kg) and the briquette containing 50% sludge mixed with 50% cow dung

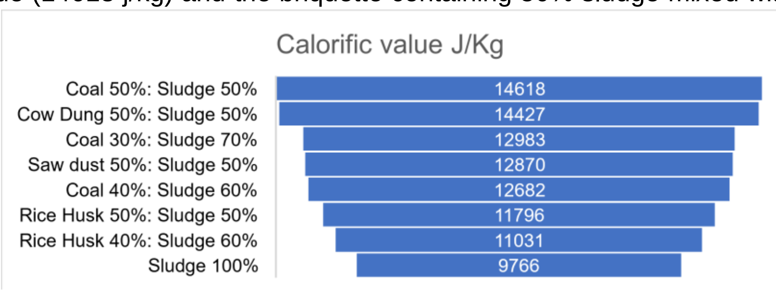

Figure 6: Calorific values of biochar briquettes

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has the second highest calorific value (14427 j/kg). Whereas, briquettes made of 100 % sludge has the lowest calorific value (9766 j/kg). The mixture of 40% Rice Husk and 60% sludge has the second lowest calorific value (11031j/kg).

Cost of biofuel preparation and marketing: The cost per kilogram of raw materials was determined by dividing the cost equivalent value by the quantity that could be handled per day. The total cost of operating was 10.87 tk. 1 kilogram of molasses was used to make 25 kilograms of briquettes. Thus, 1.8 tk worth of molasses was required per kilogram of briquettes. The cost of sludge was free, but hidden costs like as transportation and maintenance expenses were incorporated. Coal was the costliest raw material. At that time, the market value per kilogram of coal was 12 tk. Rice husk and wood, at 8 tk per kilogram, were the second-most expensive row materials. Cow manure was the most viable row material, and it cost only 1tk per kilogram.

The cost per kilogram of producing a briquette from 100 percent sludge was 13.87 tk. Here, the cost was quite low, but the energy efficiency was very low. The method of combining 50% sludge with 50% coal, however, needed 19.87 tk per kilogram. Even though its efficiency was pretty good, this was incredibly expensive. Fifty percent sludge and fifty percent cow manure comprised the optimum mixture. Because its efficiency greatly exceeds that of coal and relatively inexpensive briquette. After coal, its calorific value of only 14.37 tk per kilogram was impressive. If marketing expenses could be reduced, briquette prices may be reduced. The more the daily production of briquettes, the cheaper the guaranteed expenses will be.

Table 1. Cost of biofuel preparation and marketing

Material	Price BDT/kg	Operational Cost BDT/kg	Marketing Cost BDT/kg	Total Cost BDT/kg
Sludge 100 **%**	0	10.87	3	13.87
Cow dung 50%: Sludge 50%	1	10.87	3	14.37
Saw Dust 50%: Sludge 50%	1.625	10.87	3	15.495
Rice Husk 40%: Sludge 60%	3.2	10.87	3	17.07
Coal 30%: Sludge 70%	3.6	10.87	3	17.47
Rice Husk 50%: Sludge 50%	4	10.87	3	17.87
Coal 40%: Sludge 60%	4.8	10.87	3	18.67
Coal 50%: Sludge 50%	6	10.87	3	19.87

Discussion

As the purpose of the study was to create a low-cost biofuel from dried fecal sludge, it was determined that the fecal sludge needed to be dried. In this manner, the fecal sludge was initially treated. Since dried fecal sludge was not determined to be an effective biofuel, it was combined with other organic materials that were also treated. Locally sourced organic resources such as rice husk, animal dung, sawdust, wood, and coal were used. The mixture was then carbonized and made into briquettes. The effectiveness was determined by water boiling test. In the water boiling test, the briquette composed of 50 percent coal and 50 percent sludge was the most effective, reaching the boiling point in only 14 minutes. A mixture of 50 percent cow dung and 50 percent sludge yielded the second-best results. It took 23 minutes for the water in its boiling test to reach the boiling point. The laboratory calorific value test was also used to measure the efficiency. Interestingly, the briquette composed of 50 percent coal and 50 percent sludge has the maximum calorific content, 14618j/kg. The second-best result was determined to be Cow Dung 50%: Sludge 50%, with a calorific value of 14427 j/kg. The lowest result was for 100% Sludge, which had a calorific value of 9766 kcal/kg. One may therefore conclude that solely the calorific value of sludge fell short of expectations. In terms of cost effectiveness, however, the briquettes comprised of 50 percent coal and 50 percent sludge were found to be expensive, with 1 kilogram of briquette production and packaging costing 19,87 Tk. In contrast, the packing cost for briquettes comprised of 50 percent sludge and 50 percent cow dung is 14.37 taka per kilogram. Therefore, from a Bangladeshi market viewpoint, the most practical, cost-effective, and high-efficiency biofuel was briquettes comprised of 50 percent sludge and 50 percent cow dung.

Conclusion: In rural areas of Bangladesh, there is a pressing need for an alternative fuel source that is efficient, ecologically friendly, safe, and sustainable, to replace the conventional use of biomass. This study aims to pave the way in characterizing fecal sludge as a fuel beyond the conventional method of calorimetry. The ash speciation and leaching of fecal sludge make it subject to the same level of scrutiny as other biofuels, which has helped to inform discussions surrounding the use of fecal sludge as a fuel. By carbonizing samples of fecal sludge, the thermal properties of the fuel can be improved, resulting in a significant increase in its heating value. The study found that, with few exceptions, fecal sludge has the potential to compete with other solid biofuels in general. The conversion of this sanitation hazard and disposal issue into a valuable energy resource justifies careful consideration and further quantified scientific application.

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